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# INTERGRATED LUMINAIRE-DIFFUSOR FOR CLASSROOM ACOUSTIC

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## ABSTRACT

It is necessary for a classroom to have good acoustical, lighting, and thermal conditioning. All of these aspects need enough space to be working effectively. Thus, if this two of three aspects can be combined, space efficiency can be reached. This paper studied the integration of *luminare-diffusor* effects to lighting and acoustical performances.

This research did experiments with four lamps luminaries attach with a varied diffusor on it's surface. There are four diffusor variation which are QRD N7 $d_{max}$ 15 cm, QRD N7 $d_{max}$ 10 cm, QRD N11 $d_{max}$ 15 cm and QRD N11 $d_{max}$ 10 cm. All these diffusors works on human speech frequencies. Photometric data of the luminaries were taken before and after the integration took place in order to analyze the significant difference between the two conditions. The diffuse coefficient measurements were also taken to distinguish the quality of the acoustical performance. Result shows that acoustic panel diffusers variation did not change the lighting intensity distribution and the average illuminance on the work space significantly. Thus, the best integration determine by the highest diffuse coefficient was acquired by QRD N11 $d_{max}$ 10 cm.

## 1. Introduction

Classrooms in Indonesia often have poor acoustic condition. Un-even sound distribution in the classrooms fails to create a good sound clarity. However, a better sound clarity was obtained after diffusors placed in it[1]. Diffusors works most effectively when placed in the ceiling [2], but it needs more space since there are already luminaires mounted on the ceilings. Under this consideration, in this paper a proposal of an integrated luminaire-diffusor in order to achieve good acoustical and lighting condition and to save space in the ceiling was discussed.

There are four variations of diffusors that were used for the integration experiments. All four, theoretically, works in human voice frequency which are QRD N7 $d_{max}$ 15 cm, QRD N7 $d_{max}$ 10 cm, QRD N11 $d_{max}$ 15 cm and QRD N11 $d_{max}$ 10 cm. The diffusors were attached onto the front surface of the luminaires.

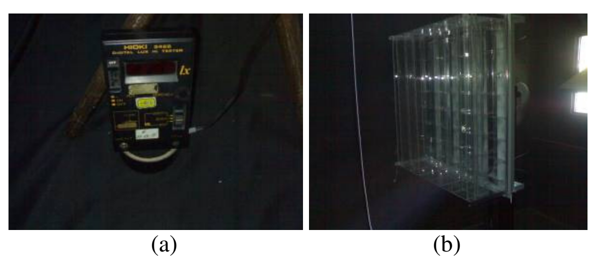
## 2. Experimental Set Up

### 2.1. Photometric data

The first photometric data was retrieved to analyze the lighting performance by measuring the lighting distribution. The lighting intensity distribution of the luminaire before and after integration was measured. Lighting intensity distribution measured by using luxmeter. The luxmeter was placed in a distance of five times the luminaire's dimension and the lighting distribution measurement were taken at four angle planes which were at $0^o$, $45^o$, $-45^o$, and $90^o$ plane [3]. The results are in illuminance level in various positions. These vaues were therefore needs to be converted in to lighting intensity using equation 1.

$$E = \frac{\mathrm{I}(\theta)}{\mathrm{R}^2} \qquad (1)$$

*Where* $E$ is illuminance (lux), $I(\theta)$ is lighting intensity (cd), and $R$ is distance beetwen luxmeter and ingtegrated luminaire-diffusor (m).



(a) (b)

Source: (Author,2010)

**Figure 1.** (a). Luxmeter, (b). Integrated luminaire-diffusor

The second photometric data needed was the illumination on work plane in an imaginary classroom. Illuminations on work plane before and after integration obtain using lighting distribution data. The imaginary classroom used is show in Figure 2.

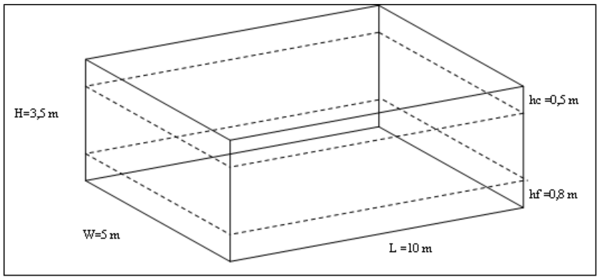



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**Figure 2.** Imaginary classroom dimension

The imaginary classroom characteristics are described as the following:

- Ceiling reflection = 75 %
- Room reflection = 50 %
- Floor reflection = 25 %
- 20 meters length (L), 3.5 meters height (H) and 10 meters wide (W).
- Luminaire placed 2.7 meters from the room ceiling (hc).
- Work plane placed 0.8 meter from the room floor (hf).
- Luminaires placed in two rows, five luminaires each.

