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To cite this article: S N N Ekasiwi et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 126 012049

View the article online for updates and enhancements.
Correlation of classroom typologies to lighting energy performance of academic building in warm-humid climate (case study: ITS Campus Sukolilo Surabaya)

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Abstract. Classrooms in educational buildings require certain lighting requirements to serve teaching and learning activities during daytime. The most typical design is double sided opening in order to get good daylight distribution in the classroom. Using artificial light is essential to contribute the worse daylight condition. A short observation indicates that during the lecture time the light turned on, even in the daytime. That might result in wasting electrical energy. The aim of the study is to examine the type of classroom, which perform comfortable lighting environment as well as saving energy. This paper reports preliminary results of the study obtained from field observation and measurements. The use of energy and usage pattern of artificial lighting during the lecture is recorded and then the data evaluated to see the suitability of existing energy use to building energy standards. The daylighting design aspects have to be the first consideration. However, the similarity in WWR of the classroom, the Daylight Factor (DF) may differ. It depends on the room depth. The similarity of the increase of WWR and Ratio of openings to floor area do not directly correspond to the increase of DF. The outdoor condition of larger daylight access and the room depth are the influencing factors. Despite the similarity of physical type, usage pattern of the classroom imply the use of electrical energy for lighting. The results indicate the factors influencing lighting energy performance in correlation to their typologies.

1. Introduction

1.1. Why is energy saving in academic building important?

Typical breakdown reported that educational facility consumed lighting energy about 14% of the total one. That shows the second largest amount of energy in buildings after heating, ventilation, and air conditioning (HVAC) systems. [1]. In Malaysia, the use of energy 25 % for artificial lighting, 25% for electrical equipment, and 50% for air conditioning [2]. Those facts inform that lighting energy becomes a significant component, which one has to notice. Also today’s society has the tendencies to create high illumination lighting environment, both for aesthetic and visual comfort purposes. Consequently, they consume abundant energy for lighting. Therefore, we have to promote actions for saving electrical energy, in some sense by producing energy saving electrical equipment, or using artificial light as a supplement to natural light, known as hybrid lighting [3].

Energy conservation concept emphasizes that in designing buildings, we should consider to utilize natural resources in achieving comfortable condition of the user. Daylighting is a common strategy to support it. That strategy has the consequence to create large opening to allow airflow and natural light into the buildings. ITS campus, which established more than 30 years ago, demonstrates the idea of utilizing natural energy. Shallow-type-room-shape, with a double-sided opening, promote in
performing good visual environment. In the second decade of the campus establishment, some research reported good daylighting performance in classrooms. Along with the development of teaching and learning method from year to year, the usage pattern, designs and equipment changed respectively. Moreover, the need of more comfortable conditions stimulates the user to operate electrical equipment, which may result in the increase of operation energy.

1.2. What is the relationship between energy consumption and daylighting in buildings?

In the region with a warm-humid condition, we experience 7-8 hours duration of sunshine. This provides opportunity to involve natural lighting in the building design. Some factors has to be taken into account for having daylight in the room. They are the area and position of the openings, the obstruction of the light passage (of the opening), and the color of interior material. [4]

Along with the changes of utilizing modern devices in teaching and learning, which consumes electricity, may lead increasing energy consumption. The traditional teaching medium (chalkboard and blackboard) changed into in-focus projector, LCD projector, and electrical operated screen. Moreover, the Air Conditioning (AC) used in classrooms are increasing. Regarding some cases, utilizing LCD projector need to consider adequate lighting condition near the projector screen for comfortable seeing the object on the screen. The kind of active control system is supported by grouping and switching the lamps. The provision of indoor fabric screen supports passive control system of lighting environment. User may operate it to adjust the lighting environment they required.

