REGULAR ARTICLE

DAYLIGHT SIMULATION OF DIFFERENT LIGHT WELL TYPES IN SINGLE STORY TERRACE HOUSES

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ABSTRACT

Indoor environment quality inside a house is greatly dependent upon good daylighting. Thus, an opening plays an important role in influencing the effectiveness of daylight distribution in building. A commonly used element in terrace house to admit natural lighting is light well. This study reviews different light wells typology in single story terrace houses, conducts daylighting simulations of different light well types and 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 using Integrated Environmental Solution - Virtual Environmental (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 in single story terrace houses. These new rules of thumb are actually simplified formulas to aid architects in estimating daylight levels in terrace house light wells.

Keywords: *: Daylighting, rules of thumb, light well, terrace houses, indoor environment*

1. INTRODUCTION

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 (N. Lechner, 2009). 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 (Undang-undang Kecil Bangunan, 2008). 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. Figure 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 (Amran Atan & Nik Lukman Nik Ibrahim, 2017).

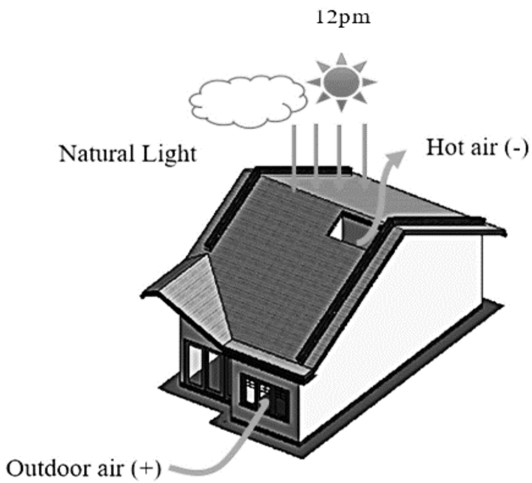

Figure 1: The role of light wells in providing daylight and natural ventilation for terrace houses

Light well renovations without proper consideration of its functions in terraced houses can result in dark interiors. Frequent complaints from the residents of terrace houses with light wells include the issue of security as the provision can facilitate house break-ins through the opening of the light well. Other problems include water leakage during rain falls and the growth of fungi and moss. Besides, dirt on the roof may also block the light well apertures. These problems have led the residents to obstruct or eliminate light wells in their houses completely without realizing their action is a violation of the UBBL (1984), which requires natural lighting and ventilation openings of not less than 5% of the floor area. Generally, the residents of terraced houses are not aware about this rule of law.

Based on a previous study by A. Atan and N. L. Nik Ibrahim (2016), there are various modifications made on light wells in terrace houses. 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 (2016), there are four light well types (Figure 2) usually found in terrace houses in Merlimau, Melaka 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, occupants survey carried out by A. Atan and N. L. Nik Ibrahim (2016) shows that light well with roof monitor and two side openings provides better daylight and receives better responses amongst residents. Renovation that maintains the basic function of light wells is very important to ensure effective ventilation and natural lighting in terrace houses. Typical light wells in terrace houses usually meet the UBBL criteria for the allocation of 5% opening area to floor area for ventilation and daylighting purposes.

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. According to Nik Lukman, N.L. (2002) daylighting rules of thumb in architecture are simple and comprehensive principles, which can be readily applied in the design process in order to quickly predict daylight levels in interior. The study also aims to identify effective aperture sizes in light well designs. IES-VE software is the simulation tool used in the daylighting experiments conducted.

