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Assessment on Accuracy of Design Science Research (DSR) Framework as a Daylighting Measurement Tool for Islamic Religious School

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Abstract
Daylight efficiency correlates to window design. Standards and guidelines recommended 20% window to floor ratio (WFR) at 800mm to 900mm windowsill height for classrooms, where it should provide the recommended illuminance level between 300 lx to 500 lx measured at working plane height (WPH) between 800mm to 900mm. Instead, Islamic religious schools use 'rehal' at 300mm WPH. Since that the WPH is lower, the measured illuminance level is at different intensity. This paper assesses the accuracy of Design Science Research (DSR) methodology framework adaptation in measuring and designing daylight consideration in Islamic religious schools that uses lower working plane height.

Keywords: Daylighting; Islamic religious school; methodology framework

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1.0 Introduction

Many research shows that students' learning performance is affected by daylight conditions. Due to its importance to human well-being, standards and guidelines were introduced to recommend various parameters for classroom design, such as the average illuminance level and the window-to-floor ratio (WFR). Illuminance level is defined as the reflected light from a source on a working plane, then received by the human eye. Most standards and guidelines recommended 300 lx to 500 lx of illuminance level in any learning space (MS1525, 2014). The illuminance level is measured at 800mm to 900mm working plane height (GBI, 2009). However, the Islamic religious schools in Malaysia uses a table with a significantly lower working plane height known as 'rehal'. The working plane height of the 'rehal' is suited for tasks at 300mm height, suitable for sitting in a cross-legged position (Neufert, et al., 2012). Meanwhile, these standards and guidelines also recommend the design of the learning spaces' window.

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The windowsill height should be at the same height as a typical table height, which is between 800mm to 900mm height, while the WFR should be at 20 per cent spaces (MS1525, 2014). This shows that the current guidelines and standards for window design in learning spaces lack the consideration of different education systems, such as in Islamic religious schools that use 'rehal' as a working plane for learning tasks (Yazit, 2020).

Islamic religious schools in Malaysia adapted the 'Ulul Albab' education model, where the learning tasks such as reading, and writing are based on Arabic alphabets instead of the commonly used English alphabets (Mustafa & Basri, 2014). Detailed Assessment Speed Handwriting (DASH), Handwriting Proficiency Screening Questionnaire (HSPQ) and Children's Questionnaire for Handwriting Proficiency (CHaP) are commonly used to evaluate students' writing performance in English language and alphabets (Engel-Yeger, et al., 2009; Prunty, et al., 2013). Even though writing performance assessment tools commonly refers to the English language and alphabets, there is Hebrew Handwriting Evaluation (HHE) (Preminger, et al., 2004) and the modified Balsam Alabdulkader-Leat (BAL) eye chart (Alabdulkader & Leat, 2017; Yazit, 2020) that evaluates Hebrew and Arabic handwriting performance, respectively. Syaheeza's DRT for Islamic religious schools were developed by adapting the Design Science Research (DSR) framework (Venable, 2006) that consists of Theory Building (literature review), Naturalistic Evaluation (illuminance spot measurement, survey studies and Arabic handwriting performance assessments), Artificial Evaluation (computer-generated daylighting simulation), and Design Solution (daylight rule of thumb), as shown in Fig. 1 below (Yazit, 2020).

Fig. 1: Design Science Research Concept adapted for the development of Syaheeza's DRT.
(Source: Yazit, 2020)

Other than evaluating the students' Arabic handwriting performance, field measurement (average illuminance level), surveys (students' perception on the indoor daylight condition) and computer-generated daylight simulation were also adapted in the DSR framework (Yazit, 2020). To measure the average illuminance level of the classrooms, luminance spot measurement on the classroom layout grid was used due to its suitability to measure illuminance level at various working plane heights (Zomorodian, et al., 2016). The surveys used to identify the students' perception of indoor daylighting conditions were constructed based on Bülow-Hübe's (1995) questionnaire, which highlighted the contrast, directivity, glare, light level, distribution, and colouration. Similar questionnaires (Cauwerts, 2013; Hirning, et al., 2016) were also referred to in constructing the surveys used for developing Syaheeza's DRT for Islamic religious schools. Lastly, the DSR framework adapts the use of Integrated Environmental Solution: Virtual Environment (IESVE) daylighting simulation functions to test various classroom design parameters, which identified the most suitable design parameter for Islamic religious schools. The simulation results were used to develop and propose Syaheeza's DRT for Islamic religious schools in Malaysia, as shown in Fig. 2 below (Yazit, 2020).