Passive design strategies promote the utilization of natural energy. In this case, daylighting should become the first consideration in achieving visual comfort. In the occupancy period, artificial lighting can supports for enhancing environmental condition in efficient way. Researches in audit energy for lighting in academic buildings [5][6] concerned on observing the monthly energy consumption of the whole building, in one case, or of a building with high-lighting requirement such as library. The objective of this study is to investigate the role of the design aspect to promote daylight condition, and to investigate the support of artificial light in improving the condition by considering the design aspects and using pattern. This stage may contribute to propose a model of educational building in the next study.

2. Method

Visual environment parameter is illuminance on working plane, which in this case is student college chair (for a classroom) or drawing table (for a studio). The position is agreed 75 cm above the floor (Fig.1). Parameter to determine the performance of room lighting is by measuring the amount of illuminance received on work plane along with the measurement of outside illuminance. The percentage of indoor illuminance (Ei in lux) to outdoor illuminance (Eo in lux), namely DF (Daylight factor), indicates an indoor lighting performance. The DF requires for performing visual comfort in the classrooms is 1 to 2 % [8], while the illuminance should reach 250 lux in a classroom and 750 lux in a drawing studio, respectively [9].

2.1. Measurement methods

Field measurements conducted using the Tenmars TM-203 lux meters for indoor and LX1010BS Lux meters for outdoor use. The measurement point is set based on national standard document SNI 16-7062-2004.[7] Based on the standard, the position of points measured in the classrooms are set. The equipment are set in the line located one third of the room depth, away from the wall with largest opening area. The measurement is done in several points, which are called as the Main Measured Point (Titik Ukur Utama/TUU), while others are called the Side Measured Point (Titik Ukur Samping/TUS). For the classroom case, we determine the front TUS as the point near the screen or board, while the position far away from the screen, and we mentioned as the TUS rear. Regarding the double-sided opening in the class, we determine the position of one third from right side wall as TUU backside from the largest opening.
Figure 1. Measurement Position: horizontal (left), vertical (right) [7].

Table 1. Position of measurement points in the classrooms.

| Classrooms | Position of the measured points | Position of TUS Backside |
|------------|---------------------------------|--------------------------|
| SP J-103   | 2.9m                            | 5.8m                     |
| SP I-101   | 2.9m                            | 5.8m                     |
| SPE-101A   | 2.9m                            | 5.8m                     |
| TL 101     | 2.73m                           | 5.46m                    |
| TL 105     | 2.33m                           | 4.66m                    |
2.2. Classroom typology
The classrooms have rectangular type, shallow plan, which ranged from 7.2 to 10 meter wide (depth). Hallway (selasar), shaded by 1.5-meter overhang, forms a shaded area for circulation purpose. Two-sided opening equipped with transparent surface as opening for getting daylight, partially openable for natural ventilation purpose. (Fig. 2a, and 2e). The wall facing the hallway has high windows, 2 meter high from the floor level (Fig 2e), while the opposite wall has openings 1 meter high from floor level (Fig. 2a). This large opening side is required for getting a good daylight source from the left side. In the lecture position, there is partially a closed wall (without transparent area). This means to prevent disturbing light incident to the chalkboard, whiteboard area. Such a wall-opening composition meets a typical classroom lighting concept.

Almost all observed classrooms have all the same material and surfaces, except the classroom SP E101A (Table 2), which has partially blue colour in the rear wall. Concerning the daylight concept, the interior surface may provide similar effect internal reflected component. Artificial lighting in the classrooms supported by fluorescent lamps 36 watt, composed in double lamps armature. The exception is shown in the classroom TL101. It supported by LED lamps 13 watt after retrofitting (Table 3).
### Table 2. Surface material of the classrooms.

| Room   | Wall 1     | Wall 2     | Wall 3     | Wall 4     | Ceiling  | Floor     | Table    |
|--------|------------|------------|------------|------------|----------|-----------|----------|
| SP J103 | White paint | White paint | White paint | White paint | White glossy | Brown paint |
| SP I101 | White paint | White paint | White paint | White paint | White glossy | Brown paint |
| SP E101A | White paint | White paint | White & Blue paint | White paint | White glossy | Brown paint |
| TL 101  | White paint | White paint | White paint | White paint | White glossy | Brown paint |
| TL 105  | White paint | White paint | White paint | White paint | White glossy | Brown paint |