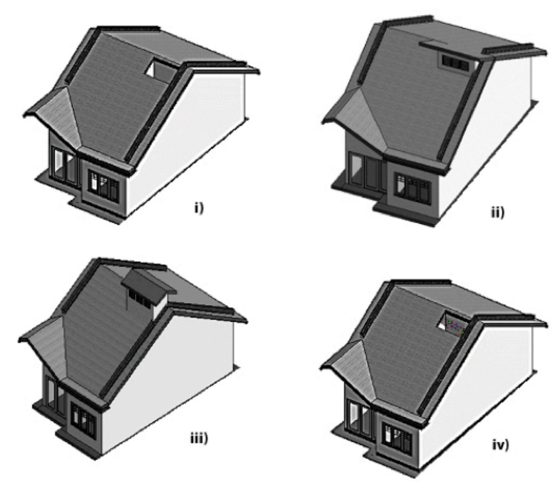

Figure 2: Four main types of light wells in terrace houses

2. EXPERIMENT PROCEDURE

A computer simulation study was conducted to investigate the effect of daylighting from different light well typologies as shown in Figure 3. The daylighting simulation study was carried out under an overcast sky condition using RADIANCE application in IES-VE 0.6 Software. The first two light well types simulated were based on the light wells of single story terrace houses in Merlimau, Melaka. The other light well typologies were modifications of the two common types. The sky condition projected was based on the annual climate data and the level of sky illumination in Melaka location (Latitude 227° North and Longitude 102.25° East). The simulation time was set at noon (12:00 pm) on March 21.

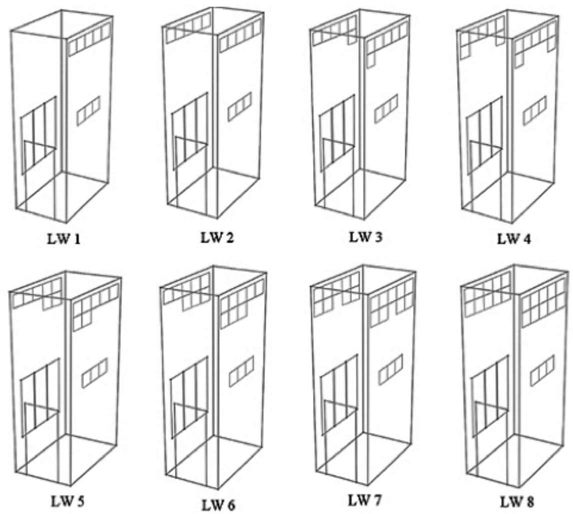

Figure 3: Eight different types of light wells in the simulation

Light well shaft parameters in this study are kept constant at 1.8m width, 2.5m length and 4.0m height, but with eight typological variations involving different aperture configurations and sizes as indicated in Figure 3 and Table 1. Glass transmittance of light well's aperture was set at 0.9 or 90 percent (a normal clear glass transmittance). Following the study by M. F. M. A. Sadin, N. L. N. Ibrahim, K. Sopian and E. Salleh (2014), the variable parameter in this experiment was the aperture glazing area or its percentage to the light well's floor area. Light well surfaces reflectance in the simulation was set to 0.3m for floor surface reflectance, 0.6m for wall surface reflectance and 0.8m for ceiling surface reflectance. These surface reflectance parameters were based on a previous study by J. E Flynn, J.A Kremers, A.W. Seencrazy and G.R Steffy (1992) in which case the surface reflectance recommended were 0.8 for ceiling, 0.6 for wall finishing and 0.2 for floor surface. Daylight illuminance was measured at the work plane of 0.9m above the floor surface as indicated by the sectional diagram in Figure 4.

Daylight factor was calculated from the illuminance levels obtained in the simulation. Daylight factor was a measure of the ratio or percentage between inside and outside illuminances or the proportion of the daylight illuminance that reaches a point inside an interior (A.M.A Rahman, M.H.A Samad, A. Baharuddin and M.R Ismail, 2009). The use of daylight factor has persisted to the present day as it has an important characteristic which is a good indicator of the overall appearance of light. This is because the brightness appearance of a place depends at least as much on the relative luminance of surfaces within the field of vision as on absolute values (P.Tregenze and M.Wilson, 2011). A standard recommended daylight factor (DF) for an effective daylight-lit space is 2%. In the other hand, IESNA and CIBSE recommend indoor illuminances of 100-200 lux for minimum activity spaces where visual tasks are only occasionally performed (P.Micheal, 2001).