All characteristics above will be use to obtain the value of illuminance using Eq. 2 describe below.

$$E = \frac{N.\Phi_L.CU.LLF}{A} \qquad (2)$$

*E* is illuminance in a work plane (lux), *N* is amount of luminaire use in the classroom, $\Phi_L$ is the bulb's flux luminus total (lumen), *CU* is coefficient of utilization which will change according change in the lighting distribution, *LLF* is light lost factor that the value were assume to be 0.58, and *A* is work plane area $(m^2)$. The actual experimental environment for measuring the illuminance could be seen in Figure 3.

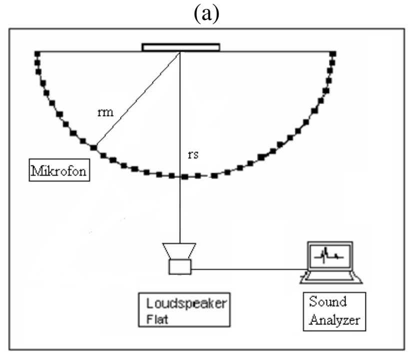
Source: (Author, 2010)

**Figure 3.** Experiment set up for illuminance measurement

### 2.2. Diffuse coefficient

The diffuse coefficient function's was used as a standard to analyze acoustic performance of the integrated luminaire-diffusor. The measurement set up was carried out based on the recommendation from AES-4id-2001 standard [4]. Measurements took place in an anechoic chamber. The first measurement was recorded at an empty anechoic chamber to get background signals on various hemisphere positions as shown in Figure 4.

(a)

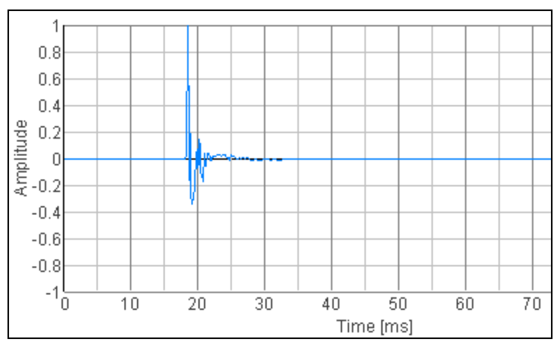



(b)

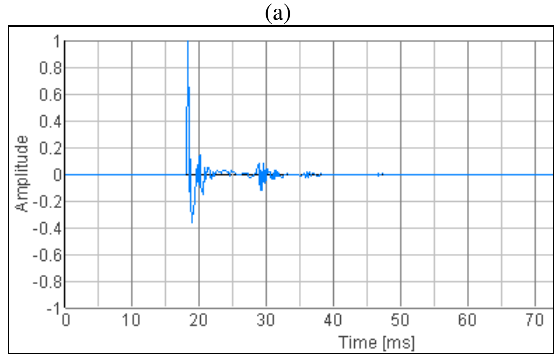
Source: (Author, 2010)

**Figure 4.** Measurement set up in (a) actual environment and (b) the experiment's sketch

The signals were recorded once more with a diffusor in the chamber to get the sample signal at the same measurement positions as before. The measurements results which were recorded with the diffusors are shown in Figure 5.




(a)

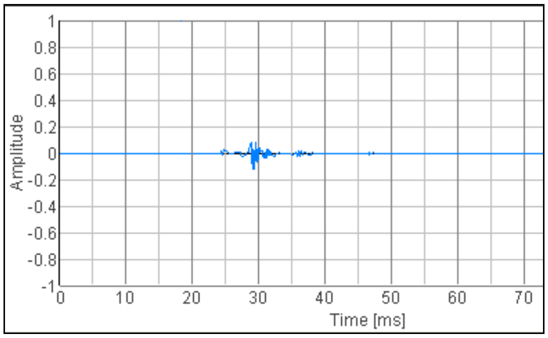



(b)

Source: (Author, 2010)

**Figure 5.** (a). Background noise + sample signal, (b). Background noise signal

The signals of the second recording still have the background signal in it. To get the pure sample signals, the second recording signals (sample signals plus background signals) were reduce by the first recording signals (the background signals only). The result of this operation is shown in Figure 6.




Source: (Author, 2010)

**Figure 6.** Sample signal

The sample signals were converted from time respond to frequency respond using FFT. The values from each position in the same frequency were calculated using the diffuse coefficient on eq.3.

