

Simulation of Different Light Well Typology by using Daylight Rules of Thumb under Overcast and Intermediate Skies without Sun



Amran Atan, Nik Lukman Nik Ibrahim, Mohd Khairul Azhar Mat Sulaiman

Abstract: The daylight conditions that are fit for an interior can be easily achieved by applying the simple and comprehensive principles, the daylighting rules of thumb in the process design. In architecture, these rules can be expressed in a different kinds of modes and are divided into categories that based on the parameters which constitute them. Since daylighting is the control admission of natural light, one of the categories can be the light well topology. Thus, an opening plays an important role in influencing the effectiveness of daylight distribution in building. One of the categories is light well typology. This study was conducted using an existing sample of single side opening and two side opening light wells with the comparison of additives to light-well typology under under overcast and intermediate skies without sun also to proposes daylighting rules of thumb for light wells. There are several types of light wells simulated for daylighting performances in this study. Light well models were simulated by conducted using IES_VE application software. Regression analysis was then carried out to find correlation between the measurements obtained in the daylighting simulation and the calculations derived from an established daylighting formula. Thus, existing daylighting formula is modified to create new daylighting rules of thumb for light wells with reflectance mirror in single storey terrace houses. These simple equations can serve as rules of thumb to help architects and engineers in calculating daylight levels for different light well designs.

Keywords : daylighting, rules of thumb, light well, reflectance mirror

I. INTRODUCTION

Houses are a form of construction that has been adapted and brought into the country by the British for decades. What is also known as the "row house" has begun to grow in the area around the city for the past 50 years or so in the 1960s and has taken up about 44% of urban housing following the increase in population. According to the Department of Statistics Malaysia in 2000, it contributed to 40% and above of all types of housing available in the city. From its design

point of view, the house has a narrow space with limited openings on the front and back facades. The typical width of a terrace house in Malaysia is between 18 feet (5400 mm) to 25 feet (7500 mm); while 65 feet (19500 mm) 80 feet long. (24,000 mm). The housing layout is usually planned repeatedly in a rectangular lot line. The border from house to house has been defined as a brick wall [1].

A study conducted by Mc Menemy [2] has shown that daytime light received by the body at its optimum level can assist the individual's mental and physical development. According to some previous studies have shown that reductions in lighting and ventilation rates in a building opening can lead to deterioration of indoor quality, which in turn leads to numerous health-related issues such as building sickness syndromes [3]. The study concluded that lighting and ventilation must be in accordance with the Building Code of Malaysia (UBBL) 1984, which provided for uninterrupted window openings of 5% to 10% of floor area. The roof, meanwhile, is the main building block of the terrace house exposed to direct sunlight. Therefore, natural lighting in the terrace house is constrained by small window ratios. In addition, tropical climates have warm and humid temperatures throughout the year. Several identifying works have been carried out on terraced homes in tropical climates by studying sustainable housing for residential-industrial areas in Malaysia by looking at some aspects of the quality of the indoor environment. Survey, physical measurements and interviews were conducted for a residential area in Malaysia.

Light well is commonly used in terrace houses to admit natural lighting. The use of natural light is important in improving the indoor environmental quality and energy efficiency of buildings [4]. In the Uniform Building By-Laws (UBBL) of Malaysia, all terraced residential buildings are required to be equipped with light wells in the living areas with suitable opening sizes [5]. Light wells are not allowed to be closed except with openable lids and roof monitors. These requirements are meant to ensure ventilation as well as admission of natural daylight as required by UBBL (1984). The use of light well as a means for daylighting in building is not a new strategy as it has been used in historical buildings. (Fig. 1) shows the concept and function of light wells in allowing natural light and ventilation simultaneously into terrace houses. If the opening size is increased, more daylight can be admitted inside the houses with light wells [6].

Based on a previous study [7], there are various modifications made on light wells in terrace houses.

Revised Manuscript Received on December 30, 2019.

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The primary reason for the renovation is the negative acceptance of the dwellers to the light well designs in their terrace houses. Occupants only accept light wells positively after modifications are made to suit their needs. According to A. Atan and N. L. Nik Ibrahim [7] there are four light well types (Fig. 2) usually found in terrace houses in Merlimau Melaka, Malaysia namely, i) open hole (original design), ii) roof monitor with single side opening, iii) roof monitor with two side openings and iv) glazed skylight. Among the typologies, light well with roof monitor and single side opening was the most frequently found in terrace houses. However, occupant's survey carried out that light well with roof monitor and two side openings provides better daylight and receives better responses amongst residents [7].