This paper reviews the adaptability, suitability, and reliability of the DSR framework and method used in developing Syaheeza's DRT for Islamic religious schools in Malaysia, where it can be benefited by Islamic religious school establishments and designers. This paper also will suggest that the DSR framework and Syaheeza's DRT can be further improved and adapted for other daylighting studies that are related to different work tasks, especially ones that require lower or higher working plane height.

Parameter	Value/Detail
Daylight condition	
Average illuminance level	220 lx to 280 lx
Uniformity ratio	0.7
Reflectance	
Walls	0.5 (50%)
Floor	0.3 (30%)
Ceiling	0.7 (70%)
Window glazing	
Transmittance	0.81 (81%).
Orientation	North/south
Window design	
Window-to-Floor Ratio (WFR)	20%
Window height	1.2m
Window sill height/window head height	300mm/1.5m
	400mm/1.6m
	500mm/1.7m

Fig. 2: Syaheeza's DRT for Islamic religious schools in Malaysia
(Source: Yazit, 2020)

1.1 Problem Statement

Existing standards and guidelines lack studies and recommendations on classroom design that requires different working plane height, different handwriting task performance, different window design and different education system. Furthermore, to develop an insertion on the standards and guidelines based on Islamic religious schools requires a different methodology to evaluate the students' Arabic handwriting performance. All these factors created a gap in learning spaces design standards and guidelines, especially for Islamic religious schools. These factors also created a gap in the methodology framework suitable for identifying Islamic religious schools design in Malaysia. Thus, Syaheeza's DRT for Islamic religious schools in Malaysia will be referred to in this paper to identify whether the DSR framework and methods are adaptable, suitable, and reliable to identify and evaluate different required parameters in classroom designs.

1.2 Aim and Objectives

The aim of this paper is providing a suitable and reliable DSR methodology framework to evaluate Islamic religious schools design, as well as its adaptability to other different school designs that required unique or different parameters. The objectives of this paper are:

1. To evaluate the suitability of DSR framework methodologies based on the literature review of other previous research methodologies.
2. To identify the correlation between each method used in the DSR framework, thus its adaptability to different types of classrooms.
3. To confirm the reliability of the DSR framework based on each of its methodologies used in developing Syaheeza's DRT.

2.0 Literature Review

The literature review refers directly to the methodological components of the DSR, which are Theory Building (daylighting theories), Naturalistic Evaluation (field measurement, survey studies and Arabic handwriting performance), and Artificial Evaluation (computer-generated daylighting simulation).

2.1 Theory Building; Daylighting Theories

The most common theory for daylight is Daylight Factor, which provides illuminance level value from; Illuminance = SC + ERC + IRC, where the sky component (SC) is direct light from visible sky at the measured point, externally reflected component (ERC) is reflected light from exterior surfaces, and internally reflected component (IRC) is light entering through windows and openings (Szolokay, 2004), as shown in Fig. 3 below.

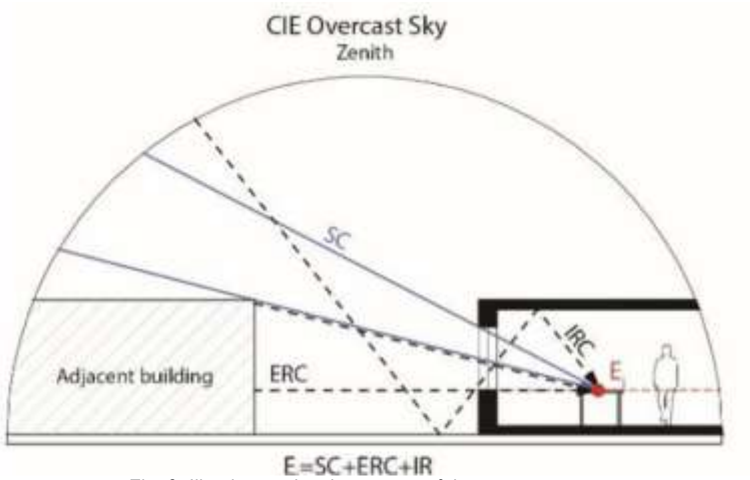


Fig. 3: Illuminance level as a sum of three components
(Source: Szokolay, 2004)

Light inefficiency for specific tasks, shades and shadows, daylight uniformity distribution, veiling reflections, lighting fixture flicker, and glare are lighting aspects that should be considered in evaluating the visual comfort of occupants in a space. Bright light source causes direct glare, while high reflectivity of surfaces (walls, ceilings, and floors) causes reflected glare (Zumtobel, 2018).

