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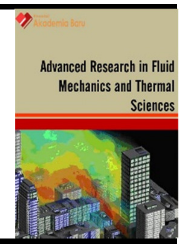

Illuminance Uniformity Using Public Works Department (PWD) Standard Design for Public Schools Classroom Design in Malaysia

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ABSTRACT

Illuminance or lighting level is an important factor in ensuring conducive environment for studying in Malaysian public school. The design lighting level is based on the existing Public Work Department standard design which will help to evaluate on the daylight distribution in public school. However, despite the present of the existence PWD standard design, research still had to be carried out to determine, review, and identify the level of deficiency and improvement needed to be taken upon the PWD standard design to evaluate on the daylight distribution levels. This is because based on the current research related to illuminance value showed that there were some poorly lit spots within the classroom which are uneven that will affect the students' performance. Based on this research study, analysis is carried out based on physical data and IES simulation software which enable to test the classroom under different sky conditions, orientations and time frame which allows the classroom to receive optimum daylight value.

1. Introduction

Daylight is a light that is transmitted via sunlight which is then reflected on the surface before illuminating into a space or an area. It is also a main architectural strategy in the design of high-performance schools which gives an impact on students & teachers health and increases their performance in the learning environment [1]. Besides health, there are other benefits contributed by proper daylight such as reducing the cooling and lighting energy cost [25]. Cooling cost can be

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reduced with a suitable daylight design for a building which will reduce the overall heat inside the building. Automatic switching off the artificial lighting when sufficient daylight is available will dramatically reduce the lighting cost. Based on expectation mentioned by Innovative Design (2004), day lighting design should be based on several expectations such as

a) Daylighting is superior to electricity lighting
b) Eliminate direct radiation, sunlight should reflect, redirected or filtered
c) Reduce implementation of blinds which decrease performance, increase first cost and cause greater long-term maintenance
d) Only use shade if entire space needs to be darkened especially for in a classroom with projector or television
e) Don't count on window for view only and focus one other daylighting means such as roof monitors
f) Concentrate on most utilized spaces where there are more students and daylighting strategies can save financial cost.
g) Utilize low windows at eye level to provide visual connection to outdoors environment

Besides that, in Malaysia due to the inadequate architectural standards and unsuitable designs, it's not hard to find a school building that has a poor performance and energy efficiency. Based on a daily basis activity in Malaysian schools, all the lights will be turned on throughout the day and only be turn on during recess time and at the end of the class. There are many reasons that justify considering daylight as a useful light source in almost every type of buildings especially in learning environment. The strong reason in choosing natural light is because of the quality of light is far better than any electrical lighting to be used as a task lighting for reading and writing purposes. The luminous efficacy of daylight in Malaysia is excellent and could meet most of the required luminance during the day [3]. The fact is if students have good daylighting in their school's interior environment, they would be more academically successful. Poorly lit classroom environment, leads to poor attention and their performance would be affected due to excessive glare or poor level of daylight in the classroom especially on the working desk level where most of the reading and writing activity will take place. Previous study mentioned that, when students have a classroom with badly designed windows and lighting, students' performance is negatively affected. In school building daylight is a fundamental design criterion arising from human needs and environmental sustainability.

The aim of this study is to analyse daylight distribution in a typical classroom under the Malaysian skies. These are the main objectives.

(i) To evaluate the daylight condition in several public-school classrooms in Ipoh, Perak based on its typical design of space & openings.
(ii) To identify different classrooms characteristic that influence daylighting in Ipoh, Perak.
(iii) To propose a general recommendation to improve daylighting for classroom in Ipoh, Perak.

From the literature study conducted, it is found that research on the daylighting performance in PWD standard design classrooms in Malaysia is rare. There are also no obvious guidelines or rules in designing the classrooms based on the Malaysian tropical environment. Therefore, this research address an issue that requires attention and awareness about the wellbeing of the students and teachers.