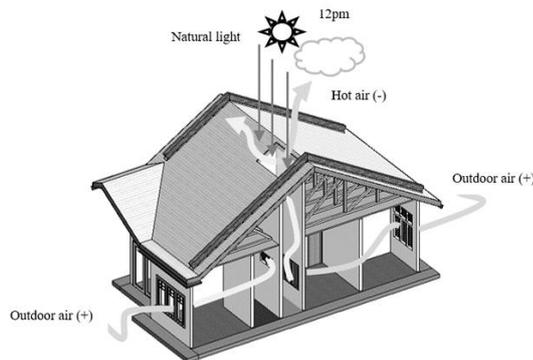


Fig. 1. The concept light wells in allowing natural light and ventilation for terrace houses

Further study proceeds to evaluate the effectiveness of various light well typologies in daylighting performances. Another objective of the study is to generate daylighting rules of thumb or simplified formula for light wells. In accordance to Nik Lukman, N.L. [8] in architecture, the simple and comprehensive principles of daylighting rules of thumb can easily be applied in the design process in order to have a quick prediction of daylight levels for the interior. The study also aims to comparison addition of material to light well typology. Among the materials analyzed in this study were variable reflective mirror materials on the roof ceiling for each type of light well typology. IES-VE software is the simulation tool used in the daylighting experiments conducted.

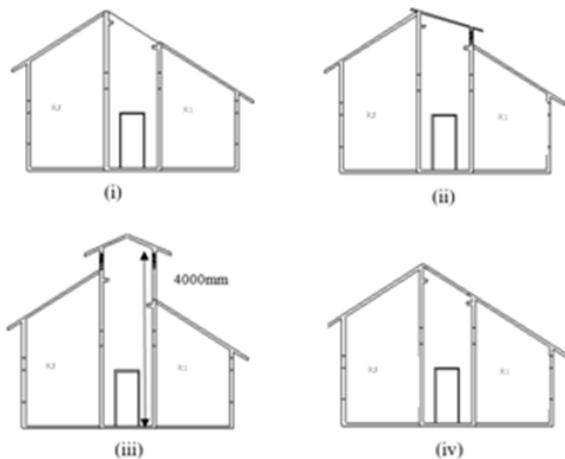


Fig. 2. Four main types of light wells in terrace houses

II. OBJECTIVES

The main objective of the study is to establish the impact of numerous reflectance mirrors on a ratio of ceiling area to floor area in the daylighting rule of thumb. It also strives to initiate further on daylighting rules of thumb which focusing on variety reflectance mirror.

III. EXPERIMENT PROCEDURE

A computer simulation study was conducted to investigate the effect of daylighting from different light well typologies with reflectance mirror on a ceiling area in the simulation as shown in (Fig. 3). The daylighting simulation study was carried out under an overcast sky and intermediate sky without sun condition using RADIANCE application in IES-VE 0.6 Software and used before in similar works by Amran [9]. The first two light well types simulated were based on the light wells of single story terrace houses in Merlimau Melaka, Malaysia. The other light well typologies were modifications of the two common types. The sky condition projected was based on the level of sky illumination in Melaka location (Latitude 227° North and Longitude 102.25° East) and the twelve-month of climate data; while the stimulation time was set at noon (12:00 pm) on March 15 [9].

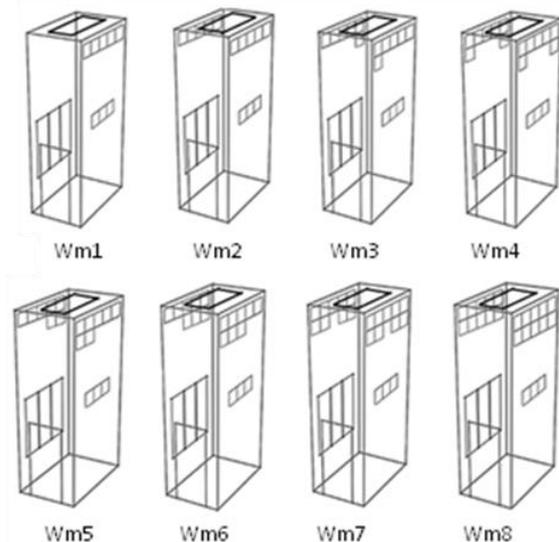


Fig. 3. Eight different types of light wells with reflectance mirror on a ceiling area in the simulation