2.2 Naturalistic Evaluation; Field Measurement

Most current studies refer to the illuminance level as an indicator of daylight quantity and quality in a space. It is described that illuminance level is the amount of luminous flux emitted on a plane per unit area (Husini, et al., 2018). The rule of thumb commonly used for the luminance spot measurement method is that the grid should be 1m x 1m, where this can identify the daylight distribution uniformity. Measuring the daylight distribution uniformity is suitable for overcast or intermediate sky conditions in Malaysia (Subramaniam, 2013; Zomorodian, et al., 2016).

2.3 Naturalistic Evaluation; Survey Studies and Arabic Handwriting Performance

Cauwerts (2013) introduced a 6-scale descriptive scale that evaluates the occupants' perception of the brightness and glare of the room, where the factors above were used as the questionnaire's basis. Another previous research questionnaire evaluates the occupants' perceptions of the visual environment of the classroom (Hirning, et al., 2016).

Studies that selected school students as the respondent usually involves students at the age of 11 years old or above to avoid any limitations on the students' reading skills (Vi Le, et al., 2016). Doulos et al. (2007) inserted another important factor in the questionnaire, which is the occupants' perceptions of the size of the windows.

The common practice of evaluating students' handwriting performance is by recording the speed of the students' handwriting performance based on five (5) tasks, which are 'Best' copy, 'Fast' copy, Writing alphabets, 10-minute freewriting, and non-language-based tasks (Prunty et al., 2013). Both Handwriting Speed Test (HST) and Handwriting Performance Test (HPT) requires the students to write the given sentences within time limitation (Ziviani and Watson-Will, 2010). Some assessments record the students' speed instead of giving the students a time limit, such as the Test of Legible Handwriting (TOLH). The recorded speed is required in assessing the students' word per minute (wpm) score, which determine the students' handwriting performance (Rogers and Case-Smith, 2002). The wpm is identified by dividing the speed per alphabet with the average alphabet per word, which is commonly 5 alphabets per word (Ziviani and Watson-Will, 2010).

Handwriting Proficiency Screening Questionnaire (HSPQ) and Children's Questionnaire for Handwriting Proficiency (CHaP) are among a few that uses Likert scale type questionnaires to indicate students' performance. Both consist of legibility, performance time, and physical and emotional well-being as the scope of the assessment (Engel-Yeger, 2009). A commonly used assessment are Detailed Assessment Speed Handwriting (DASH), which also consist of a similar five task performance mentioned previously (Prunty et al., 2013). Other than the English language and alphabets, Hebrew and Arabic language also have their handwriting assessment tool, which is Hebrew Handwriting Evaluation (HHE) (Preminger, 2004) and modified Balsam Alabdulkader-Leat eye chart (Yazit, 2020; Alabdulkader and Leat, 2017) respectively.

2.4 Artificial Evaluation; Computer Simulation

Nowadays, building simulation software is in abundance, even though each software has its pros and cons. DAYSIM is an example of software that includes climate, daylight factor, daylight autonomy and daylight illuminance (Jovanović, et al., 2014). Integrated Environment Solution – Virtual Environment (IESVE) commonly used to simulate the illuminance level based on real-time and current weather data, while the design of the window is also considered in the simulation process. IESVE also included a ray-tracing software known as Radiance-IES, which simulates daylighting accurately. A study to identify the reliability of IESVE lighting analysis shows that the marginal error for IESVE accuracy is lower than 10 per cent, which can be considered reliable (Nikpour, et al., 2013).

