Influence of a facade design on thermal and visual comfort in an elementary school classroom

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Influence of a facade design on thermal and visual comfort in an elementary school classroom

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Abstract. Thermal and visual comfort are important elements in the learning process. The object chosen was the classroom of the Sawah Besar 01 public elementary school, Semarang where the building tends to have a homogeneous facade design but with openings that have varying orientation directions. This affects the level of comfort both thermal and visual in the classroom. Data analysis was carried out quantitatively, namely to obtain a thermal comfort index and natural lighting comfort index according to the Indonesia National Standard. The thermal comfort conditions of all selected rooms on the 1st and 2nd floors did not meet the comfortable thermal comfort standard for classrooms. Rooms 1 and 2 on the 1st floor tend to be above the minimum level of classroom lighting. Room 3 on the 2nd floor tends to be stable and all of them are above the minimum limit. In room 4 on the 2nd floor, the general lighting level has exceeded the minimum limit. New façade opening designs and mechanical ventilation aids need to be applied to improve thermal and visual comfort according to the Indonesia National Standard.

1. Introduction

There are comfort factors in buildings that must be considered while designing a building. In the case of this research, there are visual comfort and thermal comfort. Visual and thermal comfort in buildings is needed so that people can do their activities properly for a prolonged time. The level of productivity and human health is influenced by local climatic conditions. That is why it is important to accommodate human comfort [1]. One of the factors that influence visual and thermal comfort is the building façade [2]. The building facade is a part of the building that is often exposed to solar radiation. The direction of building orientation has a major influence on the effectiveness of the function of the building facade. One of the tasks of the building facade is to regulate the conditions around the outside of the space, which aims to ensure comfortable conditions inside the room.

1.1. Recommended level of thermal comfort

The thermal comfort limit for equatorial conditions ranges from a lower limit of 19°C TE to 26°C TE. The most suitable comfort limit for Indonesians used in this study is the Mom-Wiesebron comfort limit as follows [3].

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Table 1. Mom-wiesebron comfort zone criteria.

Criteria	Effective Temperature (TE)
Cool Comfortable	20,5°C TE - 22,8°C TE
Optimal Comfortable	22,8°C TE - 25,8°C TE
Warm Comfortable	25,8°C TE -. 27,1°C TE

1.2. Recommended level of lighting

The main function of Sawah Besar 01 Elementary School Semarang classroom is for reading and writing activities. However, classrooms are also used for scientific experimentation and artistic activities such as playing musical instruments, singing, and drawing. This affects the recommended minimum lighting level so that the user's visual comfort is achieved as described between 250-750 Lux [4].

2. Methods

The object chosen by the researcher in the classroom of Sawah Besar 01 Semarang state elementary school. Public elementary school buildings tend to have a homogeneous building facade design with openings on both sides of the wall as shown in figure 1. Facade designs that tend to be the same but have varied orientation directions affect the level of comfort both thermal and visual in the classroom.

Field measurements for the room temperature were carried out in the time range from 07.00 – 16.00 WIB on Wednesday, June 2, 2021. Data collection points are air movement, dry temperature, and air humidity by opening window openings in the room and without artificial air conditioning. By using the data that has been obtained then an analysis is carried out, obtaining effective temperature data. The measurement point for the level of lighting in the selected classroom is carried out as shown in figure 2 [5]. The measurement results obtained are then compared with the recommended lighting levels [4].

