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The Potential of Natural Daylight Utilization for the Visual Comfort of Occupants in Two Units of Service Apartments Certified as Green Buildings in Kuala Lumpur, Malaysia

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Abstract: Visual comfort is one of the most salient aspects of the architectural design of a residential unit. This paper is the result of a research on the visual comfort evaluations made in two residential units, in service apartments certified as green buildings in Kuala Lumpur, Malaysia. The analysis focuses on evaluating visual comfort based on three matters. The first, a simulation of lighting levels or illuminance value in residential units, using Dialux version 4.12 software. The second, the results of actual measurements of the level of illumination inside the residential unit, using a lux-meter measuring instrument. The third, visual perceptions and preferences of the users of the AU as respondents through a brief interview. The results show that the potential for using natural lighting for the visual comfort of apartment users can only fulfill the bedroom, and the sitting room, while other spaces must still rely on artificial light. This situation relates to the influence of the spatial design of space settings in residential units. The results of the research are essential for all parties involved in architectural design, management, and users of residential units in service apartments certified as a green building.

Keywords: Service apartment, green building, visual comfort

1. Introduction

Making the architectural effort to provide access to natural light into each room according to the needs of the occupants is the critical thing. We spend most of our time in the rooms. The natural light that enters the room makes humans interact with an outside view and makes the room more attractive. Natural light gives orientation even though we are inside a building. Lack of access to natural light causes depression and stress.

Natural light can make the skin look natural, improves one's mood, reduces eye fatigue and headaches, and encourages enthusiasm. It makes the room seem more spacious and also more hygienic; it adds the beauty of the interior space; creates a variety of ambiance of spaces according to light intensity. It gives an attractive look to the room; reduces the humidity level in the room; it also saves electricity, and it reduces the use of artificial light, to save energy consumption and reduce pollution levels.

One source of natural light is sunlight that is very useful for everyday life. Sunlight can give a warm impression, increase cheerfulness, and increase the spirit of enthusiasm in space [1]. Sunlight as a time marker, being in a closed

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space that does not receive sunlight can disrupt time orientation, disorientation, and isolation from changing conditions. This condition hurts psychology and disturbs the human biological clock [2].

Sunlight functions for the health of the body to support one's growth. The benefit of morning sunshine is to turn pro-vitamin D into vitamin D; reduce blood sugar and cholesterol; to protect from infections and bacterial killers; improve fitness and quality of breathing; improve immunity; enhance bone formation and the healing process.

The benefit of sunlight is to build a natural immunity to the harmful effects of ultraviolet light. Ultraviolet light in the sun acts as a natural antiseptic, killing viruses, bacteria, mold, yeast, and mites in the air, water and various surfaces, including human skin. Getting regular sun exposure will help protect the body skin. Sunlight helps cure skin diseases such as acne, boils, athlete's foot, diaper rash, psoriasis, and eczema.

Sunlight is one of the most effective healing agents, as it encourages circulation, and stimulates the production of red blood cells, increasing the amount of oxygen in the blood. Sunlight stimulates the appetite and improves digestion, elimination, and metabolism; it boosts the immune system and increases the number of white blood cells in the blood. Sunlight soothes the nerves and improves one's mood, the production of endorphins and serotonin in the brain, which makes us feel better. Sunlight helps to sleep more soundly at night. Being exposed to natural light during the day will increase melatonin production at night. Melatonin is a natural hormone made by the body that can improve sleep quality and slow down the aging process.

Unfortunately when there is too much sunlight, ultraviolet fades the color of the material used. The entry of natural light at once bringing radiation heat. Therefore a designer strives to arrange the opening of the room which can avoid direct sunlight entering into the room, and only utilizes indirect natural daylight (after this it is mentioned as NDL).

Daylight has an essential function in architectural and interior work. The distribution of natural light in space is directly related to architectural configuration, building orientation, depth, and spatial volume. The proper spread and management of daylight can provide a warmer atmosphere and make a pleasant atmosphere in the room [3]. Good lighting enables us to work and make us feel comfortable when working. Although it seems simple, this statement is the goal of lighting design, which is to create comfort, a pleasant atmosphere, and a functional space for all people in it [4].

The location of Malaysia is near the Equator, so this country receives relatively stable sunlight throughout the year and makes for only two seasons, namely the dry season and the rainy season. Sunlight begins to illuminate buildings in Kuala Lumpur in the morning lasting until the afternoon; this condition is relatively the same throughout the year.

Nowadays developers progressively build apartment buildings including in Malaysia, especially in a major city like in Kuala Lumpur. An apartment building as a vertical mass residential requires much lighting for the inside of the rooms, which further requires more energy if the lighting uses artificial or electrical lights. High-rise apartment is an apartment building consisting of more than ten floors. It provides many opportunities for harvesting and utilizing natural daylight to illuminate the rooms in the building. Some building users, unfortunately, do not use NDL and tend to use artificial lights even during the day, rather than using NDL optimally as a gift of nature. This tendency is less beneficial for the sustainable development of the built environment.

One apartment unit (after this it is mentioned as AU) usually has one to three bedrooms beside the sitting room, bathroom, kitchen, and laundry room. There are some types of apartments based on socio-economic strata, namely medium apartments, luxury apartments, and super luxury apartments.

Based on management, there are some types of apartments, namely rental apartment, service apartment, and owners' self-management apartment. In rental apartments, the owner builds and finances the operation and maintenance of the building, and the occupants pay rent for a certain period. There is some service apartment in Kuala Lumpur, Malaysia. A serviced apartment is an apartment that is managed thoroughly by certain management; usually, it resembles the way of managing a hotel. Residents enjoy services in the style of a five-star hotel, for example, a fully furnished unit, housekeeping, room service, laundry, and a business center.

The division of this apartment space is like an ordinary house. It has a separate bedroom as well as a sitting room, a dining room, and a kitchen. The area of this apartment is very diverse, depending on the type and number of rooms. The building has an underground or lower floor parking area, a security system, and full service. Some users of service apartment assume that the pay for the service, they often tend to use most of the available facilities in the apartment, including using artificial lights during the day excessively. This tendency is also less beneficial for the sustainable development of the built environment.

2. Overview of Natural Daylight System

In an article, entitled natural lighting utilization in townhouse type house in Surabaya by Dora & Nilari [5], it was found that daylighting reduces the need for artificial lighting and passive solar gain reduces the need for space heating. The key to optimizing the solar potential of the site is to orientate buildings broadly to the south. Suriansyah [6] studies regarding Apartment Sarijadi Bandung (ASB) and found that the study aims to determine the extent of natural lighting at ASB designed with the optimization approach of natural lighting. The study used quantitative methods, namely a field surveys to obtain data of (1) physical spatial configurations of architectural elements, and (2) illuminance of the residential units, in order to analyze how much the potential of natural lighting utilization available in the residential units at ASB. The finding of the research is the innovations of disclosure of influential factors of the architecturally physic-spatial configuration on the daylighting potential in vertical residential building typology as in the ASB.

