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).
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 rainfalls 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.
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 22.7° 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](image)

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 0.8m 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).

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

DF\textsubscript{avg} - average daylight factor

\(A_g\) - window glazing area (m²)

\(T_w\) - transmission of window glazing

\(\theta\) - skylight angle measured at the centre of the window in degree

\(A_s\) - total area of the room surfaces ceiling, floor, walls and windows (m²)

<table>
<thead>
<tr>
<th>Light Well</th>
<th>LW1</th>
<th>LW2</th>
<th>LW3</th>
<th>LW4</th>
<th>LW5</th>
<th>LW6</th>
<th>LW7</th>
<th>LW8</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A_f) (m²)</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>(A_g) (m²)</td>
<td>1.1</td>
<td>2.2</td>
<td>2.7</td>
<td>3.3</td>
<td>3.5</td>
<td>3.8</td>
<td>4.3</td>
<td>4.7</td>
</tr>
</tbody>
</table>

\(A_f\) - floor area of light well, \(A_g\) - area of window or light well’s opening
Figure 4 shows the general center line illuminance in the light wells simulated.

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

<table>
<thead>
<tr>
<th>Light Well</th>
<th>LW1</th>
<th>LW2</th>
<th>LW3</th>
<th>LW4</th>
<th>LW5</th>
<th>LW6</th>
<th>LW7</th>
<th>LW8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_s$ (m²)</td>
<td>24.0</td>
<td>48.0</td>
<td>60.0</td>
<td>72.0</td>
<td>77.6</td>
<td>84.0</td>
<td>96.0</td>
<td>155.3</td>
</tr>
<tr>
<td>$A_g$ (m²)</td>
<td>1.1</td>
<td>2.2</td>
<td>2.7</td>
<td>3.3</td>
<td>3.5</td>
<td>3.8</td>
<td>4.3</td>
<td>4.7</td>
</tr>
<tr>
<td>DF$_{avg}$ (%)</td>
<td>1.0</td>
<td>1.5</td>
<td>1.7</td>
<td>1.8</td>
<td>1.9</td>
<td>2.0</td>
<td>2.1</td>
<td>2.3</td>
</tr>
</tbody>
</table>

$A_s$ - surface area of light well, $A_g$ - 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 graph 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 ($A_g$) can be regarded as a prominent criterion in light well designs for daylighting.

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

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

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

**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 4m² to 7m² 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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