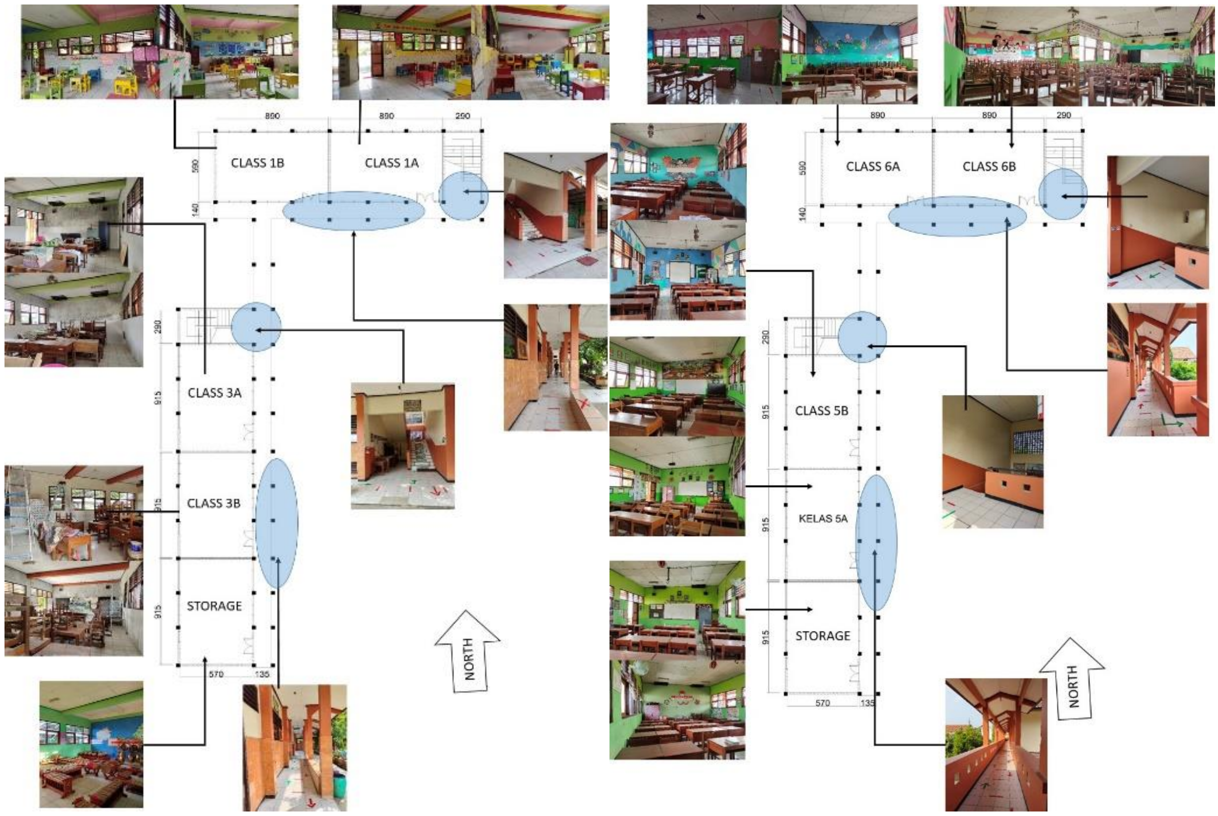


Figure 1. Sawah Besar 01 elementary school layout 1st floor (left) and 2nd floor (right).

Data collection was taken in 2 classrooms on the 1st floor, Class 3B or Room 1 and Class 1A or Room 2, with openings facing the same direction east and west. And also 2 rooms on the 2nd floor, Class 5A or Room 3 and Class 6B or Room 4 with openings facing north and south.