3.0 Methodology

This section of the paper highlights the methods described in the DSR framework, which are field measurement, survey studies, Arabic handwriting performance and computer-generated daylight simulation. The respondents were required to:

1. Answer the first section of the questionnaire within the located time (demography, daylight condition perception).
2. Rewrite the BAL eye chart in the second section. No time restriction.
3. Record the Arabic handwriting speed based on the provided stopwatch. This is to evaluate the students' wpm.
4. Answer the second section of the questionnaire within the located time (handwriting performance perception).

3.1 Field Measurement for Illuminance Level

The layout design and the Window-to-Floor Ratio (WFR) were the factors considered in selecting classes for the experiment. To obtain an appropriate degree of illuminance in the classroom, the WFR were at 20%, as indicated by Malaysian regulations and guidelines. GRBP propose a floor space of 2.5 m^2 per student for the classroom layout design. The students selected were in secondary schools ranging in age from 13 to 17. Three rows of students make up each classroom. The illuminance level was determined by placing a data logger on tables and *rehals* with working plane heights of 900mm and 300mm, respectively, in each independent experiment.

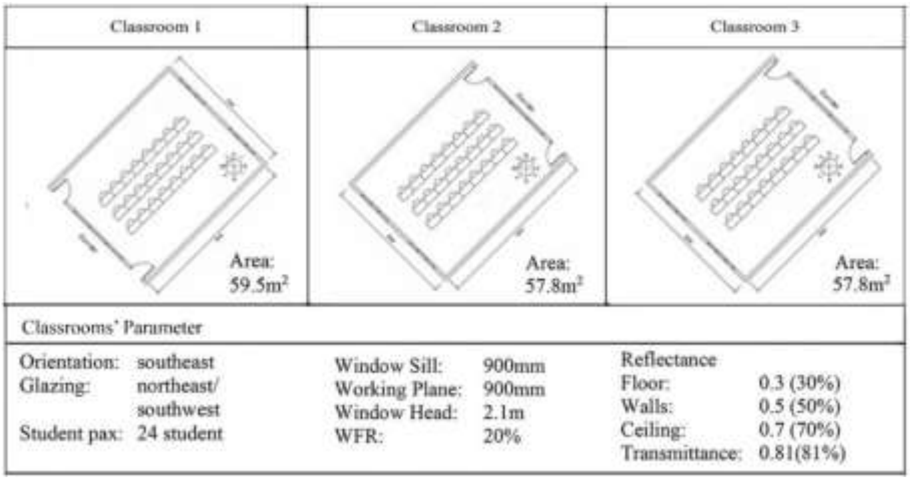


Fig. 4: Information of Kolej Genius Insan selected classrooms.
(Source: Yazit, 2020)

Malaysia is a tropical country with cloudy skies, with the greatest hourly illumination reaching 80,000 lx in between February and April, or between August and October, while the lowest at 60,000 lx in December (Zain-Ahmed, et al., 2002). According to Nedhal et al. (2016), the best period to prevent direct sunlight penetration when only diffuse daylight is available in the room is between 10 a.m. and 4 p.m., which were adopted in this research. A 1mx1m grid layout is used to set up the data logger in the classroom. The data logger was set at a working plane height of 300mm. The illuminance level data logger position in each classroom for the data collecting is shown in Fig. 5. The artificial lighting was off during the illuminance level measurement to measure the daylighting in totality, therefore no illuminance level adjustment required.

