The standard value of the horizontal illuminance from unobstructed sky is considered very essential and fundamental for the energy conservation in the field of lighting design in order to keep the minimum level of the illuminance in interiors. According to the recent progress of the way of thinking on the visual environment and the change of the energy circumstances, many improved models have proposed for the estimation of the illumination level in interiors. The estimations based on these models proved that the sky illuminances vary in different locations and countries. In order to investigate daylight availability data in low latitude/tropic area which extremely lacking at the present stage, a measurement of daylight and solar radiation was done in Makassar–Indonesia. After the records of the data strictly inspected, the data of the diffuse illuminance has been rearranged into a classification based upon the sky conditions of the whole day specified by cloud ratios. Based upon the diffuse horizontal illuminance data gathered in Makassar–Indonesia during 1995 to 2000, a preliminary study on the values of the horizontal illuminance from the unobstructed sky by the statistical analysis can be proposed.

Keywords: daylight and solar radiation, horizontal illuminance, measurement data, sky conditions.

INTRODUCTION

The standard value of the horizontal illuminance from unobstructed sky is considered very essential and fundamental for the energy conservation in the field of lighting design in order to keep the minimum level of the illuminance in interiors. According to the recent progress of the way of thinking on the visual environment and the change of the energy circumstances, many improved models have proposed for the estimation on the illumination level in interiors. The estimations based on these models proved that the sky illuminances vary in different locations and countries. A study about horizontal illuminance in Indonesia have done by M.U. Adhiwijogo in order to propose the selection of the design sky for Indonesia based on the illumination climate of Bandung. The study based upon the observations and measurements throughout the whole year of 1964. He proposed a result for the blue cloudiness sky and the grayish overcast sky, giving an equivalent illumination of 10,000 lumen/m² are to be used as the design sky for Indonesia [1].
Based upon the diffuse horizontal illuminance data gathered in Makassar-Indonesia during 1995 to 2000 a proposal on the values of the horizontal illuminance from the unobstructed sky can be made by the statistical analysis.

**SKY CONDITIONS SPECIFIED BY CLOUD RATIO**

Two CIE standards, that is, the CIE Standard Clear Sky and the CIE Standard Overcast Sky already recommended as the standards of sky luminance distribution. Unfortunately, those skies only represent for two extreme sky conditions, that is, the completely clear sky and the heavily cloud sky. However, most of real sky conditions are not similar to them. They are between both extreme skies above stated, called “intermediate sky”.

In analyzing the measured data of daylight and solar radiation, it is necessary to sort the data by sky conditions. They are divided conveniently in three sky conditions, such as the clear sky condition (including quasi-clear sky), the intermediate sky condition and the overcast sky condition (including quasi-overcast sky). However, the sky conditions were recorded three times a day in a measurement diary (log book), it is not satisfactory to know the sky conditions of the whole day. For purpose, a parameter which can specify the real sky conditions is absolute necessary.

The ratio of the diffuse illuminance and/or irradiance to the global illuminance and/or irradiance is defined and named Cloud Ratio, which have been considered as the most practical and convenient parameter for this purpose.

**Definition of Cloud Ratio**

The Cloud Ratio has originally defined as the proportion of the diffuse irradiance to the global irradiance and used for to the estimation of solar radiation, that is, for solution of heating and cooling problems in building interior. A few recent research papers [4-7] are found which applied the ratio of the diffuse illuminance to the global illuminance to the daylight research works.

In this study, the ratio on irradiance is called “Cloud Ratio on Irradiance (Ce)” and the ratio on illuminance is called “Cloud Ratio on Illuminance (Cv)”. Cloud ratio on irradiance can be calculated theoretically by the following equation:

\[
Ce = \frac{E_{ed}}{E_{ed} + E_{es}} = \frac{E_{ed}}{E_{eg}}
\]  \hspace{1cm} (1)

Where : E_{eg} is global horizontal irradiance [W/m^2], E_{ed} is diffuse horizontal irradiance [W/m^2], and E_{es} is direct solar horizontal irradiance [W/m^2].
Cloud ratio on illuminance \((C_v)\) is defined in a similar way to cloud ratio on irradiance \((C_e)\). Cloud ratio on illuminance can be calculated theoretically by the following equation:

\[
C_v = \frac{E_{vd}}{(E_{vd} + E_{vs})} = \frac{E_{vd}}{E_{vg}} \quad \ldots (2)
\]

where : \(E_{vg}\) is global horizontal illuminance \([\text{lx}]\), \(E_{vd}\) is diffuse horizontal illuminance \([\text{lx}]\), and \(E_{vs}\) is direct solar horizontal illuminance \([\text{lx}]\).