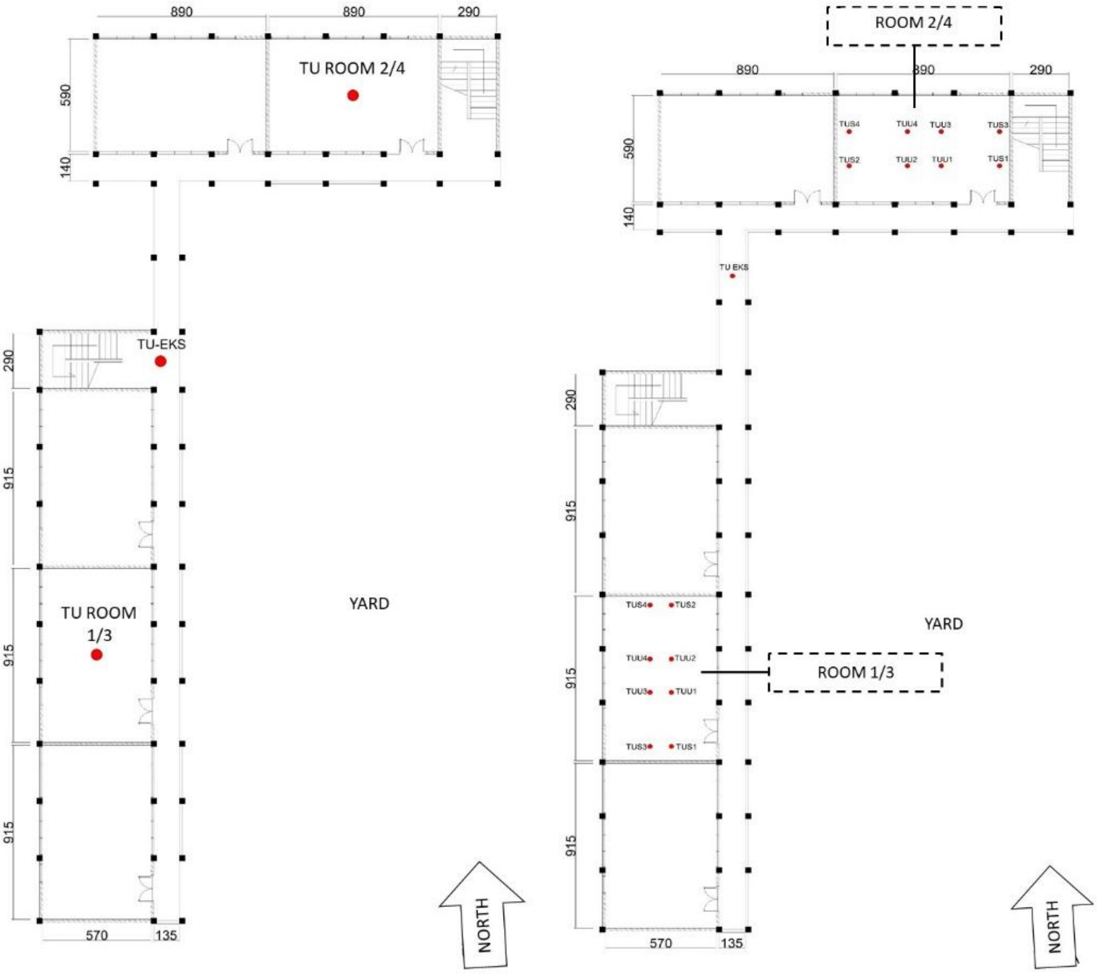


Figure 2. Measuring point for thermal comfort (left) and visual comfort (right).

Measuring instruments as shown in table 2 for the implementation of direct measurements on objects in accordance with the required research variables. Quantitative data analysis to obtain a thermal comfort index by Indonesian standards and a natural lighting index using measurement theory according to Indonesian standards [4]–[6].

Table 2. Measuring instruments used in the current research.

Tools	Type	Function
Hot Wire Anemometer	Lutron AM 4234SD	Measure wind speed, temperature, and humidity
Lux Meter	AEMC Instruments CA813	Measuring lighting levels
Laser Distance Meter	KXL-E100	Measuring the dimensions of space

3. Result

3.1. Air movement

Air movement is influenced by the shape and orientation of the opening in each room, the elevation of the room, and the wind speed outside the room. The wind speed itself is influenced by differences in air pressure, location, altitude, and time [7].

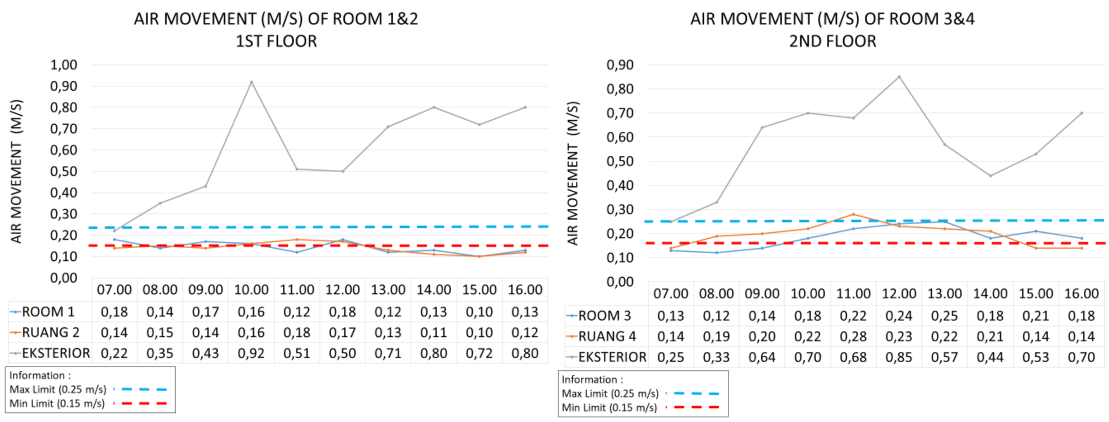


Figure 3. 1st floor and 2nd floor air movement chart.