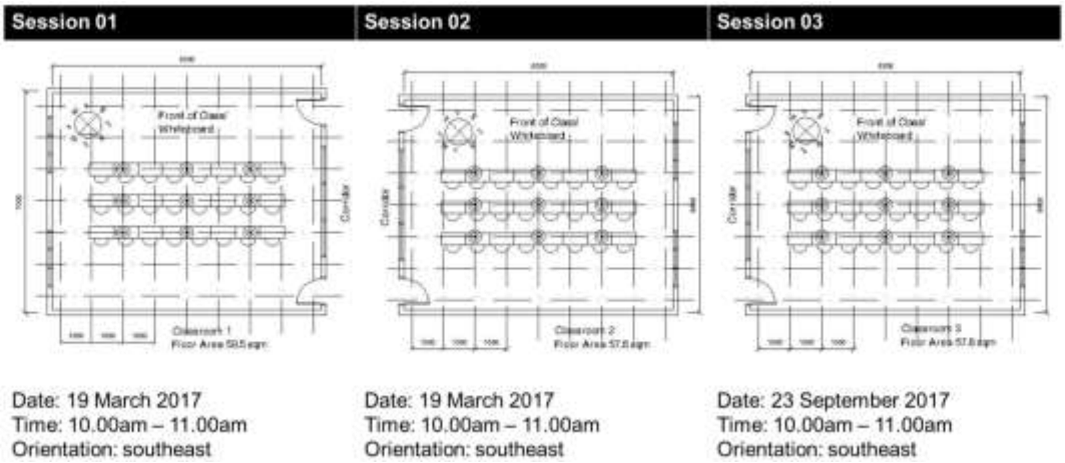


Fig. 5: Illuminance Level Data Logger Position
(Source: Yazit, 2020)

On both sides, the data logger is situated 2 meters away from the windows. There were nine illuminance data loggers in three rows, each with three measurement points. In each row, the data loggers were spaced 2 meters apart. The measurement was taken to determine the average level of illuminance in the classes.

3.2 Survey Studies and Arabic Handwriting Performance

The daylight perception questionnaires and visual eye acuity tests were two parts of the survey. This experiment did not limit their time to write the BAL eye chart supplied with the survey. Instead, students used the given timer at the front of the classroom to record their Arabic handwriting speed. The students' average words per minute were used to measure their Arabic handwriting skills (wpm). The questionnaire was written in the style of Hirning (2016) and Doulos et al. (2007), and it was built on responses from students' space visual environment.

Other sources include the space's brightness level and the daylight environment (Cauwerts, 2013). The survey also includes window widths depending on respondents' perceptions (Doulos et al., 2007). The respondents' range of visual comfort or discomfort, judgments of daylighting, and visual comfort during Arabic handwriting activities were all measured using the Likert Scale. The scale contained five levels, with the lowest number indicating strong disagreement with the question and the highest number indicating strong agreement with the issue. Descriptive Statistic Analysis was used to evaluate the survey.

Section 2: Daylight Condition
Seksyen 2: Keadaan Pencahayaan

No	Question	1	2	3	4	5
		Too dim *Terlalu gelap*	Dim *Gelap*	Neutral	Bright *Terang*	Too bright Terlalu terang
1	The brightness of the room *Keterangan cahaya bilik darjah*					
2	The size of the classroom window *Saiz tingkap bilik darjah*	Too small *Terlalu kecil*	Small *Kecil*	Normal *Biasa*	Big *Besar*	Too big Terlalu besar
3	Amount of daylight in classroom *Tahap cahaya di dalam bilik darjah*	Too low *Terlalu rendah*	Low *Rendah*	Normal *Biasa*	High *Tinggi*	Too high Terlalu tinggi

Section 2: Questionnaire – Learning Task Performance
Seksyen 2: Soal Selidik – Prestasi Tugasan Pembelajaran

Answer this section based on your task in the previous section.
Jawab bahagian ini berdasarkan tugasan anda di bahagian sebelumnya.

No	Question	1	2	3	4	5
		Very Disagree *Sangat Tidak Setuju*	Disagree *Tidak Setuju*	Neutral	Agree *Setuju*	Very Agree Sangat Setuju
1.	You can read the Eye Chart clearly. *Anda boleh membaca Carta Mata dengan jelas.*					
2.	You can rewrite the Eye Chart clearly. *Anda boleh menulis semula Carta Mata dengan jelas.*					

Fig. 6: Daylighting Perception Questionnaire
(Source: Yazit, 2020)

Fig. 7: Modified Balsam Alabdulkader-Leat eye chart
(Source: Yazit, 2020)

Following that, they must read and rewrite the attached BAL chart. There is no time constraint for the students to rewrite the BAL chart. Students are given a timer to keep track of their time in front of the classroom. The modified BAL chart is made up of seven two-lined statements that are of the same length. The Arabic alphabet was made up of several words that were built in the same way as "the fox jumps over the lazy dog." The BAL chart has 700 Arabic letters in total, with an average of 100 Arabic letters in each paragraph. The average number of Arabic words in each paragraph is 20; the total number of Arabic words in the BAL chart is 140.

Evaluation of the student's words per minute (wpm) for the writing task is the approach used to identify the students' writing performance. The written letters are divided by the number of minutes it took the students to complete the activity and multiplied by five to get the student's average word per minute rate.

