The Impact of Aspect Ratio

by FENY ELSIANA

The Impact of Aspect Ratio of Buildings Implementing Horizontal Light Pipe and Shading Systems on Daylight Performance

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Deep-plan buildings limit daylight use in spaces far from the building perimeter, leading to uneven daylight distribution. Integrating a Horizontal Light Pipe (HLP) as an optical daylighting system, reflective light shelves, and blinds as shading systems can reduce excessive daylight levels at the perimeter area of a building and improve daylight uniformity. Earlier investigations of HLP daylight performance concentrated on fixed building geometries, but few studies focused on the building aspect ratio, one of the design variables of building geometry that greatly influences daylight performance. This study aims to investigate the impact of the aspect ratio of buildings implementing HLP and shading systems on daylight performance. The research method was experimental, using IES-VE simulation as a tool. The daylight factor (DF), uniformity daylight factor (UDF), and useful daylight illuminance (UDI) of various aspect ratios and depths of office buildings implementing HLP and shading systems were analyzed. The results show that increasing the building aspect ratio from 1:1 to 2.1:1 sequentially increased the average DF and UDF values by 18.47% and 17.2%, respectively. Improving the building aspect ratio from 1:1 to 2.1:1 along the east-west axis improved the UDI by 3%, whereas the north-south axis decreased it by 10.2%.

Keywords: building aspect ratio; daylight performance; horizontal light pipe; shading system; tropics.

1. Introduction

Daylight use can reduce the energy consumption of a building and decrease the cooling load and peak demand. Proper daylighting use in buildings can decrease the energy used for electric lighting and the energy consumption of the entire building [1,2,3]. Natural daylight also reduces the sensible cooling load amount due to electric lighting [4] and lowers the cooling load of buildings [5]. Proper daylighting design lowers the air-conditioning system's [6] and the building's peak power demand [4]. Reducing peak demand is necessary for office buildings occupied in the daytime. Peak demand usually occurs when daylight is most abundant [5].

Daylight also positively affects human comfort and health. Daylight is the best source of light that is the most probable equivalent to the human visual response [6]. It also makes the interior space appear livelier and more attractive. Building users prefer good daylighting in their working and living environments [7]. Daylight is also associated with serotonin and melatonin hormone production, which regulate circadian rhythms. Inadequate daylight exposure and serotonin or melatonin cycle disturbances can cause seasonal affective disorder (SAD) [5]. Daylight has also become one of the most effective antidepressants available [8]. Therefore, buildings should provide human exposure to sunlight to facilitate cutaneous photosynthesis, which provides most or all human vitamin D needs [8].

Other essential aspects of daylighting include user productivity and economic value. Daylighting improves productivity in workplaces [9]. Tenants spend 5-6% more on office areas with high daylight than those with low daylight presence [10]. Spaces with high view and daylight access also have a 6% effective rent premium over areas with inadequate access to view and daylight [11].

The potential for daylight utilization in the tropics is high. Daylight is abundant in this area because of the high sun intensity and long illumination period during the daytime [12]. Studies of daylighting in the tropics need to consider inconsistent cloud formation of intermediate skies, which are neither clear nor overcast [13]. Global illuminance at noon reached 80 Klux in March and 60 Klux in December [14].

From the architectural design standpoint, a building should have a narrow plan to optimize daylighting [15]. Nevertheless, deep-plan buildings are commonly developed to maximize the net floor area [Hansen, 2006 and Lashina et al., 2019]. A deep-plan building design limits the daylight level in spaces far from side windows. The daylight intensity reduces as the distance from the side window increases [16], leading to uneven daylight distribution and glare problems [17]. (Heng et al., 2020 and Mayhoub, 2014). A core daylighting system is required to bring daylight in spaces distances from the building perimeter (Linhart, Witfoff 2010)

A Horizontal Light Pipe (HLP) is one of the core daylighting systems that can bring daylight further into a building's interiors. The HLP consists of an aperture, a pipe, and an opening distribution. The aperture collects, redirects, and occasionally concentrates or collimates the incoming light flux [18]. Pipe transports and opening distribution distributes daylight to the deep area of the building. HLP is placed in the plenum above the ceiling [18]. HLP increases the daylight factor (DF), and estimated indoor illuminance reaches 25% and 24%, sequentially, in deep office spaces [19].

The aperture is located at the building façade, with a flat capturing system to minimize the protrusion of the building façade [18]. The aperture is equipped with reflectors to redirect the incoming sunlight to minimize inter-reflections within the pipe and to maximize the system efficiency (Hansen, 2006; Beltran et al., 1997), especially the oblique sunbeam in cases of solar positions not in axis with the pipe (Canziani et al., 2004). Material of reflectors is a highly reflective specular material, such as an aluminum sheet [Obradovic et al., 2021; 18; Hien and Chirarattannanon 2009]; silver, mirror folium with a reflectivity of 99% [Obradivic et al., 2021]. The aperture is covered by clear glazing [Hien and Chirarattannaon, 2009] with a visible transmittance of 88%.

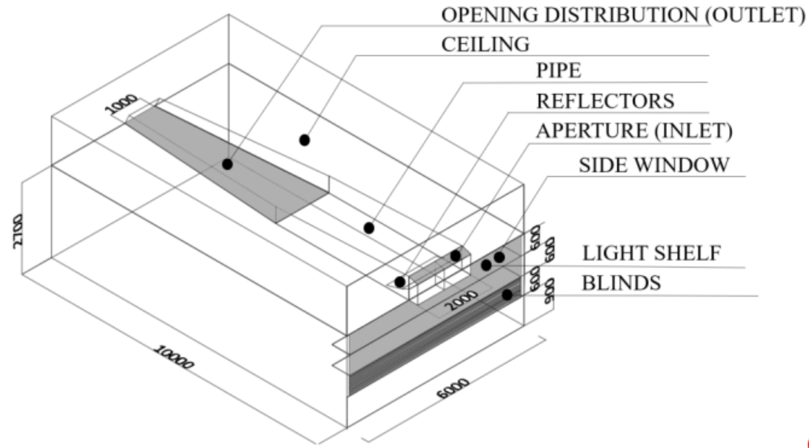
The pipe transports the light with the principle of multiple specular reflections. The efficiency of a mirror Light Pipe depends on the area, the pipe's geometric form, the material's reflectivity, and the light sources' directional properties (Garcia et al., 2003). The pipe materials are highly specular, such as specular reflective film with a reflectance of 95% (Canziani, 2004; Beltran et al., 1997), polished aluminum with a reflectivity of 85%, or silvered aluminum with a reflectivity of 95%. In cross-section, the pipe is tapered towards the rear of the room (Beltran & Mogo, 2007).

The opening distribution or diffuser transmits daylight to the deep area of the building. The opening distribution is located at the ceiling plane (Figure 1), at 4.5 m from the side window to the building depth, to optimize the light pipe efficiency [Beltran, 1997]. The material of opening distribution is translucent sheets (Chirarattananon et al., 2000), clear glass with egg-crate reflectors (Elsiana et al., 2020), clear glazing (Elsiana et al., 2021), laser cut panels (Hansen & Edmonds, 2003; Kwok & Chung, 2008).

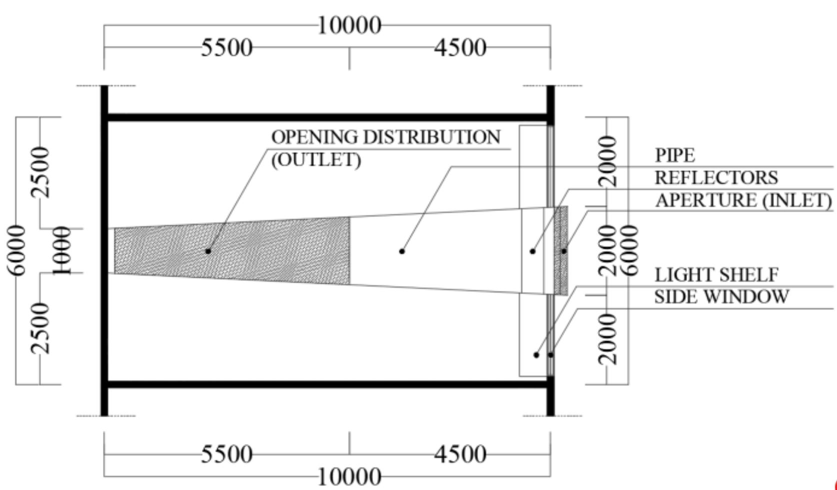
The HLP obtains daylight from half of the hemisphere in front of the aperture [20]. HLP captures and utilizes direct sunlight. HLP can be installed on any building floor [20], supplement the daylight provided by a side window, and become the primary daylight source in deep areas of the building [21].

In the tropics, HLP should be combined with shading systems [22] to reduce high daylight intensity adjacent to the perimeter window [19, 23] and improve daylight uniformity [22]. In addition to controlling excessive daylight [13], shading systems can protect buildings from direct sunlight and reduce glare problems [24]. Internal shading consisting of reflective light shelves and blinds was used in this study. Reflective light shelves can redirect daylight to the ceiling and improve daylight distribution [25], whereas blinds can reduce luminance contrast. The combination of LS and partial blinds at a height of 1.20 m is an effective shading design for office buildings in the tropics [26].

Figure 1 shows the design of an office room with an HLP, light shelves, and blinds. The aperture captures sunlight and daylight using a fixed mirror system. The pipe transports daylight through multiple specular reflections, and the opening distribution distributes daylight through the translucent glass. Internal shading consists of light shelves that redirect sunlight to the ceiling for better daylight distribution [27] and blinds that control direct sunlight [28].



(a)



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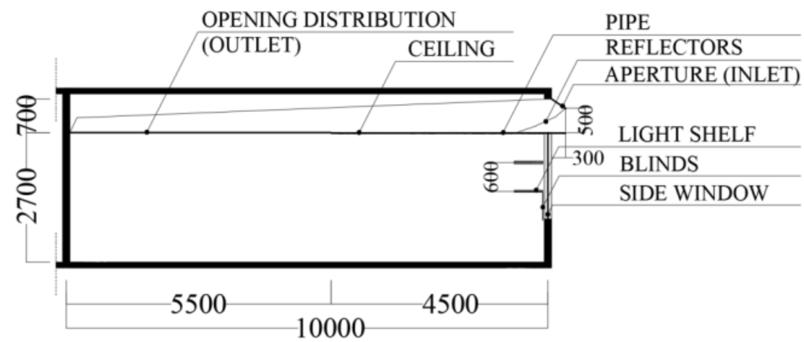


(c)

Figure 1. Office Room with horizontal light pipe and shading systems (a) perspective (b) plan and (c) section [22]

Previous research on HLP has mainly focused on improving its efficiency in capturing, transporting, and distributing daylight. This research includes modification of the HLP geometry and utilization of reflectors [21, 29]; laser cut panels at the aperture and opening distribution [30, 31]; anidolic daylighting systems [12, 19], active reflectors [18], egg-crate reflectors [32], and mirror systems [20]. In this research, building geometry, which is one of the design aspects that significantly affects the daylight and energy performance of a building [33], is studied.