Light well shaft parameters in this study are kept constant at 1.8m width, 2.5m length and 4.0m height and each of light wells added with reflectance mirror at 2.25m² above in Table I. Glass transmittance of light well's aperture was set at 0.9 or 90 percent (a normal clear glass transmittance). The assumption of 0.89 or approximate 0.9 glazing transmittance by daylight rule of thumb actually represents a typical plate or sheet of clear glass for the window [8]. The variable parameter in this experiment was the aperture glazing area or its percentage to the light well's floor area, [10]. The simulation for light well surface reflectance was set to 0.3m, 0.6m and 0.8m for floor surface, wall surface and mirror surface above, respectively.

Besides, there was a recommendation on surface reflectance for the ceiling (0.8m), wall finishing (0.6m) and floor surface (0.2m). The measuring for daylight illuminance was carried out at the work plane of 0.9m above the floor surface as indicated with reflectance mirror by the sectional diagram in (Fig. 4).

Table- I: Floor areas, window sizes and reflectance mirror of the light wells simulated

Light Well	Wm1	Wm2	Wm3	Wm4	Wm5	Wm6	Wm7	Wm8
A _f (m ²)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
A _g (m ²)	1.4	2.7	3.2	3.8	4.0	4.6	4.7	5.4
M (m ²)	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25

A_f - floor area of light well, A_g - area of window or light well's opening M- area of reflectance mirror

Daylight factor was calculated from the illuminance levels obtained in the simulation. Daylight factor is very vital and used to this day since it is a good indicator for the overall light appearance. This is because of the relative luminance of surfaces within the field vision influence the brightness appearance of a place [11]. Based on the standard daylight factor (DF), a recommended value for effective daylight-lit space is 2%. In Table II, the visual tasks with suitable daylight levels are outlined in more detail [12].

Table- II: Amount of daylight levels for adequate visual performance

Visual Task	Illumination Levels (Lux)	Daylight Factor (%)
Casual reading, ordinary factory bench work, etc.	75-100	1.2-2
Prolonged reading, school and office work, etc.	100-150	2-3

A previous study that had run the stimulation by using AGI-32 software. It had shown that the average daylight factor could be achieved approximately 5% for the interior by implementing 20% window to floor area [13]. This is in accordance with the Chartered Institution of Building Services Engineers (CIBSE) description of a cheerful daylight interior condition. For minimum activity spaces that less frequent for any visual tasks, CIBSE suggests the indoor illuminances of around 100-200 lux [14]. For the overcast sky, previously the original of Littlefair's formula was used to calculate the daylight factors which will correlate to the simulations data. However, an intermediate sky without sun type is the one that suitable for Malaysia. The original Littlefair's daylight factor formula [15] is shown below:

$$DF_{avg} = \frac{T_w A_g \theta}{A_s (1-R^2)} \quad (1)$$

- DF_{avg} average daylight factor
- A_g window glazing area (m²)
- T_w transmission of window glazing
- θ sky angle measured at the centre of the window in degree
- A_s total area of the room surfaces ceiling, floor, walls and windows (m²)

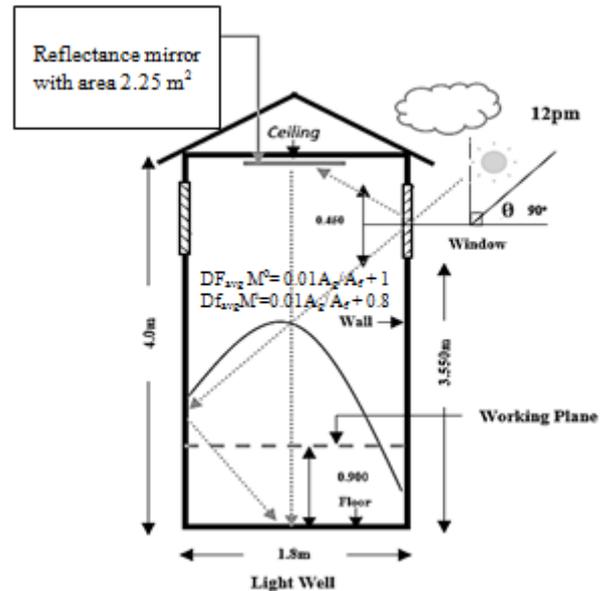


Fig. 4. Sectional diagram of the simulated light well model with reflectance mirror