3.3 Computer Simulation through Integrated Environmental Solutions; Virtual Environment (IESVE)

Virtual Environment software is used for the simulation process by Integrated Environmental Solutions. The function Day Lighting Analysis is used to evaluate daylighting, and it allows you to change the meteorological data and internal reflectance value based on the spaces you choose. For the average illuminance level recorded, the daylighting simulation boundary configuration follows the classroom design and circumstances.

Table 1. IESVE Daylight Simulation Parameter

Parameters	Unit/value
Dimension (layout)	7m x 8.5m
Orientation	North
Windows orientation	Both sides, North/South
Obstruction margin	0.5m
Point measurement grid	0.5m
CIE	Intermediate sky
Weather data	Kuala Lumpur
Time	10.00 am
Month	March/September
Windowsill height	300mm
WFR	20%
Window dimension	5m x 1.2m
Classroom height	3.5m (with the false ceiling)
Working plane height	300mm
Wall reflectance	0.5(50%)
Floor reflectance	0.3(30%)
Ceiling reflectance	0.7(70%)
Window transmittance (single glaze)	0.8(80%)

(Source: Yazit, 2020)

4.0 Findings and Discussions

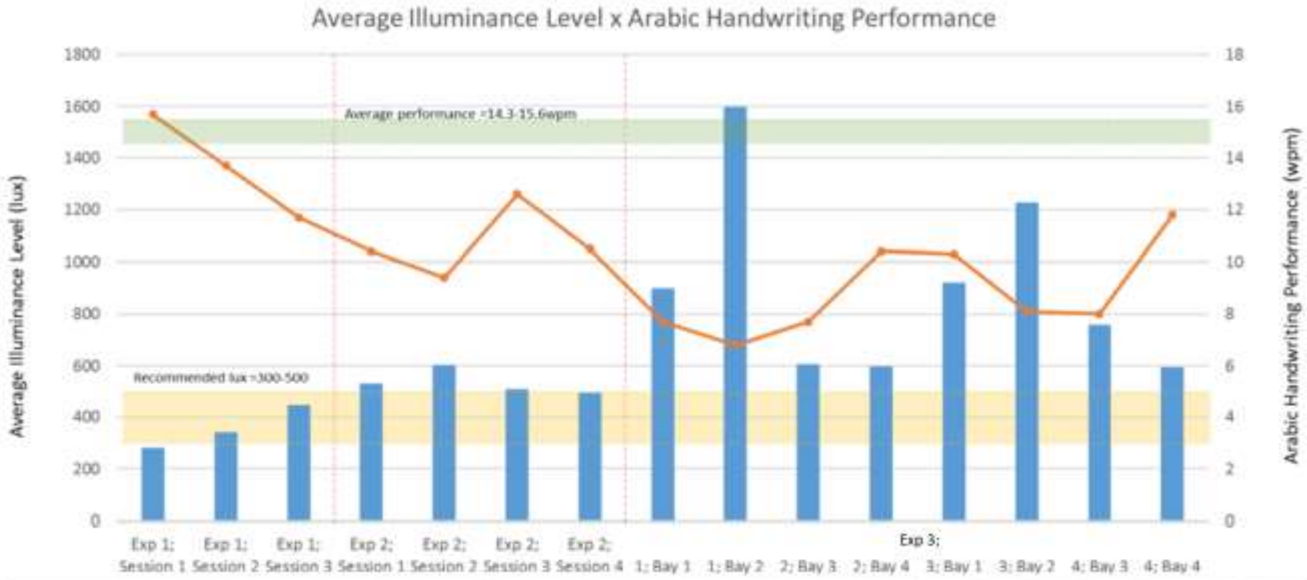
This section of the paper highlights the findings and results obtained from Naturalistic Evaluation and Artificial Evaluation. Acknowledged that the data and illustrations that came with it were extracted from first author’s PhD thesis. The findings provided in this section is to validate the usability and reliability of the proposed DSR method.

Fig. 8 shows that only Experiment One; Session One students had an average Arabic handwriting performance for hafazan learning that was higher than the average word per minute for the same age group, even though the illuminance level were low. This supports the theory that children’s’ eye is more sensitive and received more light compared to adults at the same illuminance level (Read et al., 2015), thus the recommended minimum lux of 300 lx should be lower. The R^2 value for result shown above was 0.98 (98%), which shows a high correlation between the two items. The p-value of the study was 0.1 at 95% confidence interval. Low p-value indicated that the study was statistically significant.