2. Literature Review

Based on a previous published simulation paper reported by Dass, the schools that was identified for the experiment was constructed based on the standard PWD design schools where the sizes and the openings are similar with the other schools that was analysed [1]. Measurements were taken on the overall built in reality area of the classroom. Figure 1 shows the floor plan layout of the classroom and the location of the openings. The daylight readings that was obtained inside the classroom, was during an overcast sky and partially clouded condition at 12pm.

The classroom floor area is about 63sqm and the height from floor to ceiling at 3 meters. These classrooms are facing the North East & South West directions from the openings side of view. The floor is mainly cement rendered which does not have much reflectance while as for the asbestos ceiling it has the most reflectance surface because of its white colour. The windows are fitted with adjustable louvers with horizontal plank glass. Each window has 4 bays of louvers panel and fixed with wire mesh frame on top of every window frame which has less obstruction. This allows continuous circulation of air and daylight penetration into the classroom [1].

A school with insufficient light can also reduce a student's ability to learn due to the effect lighting has on physiology. Poor spectral light can create strain on students' eyes, leading to a decrease in information processing and learning ability, causing higher stress levels [4]. Walker found that stress impacts certain growth hormones. He determined that "persistent stress stunts bodily growth in children" because the activity of the growth-inhibiting hormones cortisol and ACTH increase under stress [5]. Students in the Canadian full-spectrum fluorescent schools grew 2.1 cm more in two years. Hathaway *et al.,* compared to students who attended traditional fluorescent-lit schools [6]. The increased activity of these hormones supports researchers' observations that children under electric lights all day have decreased mental capabilities, agitated physical behavior, and fatigue.

Rosenfeld discussed that, everything from the school's placement and orientation on the site, the shape of its unique footprint, the development of the building's cross sections, the educational programming for each space, the building's mechanic / electrical systems and the architectural details / aesthetics were all about light, ambient light levels and light controls [7]. Penetration of natural lighting into a classroom depends on many parameters of design, which includes ceiling height, internal reflectance's, depth of room, shape and size of glazing area [10]. The relation of Window area to Floor area (WFR) is a classroom was also studied which confirms that by providing a visual comfort for students it can decrease the energy consumption in a tropical area such as Malaysia [11]. The classroom specification plays an important role in achieving an excepted day lighting levels within the room. Neuman stated that the researchers believe that the length to width of the classroom should be approximately 3:2 and ceiling height should be at least 3 meters for a small classroom [12]. While Neufert mentioned that according to the standard classroom design, space per student require 1.9 to 2 meters space in the classroom [13].

Illuminance uniformity has been said to be highly desirable, both across the working surface and across rooms [14]. Excessive variation in horizontal illuminance may contribute to transient adaptation problems and should be avoided [16]. Therefore, lighting standards often contain recommendations regarding the uniformity of illuminance on the work plane. These recommendations are expressed as the quotient of the minimum to the average or to the maximum illuminance on the work plane. Note, however, that Bean and Bell found that illuminance uniformity was far less important than illuminance level when they tried to correlate judgements of lighting quality by office workers and lighting performance index [17].

Fontoynont and Avouac-Bastie found that illuminance uniformity on the desk of 0.8 (minimum/average) was preferred for reading or writing and that the preferred ratio was somewhat higher for receiving visitors in the room [18]. Slater *et al.,* observed that the ratings of the difference in illuminance rise sharply when the illuminance ratio between desks in an office room is less than around 0.6 [19]. They concluded that an illuminance ratio of at least 0.7 (minimum/maximum) between work area was unlikely to pose problems, confirming previous results of Saunders [20]. Researchers focused on the uniformity of the desk and suggested a minimum to maximum illuminance ratio of 0.7 or 0.5 if the work is primarily done in the central area of the desk [21,22]. In most offices, the actively worked area on most desks is the central part, which is about 1m in width [21]. In a further study, some researchers investigated the acceptable illuminance differences between working areas and adjacent ancillary areas in a simulated office and demonstrated that an illuminance ratio between the two of least 0.5 is likely to be satisfactory as shown in Table 1 [23].