IV. RESULT AND DISCUSSION

(Fig. 5) shows the general center line illuminance in the light wells simulated. Maximum illuminance obtained under overcast sky and intermediate sky without sun was higher than 150 lux. Furthermore, illuminance of not less than 150 lux can be maintained under overcast sky and intermediate sky without sun in Merlimau, Melaka. From the simulation, the performances of Wm^o1 and Wm^o2 are better under overcast sky and Wmⁱ2, Wmⁱ3 and Wmⁱ4 under intermediate sky without sun. Wm^o3, Wm^o4, Wm^o5, Wm^o6, Wm^o7 and Wm^o8 provide adequate illuminance under overcast sky and Wmⁱ5, Wmⁱ6, Wmⁱ7 and Wmⁱ8 under intermediate sky without sun while Wmⁱ1 are not satisfactory under intermediate sky without sun. Therefore, the light wells with larger openings on two sides are better typologies for daylighting in additional with reflectance mirror.

Table- III: Daylight factors for different light wells under overcast and intermediate skies without sun

Light Well	Overcast Sky / Wm ^o							
	Wm ^o 1	Wm ^o 2	Wm ^o 3	Wm ^o 4	Wm ^o 5	Wm ^o 6	Wm ^o 7	Wm ^o 8
A _s (m ²)	47.0	48.6	49.2	49.5	49.6	50.3	50.7	51.5
A _g (m ²)	1.4	2.7	3.2	3.8	3.9	4.0	4.6	5.0
DF _{avg} M ^o (%)	1.6	1.9	2.2	2.3	2.4	2.5	2.6	2.8
Light Well	Intermediate Sky without Sun / Wm ⁱ							
	Wm ⁱ 1	Wm ⁱ 2	Wm ⁱ 3	Wm ⁱ 4	Wm ⁱ 5	Wm ⁱ 6	Wm ⁱ 7	Wm ⁱ 8
A _s (m ²)	47.0	48.6	49.2	49.5	49.6	50.3	50.7	51.5
A _g (m ²)	1.4	2.7	3.2	3.8	4.0	4.6	4.7	5.4
DF _{avg} M ⁱ (%)	1.2	1.7	1.8	1.9	2.0	2.1	2.2	2.4

A_s - surface area of light well, A_g - area of window or light well's opening, DF_{avg} M^o - average daylight factor under overcast sky, DF_{avg} Mⁱ - average daylight factor under intermediate sky without sun

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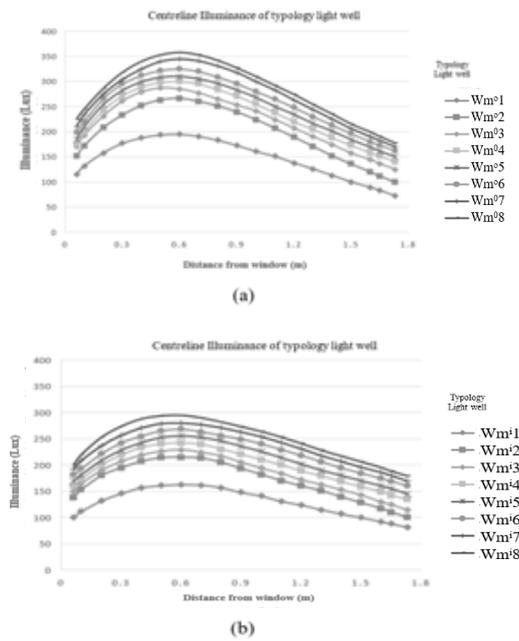


Fig. 5. Center line illuminance of the light wells simulated under (a) overcast sky and (b) intermediate sky without sun

Table III shows the daylight factors for the eight different light wells with reflectance mirror simulated. M is reflectance mirror, A_s is the surface area of the light well and A_g is the area of window or light well's aperture with standard clear glass transmittance. Light wells Wm^3 , Wm^4 , Wm^5 , Wm^6 , Wm^7 and Wm^8 under overcast sky and Wm^5 , Wm^6 , Wm^7 and Wm^8 under intermediate sky without sun have generous aperture sizes which contribute to higher percentages of daylight factors. The graph in (Fig. 5) shows that in different types of light wells under overcast sky and intermediate sky without sun, the ones with larger apertures located on two sides obtain better daylight factor. Therefore, with this finding, the size of light well aperture (A_f) can be regarded as a prominent criterion in light well designs for daylighting.