In Thojib et al. [7], the position and dimensions of openings, sun shading, and room furnishings are the variables of the study. It used Dialux simulation in two apartments, namely Sukarno Hatta Malang and Buah Batu Park in Bandung. The study shows that the orientation of the building and the width of openings in the residential affect the existing levels of light intensity. Meanwhile, Suriyanto et al. [8] evaluated the natural lighting optimization in Rumah Susun Kampung Pulo in East Jakarta. The study used Archicad software for simulation purposes and indicated that the optimal openings are 20% in the north direction.

The natural lighting level in Rusunawa Mariso was conducted by Risfawany et al. [9]. The study dealts with the availability of natural lighting in the living room, the bedroom, and the kitchen in the simple rental apartment. The study used observations, interviews with residents, and measuring the level of natural lighting available in residential units. The sample included the selected occupants based on the following considerations: (1) occupancy position in the corner and near the stairs, (2) floor level, and (3) East-West unit orientation. The result of the study is that the level of illumination at each level is different. The higher the floor level, the higher the chances of natural lighting entering. The illumination level that enters the residence does not meet the natural lighting standards for residential flats, namely 60–250 lux. The optimal lighting level is at 8 a.m., 10 a.m. and noon. The dwelling unit at a position adjacent to the stairs has a too low illumination level of 57 lux, and the highest is only in the bedroom. Without artificial light, the dwelling unit becomes darker from 8 a.m. until 4 p.m. By measurements every 2 hours, the study concluded the relationship between daylight and time, duration, and space position.

Mustika [10] made a study of daylighting optimization for energy efficiency in low cost flat with tower configuration in Denpasar. The case study is a low-cost flat of Dinas Kepolisian Daerah Bali. The use of natural lighting in a dwelling is one way to attain energy efficiency where natural lighting can replace artificial lighting during the day. Flats with tower configurations have the potential to obtain natural lighting from the building facade but have constraints related to the depth of space. The use of atrial and two-sided openings is a strategy for natural lighting design in tower configuration flats to obtain the quantity of natural lighting according to the activity needs and to be visually comfortable. The study is an experimental work using computer simulation with Desktop Radiance 1.02 and Autocad 2000 software. To find out the effect of the quantity distribution of illumination on visual comfort and the potential for glare caused by the comparison of the lowest and highest illumination exceeding 140 as a controlling device. Using the measurements method and field observations, initial simulations according to field conditions, comparing the results of field measurements with the results of the initial simulation to find out natural lighting characteristics in the research object. The finding is that inadequate illumination occurred in the living room and excessive illumination in the main bedroom and the secondary bedroom. Furthermore, taking two-stage to optimize the natural lighting in the living room and the reduction of the glare potential in the main bedroom. Optimization is by changing the atrial roof, and the result is the increased illumination in the living room. The accomplishment of optimization of the potential glare reduction is by changing the length of the edge plank (fascia board) from 1 m to 12 and 15 m, so that visual comfort increases by lowering the illumination contrast ratio and increasing the percentage of daylight factor in a comfortable range.

The study by Sari et al. [1] is concerning the effect of window-to-wall ratio on visual comfort in student apartments in Surabaya aims to determine the effects of the window-to-wall ratio on the visual comfort of dwellers and the design of windows suitable for lighting requirement. This study uses a quantitative descriptive analysis through field observation and data validation with Dialux 4.12 daylighting software simulation and design result evaluation. The scope of study consists of four residential units, two bedrooms type, of 30 m^2 of Puncak Kertajaya Apartment with different facing directions on the 19^{th} floor. The result of the study is that the performance of windows increased after the design modifications. Design recommendations for the effective window-to-wall ratio for residential units by 50%-60% can improve the visual comfort of up to 15%.

Daylighting as a passive solar design strategy in tropical buildings, a case study of Malaysia was investigated Zain-Ahmed et al. [12]. According to this study, the use of daylighting in buildings and architecture is not new. Natural lighting has gone out of vogue due to the availability of cheap electricity, the predictability and the ability to control illumination levels due to artificial lighting. However, the alarm over rapid depletion of energy resources and the environmental effects of their applications have led designers to reuse daylighting strategies in buildings in order to minimize energy use for lighting and air conditioning because of heat gains from the daylight sources and the electrical fixtures. The study describes the savings achieved by using daylighting in the passive design of buildings and the size of windows. Simulation on exterior illuminance levels based on long-term measured solar irradiation and cloud cover data was performed to estimate interior illumination on a normal working plane using simple buildings configurations. By decreasing illumination on these planes, it can decrease the need for artificial lighting. Thus, it can save energy. The research used a simple algorithm to calculate the overall cooling load to ascertain that the daylighting strategies used do not invoke an increase in thermal gains through walls and glazing. The findings from this study show that simple daylighting strategies produce at least 10% energy savings.

Nikpour et al. [13] Iinvestigated the daylight quality using self-shading strategy in energy commission building in Malaysia. It was revealed that there are many office buildings without strategies for daylight utilization. The study also suggested different strategies for better use of daylight, like a self-shading strategy to eliminate direct solar radiation to minimize energy use for cooling in offices but reducing the amount of daylight penetrating the building. The study investigated the effectiveness of self-shading strategy on daylight through the experimental method. The measurement of daylight parameters was in two individual office rooms in the energy commission building as a model of self-shading buildings. The research objective is to investigate daylight quality in individual office rooms based on different criteria such as work plane illuminance, relative daylight ratio, surface luminance, and to compare these with recommended values. The research findings demonstrated that by employing the self-shading strategy, the amount of daylight that enters the space could to reduce, but by applying, other strategies like light shelves and Venetian blinds, with self-shading strategy can achieve acceptable performance concerning daylight quality. The future design of office buildings can employ these strategies to reduce energy consumption for lighting as well as to comply with the goal of sustainable architecture.

Daylight ratio, luminance, and visual comfort assessments in typical Malaysian hostels was studied by Dahlan et al. [14]. The study described that conventional tropical building designs are experiencing a new paradigm in their environmental response to improve lighting ambiance and the visual comfort of occupants through the exploitation of daylighting. However, it is essential for architects to understand that flaws in daylighting strategies could lead to disadvantages as they could hinder vision, cause discomfort, increase interior heat gain, and result in excessive energy demands. The objective of the study is to assess how occupants perceived their visual conditions through daylight ratio and luminance level measurements. Measurements have been made throughout a two-month period starting from 12th May to 3rd July 2007. The research conducted the study at three typical Malaysian hostels as case studies in the Klang Valley. Those selected hostels include: (1)Twelfth Residential College, Universiti Malaya, (2) Eleventh Residential College, Universiti Putra Malaysia and (3) Murni Student Apartments, Universiti Tenaga Nasional. The daylighting source in all these case studies is from side-lit windows. Overall, the findings suggest that occupants were at ease with the level of daylighting available in their rooms even though projecting balconies shaded rooms were dimmer than the rooms that were not.