Building geometry is one of the most essential architectural decisions made in the early design stage (Fang & Cho, 2019). Exploring design possibilities in the early design stages, including building geometry, is important. Building geometry and fenestration selections significantly impact energy uses, making them a key area of attention for performance enhancements to reach low or zero-net energy buildings (Konis et al., 2016). Building geometry determines the quality of light distribution (Egan & Olgyay, 2002).

Earlier studies on building geometry commonly focused on thermal performance [34, 35, 36] and energy performance [37, 38]. Earlier investigations concerning daylight performance concentrated on fixed building geometries. The design variables of these studies included the window-to-wall ratio, window orientation, wall reflectance [39], window type, and window-to-wall ratio [40].

Previous studies on daylight performance evaluation and building geometry have focused on buildings with skylights [33], side window strategies [41], and shading [42,43] in non-tropical areas. Building geometry influences daylight performance differently for different climate zones (Fang & Cho, 2019). Studies on building geometry concerning daylight performance in the tropics are limited, particularly those integrating HLP as a light transport system.

This study focuses on building aspect ratio, the ratio between the building length and width [34], as one of the design variables of building geometry. Building aspect ratio is one of the most important factors daylight performances (Fang & Cho, 2019; Kibert, CJ, 2008). This study evaluates the impact of the aspect ratio of buildings implementing HLP and shading systems on daylight performance. The optimum aspect ratio of building implementing HLP and shading systems which has the highest daylight factor, uniformity daylight factor and useful daylight illuminance were also presented. The study location is Surabaya (7°21` S, 112°36' E), a city in the Tropics. The research will provide valuable information for architects in designing the geometry of building integrating HLP and shading system in early design stages. The integration of HLP and shading systems in different building aspect ratio can contribute to enhanced daylight performance.

2. Sky Condition of Surabaya

Surabaya, Indonesia, is one of the cities in the Tropics. The tropical sky is predominant with the intermediate sky, which means it is neither overcast nor clear [12, 13]. The following section focuses on the determination and classification of three sky conditions: overcast, intermediate, and clear sky in Surabaya, using the sunshine duration method [44].

Sunshine duration data from 2016-2020 measured at the Tanjung Perak II Station of Indonesia's Meteorological, Climatological, and Geophysical Agency in Surabaya were analyzed. Figure 2 shows Surabaya's solar radiation data profile from 2016-2020. The profile indicates that the shortest average sunshine duration occurred in December, as high as 49.3%. The longest average sunshine duration was observed in August, as high as 92%. The average sunshine duration in Surabaya from 2016-2020 was 72.3%.

Relative sunshine duration is the ratio of the sunshine duration to the maximum possible duration in a certain period [44]. The monthly mean value of the relative sunshine duration (σm) is employed to estimate the probability of occurrence of the clear (Pcl), intermediate (Pin), and overcast sky (Poc). The equations for the monthly probabilities of the occurrence of clear, intermediate, and overcast skies are:

$$Pcl = \frac{5.689}{1.054 - \frac{\sigma m}{100}} - 5.397 \quad (1)$$

$$Pin = \frac{100\text{-}5.689}{1.054 - \sigma m/100} - \frac{78.629}{0.551 + \frac{\sigma m}{100}} \quad (2)$$

$$Poc = \frac{78.629}{0.551 + \sigma m/100} - 50.649 \quad (3)$$

where:

Pcl (%) = monthly probability of occurrence of clear sky

Pin (%) = monthly probability of occurrence of intermediate sky

Poc (%) = monthly probability of occurrence of overcast sky

σm (%) = monthly mean value of relative sunshine duration

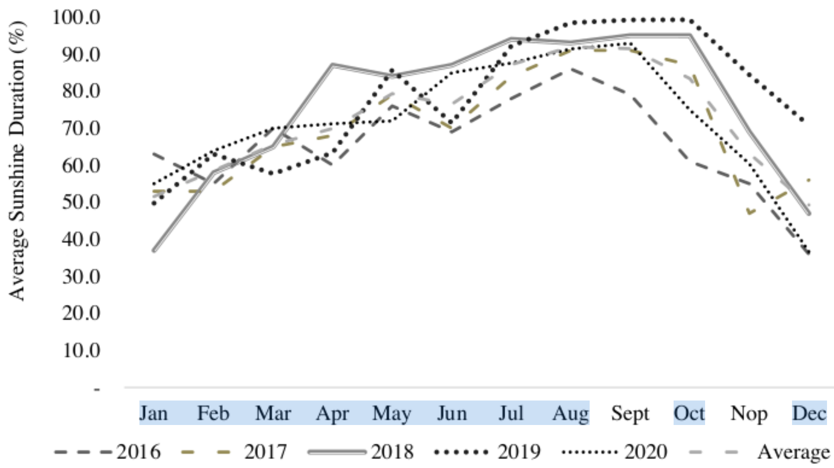


Figure 2. Average Sunshine Duration of Surabaya [45]

Figure 3 shows the average sunshine duration and the estimated probability of occurrence of clear, intermediate, and overcast sky conditions. The yearly relative frequency of occurrence of overcast (Poc), intermediate (Pin), and clear sky (Pcl), corresponding to the working period in Surabaya, were 11.9%, 72.1%, and 16.1%, respectively. The intermediate sky had the highest probability of occurrence of sky conditions in Surabaya. These results align with the previous study about sky conditions in the Tropics [13].

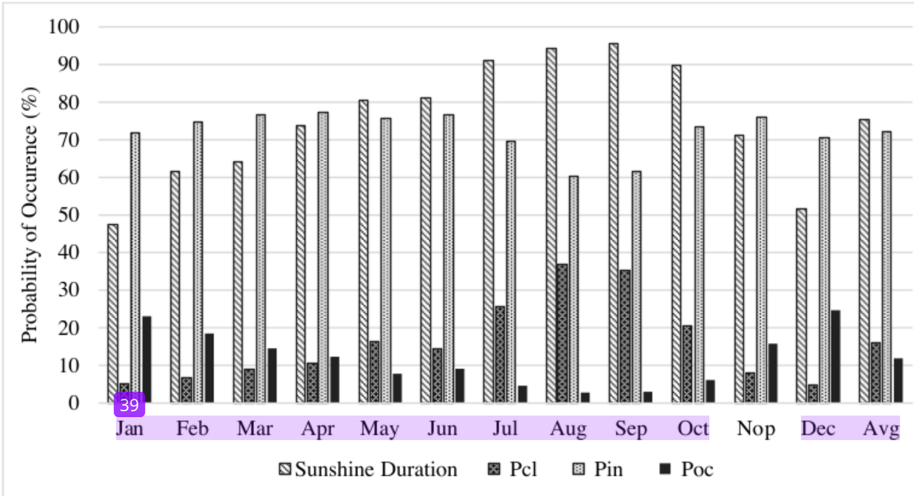


Figure 3. The average sunshine duration and the estimated probability of occurrence of clear, intermediate, and overcast sky conditions

3. Methodology

The method of the research was experimental, using simulation as a tool. Integrated Environment Solution-Virtual Environment (IES-VE) daylight simulation was used to study the daylight performance of various aspect ratios of buildings implementing HLP and shading systems. The IES-VE is based on radiance, which uses a raytracing calculation method and considers surface transmission, reflection, and refraction values [13,19]. Radiance has been extensively validated and is an unbiased daylight simulation tool [46]. IES-VE is stable, tested, and based on validated Building Performance Simulation results [47]. IES-VE is widely used worldwide and can simulate various daylighting systems and lighting design features.

IES-VE has been validated in previous research on HLP [19], dynamic internal light shelves [13], light shelves, anidolic systems, translucent materials, light shelves with external reflectors [48], light shelves, external horizontal louvers, internal horizontal blinds [49], and anidolic daylighting system [12]. The correlation of the daylight factor and daylight ratio of IES-VE simulation results and physical scaled model 1:10 measurements results focusing on HLP, and dynamic internal light shelves were in the range of 0.92 to 0.95 [19] and 0.83-0.99 [13], sequentially. The root mean square error of real measurements and IES-VE simulation was less than 10% [48]. Validation studies showed that the IES-VE software is reliable for calculating daylight performance from various daylighting systems such as light pipes, light shelves, and anidolic daylighting systems in tropical areas using daylight ratio and daylight factor.

3.1 Experimental with simulation as a tool

Experimental with IES-VE simulation was employed to study the impact of geometry of building implementing HLP and shading system on daylight performance. The daylight performance of the base case, an office building implementing HLP and shading systems with an aspect ratio of 1:1, was compared with various aspect ratios of office buildings implementing HLP and shading systems. The evaluated daylight performance consisted of average daylight factor (DFav), uniformity daylight factor (UDF), and useful daylight illuminance (UDI).

The simulation employed the weather file of Juanda International Airport and used the radiance parameters, as displayed in Table 1.

Table 1. Radiance Parameters in IES-VE Simulations

Parameters	Values
Ambient bounces (-ab)	5
Ambient divisions (-ad)	2048
Ambient accuracy (-aa)	0.2
Ambient resolution (-ar)	64
Ambient super-samples (-as)	512

Figure 4 shows the office building configuration that implements HLP and shading systems. The base case was rectangular in the floor plan and had an area of 1.600 m^2. The building length and leasing depth span were 40 m and 10 m, respectively, representing a typical office building with medium-depth space [50]. The floor-to-ceiling height was 2.7 m, based on the office floor-to-floor height consideration of Kohn and Katz [51]. The office building had a single zone, a central core area of 400 m2, and an open-plan work area of 1200 m2. The office building was oriented to the north.

A typical office building floor was divided into smaller rentable units for different tenants, consistent with previous research on high-rise offices [52]. The smallest office room had an area of 60 m^2 and employed ten workers with a minimum floor area per workstation of 6 m^2 [53]. The building core functions as a service and circulation area and was excluded from the daylight performance analysis.

The side window in the office building had a window-to-wall ratio of 67%. The window glazing material was clear glass with a visible transmittance (VT) of 0.76. Shading systems consisting of two refective light shelves with 0.6 m in width and partial blinds (Figure 5) were integrated into office buildings as effective internal shading in the tropics [26]. Following previous study results from Lim et al. [54], modifying tinted glazing to clear glass VT 0.75, external shading devices, light shelves, and blinds can significantly increase the daylight quantity and quality in office buildings in the tropics.