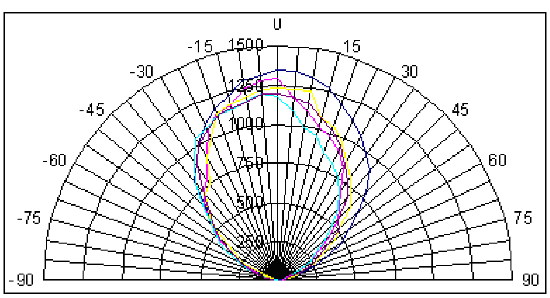
$$d_{\psi} = \frac{\left(\sum_{i=1}^{n} 10^{Li/10}\right)^2 - \sum_{i=1}^{n}\left(10^{Li/10}\right)^2}{(n-1)\sum_{i=1}^{n}\left(10^{Li/10}\right)^2} \quad (3)$$

Where $d_v$ is the diffuse coefficient, $L$ is the sound level in measurement positions (dB), and $n$ is the numbers of measurement positions. Only the diffuse coefficient of 250-8000 Hz was measured considering the human voice rarely has frequency range less than 4000 Hz and the dominant is at 500 Hz.

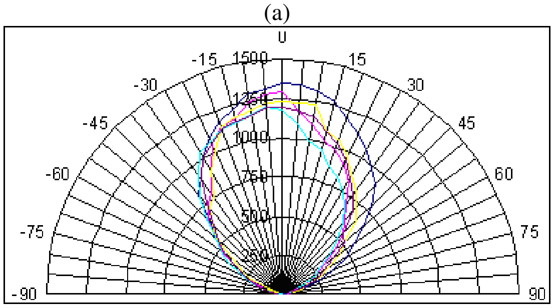
## 3. Results

### 3.1. Photometric data

The lighting distribution measurement of each integration plotted in a four plane polar graphic which were distributed at $0^o$, $45^o$, $-45^o$, and $90^o$ of the plane. The results are shown in Figure 6.



(a)



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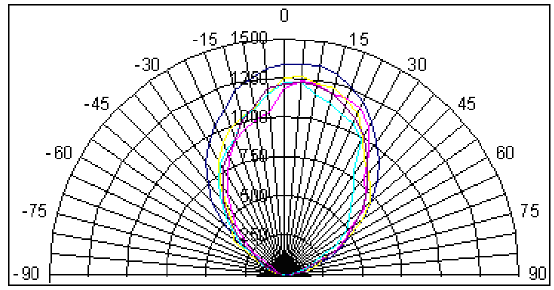
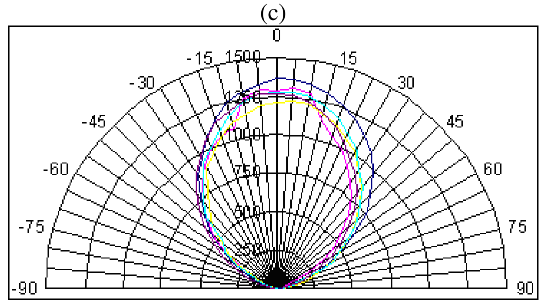


(c)



(d)

Source : (Author, 2010)

**Figure 7.** Lighting distribution for (a) $0^o$ plane (b) $45^o$ plane (c) $45^o$ plane and (d) $90^o$ plane

From the diagrams in Figure 7, it can be seen that there were changes in the lighting distribution. To find how significant the changes, statistical analysis by calculating the variance homogenity, ANOVA, and homogeneous subset were used.

The significant value of variance homogenity analysis result was at 0.625 which is higher than the limit of 0.05. The F value in ANOVA analysis is 0.262 which is under the F value of the F table. It was also figured that result from homogeneous subset has only one subset. These three conditions determined that the changes of lighting distribution caused by all types of the integration were insignificant.

The next photometric data used to measure the lighting performance is the illumination's intensity on a work plane. Using the above lighting distribution measurements, the value of illumination on work plane can be achieved through simulation. The values of the illumination ($E$) are shown in Table 1.

**Table.1.** Illuminance before and after integration

| Luminaire Condition | E (lux) |
|---|---|
| Original | 280.23 |
| Integrated with N 7 dmax 10 cm | 247.90 |
| Integrated with N 7 dmax 15 cm | 233.16 |
| Integrated with N 11 dmax 10 cm | 251.08 |
| Integrated with N 11 dmax 15 cm | 240.50 |

Source: (Author, 2010)

From table 1, it can be seen that the original luminaires gives 280.23 lux on work plane. The illumination value after integration with the difussor decreased of about 30-50 lux. Since human eyes are able to recognize illumination changes if the value of the illumination changes more than 1.5 times from its original value, the illumination changes caused by integration of luminaire-diffusor are insignificant.