### Table 3. Classroom types and the operation of artificial lighting (lamps).

![Classroom diagram]

Keterangan:
- Meja kelas
- Tiiki Pengukuran
- Layar LCD
- Tiiki Lampu menyala
The table 3 shows the type of the lamp arrangement in the classroom. In the classroom TL101 and TL 105 the lamps are mounted at the concrete beam seen at the ceiling. (See Fig. 2c). The lamps in the other classrooms bounded to the cable tray, 50m below the ceiling.

The left column of the table 3 presents the observation result of the classroom lighting. The rooms turn on the lamp during the class. Four out of five classrooms operate a part of the lamps, which installed. Only the classroom I 101 turn on all lamps installed, during teaching time. Most of them turn off the lamps at the position near the projector screen. This indicates that dimming in that area is essential to enhance visual quality around the screen.

3. Results and Discussions

3.1. Daylight condition in classrooms

Fig. 4 a, and 4 b show the relationship between design aspects of the classrooms (Table 4) to the Daylight Factor (DF), analyzed from measured data. The required DF of the task illuminance evaluated in three condition of lighting: full daylight, fully supported, and partially supported by...
artificial lighting. In fully daylight condition, the classroom TL 101 and TL 105, namely 0.3% and 0.6% respectively. Those values are lower than required (1-2%). The classroom SP I101 and SP J103 demonstrate the value of 3.3% and 7.1%. The value exceeded the requirement for classroom condition. Only the classroom SP E101A confirm the standard or requirement of the daylight condition. The DF value is 2%.

Daylight environment of room expect the daylight penetrated from the opening. The statement has the consequence to the design aspects of the rooms namely the Window to Wall Ratio (WWR) and Opening to Floor Area Ratio. Figure 4a shows the importance of the WWR order. The WWR of the classroom surveyed ranged from 23.9% to 32.9%. The DF raises due to the increase in WWR of the rooms. The pattern of the WWR addition show the same pattern of the DF increase. The exception arises in classroom type TL 101 and SP I 101.

The ratio of opening to floor area examined in Fig 4.b. The figure shows the percentage of 21.6% to 27.7%. Similar to that of the WWR, the figure shows the pattern of the increase in the Ratio of Opening to Floor Area. It conforms the increase in DF of the room, except in the classroom SP I101.

Examining the elevation of the classroom TL101 and TL105, both of the classrooms have similar type in the aperture design. (Fig.3). The small-high openings are oriented to the hallway side, while the larger openings are in the opposite side. The room has similar area for daylight access, both on the perimeter wall (Wall 1 and Wall 2). Although the total WWR of the classroom TL 101 is higher than that of the classroom TL 105, the DF in TL101, however, it is lower than that in TL 105 (see Fig. 4 a). This because the room depth of the TL 101 is larger than that of TL105.

In other case, we examine the classrooms SP J103 and SP I101. They have almost the same physical type. This means, both of the classroom have the same WWR as well as the Ratio opening to floor area. On the contrary, they demonstrate different DF value. That is because the orientation of the surfaces with larger window are different. The larger opening of the room SP J103 oriented to a less shaded outdoor area, while of SP I101 is oriented to shaded area. A less shaded area causes more daylight enter to the room.

Particularly for double-sided opening, it define three categories of the proportion of WWR in the right side wall and that in the left one: 1;1 ; 1.5:1 ; and 2:1. The room with the WWR-wall proportion 2:2 should have the best daylight performance. On the contrary, it gives the lowest DF, because of outside obstruction facing the largest opening. It conform the criteria of the TUU (MMP) position. The position is 1/3 of the room depth from the wall with largest opening. When the opening is facing to the shaded area or heavy obstructed area, the DF is lower than expected, although the WWR of the room is high.