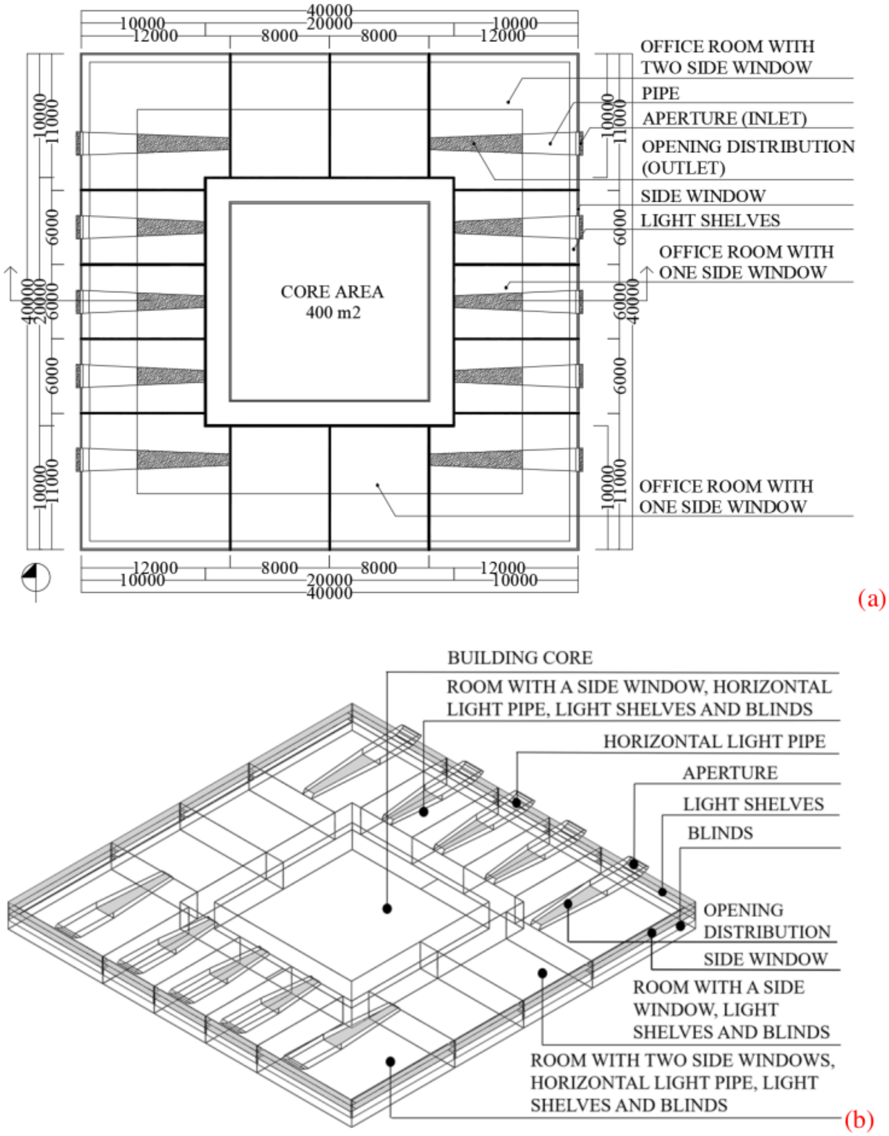


Figure 4. Geometrical parameters of the base-case office building implementing horizontal light pipe and shading systems

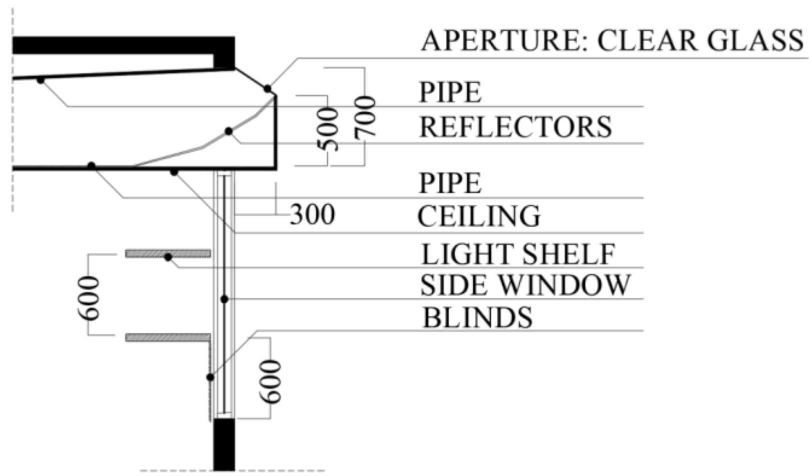


Figure 5. The aperture of horizontal light pipe and shading systems

HLP was integrated into the building with an aperture-oriented east or west, following its best orientation in the tropics [15]. The width, length, and height of HLP were 2 m, 10 m, and 0.7 m, respectively. The aperture of HLP collects sunlight from the building façade (Figure 5) and transfers it through the pipe with a highly specular material on its inner surface. The aperture is equipped with reflectors to redirect the incoming sunlight to minimize inter-reflections within the pipe and to maximize the system efficiency (Hansen, 2006; Beltran et al., 1997). The opening distribution emits daylight through a transparent glass. No daylight is distributed through the HLP at a distance of 0 to 4.5 m from the side window to maximize its efficiency and daylight distribution within the space. The HLPs were placed every 6 m to uniformly illuminate the open-plan office space, in line with previous research by Beltran [21].

Figure 6 shows the location of sensor points in the building plan. The height of sensor points is 0.8 m above the floor (work plane) with a grid of 1 m x 1 m. UDI is based on work-plane illuminances (Nabil & Mardaljevic, 2006) and considers daylight “useful” if all work-plane sensor points simultaneously within the 100-2000lx range

(Nabil & Mardaljevic, 2005). The occupancy hours used are 3650 for the period of 8:00-18:00 for the entire year.

There are three types of office rooms in terms of daylighting access: an office room with a side window, HLP, and shading systems; an office room with two side windows, HLP, and shading systems; and an office room with a side window and shading systems (Figure 7). The office room with a side window, HLP, and shading systems facing the east or west, whereas the office room with two side windows and shading systems facing the north or south.

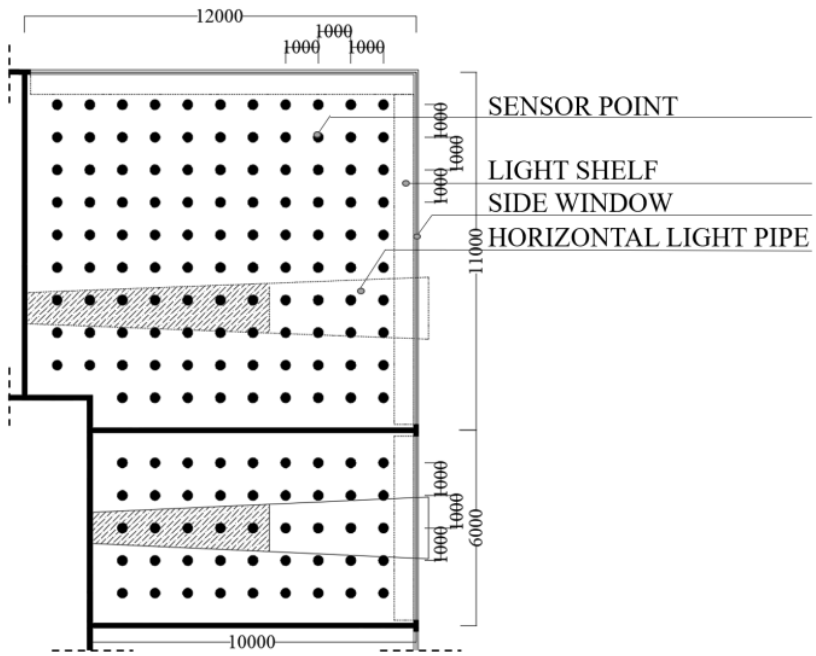


Figure 6. Sensor points in building

For the same building, core, and work area, the building aspect ratio varied from 1:1 to 2.1:1 (Figure … and Table 2). The maximum aspect ratio was 2.1:1, considering the maximum lease span for office function without a single tenant group [55] and daylight attenuation by increasing HLP length with a static reflector [12]. Cases AR 1.1:1 to AR 2.1:1 were buildings with an increased aspect ratio along the east-west axis, whereas cases AR 1:1.1 to 1:2.04 were buildings with an increased aspect ratio along the north-south axis.

All cases were modeled in the IES-VE to analyze daylight using a 1x1 m grid. The height of the analysis grid was 0.8 m above the floor. The materials and surface properties of the office room, side window, HLP, and shading systems are summarized in Table 3. The impact of the aspect ratio of building implementing HLP and shading system on daylight performance was then analyzed using regression analysis through SPSS software.

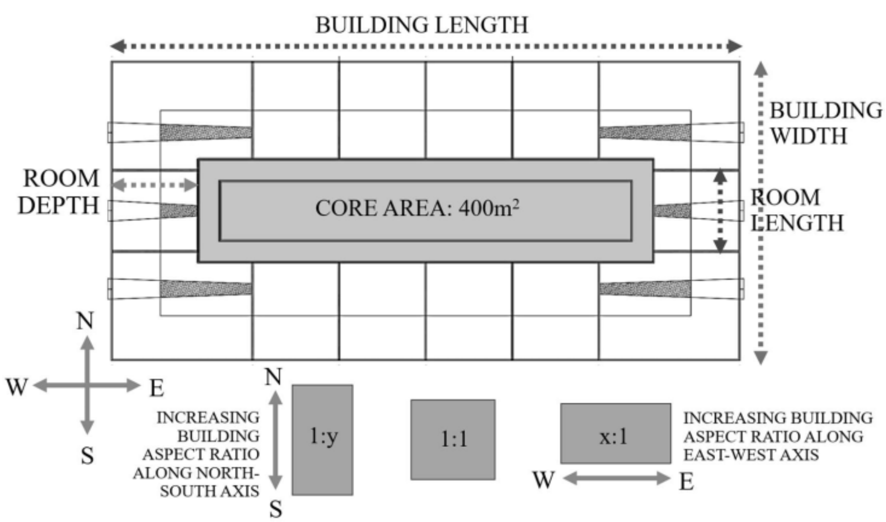


Figure 7. Increasing building aspect ratio along specific axis

Table 2. The configuration of base case and cases

Building parameters	Base Case	AR 1.1:1	AR 1.2:1	AR 1.3:1	AR 1.4:1

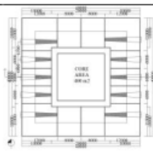
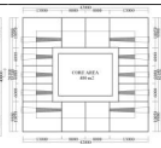
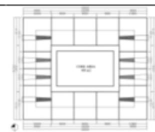
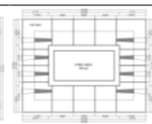
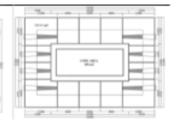
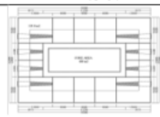
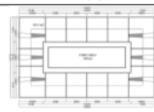
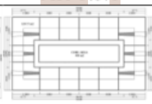
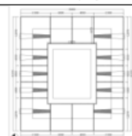
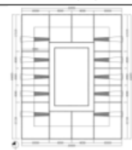
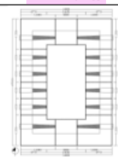
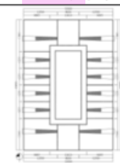
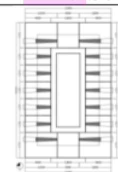
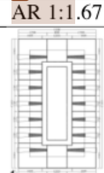
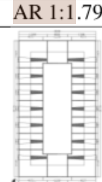
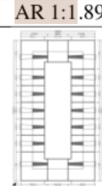
					
length (m)	40	42	44	46	48
width (m)	40	38.1	36.4	35	33.3
aspect ratio	1:1	1.1:1	1.2:1	1.3:1	1.4:1
	AR 1.56:1	AR1.68:1	AR 1.8:1	AR 1.96:1	AR 2.1:1
					
length (m)	50	52	54	56	58
width (m)	32	30.8	29.6	28.6	27.6
aspect ratio	1.56:1	1.68:1	1.8:1	1.96:1	2.1:1
	AR1:1.1	AR1:1.2	AR 1:1.3	AR 1:1.47	AR 1:1.56
					
length (m)	38	36	34	33	32
width (m)	42.1	44.4	47	49	50
aspect ratio	1:1.1	1:1.2	1:1.3	1:1.47	1:1.56
	AR 1:1.67	AR 1:1.79	AR 1:1.89	AR1:2.04	
					
length (m)	31	30	29	28	
width (m)	52	53	55	57	
aspect ratio	1:1.67	1:1.79	1:1.89	1:2.04	