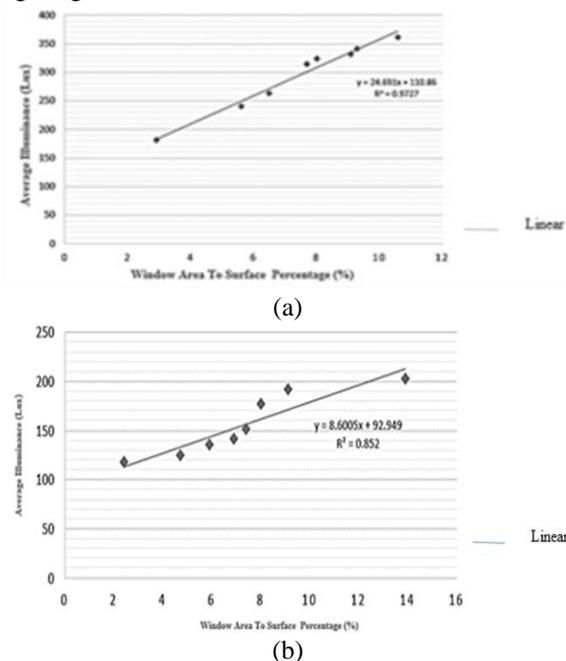


Fig. 6. Average illuminance vs window area to surface area (a) under overcast sky and (b) Intermediate sky without sun

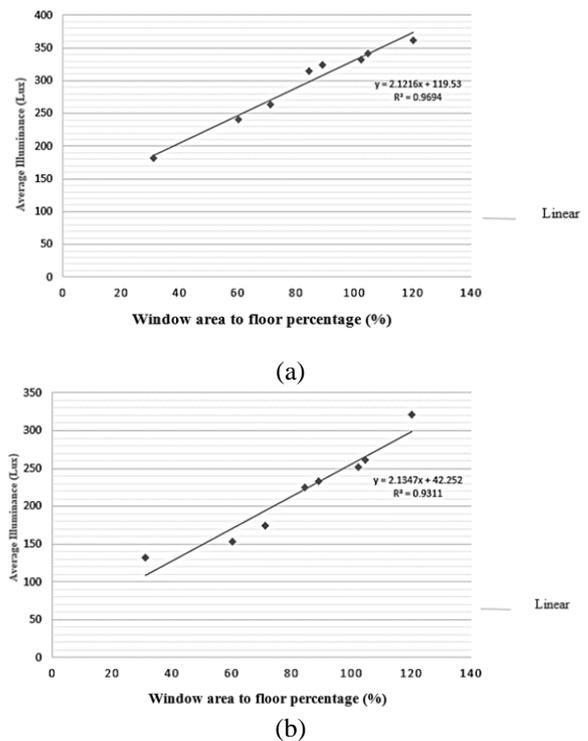


Fig. 7. Average illuminance vs window area to floor area under (a) overcast sky and (b) intermediate sky without sun

(Fig. 6) and (Fig. 7) show the correlations between average illuminance inside the light wells with the percentage of window area to floor area and surface area respectively under overcast sky and intermediate sky without sun. Sufficient average illuminance of about 260 lux can be achieved inside light well with window to surface area ratio of 70% under overcast sky while about 150 lux can be achieved and area ratio of 70% under intermediate sky without sun. An average illuminance of approximately 225 lux can be obtained with window to floor area ratio of 70% under the overcast sky while 230 lux and area ratio of 80% under intermediate sky without sun. The correlative equations between average illuminance and the percentage of window area to surface area and floor area of the whole light wells is shown in Table IV:

Table- IV: Correlative equations between average illuminance and the percentage of window area

Percentage of window area	Overcast Sky	Intermediate Sky without Sun
Surface	$E_{as}M^o = 17A_g/A_s + 100$	$E_{as}M^i = 15A_g/A_s + 86$
Floor	$E_{af}M^o = 1.5A_g/A_f + 107$	$E_{af}M^i = 1.3A_g/A_f + 91$

$E_{as}M^o$ - average illuminance, A_g - light well's aperture size (m^2), A_s - light well's surface area (m^2), A_f - light well's floor area (m^2), $E_{af}M^i$ - average illuminance

Regression analysis which has been conducted between the simulation average daylight factors and the average daylight factors obtained from Littlefair's formula as shown in (Fig. 8).