Table 1: Floor areas and window sizes of the light wells simulated

Light Well	LW1	LW2	LW3	LW4	LW5	LW6	LW7	LW8
A_f (m^2)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
A_g (m^2)	1.1	2.2	2.7	3.3	3.5	3.8	4.3	4.7

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

The daylight measurements obtained in the simulation were used to modify Littlefair's daylight factor formula which was meant for rooms with normal windows. In this case, the formula was modified to address different light well typologies simulated under an overcast sky in Merlimau, Melaka. The original Littlefair's daylight factor formula (J. A. Lynes, 1992) is shown below:

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

DF_{avg} average daylight factor
A_g window glazing area (m^2)
T_w transmission of window glazing
Ø sky angle measured at the centre of the window in degree
A_s total area of the room surfaces ceiling, floor, walls and windows (m^2)

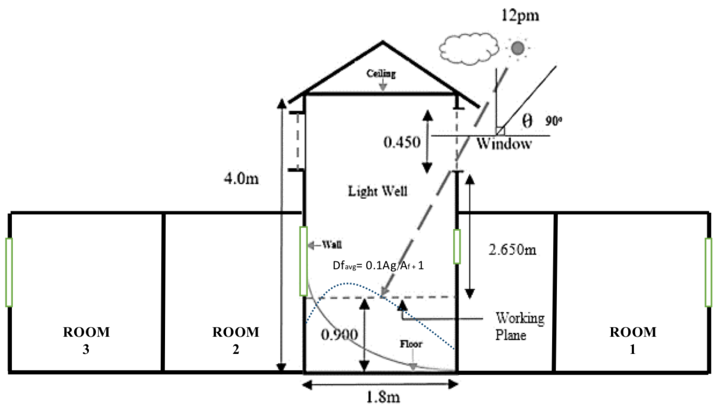

Figure 4 shows the general center line illuminance in the light wells simulated.

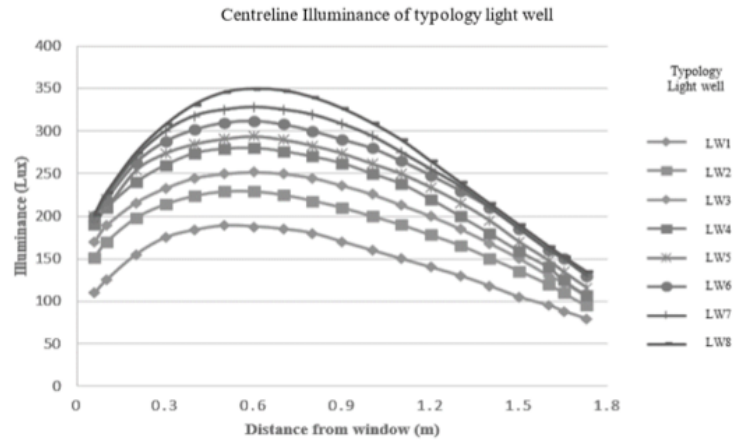

Figure 5: Center line illuminance of the light wells simulated under overcast sky

Table 2: Daylight factors for different light wells under an overcast sky

Light Well	LW1	LW2	LW3	LW4	LW5	LW6	LW7	LW8
A_s (m^2)	24.0	48.0	60.0	72.0	77.6	84.0	96.0	155.3
A_g (m^2)	1.1	2.2	2.7	3.3	3.5	3.8	4.3	4.7
DF_{avg}(%)	1.0	1.5	1.7	1.8	1.9	2.0	2.1	2.3

A_s - surface area of light well, A_g - area of window or light well's opening, DF_{avg} - average daylight factor

Table 2 shows the daylight factors for the eight different light wells simulated. 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 LW6, LW7 and LW8 have generous aperture sizes which contribute to higher percentages of daylight factors. The graft in Figure 5 shows that in different types of light wells, 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.