Table 3. Materials and surface properties in IES-VE simulation

Elements	Materials	Reflectance (%)	Specularity	Roughness	Visible Transmittance
Interior wall	Plastic: white paint	0.75	0.00	0.02	N/A
Interior ceiling	Plastic: white paint	0.75	0.00	0.00	N/A
Interior floor	Plastic: light grey	0.45	0.00	0.03	N/A
Light pipe inner surfaces	Metal: mirror acrylic	0.85	0.90	0.02	N/A
Light pipe's aperture	Clear glass	N/A	N/A	N/A	0.88

Light pipe's opening distribution	Clear glass	N/A	N/A	N/A	0.85
Light shelf	Metal: mirror acrylic	0.85	0.90	0.02	N/A
Blinds	Plastic	0.40	0.04	0.03	N/A
Side window	Clear glass	N/A	N/A	N/A	0.76

3.2 Daylight Metrics

Three daylight metrics were evaluated to study the impact of the aspect ratio of buildings implementing HLP and shading systems. The daylight performance analysis included the average daylight factor (DFav), uniformity daylight factor (UDF), and useful daylight illuminance (UDI). DFav was used to evaluate the daylight quantity. Building aspect ratio, one of the building geometry parameters, impacts DF [56]. In an office building, evaluation of daylight distribution, which has a strong relationship with visual comfort and describes daylight quality [57], is essential. The daylight distribution was assessed by using the uniformity of light. UDI, one of the dynamic daylight performance metrics, was then used to evaluate daylight sufficiency during occupied hours in the year.

The DF (Eq.4) is the ratio between indoor (Ei) and exterior illuminance (Eo) in an unshaded area under CIE standard overcast sky conditions [58]. The average daylight factor (DFav) is the mean DF at all sensor points placed on the work plane height, 0.8 m above the floor. The recommended DF range for workspaces is 2-5% (British Council for Offices Guide in 6). Rooms with an average DF of less than 2% will look gloomy, and a room with a DF of more than 5% appear very bright [59].

$$DF= \frac{Ei}{Eo} x100\% \qquad (4)$$

The uniformity DF (Eq.5) shows the degree of homogeneity in the light distribution [60]. UDF value is determined by dividing the minimum DF value (DF min) by the average DF value for the entire room (DFav). The UDF required for the working environment should be a minimum of 0.4 [61].

$$\text{UDF}= \frac{\text{DF min}}{\text{DF avg}} \tag{5}$$

Useful Daylight Illuminance (UDI)$_{100\text{-}2000lx}$ is the percentage of occupied hours in the year with daylight illuminance within the range of 100-2000lx (Eq.6) [62]. UDI is a climate-based daylight analysis based on daylight due to multiple sky conditions in the occupied hours of the year in specific geographical locations [63].

$$\text{UDI}_{\ 100\text{-}2000lx}= \frac{t100\ lx\leq E\leq 2000\ lx}{T} x100\% \tag{6}$$

where t is the duration of daylight illuminance (E) ranging from 100-2000lx, and T is the total number of occupied hours in the year.

Daylight illuminances higher than 2000lx (UDI exceed) tend to produce thermal or visual discomfort, whereas illuminances lower than 100lx are considered insufficient as the only source of illumination [5]. Daylight illuminances in the range of 100-500lx (UDI supplementary) and 500-2000lx (UDI autonomous) are considered effective in complementing electric lighting and are sufficient as a main source of illumination, sequentially [56]. The minimum criteria of UDI$_{100\text{-}2000lx}$ are 50% [39, 64].

4. Results and Discussion

4.1 Daylight performance results and analysis

4.1.1 Average Daylight Factor Analysis

The simulation results showed that all cases had a DFav level of 3.14% to 3.74%. The base case, with a building aspect ratio of 1:1, exhibited the lowest average DF level of

3.14%. Office building AR 1:2.04 had the highest average DF level of 3.74% (Figure 8). The average DF level of all cases was within the recommended DF range for workspaces of 2-5%.

Figure 9 shows the percentage of the DFav improvement in the cases compared to the base case. The results showed that buildings implementing HLP and shading systems with higher aspect ratios had a higher DFav level. A higher building aspect ratio implies that the building perimeter form is extended, allowing daylight to reach most building spaces and increasing the total daylighting area. These results align with previous research [33], showing that larger building aspect ratios have a higher daylight performance in a hot climate. Following a previous study [12], the increase in the building aspect ratio also indicates a reduction in the HLP length in rooms oriented east and west, improving daylight levels within the space.

Increasing the aspect ratio of the building implementing HLP and shading systems along the north-south axis resulted in a more significant improvement in DFav than that along the east-west axis. The percentage of DFav improvement ranged from 5.73% to 18.47% in building elongated along the east-west axis and from 7.32% to 19.11% in buildings elongated along the north-south axis. Building AR 1:2.04, which was elongated along the north-south axis, significantly improved the DFav more than building AR 1.96:1, which was elongated along the east-west axis. The improvements in the DFav of building AR 1:2.04 and AR 1.96:1 were as high as 19.11% and 17.2%, respectively. With a similar building aspect ratio, building AR 1:2.04 has a higher perimeter area that receives daylight from the east and west and a higher HLP integrated into buildings than building AR 1.96:1.

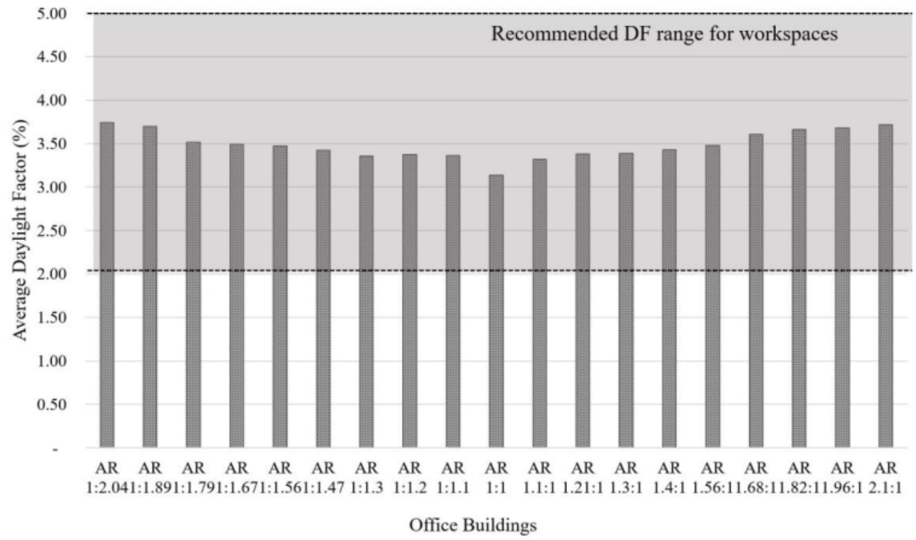


Figure 8. Average Daylight Factor of office buildings with various building aspect ratio

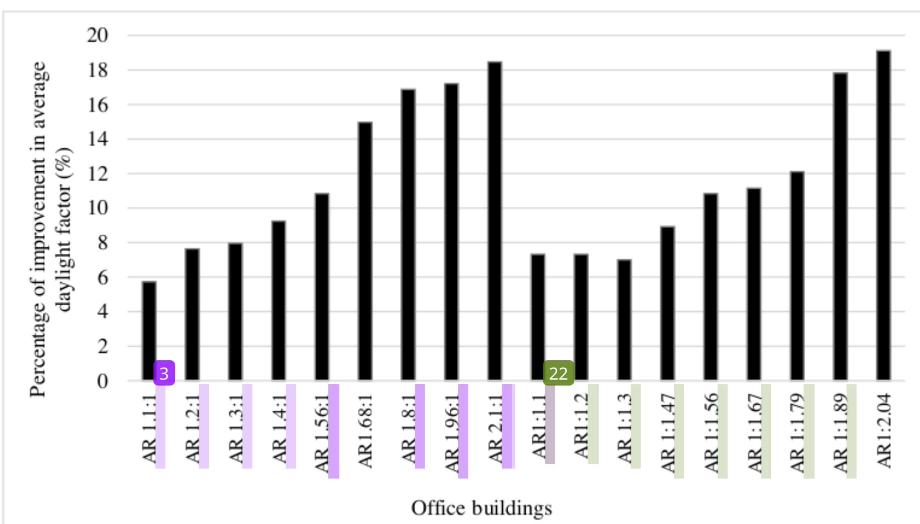
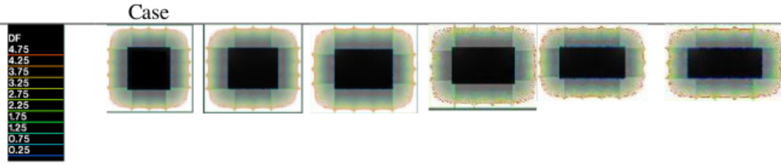
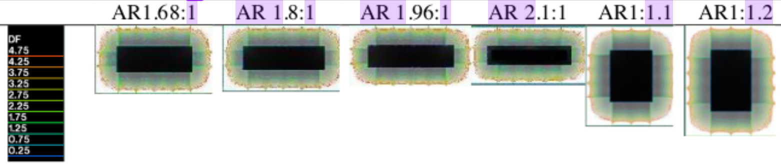


Figure 9. Percentages of average daylight factor improvement of office buildings with a different aspect ratio

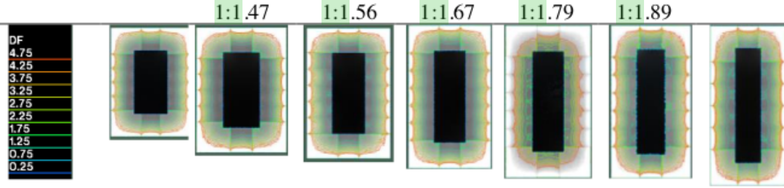
Table 4 summarizes the DF comparison between the base case and cases. Office building AR 2.1:1, which had an aspect ratio of 2.1:1, had the highest percentage of sensor points with a DF level of 2-5%, which reached as high as 50.3%. The lowest percentage of sensor points with a DF level of 2-5% was in the base case, which reached 31.34%.