The generated correlative equations are the basis for the rule of thumb formulated for the light wells. As the linear correlation is rather accurate and in much simpler equation than the polynomial correlation, the proposed rule of thumb for the light well typologies is shown in Table-V:

Table- V: Simplified rule of thumb

	Overcast Sky	Intermediate Sky without Sun
Regression Analysis	$DF_{avg}M^0 = 0.01A_g/A_s + 1$ $(R^2 = 0.9813)$	$DF_{avg}M^i = 0.01A_g/A_s + 0.8$ $(R^2 = 0.9834)$

$DF_{avg}M^0$ - average daylight factor, A_g - light well's aperture size (m²), A_s - light well's surface area (m²),

$DF_{avg}M^i$ - average daylight factor

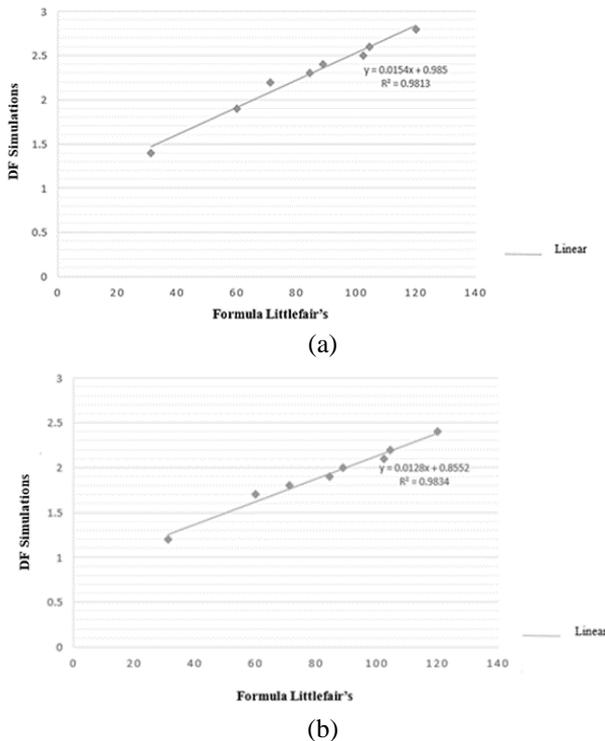


Fig. 8. Simulation average under (a) overcast sky and (b) intermediate sky without sun

V. CONCLUSION

The comprehensive and simplified equations which also known as the rules of thumb which are the outcome in this study are significant for the light well typology of 1.8m width, 2.5m length and 4.0m height in single storey terrace houses with reflectance mirror its aperture. Since this issue needs to be address, a simulation has been conducted although it is limited to a medium-size room [16]. As for the average illuminance, about 260 lux can be achieved inside light well with 70% ratio of window to surface area under overcast sky while only 150 lux is achieved under intermediate sky. For 70% ratio of window to floor area under overcast sky, 225 lux was obtained while 80% ratio under intermediate sky only achieved 230 lux. Regression analysis is carried out to find correlations between the measurements obtained in the simulations and the calculations derived from Littlefair's daylighting formula.

These simplified equations which are $DF_{avg}M^0 = 0.01A_g/A_s + 1$ ($R^2 = 0.9813$) and $DF_{avg}M^i = 0.01A_g/A_s + 0.8$ ($R^2 = 0.9834$) as representing overcast and intermediate sky without sun respectively can be considered as rules of thumb for predicting daylight levels inside light well spaces. The experiments show that typical light wells with approximately 4m² to 7m² area of aperture with reflectance mirror 2.25m² above can supply adequate lighting for interior illuminance under the overcast and intermediate sky without sun in Merlimau Melaka, Malaysia. In sum, all these successfully resulted equations can be considered as simple formulas that can ease everybody to estimate daylighting based on parameters mentioned above.

ACKNOWLEDGMENT

This research work was carried out under grateful to Archi Idea Sdn. Bhd. (Architecture, Int. Design & Home Renovation) for some assistance given during the study.

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