From a study of natural light obtainment condition, it would provide valuable information dealing with the potential of NDL utilization. Therefore, it is essential to research on evaluating visual comfort related to daylight utilization especially in an AU that has many side-lit windows as a potential to harvest the NDL. Moreover, it is also essential to complete the research with the data of occupants' perceptions and preferences of their visual comfort experience in AU rooms. Therefore, this research aims to gain a more comprehensive description of daylighting phenomena in AUs quantitatively and qualitatively.

3. Methods

The analysis of this study focuses on evaluating visual comfort based on three matters. The first, a simulation of lighting levels or illuminance value in residential units, using Dialux version 4.12 software. The second, the results of actual measurements of the level of illumination inside the residential unit, using a lux-meter measuring instrument. The third, visual perceptions and preferences of the users of the AU as respondents through a brief interview.

The modeling process of Dialux is a simulation by four actions. The first is to draw the three-dimensional model of the AUs at once to determine the dimensions of the rooms, complete with its furniture. The second is to enter the illuminance range so that it can display it on the simulation results, the simulation dates, the exterior sky condition; and the format of the requested result. The third is to calculate automatically by the software to generate the simulation result in the form of 3-dimensional illuminance isoline figure with interior spaces background. The fourth is to retrieve the calculation result in the form of a graphical diagram that consists of the monochrome diagram, false color diagram, table of illuminance, and uniformity of illuminance throughout the room to make the interpretation and explanation of the results furthermore.

The considerations to take the Dialux simulation include a scientific and operational consideration. The scientific consideration is because of this software as a mature software, which has evolved since its initial version up to version 4.12, through a series of research and development, the trial and error process, and users' evaluations both from industrials as well as academicals point of views. This software allows entering contextual specific parameters to the object of this study, such as geographical coordinates, suitable for tropical sky condition, some types of furniture and other interior elements, and has customization setting as needed. User-friendly and as open source software is the operational consideration to use it. The simulation setting is the date of July 21, 2018, and the time is at 10.00 am, with sky type reference is the overcast sky. The other parameters for running the simulation are the height of the rooms 2.820 m, maintenance factor 0.80, and the height of work plane 0.760 m.

4. Object of Study (Building)

The object of this study consists of two units of a service apartment in southern Kuala Lumpur, Malaysia. The location of the AU #1 is in the longitude of 101.70°, the latitude of 3.20°, and at North deviation of 189.0°. The location of the AU #1 is in the longitude of 101.40°, the latitude of 3.20°, and at North deviation: 189.0°.

This building sought to revitalize the neighborhood with its modern layout and classy façade, together with the niche boutique-style shops located on the ground floor fronting the street. At the back and left side of the site is a row of existing houses, on a higher ground than the site. This building consists of 198 AUs, two of them are the objects of this study. Both of them have an L-shaped space layout, and the area is 36 m^2, the position is on the 11th floor. This apartment design used some features of green Building principles that adhered to the Green Building Index (GBI) accreditation guidelines and was awarded Gold based on the Design Assessment conducted by the GBI panel before the Provisional Certification. The apartment building comprises a 28-story single tower with units ranging from one bedroom to one study room.

Each AU consists of a bedroom, a living or sitting room, a pantry or kitchen, a dining room, and a laundry room. The units also have a foyer and a balcony as a space outside the interior space. Only one access in the form of a door that separates and at once which connecting the outside space, the foyer next to the corridor, and the inside of the AU. The existing space opening is in the form of operable windows on the exterior wall, namely in the bedroom and the sitting room. Besides that, there are some openings of the space on the wall of the kitchen and the laundry room located next to void space and the corridor. There are also openings on the high parts of the bathroom wall that are side by side with the void space outside.

In these two AUs, the apartment building manager provides some furniture and household appliances the residents can use all of those things. The layout of the interior elements of the AUs as shown in Fig.1 for the AU #1, and Fig. 2 for the AU #2. There are some interior elements inside the AUs as specified in Table 1.

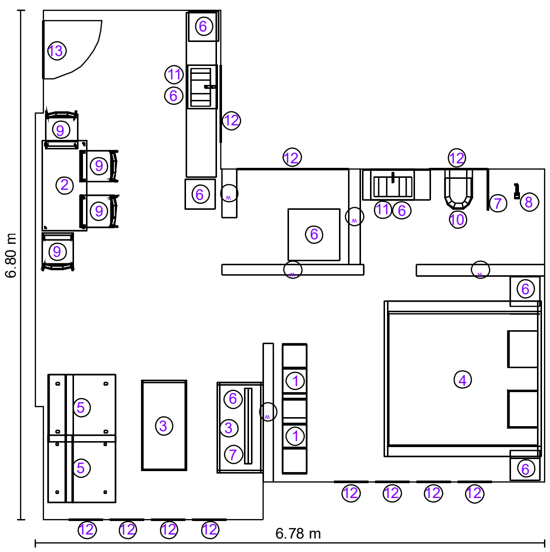

Fig. 1 - The layout of the interior elements of the AU #1

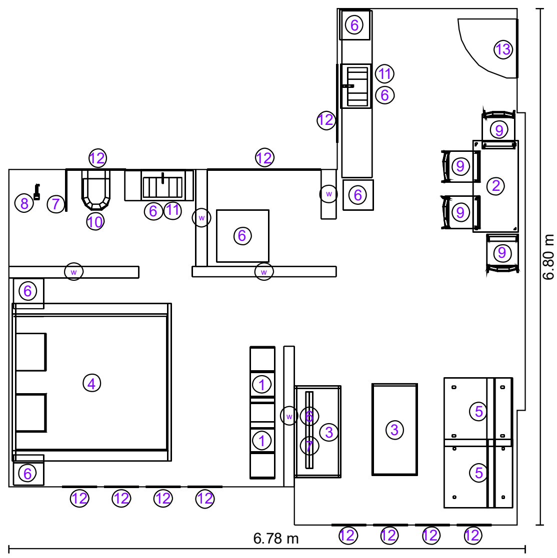

Fig. 2 - The layout of the interior elements of the AU #2

Table 1 - The list of interior elements in AUs

No	Pieces	Room elements
1	2	100x200 rack
2	1	120x60 standard dining table
3	2	60x120 couch
4	1	One broad bed
5	2	Block sofa center
6	8	Cube
7	2	Glass plate
8	1	Shower fittings
9	4	Simple chair
10	1	Toilet
11	2	Washbasin
12	11	Window
13	1	Door

5. Results and Analysis

5.1. Simulation of Daylighting Performance in the AUs

Measuring the potential of natural daylight in the two AUs to gain the amount of the potential of natural daylight in the AUs quantitatively is by daylight performance simulation using the Dialux software version 4.12. The simulation result of the AU #1 is in Fig. 3, and of AU#2 in Fig. 4 shows the illuminance isoline diagram inside the AUs. The value unit of illuminance (E) is in lux. The description of the results as follows.