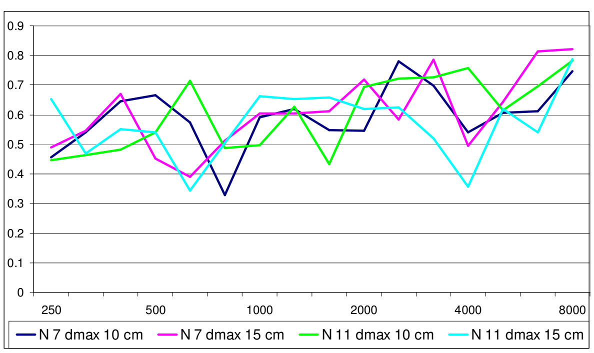
### 3.2. Diffuse coefficient

Diffuse coefficient measurement and calculation results are shown at Table 2 and Figure 8.

**Table 2.** Diffuse coefficients for all types of integration

| Freq. (Hz) | N 7 dmax 10 cm | N 7 dmax 15 cm | N 11 dmax 10 cm | N 11 dmax 15 cm |
|---|---|---|---|---|
| 250 | 0.46 | 0.49 | 0.45 | 0.65 |
| 315 | 0.54 | 0.55 | 0.46 | 0.47 |
| 400 | 0.65 | 0.67 | 0.48 | 0.55 |
| 500 | 0.67 | 0.45 | 0.54 | 0.54 |
| 630 | 0.57 | 0.39 | 0.71 | 0.34 |
| 800 | 0.33 | 0.51 | 0.49 | 0.5 |
| 1000 | 0.59 | 0.6 | 0.5 | 0.66 |
| 1250 | 0.62 | 0.6 | 0.63 | 0.65 |
| 1600 | 0.55 | 0.61 | 0.43 | 0.66 |
| 2000 | 0.55 | 0.72 | 0.69 | 0.62 |
| 2500 | 0.78 | 0.58 | 0.72 | 0.62 |
| 3150 | 0.7 | 0.78 | 0.73 | 0.52 |
| 4000 | 0.54 | 0.5 | 0.76 | 0.36 |
| 5000 | 0.61 | 0.64 | 0.61 | 0.62 |
| 6300 | 0.61 | 0.81 | 0.7 | 0.54 |
| 8000 | 0.75 | 0.82 | 0.78 | 0.79 |
| Average | 0.59 | 0.61 | 0.61 | 0.57 |
| 250-4k Average | 0.58 | 0.57 | 0.58 | 0.55 |

Source: (Author, 2010)




Source: (Author, 2010)

**Figure 8.** Diffuse coefficient vs frequency graphic for all types of integration

The highest average diffuse coefficient for frequency range of 250-8000 Hz were QRD N 7 $d_{max}$ 15 cm and QRD N 11 $d_{max}$ 10 cm with both having 0.61. Since human voice frequency are rarely greater than 4000 Hz, another average value is considered for frequency range of 250-4000 Hz which is the highest value achieved by QRD N 11 $d_{max}$ 10 cm.

## 4. Conclusion

Lighting and acoustical performances of four type integrated luminaire-diffusor were measured. The results show that all four types did not change the lighting distribution and illuminance on work plane significantly. The best integration achieved by the diffusor with the highest diffuse coefficient average that is QRD N 11 $d_{max}$ 10 cm.

## 5. References

1 Martua Silitonga, Darto, *Schroeder Diffusor influence to Diffusity and room acoustic parameters*, Engineering Physics Department Bandung Institute of Technology (2002)

2 Sang-bong Shin, Chan-hoon Haan, *Effects of Sound Diffusers and Panel Absorbers on the Sound Clarity in Classrooms*, 19th International Congress on Acoustics, Madrid (2007)

3 Ryer, Alex, *Light Measurement Handbook*, International Light Inc. (1998)

4 AES-4id-2001, *AES Information document for room acoustics and sound reinforcement systems – characterisation and measurement of surface scattering uniformity*, J. Audio Eng. Soc., 49(3), 149–65 (2001)

5 T. J. Cox, Peter D. Antonio, *Acoustic Absorbers and Diffusers*, Taylor & Francis, London, New York (2009)

6 Jones, J.R., Neidhart, J.J., *Coefficient of Utilization with Concentrating Distributions*, National Technical Conference of the Illuminating Engineering Society, Ohio (1951)