Table 1
Daylight Illuminance Uniformity Indicator for Office Buildings Sourced

Illuminance Uniformity on the Work Plane	
E_{min} / E_{max} > 0.5	Acceptable
E_{min} / E_{max} > 0.7	Preferable

According to an IEA 2000 report, for the evaluation of daylight conditions prevailing in classrooms, where the adequacy of daylight is the main objective, the daylight factor was considered as the most appropriate parameter for indicating the quantity of admitted daylight and consequently the efficient of the daylighting design. According to MS1525:2014, a good daylighting system consists of five major factors which are

(a) Space orientation and organisation
(b) Physical and optical properties of glazing through which daylight will transmit
(c) Internal floor, wall and ceiling surface properties
(d) Visual contrast between adjacent surfaces
(e) Protection from visual discomfort caused by external and internal building elements.

Daylight Factor (DF) refers to simplest form of the daylight distribution, penetration and intensity. This is the ratio of the internal illuminance (^{E}internal) at a point in a room to the instantaneous external illuminance (^{E}external) on a horizontal surface.

$$DF = \frac{E_{internal}}{E_{external}} x100\% \quad (1)$$

Based on Table 2, values of daylight factor ranging from 1% to 6% are reported as satisfactory. Furthermore, the homogeneity of the luminance distribution contributes to the rating of the ability of the daylighting system to attenuate glare. The quality of daylighting can be depicted by the visualization of each classroom's interior, since the possible of glare occurrence is associated to the excessive contrast of luminance between the various indoor surfaces. Illuminance ratios, such as minimum-to-maximum can be used in order to quantify lighting uniformity.

Table 2
Daylight Factors and Impact

DF%	Lighting	Glare	Thermal Comfort
>6.0	Intolerable	Intolerable	Uncomfortable
3.5- 6.0	Tolerable	Uncomfortable	Tolerable
1.0 – 3.5	Acceptable	Acceptable	Acceptable
< 1.0	Perceptible	Imperceptible	Acceptable

3. Methodology

The objective of this research is to evaluate the daylight condition in eight public school classrooms in Ipoh by identifying the classroom typologies and parameters which provide adequate daylight illuminance in the classroom. The research was done based on two methods where the first method is to collect data from the actual site of the classroom and the second is to simulate the conditions via computer simulation software (IES). Two experiments were conducted to test the efficiency of daylighting performance in illuminating the interior spaces in the classroom to allow the data be validated with the simulation data. The experiment was conducted in two stages.

(i) Field measurements at the school, the classroom layout size and window openings were identified. The lux reading was taken from inside and outside the classroom using lux meters on the working surface to measure the natural light illumination. The readings were taken during cloudy or overcast sky condition at the time range between 10am to 3pm. The measurements were taken bilaterally by positioning the lux meter every 600mm grid points on the working plane surface from both sides of the wall which has window openings.
(ii) Daylighting simulation of the classroom model using computer software simulator, known as IES (Integrated Environmental Solutions) under the <Radiance-VE Module> for daylight analysis. The simulation was set under overcast and cloudy sky without sun condition and located in Setiawan, Ipoh without any outdoor obstruction.