The illuminance isoline in the work plane of the AU #1 has shown that daylight can enter the room effectively enough to illuminate the rooms. It means the rooms have sufficient potential to gain energy efficiency without using artificial lighting in the daytime. In AU #2 the lighting performance is nearly similarly as AU #1, although the layout is different. The layout of AU #2 is a mirror version of AU #1 layout.

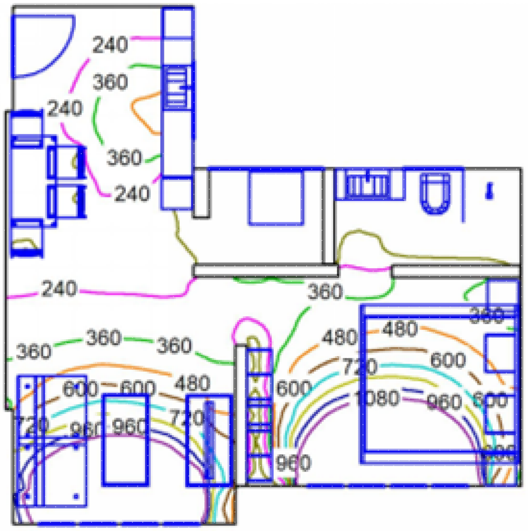

Fig. 3 - Diagram of illuminance isoline in AU #1

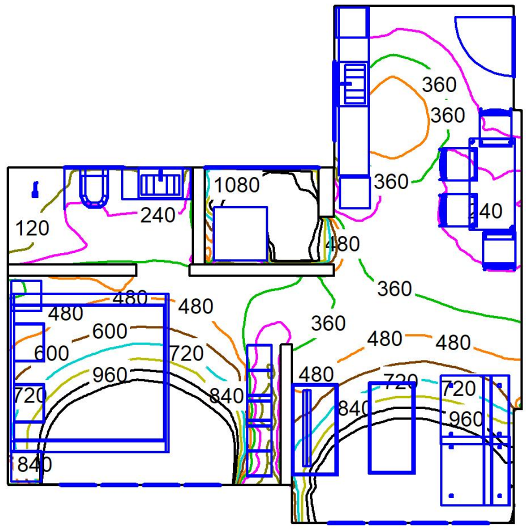

Fig. 4 - Diagram of illuminance isoline in AU #2

Dialux simulation has the output in the form of average illuminance (Eav), minimum illuminance (E_{av}), minimum illuminance (E_{min}), maximum illuminance (E_{max}), and illuminance uniformity on the working plane (u0). Table 2 shows those outputs of the AU #1, and Table 3 shows those outputs of the AU #2.

Table 2 - Illuminance and light uniformity value in the AU #1

Surface	ρ (%)	E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	u0
Work plane	/	554	10	2597	0.019
Floor	20	369	2.78	2640	0.008
Ceiling	80	115	18	213	0.160
Walls (13)	50	154	7.04	889	/

Table 3 - Illuminance and light uniformity value in the AU #2

Surface	ρ (%)	E_{av} (lux)	E_{min} (lux)	E_{max} (lux)	u0
Work plane	/	589	37	2488	0.063
Floor	20	394	3.24	2540	0.008
Ceiling	80	130	41	385	0.313
Walls (13)	50	173	16	876	/

E_{av} (lux)	Average illuminance
E_{min} (lux)	Minimum illuminance
E_{max} (lux)	Maximum illuminance
u0	Uniformity of illuminance

In the AU #1, by E_{av} on working plane 554 lux is sufficient to illuminate the room. Unfortunately, uniformity of illuminance is low, u0 is 0.019 (1:53), so some points inside the room only have a minimum amount of illuminance. It means there are some spaces have sufficient illuminance, even exceeded the illuminance standard, and some other spaces have insufficient illuminance. The ratio of E_{min} to E_{max} pointed out it, E_{min} / E_{max} is 0.004 (1:248).

In the AU #2, by E_{av} on working plane 589 lux is sufficient to illuminate the room. Unfortunately, uniformity of illuminance is low, u0 is 0.063 (1:16), so some points inside the room only have a minimum amount of illuminance. It means there are some spaces have sufficient illuminance, even exceeded the illuminance standard, and some other spaces have insufficient illuminance. The ratio of E_{min} to E_{max} pointed out it, E_{min} / E_{max} is 0.015 (1:67).

Table 4 shows the comparison of the illuminance and its uniformity value between AU #1 and AU #2. In AU #1 the average illuminance is higher than in AU #2. The minimum illuminance is lower than in AU #2. The maximum illuminance is higher than in AU #2. The illuminance uniformity is lower than in AU #2. These are because of the position and the layout of the AUs.

Table 4 - Comparison of iilluminance and light uniformity value in the AUs

Working plane	In AU #1	In AU #2
Average illuminance E_{av} (lux)	554	589
Minimum illuminance E_{min} (lux)	10	37
Maximum illuminance E_{max} (lux)	2597	2488
Uniformity of illuminance u0	0.019	0.063

The Dialux monochrome diagram in Fig. 5 shows the distribution and the uniformity of illuminance in AU #1, and Fig 6. shows it in AU #2. The Dialux monochrome diagram of the AU #1 in Fig 5. shows the darker areas, especially in some parts in the inner section of the room, and the brighter area in the edge of the exterior wall, that has a full of the side-lit windows. In the AU #2 as shown in Fig 6. the distribution and the uniformity of illuminance are almost similar to the AU #1, although their layout is different, as mentioned before the design of the AU #2 is a mirror version of AU #1.