**Typical Diurnal Fluctuation of Cloud Ratio**

Theoretically, the values of both cloud ratios should be equal to 1.0 when the sky is completely overcast of the whole day. Both the cloud ratios on irradiance and illuminance of a clear day of the whole day seem to be dependent on the solar position. Their values were almost constant when the solar altitude was not so low and they increased as the solar altitude became low. The ratios of the overcast day of the whole day were almost equal to 1.0 throughout the whole day. The Examples of both the cloud ratios of an intermediate day of the whole day show the frequent and rapid change of their values throughout the whole day. Their values sometimes seemed to be almost equal to those of the clear condition and instantly move to those of the overcast conditions. Most values of cloud ratio on irradiance were a little smaller than those of cloud ratio on illuminance of the same time.

**Sky Conditions**

The diurnal fluctuation of cloud ratio on irradiance has been mainly inspected and compare with the cloud ration on illuminance. The measurement diary (log book) was also checked for reference.

The result shows the sky conditions specified by cloud ratios, the clear and overcast days were 318 and 308 days, respectively and the rest, 1449 days had intermediate sky conditions (were: clear sky 15.32%, intermediate sky 69.80%, and overcast sky 14.88%, respectively).

The yearly relative Frequency of occurrence of the three skies in Indonesia has been calculated from the relative sunshine duration and is assumed to be 6 %, 73 %, 21%, respectively [10].

The differences of the results are caused by the different period of calculation. Sky conditions specified by cloud ratios are daily between sunrise to sunset, and sky conditions calculated by sunshine duration are based on 8 hours daily working time.
DIFFUSE HORIZONTAL ILLUMINANCE

Classification of Data Based upon the Sky Conditions

After the records of the data were strictly inspected, the data of the diffuse horizontal illuminance has been rearranged into a classification based upon the sky conditions of the whole day conditions of the whole day specified by cloud ratios. The general tendencies, i.e. the effects of sky conditions to the horizontal illuminance from unobstructed sky have been roughly inquired, for example:

- Under the condition of the clear sky, the values of the horizontal illuminance from unobstructed sky are often smaller than those under the other conditions.
- The values for solar altitude from 0° until 45° are small and increased correspond to the solar altitude.
- The values of the horizontal illuminance from unobstructed sky does not change or reduces inversely, if the solar altitude becomes higher than about 45°.

Data of diffuse horizontal illuminance gathered from 1995 to 2000 have been processed by half-hourly intervals and 6-degree intervals. Further, all data were processed into 6-degree intervals and recalculated while based upon the sky conditions of whole day which have been specified by diurnal fluctuations of whole day which have been specified by by diurnal fluctuation of cloud rations.

After strict examination and careful analysis, the relationships between the horizontal illuminance from the unobstructed sky and solar altitude for these three skies conditions could be formulated. They were based upon the mean for each 6 of solar altitude and classified by three skies conditions. The proposed equations are as follows:

\[
E_{cl} = 3.0 + 17 \sin^{0.9} \gamma_s \\
E_{in} = 1.1 + 48 \sin^{1.3} \gamma_s \\
E_{oc} = 0.6 + 78 \sin^{1.8} \gamma_s
\]

where: \(E_{cl}\), \(E_{in}\), and \(E_{oc}\) are the horizontal illuminance from unobstructed sky for clear sky, intermediate sky and overcast sky, respectively, and \(\gamma_s\) is the solar altitude.

Many equations have been proposed which show the relation between the horizontal illuminance from unobstructed sky (\(E_{a}\)) and the solar altitude (\(\gamma_s\)). Nakamura et al. [8-9] have been proposed. the equations of the horizontal illuminance from unobstructed the representative value, respectively. The equations are as follows:

\[
E_{u} = 2.0 + 80.0 \sin^{0.8} \gamma_s \\
E_{s} = 0.5 + 42.5 \sin \gamma_s \\
E_{i} = 15.0 \sin^{1.2} \gamma_s
\]
where : $Eu$ and $El$ are the upper limiting value and the lower limiting value of the horizontal illuminance from the unobstructed sky respectively and $Es$ is the representative value of the horizontal illuminance from unobstructed sky.

Figure 1 shows data of the horizontal illuminance from unobstructed sky for the three skies with the curves of the proposed equations (3), (4) and (5), respectively. Also compared to the upper and the lower value proposed by Nakamura.

Other equations of the horizontal illuminance from unobstructed sky have been proposed in relation to the sky conditions. The equations are as follows [2,3,11,12] :

- Krochmann  
  
  $Ea(cl) = (1.1 + 15.5 \sin^{0.5} \gamma s)$  
  
  ...(9)

- Chroscicki  
  
  $Ea(cl) = \{3 + 0.17 (\gamma s/o)\}$  
  
  ...(10)

- Krochmann  
  
  $Ea(oc) = (300+21000 \sin \gamma s)$  
  
  ...(11)

- Kittler  
  
  $Ea(oc) = 9750 (1 + 3/2 \sin \gamma s) \sin \gamma s$  
  
  ...(12)

- Feitsma  
  
  $Ea(oc) = 467 (\gamma s/o)$  
  
  ...(13)

- Hopkinson  
  
  $Ea(oc) = 215 (\gamma s/o)$  
  
  ...(14)
Horizontal illuminance from unobstructed sky both clear sky and overcast sky also can be derived from the zenith luminance value and CIE Standard Clear Sky or CIE Standard Overcast sky. Figure 2 shows data of the horizontal illuminance from unobstructed sky of the three skies with the curves of the equations (3), (4) and (5) with various equations proposed, respectively.