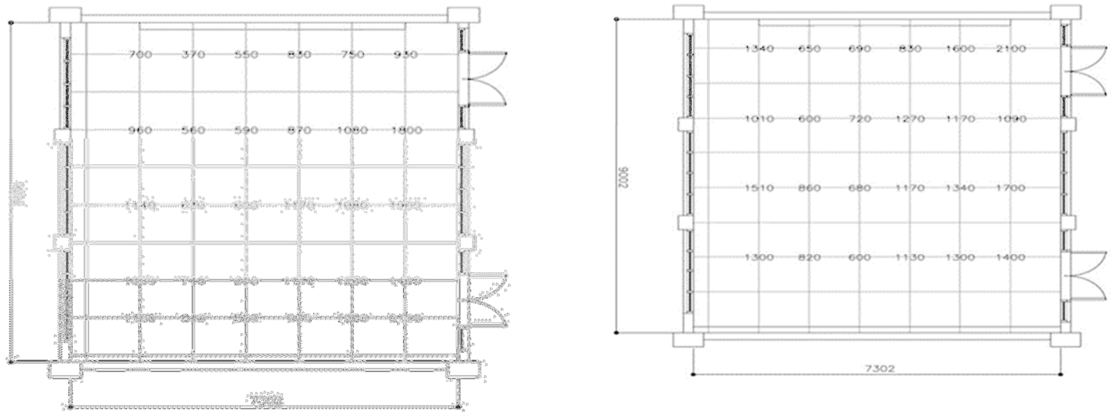
Finally, the illumination levels and performance that was achieved are compared and analyzed based on different variables.

4. Comparative Analysis of Field Measurement and Survey Findings

According to the Malaysian context, with reference to the following Uniform Building: By Laws 1984, UBBL 39 (3), Every room used for the purpose of conduction classes in a school should be provided with natural lighting and natural ventilation by means of one or more windows having total area of not less than 20% of clear floor area of the room and with openings capable of allowing a free uninterrupted passage of air of not less than 10% of the floor area. Figure 2 and 3 shows the side elevation view of the classroom.

4.1 Comparison of Average Daylight Factor

The Average Daylight Factor is a measure of the interior daylight illuminance where it is used to establish whether the room that is being measured has sufficient daylight for the specified task that is required. From the data collected and the case study results, each classroom average daylight factor are compared which will allow to identify the major contributor in enhancing the daylight illuminance inside the classroom on an overcast sky condition.



Ground Floor First Floor

Fig. 1. Classroom Layout Plan with Illumination Readings Indication on Both Floors