The average Arabic handwriting score was 15.7 wpm, with the range of students' average Arabic handwriting speed was 11.7 wpm to 15.7 wpm. However, due to the low average illuminance level recorded, the students' impression of daylight conditions was poor. Even though the perception of the daylight conditions was low, the students' perceptions of reading and Arabic handwriting performance were positive. This study indicates that a greater illuminance level in the classroom reduces student performance, whereas a lower than recommended illuminance level considerably improves student performance. Fig. 9 shows a more extensive study based on the DSR framework method, where it shows a clear correlation between students’ perception, Arabic handwriting performance and daylighting.

	Session 1	Session 2	Session 3
Illuminance Level (lux)	280	340	446
Performance (wpm)	15.7	13.7	11.7
Students' Perception			
Brightness of Classroom	dim	normal	dim
Size of Window in Classroom	small	normal	small
Amount of Daylight	low	normal	normal
Read Eye Chart Clearly	very agree	agree	agree
Write Eye Chart Clearly	agree	agree	agree

Fig. 8: Cross findings and results from DSR Framework: Naturalistic Evaluation.
(Source: Yazit, 2020)



	Session 1	Session 2	Session 3	Session 1	Session 2	Session 3	Session 4	1; Bay 1	1; Bay 2	2; Bay 3	2; Bay 4	3; Bay 1	3; Bay 2	4; Bay 3	4; Bay 4
Illuminance Level (lux)	280	340	446	530	603	507	494	899	1599	607	597	921	1227	757	596
Performance (wpm)	15.7	13.7	11.7	10.4	9.4	12.6	10.5	7.7	6.8	7.7	10.4	10.3	8.1	8.0	11.8
Students' Perception															
Brightness of Classroom	dim	normal	dim	normal	dim	normal	normal	normal	too bright	dim	dim(a)	normal	bright	normal(a)	normal
Size of Window in Classroom	small	normal	small	normal	small	small, neutral	small	small(a)	small	small	small	small	big	big	small
Amount of Daylight	low	normal	normal	normal	low	normal	low	normal	high	low(a)	very high	normal	high	normal(a)	normal
Read Eye Chart Clearly	very agree	agree	agree	agree	agree	agree	agree	very agree	very agree	very agree	agree	agree	agree	very agree	agree
Write Eye Chart Clearly	agree	agree	agree	neutral	agree	agree	agree	very agree	neutral(a)	very agree	agree	neutral	agree	very agree	agree

Fig. 9: Cross findings and results from DSR Framework: Naturalistic Evaluation.
(Source: Yazit, 2020)

The minimum, maximum, and average values of daylight factor and daylight illuminance level are shown in the simulation results for each model. The back-coloured numeric grid point values graphs that indicate the daylight distribution and uniformity are shown in the grid or point illuminance measurement result. The R^2 value was 0.87 (87%), which shows a high correlation between the two items.