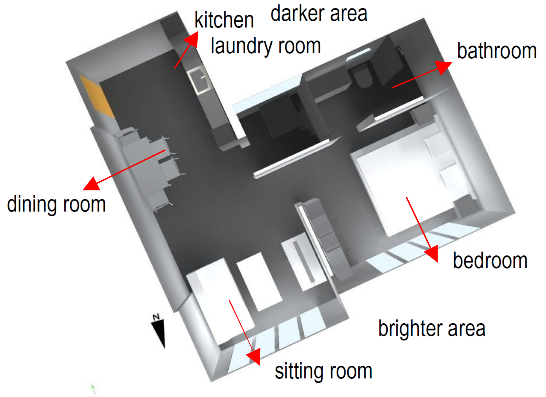

Fig. 5 - Dialux Monochrome Diagram in the AU #1

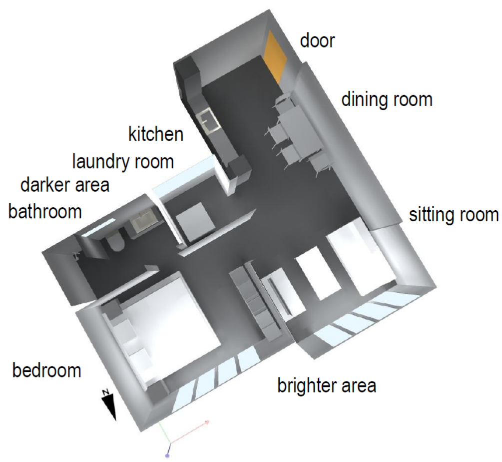

Fig. 6 - Dialux Monochrome Diagram in the AU #2

In detail, the Dialux simulation also has the output in the form of an illuminance false color diagram that shows the distribution of illuminance in the interior space of the AUs. The Dialux false color diagram in AU #1 is in Fig. 7, and for the AU #2 is in Fig. 8.

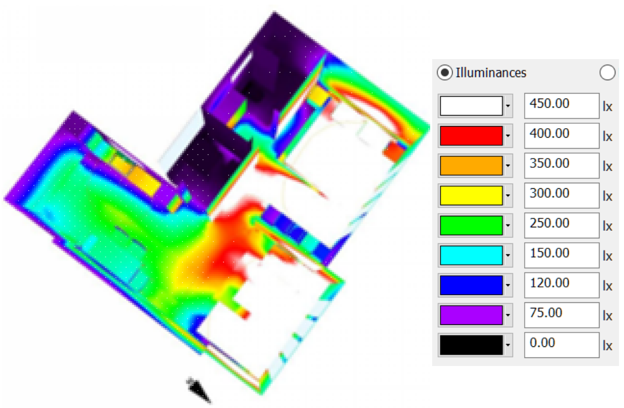

Fig. 7 - Dialux False Color Diagram in the AU #1

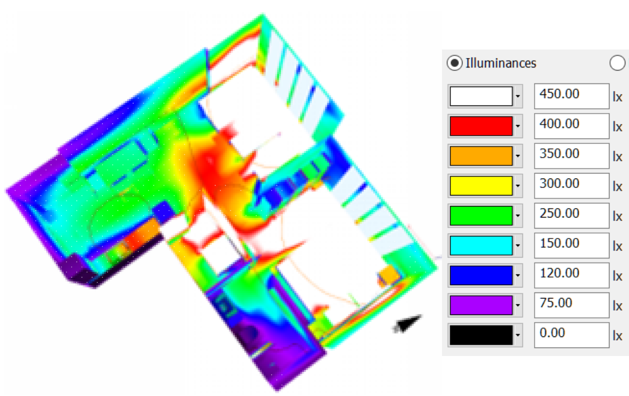

Fig. 8 - Dialux False Color Diagram in the AU #2

The Dialux false color diagram in AU #1 in Fig. 7 shows the darker area is in the bathroom, laundry room and the kitchen area. The brighter area is in the living room and the bedroom. Only the bathroom and the laundry room have not met the illuminance standard. Other rooms have. Therefore both units have a huge potential to use natural daylight. Almost similar to AU #1, in the AU #2, the brightest area is in the bedroom and the living room. The darkest area is in the bathroom and the inner section of the kitchen area, so in certain circumstances, those areas have to use artificial light to meet the illuminance standard shown in Table 5.

Table 5 - Illuminance Recommendation by SNI 03-6197-2000

Room function	Illuminance standard (E) (lux)
Terrace/balcony	60
Bedroom (BR 1) near the window	120-250
Bedroom (BR 2) near the bathroom	120-250
Bedroom (BR 3) at the workspace	120-250
Bathroom	250
Living/Sitting room (LR 1) near the window	120-150
Living/Sitting room (LR 2) at the center	120-150
Kitchen table	250
Dining room	120-250
Laundry room	250

5.2. Measurement of Actual Daylighting Performance in the AUs

This measurement describes the second methods to reveal the potential of natural daylight in the two AUs which are by actual measurements of it using lux meter device on every hour during the day and in the evening as a control variable. Duration of the measurement was from July 20 up to July 26, 2018. The results are in table 6, 7, 8, 9, 10, and 11. Table 6 and Table 7 show the illuminance measurement using lux meter at 6.00 am up to noon and 1.00 pm up to 7.00 pm in AU#1.

Performance of daylighting based on lux meter measurement in Table 6 shows that in the morning at around 6.00 am, there was no daylight entering the inside of the AUs yet. After 7.00 am, the two areas in the AUs have illuminance that met and even exceeded the standard, but the rest of the spaces did not. After 8.oo am up to noon, all space areas inside the AUs received more than sufficient natural daylight, except in the bathroom, the laundry room, and the kitchen table.

Until 3.00 pm, all space areas inside the AUs have more than sufficient natural daylight, except in the bathroom, laundry room, and the kitchen table. After 4.00 pm some space areas became gradually darker. Until 7.00 pm, only one area, namely the bedroom near the window that has sufficient illumination from natural daylight.

The illuminance in AU # 2 is almost similar to AU # 1. Table 8 shows the results of illuminance measurements using lux meters at 6.00 am to noon in apartment # 2. It shows that in the morning around 6.00 am, there was no daylight yet. After 7.00 am, two areas in the AU had illuminance that met and even exceeded the standard, but the rest did not. After 8.00 am to noon, all interior spaces have more than enough natural light, except in the bathroom, kitchen table, and laundry room.

Table 6 - Illuminance measurement using lux meter at 6.00 am up to noon in AU #1

In AU #1	6.00	7.00	8.00	9.00 am	10.00	11.00	noon
Bedroom (BR)							
BR 1 near window	0	124	2580	3840	2610	2382	2154
BR 2 near toilet	0	27	256	379	301	391	480
BR 3 at workspace	0	29	211	386	373	553	732
Bathroom	0	37	108	157	114	138	161
Living room (LR)							
LR 1 near window	0	197	2558	5760	6410	6145	5880
LR 2 at the center	0	31	384	610	453	426	399
Kitchen table	0	21	104	117	77	78	78
Dining room	0	9	246	327	166	155	144
Laundry room	0	1	42	53	29	25	21
Outside	0	227	2654	5080	5080	5740	6400

Unmet standard | Met standard | Exceed standard

Table 7 - Illuminance measurement using lux meter at 1.00 pm up to 7.00 pm in AU #1