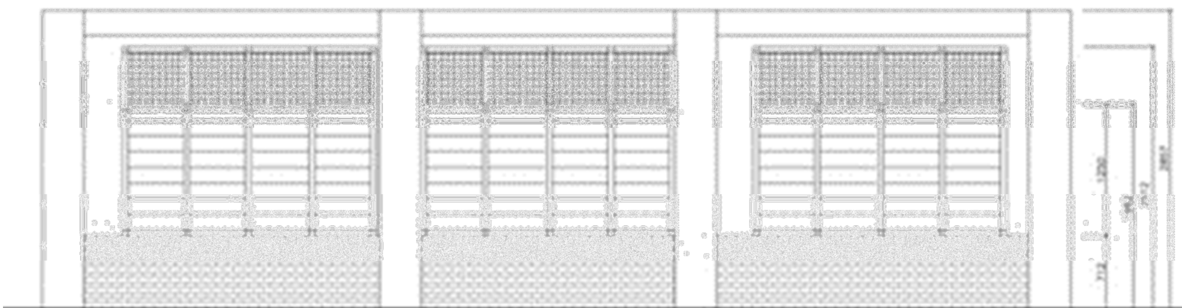


Fig. 2. Classroom Right Side Elevation View

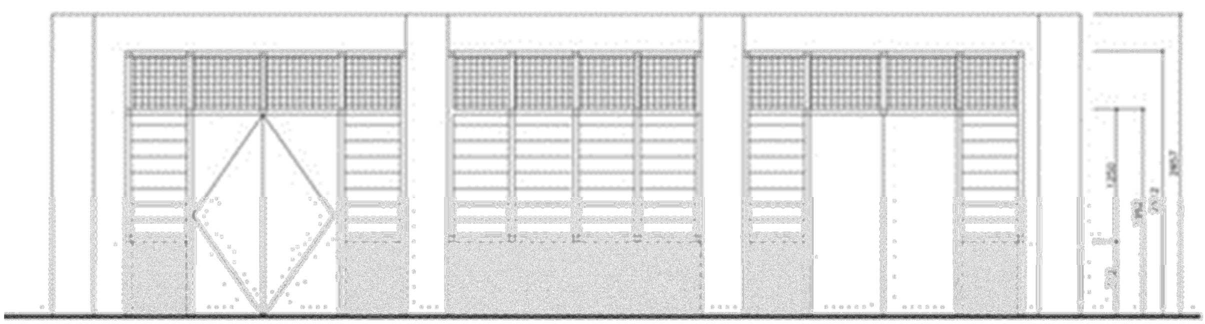


Fig. 3. Classroom Left Side Elevation View

Based on Figure 4 and Table 3, it is found that all of the schools that was investigated for the daylighting performance, has achieved the Malaysian Standard on daylight factor where it is indicated that the daylight factor between 3-6 % achieves a “Good Distribution” within the bright zone. The range that was obtained in this research was between 5.5 % and 6 % average daylight factor. Each school classroom indicates a slight difference in their average daylight factor that could be due to environment of the classroom and also the schools design. The school that has scored the highest average daylight factor is at 6.12% which was, Sekolah Menengah Sungai Pari, Ipoh. This is because the classroom in that school does not have any obstructions facing their window openings and the school building block was located between other building blocks with a generous distance between them which allowed the daylight to illuminate inside the school classroom. While as for the lowest average daylight factor, Sekolah Menengah Kebangsaan Raja Chulan, Ipoh achieved at the range of 5.56%. This was due to huge tree branches were grown near by the school classrooms which block most of the daylight source. But even with the lowest average daylight factor percentage compared to other schools, it has still achieved the required benchmark by the Malaysian Standards.

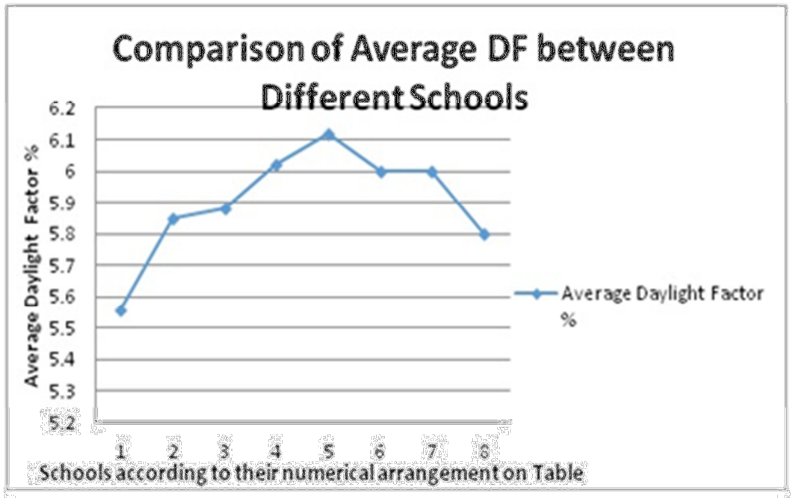


Fig. 4. The Comparison of Average Daylight Factor between Each School Classrooms Reflectance between Different Schools

Table 3
IES Simulation

No	Schools	Average Daylight Factor %	Average Illuminance (Lux)
1	Sekolah Menengah Kebangsaan Raja Chulan, Ipoh	5.56	500
2	Sekolah Menengah Kebangsaan Seri Ampang, Ipoh	5.85	380
3	Sekolah Menengah Kebangsaan Gunung Rapat, Ipoh	5.88	720
4	Sekolah Kebangsaan Sungai Rokam, Ipoh	6.02	470
5	Sekolah Menengah Sungai Pari, Ipoh	6.12	800
6	Sekolah Jenis Kebangsaan Tamil Kampung Simee, Ipoh	6.00	360
7	Sekolah Jenis Kebangsaan Cina Min Sin, Ipoh	6.00	1000
8	Sekolah Menengah Dato' Megat Khas, Ipoh	5.80	240