The increase in the building aspect ratio along the east-west axis results in a slightly higher percentage of sensor points with a DF level of 2-5% than along the north-south axis. With a similar building aspect ratio, office building AR 1:2.04, which was elongated along the north-south axis, had a lower percentage of sensor points with a DF level of 2-5% than building AR 1.96:1, which was elongated along the east-west axis. The percentage of sensor points with a DF level of 2-5% for buildings AR 1:2.04 and AR 1.96:1 were 47.9% and 50.1%, respectively. With a similar building aspect ratio, building AR 1:1.96 has a higher perimeter area that receives daylight from the north and south than building AR 1:2.04.

Table 4. Daylight factor comparison between the base case and all cases

		Base Case	AR 1.1:1	AR 1.2:1	AR 1.3:1	AR 1.4:1	AR 1.56:1
							
Daylight Factor (DF)	maximum	9.7	10.2	10	9.9	10.7	10.2
	minimum	0.8	0.8	0.8	0.8	0.9	0.9
	average	3.14	3.32	3.38	3.39	3.43	3.48
	uniformity	0.36	0.35	0.35	0.35	0.39	0.38
Percentage of changes in DF	maximum	0	5.15	3.09	2.06	10.31	5.15
	minimum	0	0	0	0	12.5	12.5
	average	0	5.73	7.64	7.96	9.24	10.83
	uniformity	0	-2.78	-2.78	-2.78	8.33	5.56
Percentage of sensor points with DF level 2-5%		45.6	44.2	42.9	44	44.1	45.34
		AR1.68:1	AR 1.8:1	AR 1.96:1	AR 2.1:1	AR1:1.1	AR1:1.2
							
Daylight Factor (DF)	maximum	10.6	10.6	10.5	10.3	10.5	10.3
	minimum	0.9	0.9	0.9	1	0.8	0.8
	average	3.61	3.67	3.68	3.72	3.37	3.37

	uniformity	0.38	0.41	0.40	0.41	0.33	0.34
Percentage of changes in DF	maximum	9.28	9.28	8.25	6.19	8.25	6.19
	minimum	12.5	12.5	12.5	25	0	0
	average	14.97	16.88	17.20	18.47	7.32	7.32
	uniformity	5.56	13.89	11.11	13.89	-8.33	-5.56
Percentage of sensor points with DF level 2-5%		46.9	49.24	50.1	50.3	43.61	45.12

		AR 1:1.3	AR 1:1.47	AR 1:1.56	AR 1:1.67	AR 1:1.79	AR 1:1.89	AR1:2.04
								
Daylight Factor (DF)	maximum	10.2	10.7	10.1	10.3	10.1	10.6	10.8
	minimum	0.8	0.8	1	0.9	0.9	1	1
	average	3.36	3.42	3.48	3.49	3.52	3.70	3.74
	uniformity	0.35	0.37	0.38	0.38	0.38	0.40	0.40
Percentage of changes in DF	maximum	5.15	10.31	4.12	6.19	4.12	9.28	11.34
	minimum	0	0	25	12.5	12.5	25	25
	average	7.01	8.92	10.83	11.15	12.10	17.83	19.11
	uniformity	-2.78	2.78	5.56	5.56	5.56	11.1	11.11
Percentage of sensor points with DF level 2-5%		45.05	45	45.2	46.8	48.7	49.8	47.9

4.1.2 Uniformity Daylight Factor Analysis

Figure 10 shows the UDF values of office buildings with different aspect ratios. The results showed that the base case had a UDF value of 0.36, below the required UDF for the working environment, which should be at least 0.4. Only five buildings had UDF ≥0.4, i.e., buildings AR 1.8:1, AR 1.96:1, AR 2.1:1, AR 1:1.89, and AR1:2.04.

Buildings implementing HLP and shading systems with UDF≥0.4 had a high building aspect ratio. A high building aspect ratio results in a higher daylight level [41]. The contrast between the daylight level in the area far from the side window and the area near the side window decreased, reducing the visual problem.

Increasing the building aspect ratio along the east-west axis resulted in a more significant improvement in UDF than the north-south axis. The UDF improvement in buildings elongated along the east-west axis was 8.33%-13.89% for buildings AR 1.4:1-

AR 2.1:1. The percentages of UDF improvement of buildings elongated along the north-south axis were 2.78% to 11.11% for buildings AR 1:1.47 to AR1:2.04. The building elongated along the east-west axis has a larger perimeter area that receives daylight from the north and south. Following previous research [52], diffused illuminance was the primary daylight source for the north and south-facing side windows, resulting in a more uniform daylight distribution.

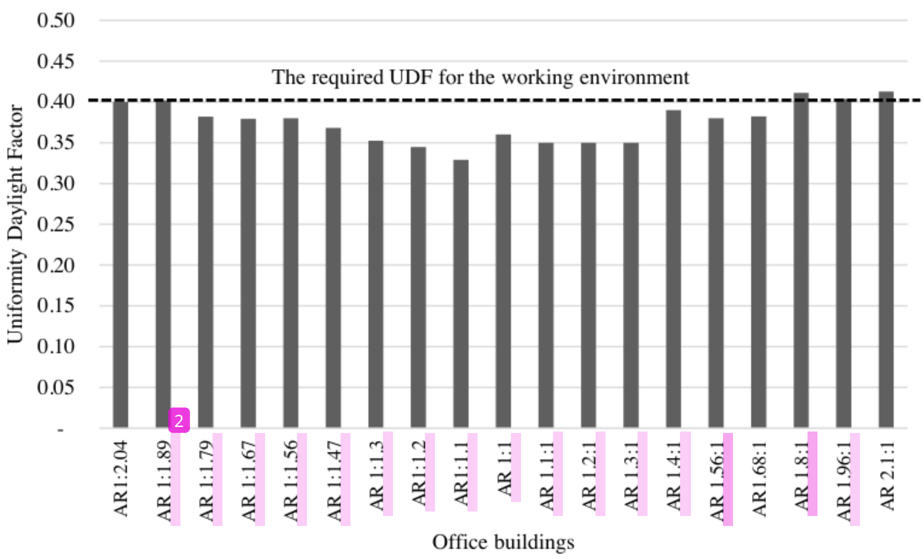


Figure 10. Uniformity daylight factor of office buildings with different aspect ratio

4.1.3 Useful Daylight Illuminance Analysis

Figure 11 shows the UDI of office buildings extended along the east-west axis. Figure 12 shows the UDI of office buildings elongated along the north-south axis. All office buildings with different aspect ratios had a UDI$_{100-2000lx}$ in the 83-95% range and were above the minimum criteria of UDI$_{100-2000lx}$. These results showed the reliability of HLP and shading systems in maintaining room lighting with UDI$_{100-2000lx}$ for over 50% of occupied hours in a year. The simulation results also showed that all buildings had no percentages of UDI fell-short (<100lx) of the working year.

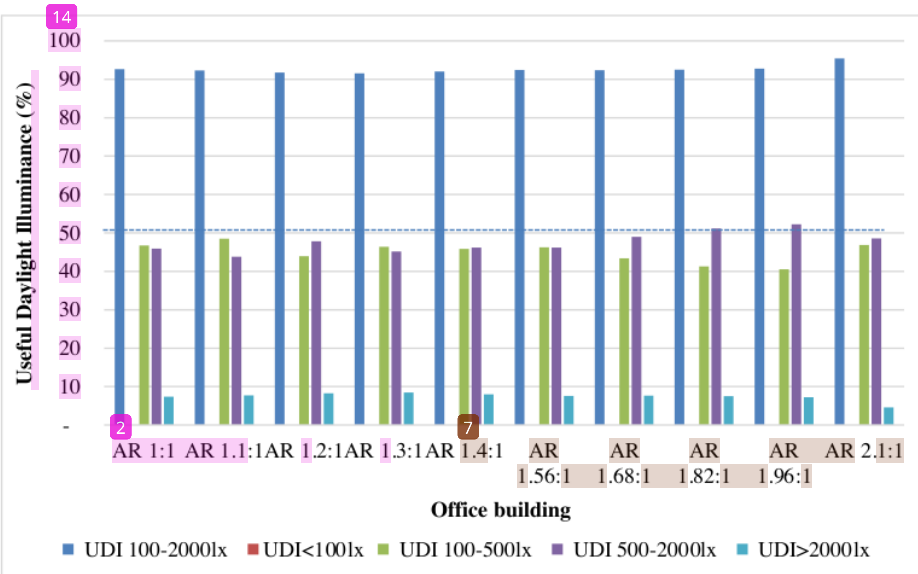


Figure 11. Useful daylight illuminance of office buildings elongated to the east-west axis

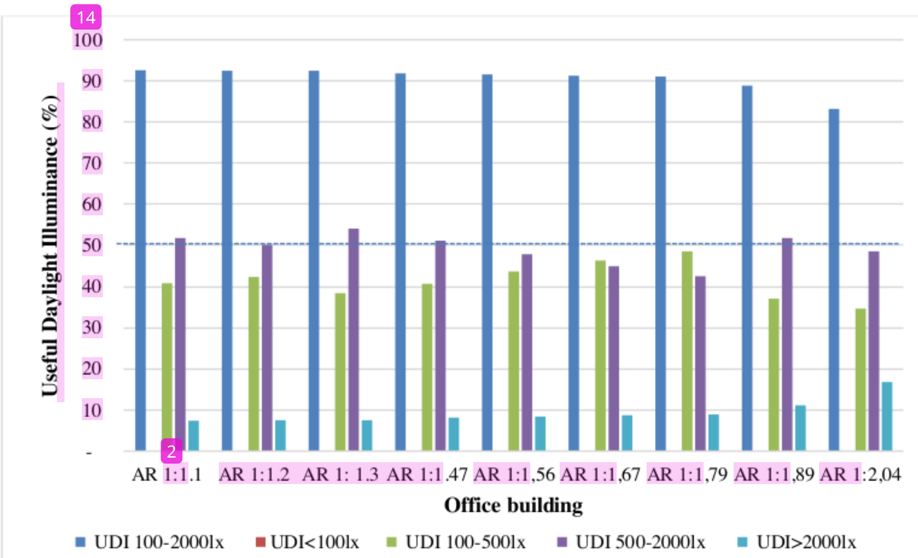


Figure 12. Useful daylight illuminance of office buildings elongated to the north-south axis

Office building AR 1: 2.04 elongated along the north-south axis had the lowest $UDI_{100\text{-}2000lx}$ value, as high as 83% of the work year. Office building AR 2.1:1 elongated along the east-west axis had the highest $UDI_{100\text{-}2000lx}$ value, which reached up to 95% of the working year. With a similar aspect ratio, office buildings elongated along the east-west axis had a higher $UDI_{100\text{-}2000lx}$ value than those elongated along the north-south axis. The reason is that office building AR 1: 2.04, elongated along the north-south axis, had a larger opening area facing east and west than office building AR 2.1:1, elongated along the east-west axis.