In AU #1	1.00	2.00	3.00	4.00 pm	5.00	6.00	7.00
Bedroom (BR)							
BR 1 near window	1825	1496	2475	1214	607	303	152
BR 2 near toilet	392	304	254	267	133	67	33
BR 3 at the workspace	523	314	215	143	71	36	18
Bathroom	157	153	143	48	24	12	6
Living room (LR)							
LR 1 near window	3945	2009	3575	824	412	206	103
LR 2 at the center	488	577	516	269	134	67	34
Kitchen table	96	113	123	94	47	23	12
Dining room	184	223	199	90	45	23	11
Laundry room	25	28	19	6	3	2	1
Outside	4209	2017	3420	1452	726	363	182

Unmet standard | Met standard | Exceed standard

Table 8 - Illuminance measurement using lux meter at 6.00 am up to noon in AU #2

In AU #2	6.00	7.00	8.00	9.00 am	10.00	11.00	noon
Bedroom (BR)							
BR 1 near window	0	323	6770	10105	9260	6545	3830
BR 2 near toilet	0	28	1129	1173	1305	887	468
BR 3 at workspace	0	30	858	955	897	684	470
Bathroom	0	10	247	345	377	234	91
Living room (LR)							
LR 1 near window	0	303	6495	10300	exceed	774	774
LR 2 at the center	0	21	1103	1162	997	719	441
Kitchen table	0	2	333	226	118	131	143
Dining room	0	7	599	399	199	200	200
Laundry room	0	6	84	83	82	57	31
Outside	0	301	7400	>15000	>15000	6600	6600

Unmet standard | Met standard | Exceed standard

Table 9 shows that until 3.00 pm, all space areas inside the AUs have more than sufficient natural daylight, except in the bathroom, laundry room, and the kitchen table. After 4.00 pm, some space areas became gradually darker. Until 7.00 pm, only one area, namely the bedroom near the window that has sufficient illumination from natural daylight. Both of the AUs have a considerable potential to utilize natural daylight, except some areas namely the bathroom, kitchen table, and the laundry room.

Table 9 - Illuminance measurement using lux meter at 1.00 pm up to 7.00 pm in AU #2

AU #2	1.00	2.00	3.00	4.00 pm	5.00	6.00	7.00
Bedroom (BR)							
BR 1 near window	3740	3650	1474	1901	951	475	238
BR 2 near toilet	349	230	197	104	52	26	13
BR 3 at workspace	385	300	219	157	79	39	20
Bathroom	78	65	49	15	8	4	2
Living room (LR)							
LR 1 near window	1497	2220	2538	284	142	71	36
LR 2 at the center	343	245	206	104	52	26	13
Kitchen table	137	131	83	96	48	24	12
Dining room	170	139	91	115	58	29	14
Laundry room	30	29	12	18	9	5	2
Outside	5040	3480	2029	1015	507	254	127

Unmet standard | Met standard | Exceed standard

The next step of this study is to measure the actual illuminance in the AUs using a lux meter device at night when the users used artificial light or electric lamps. The result is in Table 10 shows that the illuminance of all areas in both AUs is below illuminance standard. The results of illumination measurements at night when all the lights are lit inside the AU, indicating that the illumination magnitude is in the range 26 up to 99 lux in the AU #1, and between 44 up to 95 lux in the AU #2. The amount has not met the illumination standard. Table 8 shows that. E_{max} is only 99 lux in the dining room of AU #1, and 95 lux in the bathroom of AU #1. However, the users stated that lighting conditions at night with available lights are sufficient to carry out daily activities. The users feel comfortable with the night lighting conditions even though the illumination is below standard.

Table 10 - Illuminance measurement using lux meter in AUs at night when its artificial lights were turn on

Room function	Illuminance Standard (lux)	Illuminance value in AUs at night when its artificial lights were turn on	
		#1	#2
Bedroom (BR)			
BR 1 near the window	120-250	77	65
BR 2 near the bathroom	120-250	59	57
BR 3 at the workspace	120-250	26	44
Bathroom	250	75	95
Living room (LR)			
LR 1 near the window	120-150	53	46
LR 2 at the center	120-150	51	61
Kitchen table	250	43	58
Dining room	120-250	99	62
Laundry room	250	61	52

It becomes the essential finding, logically if the lighting magnitude at night is sufficient, even though the magnitude is below the standard, then the lighting during the day that is much higher, it should be adequate, and no need to turn on the lights during the day.

6. Visual Comfort Perception and Preference According to the Occupants

The third analysis in this study consists of visual comfort perceptions and preferences according to the occupants. This study uses a structured interview method, by asking the users/occupants of the AUs regarding their visual comfort perception and preference, from their experience being in the AU. The structured interviews with the occupants were conducted every 2 hours in the middle of the sitting room, in a relaxed situation.

The interview was simultaneous with the measurements of illuminance using a lux-meter device. The interview question is how they experience the visual circumstances in the AU. The first interview qualitative question is their perception of their visual experience in the space where they were in, whether it is very bright, bright, slightly bright, neutral, slightly dark, dark, or very dark. The second qualitative question is the preference of visual experience of the respondents, relate to the visual perception of them, whether they would like to see the room be brighter, no change, or be darker. This study quantified the qualitative matters of the respondents' experiences used values for perception and preference as shown in Table 11.

Table 12 - Values of perception and preference to quantify the visual experience of the occupants

What is your perception at the moment	
+3	Very bright
+2	Bright
+1	Slightly bright
0	Neutral
-1	Slightly dark
-2	Dark
-3	Very dark

Would you like to experience illuminance that is	
-1	Brighter
0	No change
+1	Darker

The perception values are +3 for the answer of very bright, +2 for bright, +1 for slightly bright, 0 for neutral, -1 for slightly dark, -2 for dark, and -3 for very dark. The preference values are -1 for the answer of would like to see brighter, 0 for no change, and +1 for would like to see darker. The result of valuing the qualitative response from the occupants is the quantitative range of the visual perception and preference of them in the AUs. Diagram in Fig. 9 shows that the blue line represents the visual perception of the respondent, and the red line represents the visual preference of them. In the diagram, the y-axis represents the average range of visual perception and preference, and the x-axis represents the time interval of interviewing the respondents, which is from 6.00 am up to 8.00 pm.

Based on those values, it found that at 6.00 am the average of occupant's visual perception indicated that they experience slight darkness so the occupants would like to perceive brighter circumstances. Between 8.00 am until 6.00 pm, the average of the occupant's visual experience indicated a condition between bright up to slightly bright and the occupants would like to perceive no change in those circumstances. After 6.00 pm, even though the visual perception and preference indicator ranged between bright and slightly bright, but the occupants would like to perceive brighter circumstances.