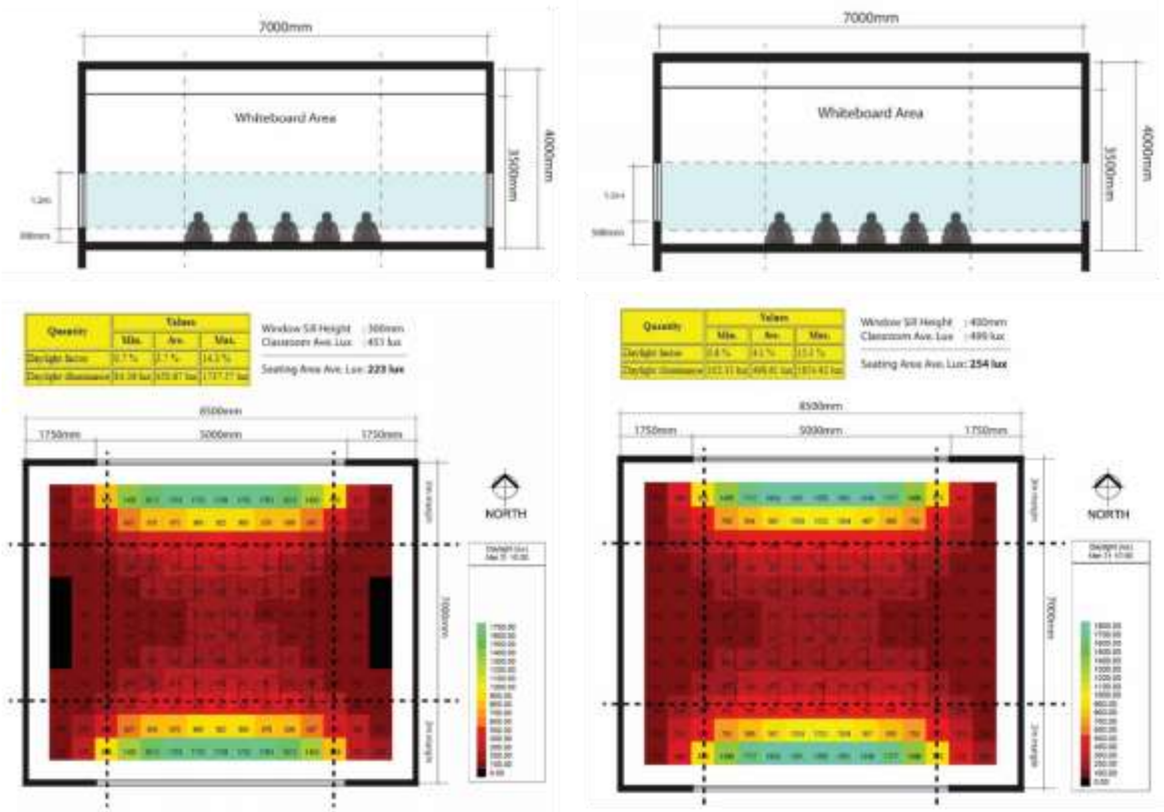


Fig. 10: Simulation results from DSR Framework: Artificial Evaluation.
(Source: Yazit, 2020)

Fig. 10 shows that when compared to the indicated 280 lx from the trial, classrooms with 300mm windowsill height got 20.4 per cent lower average illuminance, while the closest result to 280 lx was obtained in a classroom with a 500mm windowsill height, which was just 1.4 per cent higher than the required 280 lx. As a result, for Arabic handwriting activities at 300mm working plane height, the appropriate windowsill height ranged from 300mm to 500mm.

5.0 Conclusion and Recommendations

Results show that the Artificial Evaluation using computer simulation is reliable in identifying the design parameter for daylight design strategy. Field measurement and Arabic handwriting performance in Naturalistic Evaluation also shows a high correlation, thus, it is reliable to be adapted to another research. However, the same statement is not applicable for the perception questionnaire, where the results show discrepancies between the students' perceptions with their Arabic handwriting performance and illuminance level. Therefore, the DSR framework still requires improvement, where the Naturalistic Evaluation can be furthered study to identify the suitable method to accurately identify the correlation between the students' perceptions, Arabic handwriting performance and illuminance level. Recommendations based on this research are:

1. Recommended adapting the Arabic handwriting task performance evaluation method to determine the students' Arabic handwriting performance, where the results of this study have shown consistency in outcomes.
2. Recommended that architects and designers evaluate the design of the classrooms for religious schools that uses rehal or lower working plane height using this method, since that it was used to develop the Syaheeza's DRT.
3. Recommended that the DSR should be furthered studied based on other internal and external factors such as loose furniture, colours, and materials of structural components, since that these were the limitations during the experiments.

6.0 Paper Contribution to Related Field of Study

1. There was a lack of reference for evaluating students' Arabic handwriting performance in relation to daylight conditions. Thus, the review of the DSR framework implies that the methodology framework is reliable, which can be further developed to other school typologies.

2. The DSR framework can be further studied and developed as a method to evaluate different typologies of schools and introduce insertion to the existing standards and guidelines.
3. The DSR framework can be further improved to develop a triangulation between the three (3) evaluation domains (Theory, Naturalistic and Artificial.
4. The DSR framework method can improve the design of Islamic religious schools in Malaysia, and other school typologies as well once improved and adapted in another research.
5. The DSR framework and Syaheeza's DRT can be referred to as a pilot or prototype for the basis of future studies to improve Islamic religious school classroom design in Malaysia.

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