With a similar building aspect ratio, office building AR 1:2.04 elongated along the north-south axis had a higher UDI exceed (>2000lx) than office building AR 2.1:1 elongated along the east-west axis, as high as 16.8% and 4.6% of the working year, respectively. The office building elongated along the north-south axis had a larger opening area facing east and west than the office building AR 2.1:1, which elongated along the east-west axis.

Office buildings implementing HLP and shading systems had UDI100-500lx in the range of 35-49% of the working year. At those times, daylight illuminance is considered adequate as the primary source of room illumination or in combination with electric lighting [62]. Office building AR 1:2.04 elongated along the North-South axis had the lowest UDI100-500lx, which reached up to 35% of the working year. Office building AR 1.1:1 and AR 1:1.79 had the highest UDI100-500lx, as high as 49% of the work year.

Office buildings implementing HLP and shading systems had UDI autonomous (500-2000lx) in 43-54% of the working year. These results indicated that daylight illuminance was perceived as desirable or at least tolerable at 43-54% of the occupied hours in a year. Office building AR 1:1.3 had the highest UDI500-2000lx, which reached up to 54% of the work year. Office building AR 1:1.79 had the lowest UDI500-2000lx, as high as 43% of the working year.

4.2 *The Impact of Building Aspect Ratio on Daylight Performance*

The impact of the building aspect ratio on DFav, UDF, and $UDI_{100\text{-}2000lx}$ was analyzed using regression analysis. Figure 13 shows a regression analysis plot of the building aspect ratio and daylight performance. Figure 13 shows the DFav and UDF as a function of the building aspect ratio.

The regression analysis of the building aspect ratio with the DFav shows that the building aspect ratio strongly influences the DFav, with the coefficient of determination as high as 0.9089 (Figure 13). A linear relationship between the DFav and building aspect ratio can be obtained, as follows:

$$DFav = 0{,}463x + 2{,}7731 \quad (7)$$

With every 0.1 increase in the building aspect ratio, the average DF is expected to increase by a linear difference of 2.82%. This equation is valid only in this case, a building that implements HLP and shading systems.

The analysis also indicated that the building aspect ratio strongly influences the UDF, with a coefficient of determination as high as 0.7973. A linear relationship between the uniformity DF and building aspect ratio can be obtained as follows:

$$UDF = 0{,}0656x + 0{,}2731 \quad (8)$$

With every 0.1 increase in the building aspect ratio, the uniformity DF is expected to increase by a linear difference of 0.28. This equation is valid only in this case, which is a building that implements HLP and shading systems.

As one may expect, the results indicated that the higher the building aspect ratio, the higher the DFav of the entire building (Figure 13). The higher the building aspect ratio, the larger perimeter receives daylight. These results align with Lee et al. [41] that the longer the building length compared to the building width, the higher the daylight availability. In office buildings with integrated HLP and shading systems, increasing the building aspect ratio from 1:1 to 2.1:1 will increase the average DF of the entire building by 18.47%.

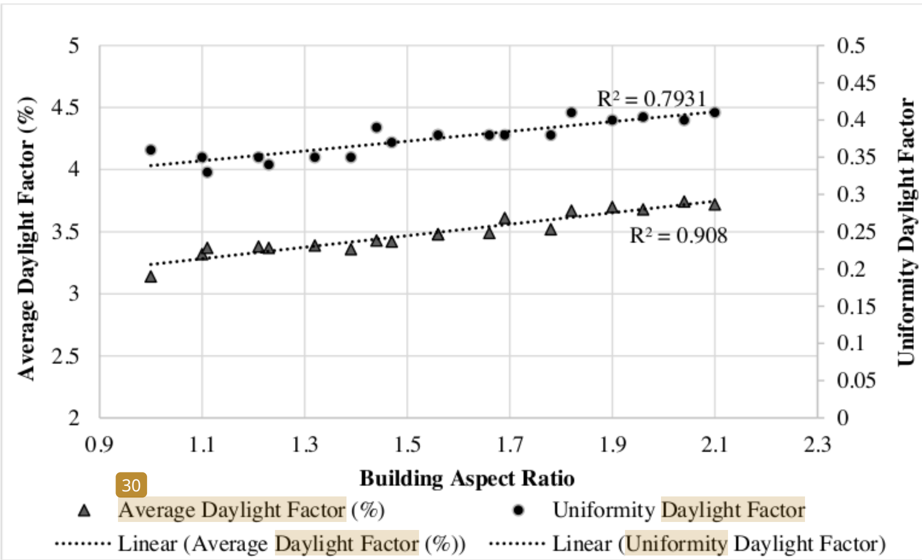


Figure 13. The relationship of building aspect ratio with average daylight factor and uniformity daylight factor

The regression analysis also showed that the higher the aspect ratio of the building integrating HLP and shading systems, the higher the UDF value. Office building with an aspect ratio of 2.1:1 has a higher UDF than office building with an aspect ratio of 1:1. The UDF improvement of office buildings with an aspect ratio of 2.1:1 reached 17.2% compared to office buildings with an aspect ratio of 1:1.

The higher aspect ratio means that the building becomes narrower in plan and reduces **room depth**. The increase in the UDF level as the building aspect ratio increases aligns with previous research by Lee et al. [41] that the smaller the room depth, the more daylight intensity enters the room. A higher building aspect ratio results in a higher daylight level [41]. The contrast between the daylight level in the area far from the side window and the area near the side window then decreased, resulting in a more uniform daylight distribution, which, in this research, is characterized by an increase in UDF value.

Figure 14 shows the $UDI_{100\text{-}2000lx}$ as a function of the building aspect ratio. The regression analysis for the aspect ratio of the building elongated along the east-west axis (Figure 14a) with $UDI_{100\text{-}2000lx}$ shows that the building aspect ratio has a weak influence on the $UDI_{100\text{-}2000lx}$, with a coefficient of determination of 0.4052 (Figure 14a). A linear relationship between the building aspect ratio and $UDI_{100\text{-}2000lx}$ can be obtained as follows:

$$UDI_{100\text{-}2000lx} = 1.8164x + 89.832 \qquad (9)$$

With every 0.1 increase in the building aspect ratio, $UDI_{100\text{-}2000lx}$ is expected to increase by a linear difference of 90.01. This equation is valid only in this case, a building that implements HLP and shading systems.

The regression analysis for the aspect ratio of a building elongated along the north-south axis (Figure 12b) with $UDI_{100\text{-}2000lx}$ shows that the building aspect ratio moderately influences $UDI_{100\text{-}2000lx}$, with a coefficient of determination of 0.6373 (Figure 12b). A linear relationship between the building aspect ratio and $UDI_{100\text{-}2000lx}$ is obtained as follows:

$$UDI_{100\text{-}2000lx} = -7.4997x + 102.28 \qquad (10)$$

With every 0.1 increase in the building aspect ratio, $UDI_{100\text{-}2000lx}$ is expected to decrease by a linear difference of 101.53. This equation is valid only in this case, buildings that implement HLP and shading systems.

Unlike the DF trends, improving the aspect ratio of buildings elongated along the north-south axis decreases the $UDI_{100\text{-}2000lx}$. The improvement in the aspect ratio of buildings elongated along the north-south axis increases the building area's side window facing west, which causes an increase in the UDI exceed (>2000lx) and a decrease in the $UDI_{100\text{-}2000lx}$. In contrast, improving the aspect ratio of buildings elongated along the east-west axis slightly improves $UDI_{100\text{-}2000lx}$, caused by the reduction of the building area's side window facing west.

In this research, the $UDI_{100\text{-}2000lx}$ trends are influenced more by the percentages of UDI>2000lx, where all office buildings had no percentage of occupied hours in the year with daylight illuminance <100lx. Area with an illuminance level of more than 2000 lx is located on office rooms facing West. In line with previous research [Boubekri and Lee, 2017], a large portion of illuminance values of more than 2000 lx are excluded from the $UDI_{100\text{-}2000lx}$ calculation and makes the building that has a larger façade area facing sunlight; in this research, the West, has a lower UDI.

Using linear regression, the building aspect ratio has a relatively weak and moderate influence on UDI100-2000lx. UDI100-2000lx trends are influenced by the percentages of UDI>2000lx, where daylight illuminances higher than 2000 lx tend to produce thermal or visual discomfort and closely correlate with the Daylight Glare Probability [Boubekri and Lee, 2017]. These results align with previous research using the Annual Glaring Index, which showed that building aspect ratios have a minor impact on glaring using linear regression [Maltais and Gosselin, 2017].

In this research, the impact of building aspect ratio elongated East-West and North-South axes on $UDI_{100\text{-}2000lx}$ is weak and moderate sequentially. These results might have occurred because $UDI_{100\text{-}2000lx}$ comes from summation over the entire floor area. The building area is constant for all UDI simulations, which might lower the impact of the building aspect ratio.

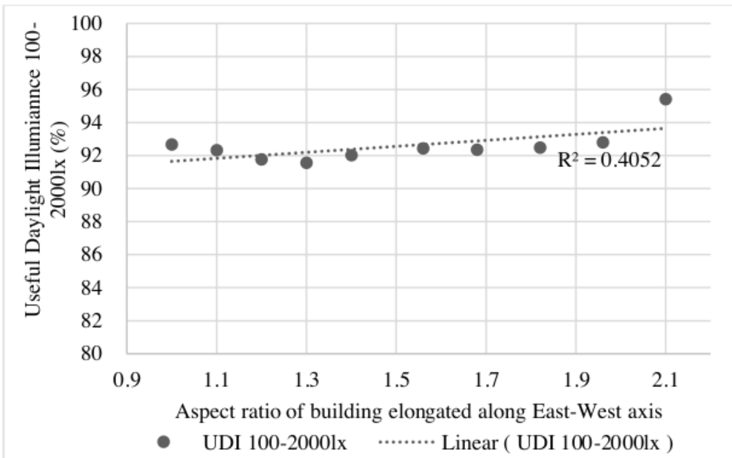
Determination of the optimum building aspect ratio involving DFav, UDF, and UDI100-2000lx showed that the optimum building aspect ratio is AR 2.1:1, which has a narrow plan and is elongated to the East-West axis. The building is 58m in length and 27.6m in width. The building has DFav, UDF, and UDI as high as 3.72lx; 0.413 and 95% of the working year, sequentially. With a similar building aspect ratio, building AR1:2.04, elongated to the North-South axis, has a lower UDI100-2000lx, as high as 83% of the working year. Building elongated along the North-South axis is not selected for the optimum building aspect ratio because although it has the highest DFav and UDF of 0.4, it has a lower $UDI_{100\text{-}2000lx}$. Considering the design of daylighting in tropical climates emphasizes controlling solar radiation entering the buildings, building elongated to the East-West axis that has a higher UDI100-2000lx than the North-South axis is selected as the optimum building aspect ratio.