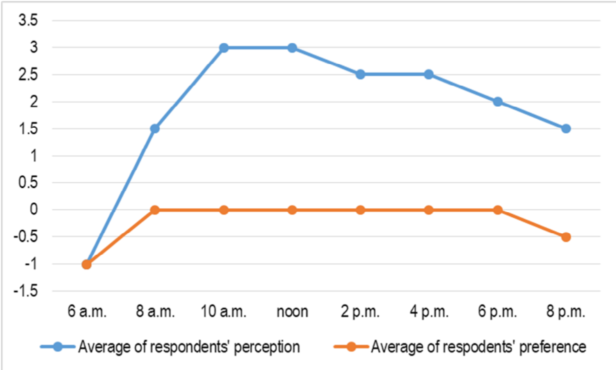

Fig. 9 - The average of the visual perception and preference of the occupants in the sitting room of the AU #1

Furthermore this study elaborated the correlation between four variables, namely (1) visual perception of the respondents, (2) visual preference of the respondents, (3) illuminance value in the middle of sitting room where the interview took place and (4) illuminance value in the next to windows of the sitting room as part of the space that gains the most illumination from exterior areas. The illuminance value is the factual based on direct measurements using a lux-meter device. Fig. 10 shows the correlation between those four variables.

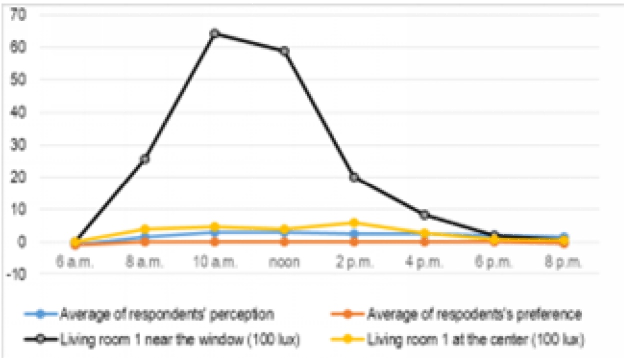

Fig. 10 - The correlation between visual perception and preference of the occupants and the amount range of the illuminance in the AU #1

At 6.00 am, there was still no illumination entering the sitting room, even though in the condition of the window and the curtain are opened, and the artificial light was turned off. Off course at that time the occupants or the respondents perceived visually as slightly dark and would like to see brighter. At the 8.00 am, the illuminance value in the middle of the sitting room is 384 lux. In that circumstance, the visual perception value of the respondents is +1.5. It means that they perceived the circumstance visually as between slightly bright and bright. They prefer there is no change for that situation. It also applies until at 6.00 pm, that respondents prefer there is no change of the illuminance conditions, even though the illuminance value is fluctuating from time to time along the day. Therefore, it also means that the respondents perceived visually comfortable in the illuminance range which is between 67-577 lux, while the illuminance standard for a sitting room is between 120-250 lux.

Heading for the afternoon, at 2.00 and 4.00 pm, the respondents perceived the illuminance value of 299 lux and 577 lux visually as between brighter and very bright (+2.5), even though actually at the 2.00 pm the illuminance value was the highest value on that day. It assumes that respondents' biological clock taking parts to influences their visual perception and preference.

At 6.00 pm when the sun almost disappears, and the natural light only enters the room as the amount of 67 lux, the respondents perceived visually as still bright and preferred there is no change of the illuminance, even though the illuminance value of 67 lux visually is below than illuminance standard. It means that as long as the windows and the window curtain are still open and natural light entered into the room, the respondents still perceived sufficient illumination. At 8.00 pm when the sun has already disappeared, but there is still a light tinge to illuminate the room as the amount of 57 lux. It is normal that the respondents perceived it visually as between slightly bright and neutral (+0.5), and they preferred to perceive between bright and just remained (+1.5). Table 12 shows the correlation between visual perception and preference of the occupants and the amount range of the illuminance in the AU #1.

Table 13 The correlation between visual perception and preference of the occupants and the amount range of the illuminance in the AU #1.

Measurement time	What is your illuminance perception at the moment	Would you like to experience illuminance that is	Living room 1, near the window (lux)	Living room 1, at the center (lux)
6.00 am	-1	-1	0	0
8.00 am	1.5	0	2558	384
10.00 am	3	0	6410	453
noon	3	0	5880	399
2.00 pm	2.5	0	2009	577
4.00 pm	2.5	0	824	269
6.00 pm	2	0	206	67
8.00 pm	1.5	-0.5	53	51

Unmet standard | Met standard | Exceed standard

The illuminance value +1.5 as between bright and slightly bright in the perception of occupants represents the illuminance range of 51-384 lux. Bright (+2) refers to the illuminance of 67 lux. Between bright and very bright (+2.5) refers to the illuminance range of 269-577 lux. Very bright (+3) refers to the illuminance range 399-453 lux. Similar to AU #1, in the AU #2 also shows that at 6.00 am the average of the visual perception according to the occupants as slightly dark (-1) and the occupants would like to perceive brighter circumstances.

In Fig. 11 shows that between 8 a.m until 6 p.m. the average of the visual perception according to the occupants as a condition between bright and slightly bright (1.5) and the occupants would like to see the no change of it. After 6 p.m. even though visually it is still indicated as between bright and slightly bright (+1.5), the occupants would like to see brighter circumstances. Fig. 12 and Table 13 show the relation between the visual perception and preference of the occupants on the one hand and the illuminance value on the other.

The indicator slightly bright (+1) as perceived by the occupants refers to the illuminance value of 104 lux. Bright (+2) refers to the illuminance range of 26-1103 lux. Very bright (+3) refers to the illuminance range of 441-997 lux. Neutral (0) refers to the illuminance value of 61 lux. Dark (-2) refers to the illuminance value of 26 lux.

Overall, there is a slight difference between AU #1 and AU #2 on illuminance value that entering into its sitting rooms. Apartment #1 has illuminance value higher than the AU #2. It is because of the layout of the AUs as mentioned previously that lay-out both of them are inverse to each other. There is a difference also between the perception and the preference of the respondents in perceiving the illuminance value as shown in Table 14.

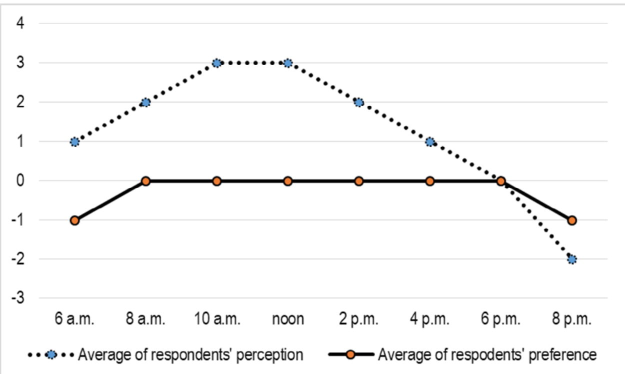

Fig. 11 The average of the visual perception and preference of the occupants in the sitting room of the AU #2