![Figure 2](image)

**Figure 2**
Data of the horizontal illuminance from unobstructed sky of the three skies with various equations proposed, respectively.

It has become necessary to fix conveniently a mean value as representative value corresponding to each solar altitude including the consideration about the distribution. Moreover, it has been desirable that the representative value has been widely applicable to a rather large territory.

The yearly relative Frequency of occurrence of the three skies in Indonesia calculated from the relative sunshine duration and is assumed to be 6 %, 73 %, 21 %, respectively [10]. Using this frequency of occurrence of the three skies, the representative value of the horizontal illuminance from unobstructed sky (Ea) could be represented as the sum of the products of each value of the horizontal illuminance of the three skies and their frequency of occurrence. The proposed equation is as follows:
\[ Ea = [ (0.06 \times Ecl) + (0.73 \times Ein) + (0.21 \times Eoc) ] \]  \hspace{1cm} \text{...(15)}

Figure 3 shows data of the horizontal illuminance from the unobstructed sky and the curve of the equation (15) with the upper and the lower limiting values by equations (6) and (8).

Cumulative frequencies of the Horizontal Illuminance

The standard of the horizontal illumination from unobstructed sky has been inevitably constructed by the statistically treatment with the frequency of occurrence of the solar altitude throughout a year and the distribution of the values of the horizontal illumination from unobstructed sky of the three skies conditions.

The calculation of the percentage and the cumulative percentage of the hours corresponding to the each horizontal illuminance from unobstructed sky to the whole working hours have been performed by the following steps :

![Figure 3](image-url)
- The solar altitude to each representative value calculated by the equation (15).
- The frequency of occurrence of the hours to each solar altitude obtained as above to the whole working hours throughout a year has been calculated.
- The frequency occurrence calculated above distributed to each mean horizontal illuminance value.
- In order to get the percentage of the hours corresponding to each horizontal illuminance from unobstructed sky to the whole working hours duration, the frequency of occurrence distributed above has been integrated at each horizontal illuminance from unobstructed sky from the value 0 lx to that of 79 Klx.
- The cumulative percentage calculated from the percentage obtained as above.
- The value of the horizontal illuminance from unobstructed sky corresponding to each round cumulative percentage reversely calculated.

For comparison to other research works on the horizontal illuminance from unobstructed sky, Table 1 shows a review of measured skylight availability data [1-3, 8-12]. Table 2 shows the standard relation between the horizontal illuminance from unobstructed sky and its cumulative percentage of the hours, for which the illuminance level is available to the working hours.

### Table 1
Review of measured skylight availability data

<table>
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<tr>
<th>Location</th>
<th>Representative Es (Klx)</th>
<th>Reference</th>
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<td>Darwin</td>
<td>12.7</td>
<td>Ruck, 1985</td>
</tr>
<tr>
<td>Brisbane</td>
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<td>Ruck, 1985</td>
</tr>
<tr>
<td>Broken Hill</td>
<td>5.9</td>
<td>Ruck, 1985</td>
</tr>
<tr>
<td>Sydney</td>
<td>8.8</td>
<td>Ruck, 1985</td>
</tr>
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<td>Paris</td>
<td>5.0</td>
<td>Fournol, 1951</td>
</tr>
<tr>
<td>Kew/Bracknell</td>
<td>3.0</td>
<td>Hunt, 1979</td>
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<tr>
<td>Roorkee</td>
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<td>Narashiman, 1970</td>
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<td>Makassar</td>
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<td>Rahim, 1994, 2004</td>
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Table 2
Relation between the horizontal illuminance from unobstructed sky and its cumulative percentage of the hours, for which the illuminance level is available to the working hours

<table>
<thead>
<tr>
<th>Cumulative Percentage [%]</th>
<th>Horizontal Illuminance [Klux]</th>
<th>Cumulative Percentage [%]</th>
<th>Horizontal Illuminance [Klux]</th>
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Latitude : 03°00' S
Longitude : 120°00' E
09.00 - 17.00
CONCLUSION

One of the crucial problems in predetermining the role of daylighting in energy efficient buildings is the need for reliable local data on daylight availability. Daylight availability defined in terms of the external skylight illuminance available on an unobstructed horizontal plane for a certain percentage of daytime working hours or for specified periods (daily, monthly and yearly). Furthermore, one of the basic aims of collecting and measuring daylight and solar radiation levels in many locations on the globe is the mutual comparison and evaluation of available data gathered.

Based upon the diffuse horizontal illuminance data gathered in Makassar-Indonesia during 1995 to 2000, a proposal on the values of the horizontal illuminance from the unobstructed sky has been 14.35 Klx proposed. This proposal has been supposed to be proper that the value at Makassar should be extended as the standard value of the horizontal illuminance from unobstructed sky in Indonesia.

REFERENCES