These results can give an insight for building designer in determining the building aspect ratio for daylight performances in early design stages. Observing various daylight metrics, in this research DF, UDF and UDI, is important in the design phase. Previous research also stated the recommendation to observe various daylight metrics in the design phase, since they have different influence with respect to the design variables (Athahillah, 2022). These research also give

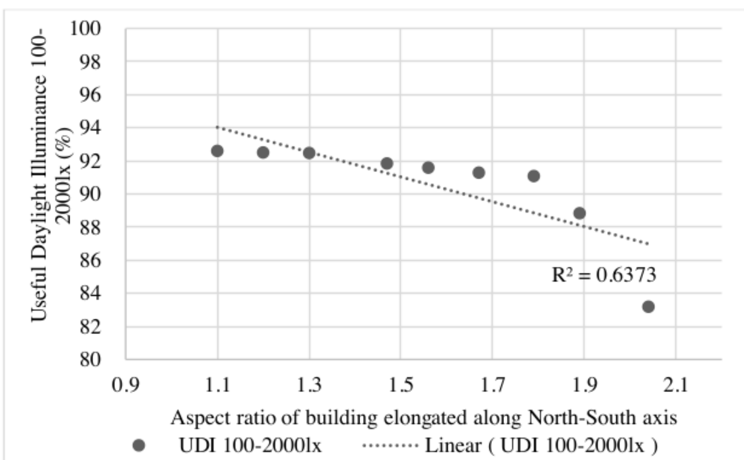
==desain office bulding darpat diperbaiki

==gap knowledge yang ditambahakan, punya practical value

Consideration of other aspects such as thermal and energy performances should be elaborated in future studies. The relationship between building aspect ratio and other design variables such as window to wall ratio, building orientation should be studied.



(a)



(b)

Figure 14. The relationship of building aspect ratio elongated along (a) east-west axis and (b) north-south axis with $UDI_{100-2000lx}$.

5. Conclusion

The impact of the aspect ratio of buildings with HLP and shading systems on daylight performance was studied. The results indicated that office buildings integrating HLP and shading systems with an aspect ratio of 1.1:1 to 1:2.04 had an average DF in the range of 2-5% and $UDI_{100\text{-}2000lx}$ in the range of 83-95%. Only five office buildings had UDF≥0.4, i.e., buildings with an aspect ratio of 1.82:1, 1.96:1, 2.1:1, 1:1.89, and 1:2.04, sequentially.

The results indicated that improving the building aspect ratio increased the average Daylight Factor and Uniformity Daylight Factor. Increasing the building aspect ratio along the north-south axis improved the average DF more than along the east-west axis. Increasing the building aspect ratio along the north-south axis reduced the UDI100-2000lx, while increasing the building aspect ratio along the east-west axis improved the UDI100-2000lx slightly. The optimum building aspect ratio involving DFav, UDF, and UDI100-2000lx then showed that the optimum building aspect ratio is AR 2.1:1, which has a narrow plan and is elongated to the East-West axis.

Future research can involve other design variables, such as building orientation and window-to-floor ratio. Future studies should also focus on the energy and thermal performance of buildings integrating HLP and shading systems. The daylight and energy optimization of buildings implementing HLP and shading systems can also be investigated. Considering the importance of users' psychological aspects, user perceptions of buildings implementing HLP and shading systems can also be included.

Funding Details

The authors report no funding.

Declaration of Competing Interest

The authors declare that they have no competing interests that could have appeared in work reported in this paper.

References

[1] Chi, Doris A., David Moreno, and Jaime Navarro. 2018. "Correlating Daylight Availability Metric with Lighting, Heating and Cooling Energy Consumptions." *Building and Environment* 132 (September 2017): 170–80. https://doi.org/10.1016/j.buildenv.2018.01.048.

[2] Chen, Yuanyi, Junjie Liu, Jingjing Pei, Xiaodong Cao, Qingyan Chen, and Yi Jiang. 2014. "Experimental and Simulation Study on the Performance of Daylighting in an Industrial Building and Its Energy Saving Potential." *Energy and Buildings* 73: 184–91. https://doi.org/10.1016/j.enbuild.2014.01.030.

[3] Wong, Ing Liang. 2017. "A Review of Daylighting Design and Implementation in Buildings." *Renewable and Sustainable Energy Reviews* 74 (March): 959–68. https://doi.org/10.1016/j.rser.2017.03.061.

[4] Li, D. H.W., J. C. Lam, and S. L. Wong. 2005. "Daylighting and Its Effects on Peak Load Determination." *Energy* 30 (10): 1817–31. https://doi.org/10.1016/j.energy.2004.09.009.

[5] Boubekri, M (2014). Daylighting Design: Planning Strategies and Best Practice Solutions. Basel: Birkhauser Verlag GmbH.

[6] Alrubaih, M S, M. F.M. Zain, M A Alghoul, N. L.N. Ibrahim, M A Shameri, and Omkalthum Elayeb. 2013. "Research and Development on Aspects of Daylighting

Fundamentals.” *Renewable and Sustainable Energy Reviews*. 21, 494–505. https://doi.org/10.1016/j.rser.2012.12.057.

[7] Li, Danny H W, and Joseph C. Lam. 2003. “An Investigation of Daylighting Performance and Energy Saving in a Daylit Corridor.” *Energy and Buildings* 35 (4): 365–73. https://doi.org/10.1016/S0378-7788(02)00107-X.

[8] Boubekri, M. (2008). Daylighting, Architecture and Health. Architectural Press. https://doi.org/https://doi.org/10.1016/B978-0-7506-6724-1.00025-7

[9] Ander, G.D. (2003). Daylighting Performance and Design, 2nd Edition. New Jersey: John Wiley & Sons, Inc.

[10] Turan, Irmak, Andrea Chegut, Daniel Fink, and Christoph Reinhart. 2020. “The Value of Daylight in Office Spaces.” *Building and Environment* 168 (October 2019): 106503. https://doi.org/10.1016/j.buildenv.2019.106503.

[11] Turan, Irmak, Andrea Chegut, Daniel Fink, and Christoph Reinhart. 2021. Development of View Potential Metrics and the Financial Impact of Views on Office Rents. *Landscape and Urban Planning* 215 (November). Elsevier:104193. doi:10.1016/J.LANDURBPLAN.2021.104193.

[12] Roshan, Mohsen, and Aliyu Salisu. 2016. “Assessing Anidolic Daylighting System for efficient daylight in open plan office in the tropics”. Journal of Building Engineering, 8, 58–69. https://doi.org/10.1016/j.jobe.2016.07.002

[13] Lim, Yaik Wah, and C. Y.S. Heng. 2016. “Dynamic Internal Light Shelf for Tropical Daylighting in High-Rise Office Buildings.” *Building and Environment* 106: 155–66. https://doi.org/10.1016/j.buildenv.2016.06.030.

[14] Zain-ahmed, A, K Sopian, and Z Zainol Abidin. 2002. “The Availability of Daylight from Tropical Skies — a Case Study of Malaysia.” *Renewable Energy*, 25: 21–30. https://doi.org/10.1016/S0960-1481(00)00209-3

[15] G-Hansen, V. R. (2006). Innovative daylighting systems for deep-plan commercial buildings. Faculty of Built Environment and Engineering, Queensland University. http://eprints.qut.edu.au/16709/

[16] Urbano Gutiérrez, R., J. Du, N. Ferreira, A. Ferrero, and S. Sharples. 2019. “Daylight Control and Performance in Office Buildings Using a Novel Ceramic Louvre System.” *Building and Environment* 151 (October 2018): 54–74. https://doi.org/10.1016/j.buildenv.2019.01.030.

[17] Mayhoub, M.S. 2014. “Innovative Daylighting Systems’ Challenges: A Critical Study.” *Energy and Buildings* 80: 394–405. https://doi.org/10.1016/j.enbuild.2014.04.019.

[18] Canziani, R., F. Peron, and G. Rossi. 2004. “Daylight and Energy Performances of a New Type of Light Pipe.” *Energy and Buildings* 36 (11): 1163–76. https://doi.org/10.1016/j.enbuild.2004.05.001.

[19] Heng, C.Y.S., Yaik-Wah Lim, and Dilshan Remaz Ossen. 2020. “Horizontal Light Pipe Transporter for Deep Plan High-Rise Office Daylighting in Tropical Climate.” *Building and Environment* 171 (December 2019): 106645. https://doi.org/10.1016/j.buildenv.2020.106645.

[20] Duc Hien, V, and S Chirarattananon. 2009. “An Experimental Study of a Facade Mounted Light Pipe.” *Lighting Research and Technology* 41 (2): 123–42. https://doi.org/10.1177/1477153508096167.

[21] Beltran, L. O., E. S. Lee, and S. E. Selkowitz. 1997. "Advanced Optical Daylighting Systems: Light Shelves and Light Pipes." *Journal of the Illuminating Engineering Society* 26 (2): 91–106. https://doi.org/10.1080/00994480.1997.10748194.

[22] Elsiana, Feny, Sri Nastiti N Ekasiwi, and I Gusti Ngurah Antaryama. 2021. "Integration of Horizontal Light Pipe and Shading Systems in Office Building in the Tropics" *Journal of Applied Science and Engineering* 25 (1): 231–43.

[23] Kim, Minseok, Seung Bok Leigh, Taeyeon Kim, and Sooyoun Cho. 2015. "A Study on External Shading Devices for Reducing Cooling Loads and Improving Daylighting in Office Buildings." *Journal of Asian Architecture and Building Engineering* 14 (3): 687–94. https://doi.org/10.3130/jaabe.14.687.

[24] Luca, Francesco De, Abel Sepúlveda, and Toivo Varjas. 2022. "Multi-Performance Optimization of Static Shading Devices for Glare, Daylight, View and Energy Consideration." *Building and Environment* 217 (January): 109110. https://doi.org/10.1016/j.buildenv.2022.109110.

[25] Hashemi, Arman. 2014. "Daylighting and Solar Shading Performances of an Innovative Automated Reflective Louvre System." *Energy and Buildings* 82: 607–20. https://doi.org/10.1016/j.enbuild.2014.07.086.

[26] Lim, Yaik Wah, Mohd Hamdan Ahmad, and Dilshan Remaz Ossen. 2013. "Internal Shading for Efficient Tropical Daylighting in Malaysian Contemporary High-Rise Open Plan Office." *Indoor and Built Environment* 22 (6): 932–51. https://doi.org/10.1177/1420326X12463024.