### Table 4. Window area composition in classroom’s wall.

| Classroom | Length | Width | Wall Area | Opening of Wall 1 | Opening of Wall 2 | Ceiling Height | WWR of Wall 1 | WWR of Wall 2 |
|-----------|--------|-------|-----------|------------------|------------------|---------------|--------------|--------------|
| TL101     | 10.7   | 8.2   | 39.1      | 13.0             | 39               | 3.7           | 33           | 15           |
| TL105     | 7.37   | 7.05  | 25.4      | 7.6              | 25               | 3.6           | 30           | 18           |
| SP J103   | 10.6   | 8.8   | 39.2      | 12.8             | 13               | 3.7           | 33           | 33           |
| SP I101   | 10.6   | 8.8   | 39.2      | 12.8             | 13               | 3.7           | 33           | 33           |
| SP E101A  | 7.2    | 8.8   | 26.2      | 6.3              | 9                | 3.7           | 24           | 34           |

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3.2. The support of artificial lighting to enhance the lighting condition in the classrooms

In the daily usage, the classrooms utilize artificial lighting, in partially or fully support (Table 5), disregard to availability of the daylight. According to the section 3.1 and the table 4, the classroom SP E101A performs the best daylight condition. This means it achieved the required DF = 2%. It composed by the WWR 24% in the wall 1, and 34% in the wall 2. The DF increases to 3.5% by operating a half of the lamp number installed in the room (partially artificial support). Moreover, the DF value is higher (4.9%) if the room is full-supported by artificial light. It indicates that the exceeded of required value may disturb the visual quality. In the case of the classroom SP I101 and SP J103, in which they have the same WWR in both sidewall (see table 4), it can be seen that the DF value exceed the required one. The support of artificial light during the teaching session seems not be essential. Of course, the partially artificial lighting support in room SP J103 increase the DF value. By the condition in full support, the value increased drastically from 8.8% to 14%. The increment of the value may influence the lighting quality, which can affect visual comfort, as well as wasting energy.
Table 5. The increment of DF by using artificial lighting.

| classroom | full daylight (%) | full artif support (%) | partial Artif support (%) | from daylight to full artificial | from daylight to partially artificial |
|-----------|------------------|------------------------|---------------------------|---------------------------------|--------------------------------------|
| SP J103   | 7.1              | 14                     | 8.8                       | 97                              | 24                                   |
| SP I101   | 3.3              | 5.2                    | NA                       | 58                              | NA                                   |
| TL 101    | 0.3              | 3.1                    | 2.4                      | 933                             | 700                                  |
| TL 105    | 0.6              | 3.7                    | 3.1                      | 517                             | 417                                  |
| SP E101 A | 2                | 4.9                    | 3.5                      | 145                             | 75                                   |

The other cases are the classrooms (TL 101 and TL 105), which have the WWR in wall 1 twice of the WWR in wall 2. They show very low DF value (0.3% and 0.6% respectively), because of very high obstruction of outside condition facing the largest opening, which interfere the daylight penetration. This result in a high dependency to the artificial lighting. The support of artificial lighting during the teaching session are necessary. By turning on the half of the lamp number, the DF value is 2.4% and 3.1%. The values are consequently higher by operating all of the lamps (3.1% and 3.7%). The use of artificial lighting is relatively close to the required (2%), although the increment seems reasonably high (Table 5). Regarding the daylight condition evaluation in this section, we have categorized the dependency to artificial lighting as follows: high dependency (DF < 1%), relatively dependent (DF=2%) and suggested free of artificial lighting (DF > 2%).

According to the variety of the need of artificial lighting to support daylight condition, it is necessary to calculate the lighting energy consumption in correlation to classroom typology.