4.2 Illuminance Uniformity in the Classroom Working Plane

The uniformity illuminance is an important feature for lighting inside a working room environment. It can be desirable or less desirable depending on the nature of the working environment and the type of the activity. A complete uniform space is mostly not preferred but an incomplete uniform lighting will create distraction and discomfort. To test the public-school classroom on the level of its uniformity, a simple calculation was done by referring to the Daylight Performance Indicator Interpretation for office buildings in Malaysia that the illuminance uniformity level should be above 0.5 to 0.7 which is within the acceptable and preferable level. Table 4 shows the results of each school illuminance uniformity to determine the level of glare. From the table 4 below indicates that most of the schools did not achieve the recommended acceptable level except for Sekolah Jenis Kebangsaan Cina Min Sin, Ipoh and Sekolah Menengah Dato' Megat Khas, Ipoh. Both has indicated the acceptable level in the ground floor. But out of these two schools, all the other schools achieved lower than 0.5 due to brighter illuminance area near the window. The illuminance range that was obtained from the NOT preferable was at 0.3 and from the NOT acceptable was at 0.4. Although the room average illuminance may be appropriate, there were other factors that would have compromise uniformity in the classroom. Factors such as surface reflectance that create an uneven illuminance distribution within the classroom. Due to this non-uniformity illuminance, some problems could occur where some area within the classroom would not have adequate light, visual discomfort in certain areas where when a task is being done, frequent shifting might be required and uneven bright areas that create distraction to the students and teachers.

Table 4
Illuminance Uniformity in the Classroom Work Plane

No.	Schools	Floor Level	E min	E max	Illuminance Uniformity	Result
1	Sekolah Menengah Kebangsaan Raja Chulan, Ipoh	Ground Floor	600	1900	0.3	Not Preferable
		First Floor	680	1700	0.4	Not Preferable
2	Sekolah Menengah Kebangsaan Seri Ampang, Ipoh	Ground Floor	145	625	0.2	Not Acceptable
		Third Floor	380	960	0.3	Not Preferable
3	Sekolah Menengah Kebangsaan Gunung Rapat, Ipoh	Ground Floor	240	764	0.3	Not Preferable
		First Floor	600	1897	0.3	Not Preferable
4	Sekolah Kebangsaan Sungai Rokam, Ipoh	Ground Floor	470	1466	0.3	Not Acceptable
		First Floor	400	847	0.4	Not Preferable
5	Sekolah Menengah Sungai Pari, Ipoh	Ground Floor	390	940	0.4	Not Preferable
		First Floor	721	1750	0.4	Not Preferable
6	Sekolah Jenis Kebangsaan Tamil Kampung Simee, Ipoh	Ground Floor	495	1200	0.4	Not Preferable
		Second Floor	495	1600	0.3	Not Preferable
7	Sekolah Jenis Kebangsaan Cina Min Sin, Ipoh	Ground Floor	840	1588	0.5	Acceptable
		Second Floor	700	1900	0.3	Not Preferable
8	Sekolah Menengah Dato' Megat Khas, Ipoh	Ground Floor	190	290	0.6	Acceptable
		First Floor	200	574	0.3	Not Preferable

5. Conclusions

This research study clearly shows that only 25% from overall number of schools which involved for this research were able to achieve the recommended daylight and illuminance acceptable level for this research as outlined in MS. This result indicates that PWD standard design classrooms in Malaysia need serious attention for improvement to an acceptable level to ensure student performance are not affected in classrooms. Besides that, there are some recommendation can be applied to the classroom such as avoid having dark painted walls and furniture's that are obstructing the daylight source openings which will improve the daylighting in the classroom. Introducing light shelf and sky lights to illuminate the classroom via reflecting the external light source to the ceiling surface would also help to distribute daylight uniformly to areas that require light. During cloudy or overcast sky condition, natural light sometimes is unable to enhance the space for instance in the centre area of the classroom. Installing light fixtures with zoning switches could help to curb the problem. While as other effort to improve the classroom illuminance uniformity can be made depending on the surrounding environment of the school building through proper planning in the early stage of design.

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