[27] Kontadakis, Antonis, Aris Tsangrassoulis, and Lambros Doulos. 2018. "A Review of Light Shelf Designs for Daylit Environments." *Sustainability* 10(1),71.

https://doi.org/10.3390/su10010071.

[28] Gomes, M. Glória, A. J. Santos, and M. Calhau. 2022. “Experimental Study on the Impact of Double Tilted Venetian Blinds on Indoor Daylight Conditions.” *Building and Environment* 225 (April). https://doi.org/10.1016/j.buildenv.2022.109675.

[29] Beltrán, L. O. & Mogo, B. M. (2007). Development of Optical Light Pipes for Office Spaces. PLEA 2007 - The 24th Conference on Passive and Low Energy Architecture, Singapore, 22-24 November.

[30] Hansen, G., and Edmonds I. (2003). Natural illumination of deepplan office buildings: light pipe strategies. In: ISES Solar World Congress 2003, 14-19 June 2003, Göteborg, Sweden.

[31] Kwok, C. M., and T. M. Chung. 2008. “Computer Simulation Study of a Horizontal Light Pipe Integrated with Laser Cut Panels in a Dense Urban Environment.” *Lighting Research and Technology* 40 (4): 287–305. https://doi.org/10.1177/1477153508094584.

[32] Elsiana, F., F. Soehartono, and L. Kristanto. 2020. “Daylight Performance of Horizontal Light Pipe with Egg-Crate Reflector in the Tropics.” *IOP Conference Series: Earth and Environmental Science* 490 (1). https://doi.org/10.1088/1755-1315/490/1/012006.

[33] Fang, Yuan, and Soolyeon Cho. 2019. “Design Optimization of Building Geometry and Fenestration for Daylighting and Energy Performance.” *Solar Energy* 191 (July): 7–18. https://doi.org/10.1016/j.solener.2019.08.039.

[34] Inanici, Mehlika N., and F. Nur Demirbilek. 2000. “Thermal Performance

Optimization of Building Aspect Ratio and South Window Size in Five Cities Having Different Climatic Characteristics of Turkey." *Building and Environment* 35 (1): 41–52. https://doi.org/10.1016/S0360-1323(99)00002-5.

[35] Yang, Jinxin, Qian Shi, Massimo Menenti, Man Sing Wong, Zhifeng Wu, Qunshan Zhao, Sawaid Abbas, and Yong Xu. 2021. "Observing the Impact of Urban Morphology and Building Geometry on Thermal Environment by High Spatial Resolution Thermal Images." *Urban Climate* 39 (July): 100937. https://doi.org/10.1016/j.uclim.2021.100937.

[36] Li, Jiayu, Bohong Zheng, Komi Bernard Bedra, Zhe Li, and Xiao Chen. 2022. "Effects of Residential Building Height, Density, and Floor Area Ratios on Indoor Thermal Environment in Singapore." *Journal of Environmental Management* 313 (March): 114976. https://doi.org/10.1016/j.jenvman.2022.114976.

[37] Mckeen, Philip, and Alan S Fung. 2014. "The Effect of Building Aspect Ratio on Energy Efficiency." *Buildings* 4: 336–54. https://doi.org/10.3390/buildings4030336.

[38] Chen, Kian Wee, Patrick Janssen, and Arno Schlueter. 2018. "Multi-Objective Optimisation of Building Form, Envelope and Cooling System for Improved Building Energy Performance." *Automation in Construction* 94 (July): 449–57. https://doi.org/10.1016/j.autcon.2018.07.002.

[39] Mangkuto, Rizki A., Mardliyahtur Rohmah, and Anindya Dian Asri. 2016. "Design Optimisation for Window Size, Orientation, and Wall Reflectance with Regard to Various Daylight Metrics and Lighting Energy Demand: A Case Study of Buildings in the Tropics." *Applied Energy* 164: 211–19. https://doi.org/10.1016/j.apenergy.2015.11.046.

[40] Lartigue, B., B. Lasternas, and V. Loftness. 2014. "Multi-Objective Optimization of Building Envelope for Energy Consumption and Daylight." *Indoor and Built Environment* 23 (1): 70–80. https://doi.org/10.1177/1420326X13480224.

[41] Lee, Jaewook, Mohamed Boubekri, and Feng Liang. 2019. "Impact of Building Design Parameters on Daylighting Metrics Using an Analysis, Prediction, and Optimization Approach Based on Statistical Learning Technique." *Sustainability (Switzerland)* 11 (5). https://doi.org/10.3390/su11051474.

[42] Sepúlveda, Abel, Francesco De Luca, Martin Thalfeldt, and Jarek Kurnitski. 2020. "Analyzing the Fulfillment of Daylight and Overheating Requirements in Residential and Office Buildings in Estonia." *Building and Environment* 180 (April): 107036. https://doi.org/10.1016/j.buildenv.2020.107036.

[43] Maltais, Louis Gabriel, and Louis Gosselin. 2017. "Daylighting 'Energy and Comfort' Performance in Office Buildings: Sensitivity Analysis, Metamodel and Pareto Front." *Journal of Building Engineering* 14 (February): 61–72. https://doi.org/10.1016/j.jobe.2017.09.012.

[44] Rahim, Ramli, and Rosady Mulyadi. 2004. "Classification of Daylight and Radiation Data into Three Sky Conditions by Cloud Ratio and Sunshine Duration." *Energy and Buildings* 36: 660–66. https://doi.org/10.1016/j.enbuild.2004.01.012.

[45] Meteorological, Climatological, and Geophysical Agency of Surabaya

[46] Ayoub, Mohammed. 2020. "A Review on Light Transport Algorithms and Simulation Tools to Model Daylighting inside Buildings." *Solar Energy* 198 (December 2019): 623–42. https://doi.org/10.1016/j.solener.2020.02.018.

[47] Negendahl, Kristoffer. 2015. “Building Performance Simulation in the Early Design Stage: An Introduction to Integrated Dynamic Models.” *Automation in Construction* 54: 39–53. https://doi.org/10.1016/j.autcon.2015.03.002.

[48] Freewan, A. A. Y., & Al Dalala, J. A. (2020). Assessment of daylight performance of Advanced Daylighting Strategies in Large University Classrooms; Case Study Classrooms at JUST. *Alexandria Engineering Journal*, *59*(2), 791–802. https://doi.org/10.1016/j.aej.2019.12.049

[49] Reffat, R. M., & Ahmad, R. M. (2020). Determination of optimal energy-efficient integrated daylighting systems into building windows. *Solar Energy*, *209*(July), 258–277. https://doi.org/10.1016/j.solener.2020.08.086

[50] Gero, Johh S dan Sudweeks, Fay (1998). Artificial Intelligence in Design’98. Springer Science+Business Media: Dordrecht. https://doi.org/10.1007/978-94-011-5121-4

[51] Kohn, A. Eugene dan Katz, Paul, (2002), Building Type Basics for Office Buildings, John Wiley & Sons, Inc. New York.

[52] Lim, Y. W., Ahmad, M. H. 2013. “Daylighting as a Sustainable Approach for High-Rise Office in Tropics.” *International Journal of Real Estate Studies*, 8(1): 30-42.

[53] Meel, J. V., Martens, Y., Jan, V. R. H. (2010). Planning office spaces: A practical guide for managers and Designers. London: Laurence King Publishing.

[54] Lim, Yaik-Wah, Mohd Zin Kandar, Mohd Hamdan Ahmad, Dilshan Remaz Ossen, and Aminatuzuhariah Megat Abdullah. 2012. Building Façade Design for Daylighting Quality in Typical Government Office Building. *Building and Environment*

57:194–204. doi:10.1016/j.buildenv.2012.04.015.

[55] Sev, Ayşin, and Aydan Özgen. 2009. Space Efficiency in High-rise Office Buildings. Metu Journal of the Faculty of Architecture 26 (2):69–89. doi:10.4305/METU.JFA.2009.2.4.

[56] Reinhart, C. F., Mardaljevic, J., & Rogers, Z. (2006). Dynamic daylight performance metrics for sustainable building design. *LEUKOS - Journal of Illuminating Engineering Society of North America*, *3*(1), 7–31. https://doi.org/10.1582/LEUKOS.2006.03.01.001

[57] Galatioto, A, and M Beccali. 2016. Aspects and Issues of Daylighting Assessment : A Review Study. Renewable and Sustainable Energy Reviews 66. Elsevier:852–860. doi:10.1016/j.rser.2016.08.018.

[58] Reinhart, Christoph F., and Daniel A. Weissman. 2012. "The Daylit Area - Correlating Architectural Student Assessments with Current and Emerging Daylight Availability Metrics." *Building and Environment* 50: 155–64. https://doi.org/10.1016/j.buildenv.2011.10.024.

[59] Mcmullan, R. (2007). Environmental Science in Building, Sixth Edition. New York: Palgrave Macmillan.

[60] Michael, A., S. Gregoriou, and S. A. Kalogirou. 2018. "Environmental Assessment of an Integrated Adaptive System for the Improvement of Indoor Visual Comfort of Existing Buildings." *Renewable Energy* 115: 620–33. https://doi.org/10.1016/j.renene.2017.07.079.

[61] BREEAM. Health and Wellbeing - Hea 01 Visual comfort. Available

online: https://www.breeam.com/BREEAM2011SchemeDocument/Content/05_health/hea01.htm (Accessed 3 January 2023).

[62] Nabil, A., & Mardaljevic, J. 2006. "Useful daylight illuminances: A replacement for daylight factors." *Energy and Buildings* 38(7): 905–913. https://doi.org/10.1016/j.enbuild.2006.03.013

[63] Mangkuto, R. A., Siregar, M. A. A., Handina, A., & Faridah. 2018. "Determination of appropriate metrics for indicating indoor daylight availability and lighting energy demand using genetic algorithm." *Solar Energy* 170(April 2017): 1074–1086. https://doi.org/10.1016/j.solener.2018.06.025

[64] Berardi, U., and Anaraki, H. K. 2015. "Analysis of the impacts of light shelves on the useful daylight illuminance in office buildings in Toronto." *Energy Procedia*, 78: 1793–1798. https://doi.org/10.1016/j.egypro.2015.11.310

Obradovic, Biljana, and Barbara Matusiak. 2021. A Customised Method for Estimating Light Transmission Efficiency of the Horizontal Light Pipe via a Temporal Parameter with an Example Application Using Laser-Cut Panels as a Collector. *MethodsX* 8. Elsevier B.V.:101339. doi:10.1016/j.mex.2021.101339.

Caruso, Gianpiero, and Jérôme Henri Kämpf. 2015. Building Shape Optimisation to Reduce Air-Conditioning Needs Using Constrained Evolutionary Algorithms. *Solar Energy* 118:186–196. doi:10.1016/j.solener.2015.04.046.

Kibert, Charles J (2008). Sustainable Construction: Green Building aDesign and Delivery. Second Edition. John Wiley&Sons, Inc. New Jersey

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