3.3. The predicted energy consumed in relation to the lighting condition in the classrooms

Table 6 shows the prediction of the lighting energy consumed, by calculating and comparing the lamp number, which is required and installed in the existing classroom. In this study, Power Density (Watt/m²) is adopted to indicate the lighting energy consumption. The standard introduced by [10] is 15 watt/m². Predicted energy consumed during the lecture, when all of the lamp in operation, or only a part of them turned on, is shown in column 9 and 10 of the table 6.

Based on section 3.1 we identify classrooms, which have high dependency on artificial light (DF <1%). Those are TL 101 and TL105. They are predicted to consume lighting energy in the range of 44-55% by operating all of the installed lamps, while by using about 70% of the lamp installed, the predicted energy consumption is 33-37%. The user prefer to turn off the light near the screen during the lecture. This reflects to the control of the lamp (switching system) in the room, which grouped perpendicular to the openings. The classrooms which categorized as relatively dependent (DF=2%) as well as the suggested free of artificial lighting (DF > 2%) are predicted to consume energy 57-61% to 31%. Those can be concluded, in case of the artificial light full operated during the lecture time, the predicted energy consumed is considerably under the standard (<15 Watt/m²).

The control system (on-off switching) in the observed classrooms supports the function of the teaching method, which utilizing LCD projector. It enables to switch off the lamps in the position near the screen. Apart from that, we have to consider the grouping system in supporting daylight, for instance, to support the decrement of daylight performance in dependant of the room depth.
Table 6. Lighting energy in relation to the type of classrooms.

| Classrooms | Floor Area (m²) | Lamp Type | Wattage (calculation) | Installed | Partially artif. light | Standard/ floor Area | Required energy in full light (watt/m²) | Required energy in part. light (watt/m²) | Predicted Energy Consumed |
|------------|----------------|-----------|-----------------------|-----------|-----------------------|----------------------|-----------------------------------------|-------------------------------------------|---------------------------|
| SP J103    | 93.28          | Fluorescent | 36                    | 22        | 12                    | 15                   | 8.5                                     | 4.6                                       | 57                         | 31                        |
| SP I101    | 93.28          | LED       | 13                    | 28.9      | 11                    | 6                    | 15                                      | 15.5                                     | 6.6                          | 10                        | 6                         |
| SP E101A   | 62.48          | Fluorescent | 36                    | 12.0      | 14                    | 8                    | 15                                      | 8.1                                      | 4.6                         | 61                        | 31                        |
| TL101      | 87.74          | Fluorescent | 36                    | 16.0      | 16                    | 12                   | 15                                      | 6.6                                      | 4.9                         | 44                        | 33                        |
| TL105      | 51.9885        | Fluorescent | 36                    | 10.0      | 12                    | 8                    | 15                                      | 8.3                                      | 5.5                         | 55                        | 37                        |

4. Conclusions

The design of lecture rooms/classrooms of ITS Campus is especially characterized by 7.2 to 10 m depth, double-sided opening, and more specific for humid climate is outside hallway (selasar), which is shaded by 1.5 overhang. Some physical characteristics determined the visual performance of classrooms are a ratio of opening to floor area and a ratio of windows to walls (WWR). The higher the WWR itself is not correlated to the higher DF value, when the largest opening facing to the hard obstructed outdoor condition. This is evident that the wall with largest opening should be as the significant influence of the DF value. This result conform the prediction method issued in national standard [7].

The typology of classrooms includes physical characteristics as well as the type of usage. The use of artificial lighting during lecture is prevalent. Those might cause lighting energy waste. Artificial lighting used as the supplement of the room daylight, however, result to the predicted lighting energy consumption of lower than that of the standard 15 watt/m², both in applying the fully or partially supported artificial lighting. Further survey on participants during the teaching session, however, is needed, to conform the lighting condition.

Considering the hybrid lighting for the lecture, it is necessary to include the control system of artificial lighting by grouping pattern parallel to the daylight access.

Acknowledgments

The authors gratefully acknowledge that Ministry of Research and Technology, and Higher Education Republic of Indonesia for providing the research grant PDUP of the Year 2017, Contract Number 564/PKS/ITS/2017.

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