To maintain comfortable conditions, the air velocity is between 0.25 m/s to 0.15 m/s [6]. At the measurement point with a height of 1m from the floor, the air velocity in rooms 1 and 2 on the 1st floor tends to be under the comfortable category. On the other hand, in rooms 3 and 4 on the 2nd floor, air movement is categorized as comfortable. Air movement is affected by the shape and orientation of the opening, the elevation of the room, and the speed of the wind outside. Wind speed itself is influenced by differences in air pressure, location, altitude, and time [7]. This condition creates air movement in the 2nd floor classroom which tends to be higher than the 1st floor classroom. This is because the openings on the 2nd floor tend not to be blocked by plants or other buildings so that outside air can enter the classroom efficiently.

3.2. Air humidity

For tropical areas, it is suitable for rooms with a dense number of people such as classrooms, the relative humidity is still allowed to range between 55-60% [6]. From the results of field measurements, the humidity is very high in the morning and tends to decrease until 14.00 WIB but rises again until 16.00 WIB. Figure 4 shows that all selected rooms on the 1st and 2nd floors do not meet the comfortable humidity standards for classrooms.

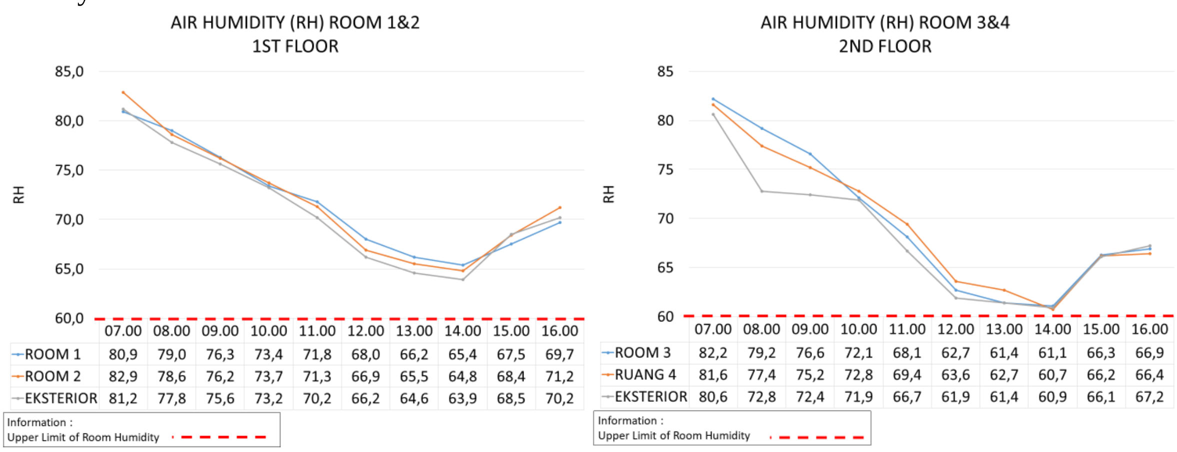
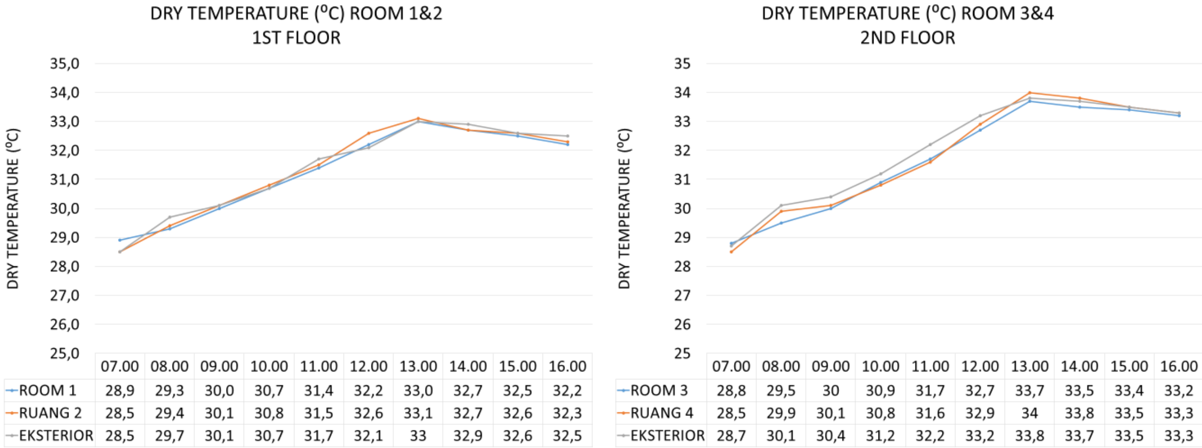


Figure 4. 1st floor and 2nd floor air humidity chart.