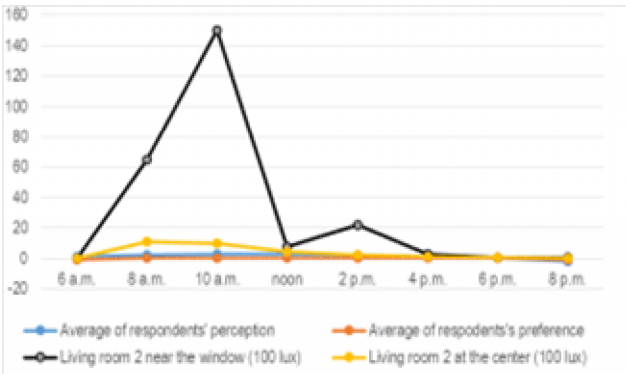

Fig. 12 The correlation between visual perception and preference of the occupants and the amount range of the illuminance in the AU #2

Table 13 - The correlation between visual perception and preference of the occupants and the amount range of the illuminance in the AU #2

Measurement time	What is your illuminance perception at the moment	Would you like to experience illuminance that is	Living room 2, near the window (lux)	Living room 2, at the center (lux)
6.00 am	1	-1	0	0
8.00 am	2	0	6495	1103
10.00 am	3	0	15000	997
noon	3	0	774	441
2.00 pm	2	0	2220	245
4.00 pm	1	0	284	104
6.00 pm	0	0	71	61
8.00 pm	-2	-1	46	26

Unmet standard　Met standard　Exceed standard

Tabel 14 - Comparison between the perception and the preference of the respondents in perceiving the illuminance value.

Value	Respondents' perception	Illuminance in AU #1 (lux)	Illuminance in AU #2 (lux)
-2	Dark	-	26
0	Neutral	-	61
1	Slightly bright	-	104
1,5	Between Slightly bright and Bright	51-384	-
2	Bright	67	245-1103
2,5	Between Bright and Very bright	269-577	-
3	Very bright	399-453	441-997

It means that the illuminance value is not a definite influence on the perception of the respondents. Hypothetically some other variables influence the perception of the respondents, among others is the biological clock of respondents, the influence of adjacent or surrounding ambiance. As long as there is a light perceived, the respondents would like to perceive no change of the circumstance, even though it is a very bright situation. The illuminance in one point cannot be separated firmly with ambiance around that perceived. It is a challenge and something matter that needs to reveal in further in-depth research. The preference or tendency of respondents that like the natural daylight is also a fundamental principle and significant potential to present the daylight into the interior space towards the sustainable indoor space and energy efficient.

9. Summary

All three analyses show similarities in the opportunities to use natural light in AUs. The potential for using natural lighting for the visual comfort of apartment users can only fulfill part of the bedroom and sitting room; while for other spaces, they still must rely on artificial lighting at certain times and durations. It relates to the influence of the spatial on the design of space settings in the AUs. In the future, this matter is the challenge to present the natural light entering the interior space.

The AU in Kuala Lumpur, Malaysia is potential to gain natural light throughout the day from sunrise to sunset, for more than 12 hours a day. The incoming natural light into the sitting room of the AU, on average is sufficient for doing daily activities without using electrical lamps according to the respondents. The sitting room is the space that the most utilized by respondents.

Respondents were not disturbed and remained comfortable with the amount of light that exceeded illuminance standards. In other words, respondents prefer natural daylight, although sometimes the habit of occupants who do not turn off the lights in the morning-noon-afternoon makes the potential of the natural daylight wasted, and makes a waste of energy because of the use of lamps all along the day.

Whereas based on illuminance standards, a state of natural lighting may have met the standards, but the habit of occupants who tend to always turn on the artificial lights makes the potential of natural light unutilized properly, and redundant in energy use. Especially in the apartment building in Kuala Lumpur, Malaysia that can make use of light tinge as natural light in the heading for the late afternoon because of astronomical twilight at 8.40 pm later than civil twilight at 7.49 pm.

The results of the research are essential for all parties involved in architectural design, management, and the user of residential units in service apartments that certified as green buildings. The motto we recommend is "let the light in." Generally, the more natural light, the better for the future of sustainable development.

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References

[1] Bean R. (2004). Interior and Exterior Lighting. Massachusetts: Architectural Press.

[2] Pilatowicz G. (1995). Eco-interiors, A Guide to Enviromentally Conscious Interior Design. Canada: John Wiley and Sons.

[3] Honggowidjaja S. P. (2003). Significant influence of light on interior design. Interior Dimensions, 1(1), 1-15.

[4] Lam J. C. & Li D. H. W. (1998). Daylighting and energy analysis for air-conditioned office buildings. Energy, 23(2), 79-89.

[5] Dora P. E. & Nilasari, P. F. (2011). Natural lighting utilization in townhouse type house in Surabaya. Proceeding of the Seminar Nasional Living Green: Mensinergikan Kehidupan, Mewujudkan Keberlanjutan, Surabaya, Indonesia.

[6] Suriansyah Y. (2014). Potensi pencahayaan alami pada rumah susun Sarijadi Bandung. Research Report - Engineering Science, Parahyangan Catholic University.

[7] Thojib J., Iyati W., Sufianto H., Budiman A., Ashita N., Sutantri, A. & Bebhi S. A. (2014). Optimasi pencahayaan alami pada rumah susun sederhana di kota Malang. Research Report - Category A, Universitas Brawijaya.

[8] Suriyanto R., Katili R. & Mariana Y. (2013). Optimalisasi pencahayaan alami pada rumah susun di Jakarta Timur. Working Paper, University Bina Nusantara.

[9] Risfawany K. S., Rahim L. D. & Hamzah, B. (2014). Tingkat pencahayaan alami pada rumah susun. Studi kasus Rusunawa Mariso. Working Paper, Universitas Hasanuddin.

[10] Mustika N. W. M. (2010). Daylighting optimation for energy efficiency on low cost flat with tower configuration in Denpasar case study low cost flat of Dinas Kepolisian Daerah Bali. Master Thesis, Institut Teknologi Surabaya.

[11] Sari D. L., Nugroho A. M. & Sudarmo B. S. (2016). Pengaruh window-to-wall ratio terhadap kenyamanan visual pada apartemen mahasiswa di Surabaya. Jurnal Jurusan Arsitektur, 5(1), 1-10.

[12] Zain-Ahmed A., Sopian K., Othman M. Y. H., Sayigh A. A. M. & Surendran P. N. (2002). Daylighting as a passive solar design strategy in tropical buildings: A case study of Malaysia. Energy Conversion and Management, 43(13), 1725-1736.

[13] Nikpour M., Kandar M. Z. & Mosavi E. (2012), Investigating daylight quality using self-shading strategy. Indoor and Built Environment, 22 (5), 822-835.

[14] Dahlan N. D., Jones P. J., Alexander D. K., Salleh E. & Alias, J. (2009). Daylight ratio, luminance, and visual comfort assessments in typical Malaysian Hostels. Indoor and Built Environment. 18(4), 319-335.