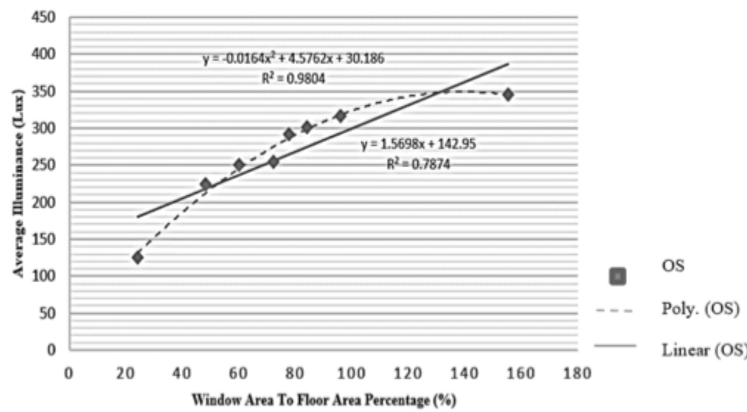

Figure 6(a): average illuminance vs window area to floor area under overcast sky

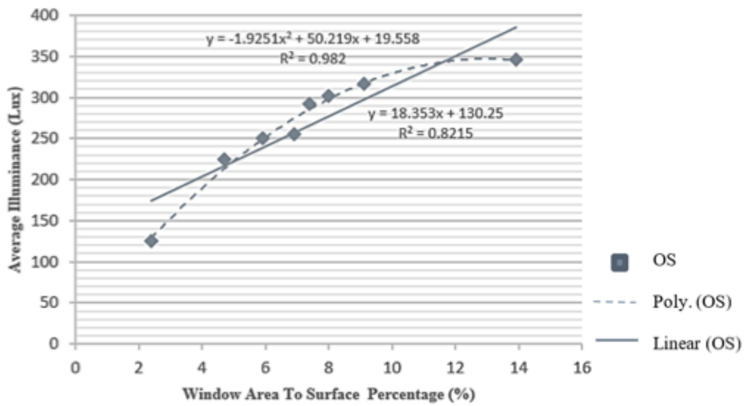

Figure 6(b): average illuminance vs window area to surface area under overcast sky

Figure 6(a) and Figure 6(b) show the correlations between average illuminance inside the light wells with the percentage of window area to floor area and surface area respectively. Sufficient average illuminance of about 250 lux can be achieved inside light well with window to surface area ratio of 70% and average illuminance of approximately 325 lux can be obtained with window to floor area ratio of 10% under the overcast sky. The correlative equations between average illuminance and the percentage of window area to surface area and floor area of the whole light wells are shown below:

$$E_{avg} = 18A_g/A_s + 130$$

E_{avg} average illuminance
A_g light well's aperture size (m^2)
A_s light well's floor area (m^2)

$$E_{avg} = 1.5A_g/A_f + 140$$

E_{avg} average illuminance
A_g light well's aperture size (m^2)
A_f light well's floor area (m^2)

Regression analysis was carried out between the simulation average daylight factors and the average daylight factors obtained from Littlefair's formula as shown in Figure 7. 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 following rule of thumb is thus proposed for the light well typologies:

$$DF_{avg} = 0.1A_g/A_f + 1 \ (R^2 = 0.8658)$$

DF_{avg} average daylight factor
A_g light well's aperture size (m^2)
A_f light well's floor area (m^2)

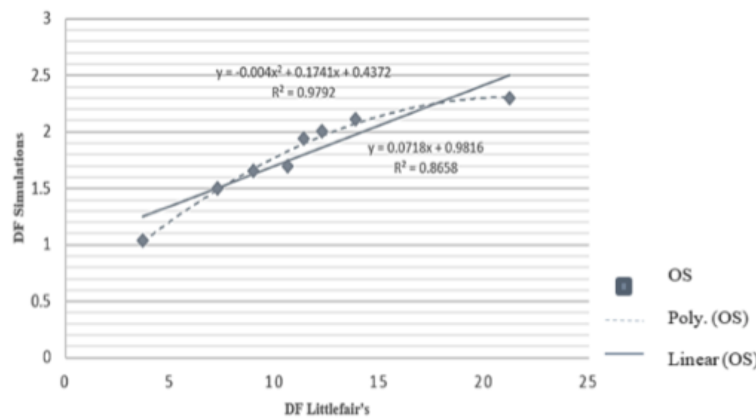

Figure 7: Simulation average daylight factor vs Littlefair's average daylight factor

4. CONCLUSIONS

The simplified equations or rules of thumb produced in this study are applicable for the light well typology of 1.8m width, 2.5m length and 4.0m height in single story terrace houses with standard clear glass covering its aperture. 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 can be considered as rules of thumb for predicting daylight levels inside light well spaces. The experiments show that typical light wells with approximately 4m^2 to 7m^2 area of aperture can provide sufficient interior illuminance under the overcast sky in Merlimau, Melaka. For future studies, more light well types can be simulated and analyzed. The rules of thumb generated and presented in this article can be used as simple guides for local authorities and architects in designing light wells in Melaka.

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