Dry temperature is inversely proportional to air humidity. Figure 4 explains that the air humidity in the morning is higher than the humidity in the afternoon because the water vapour content in the air in the morning is higher than in the afternoon. This condition occurs because of the low heat of solar radiation and dry temperatures in the morning [7]. The dry temperature on the 2nd floor tends to be higher than on the 1st floor. This is caused by several factors, namely the angle of incidence of sunlight, altitude, wind direction, ocean currents, clouds, and duration of irradiation [7].

3.3. *Dry temperature*

In determining thermal comfort, one of the influencing factors is dry temperature. In measuring the dry temperature in the selected classroom, there is a slight difference in dry temperature on the 1st floor and 2nd floor room as shown in Figure 5. The temperature in the room increases due to the heat of solar radiation entering the room, thus affecting the temperature in the room.



	07.00	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
ROOM 1	28,9	29,3	30,0	30,7	31,4	32,2	33,0	32,7	32,5	32,2
RUANG 2	28,5	29,4	30,1	30,8	31,5	32,6	33,1	32,7	32,6	32,3
EKSTERIOR	28,5	29,7	30,1	30,7	31,7	32,1	33	32,9	32,6	32,5

	07.00	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
ROOM 3	28,8	29,5	30	30,9	31,7	32,7	33,7	33,5	33,4	33,2
RUANG 4	28,5	29,9	30,1	30,8	31,6	32,9	34	33,8	33,5	33,3
EKSTERIOR	28,7	30,1	30,4	31,2	32,2	33,2	33,8	33,7	33,5	33,3

Figure 5. 1st and 2nd floor dry temperature charts.

The direction of solar radiation and protective measures against it greatly affect the entry of heat into the room [7] This condition can be seen from figure 5 where the dry temperature of Rooms 3 and 4 which are on the 2nd floor is higher than that of Rooms 1 and 2 which are on the 1st floor.

3.4. *Natural lighting level*

The level of natural lighting in Room 1 on the 1st floor tends to be higher than in Room 2. This occurs because the opening on Room 1 faces west and east without being blocked by buildings or trees and it's facing the sun path so it receives direct sunlight. Whereas opening in Room 2 faces north to another building and south to a small park, this causes the room to receive very little direct sunlight. Field measurement of Room 3, 2nd floor tends to be stable until 12.00 WIB but then increases drastically until late afternoon. For field measurements in Room 4 on the 2nd floor, the lighting level of the classroom tends to be high in the morning and lower in the afternoon.

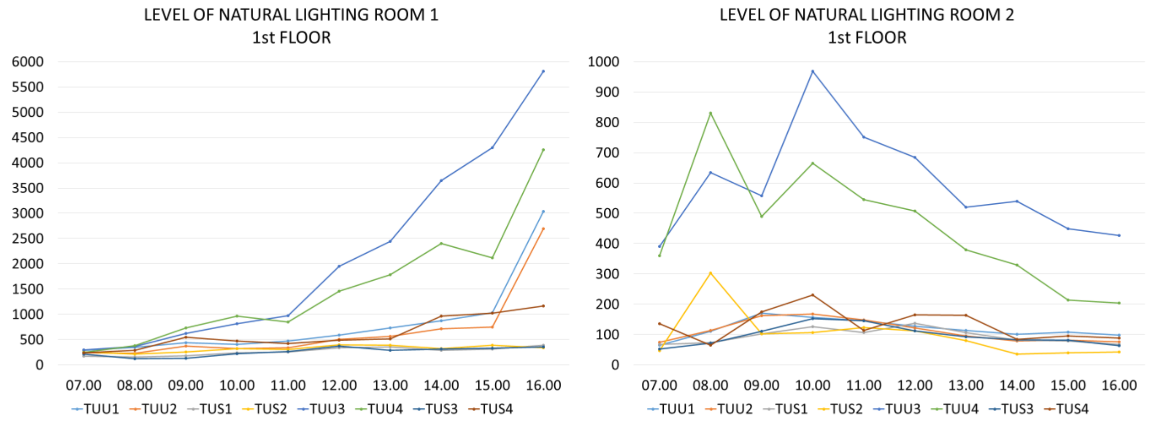


Figure 6. Room 1 and room 2 of natural lighting charts.

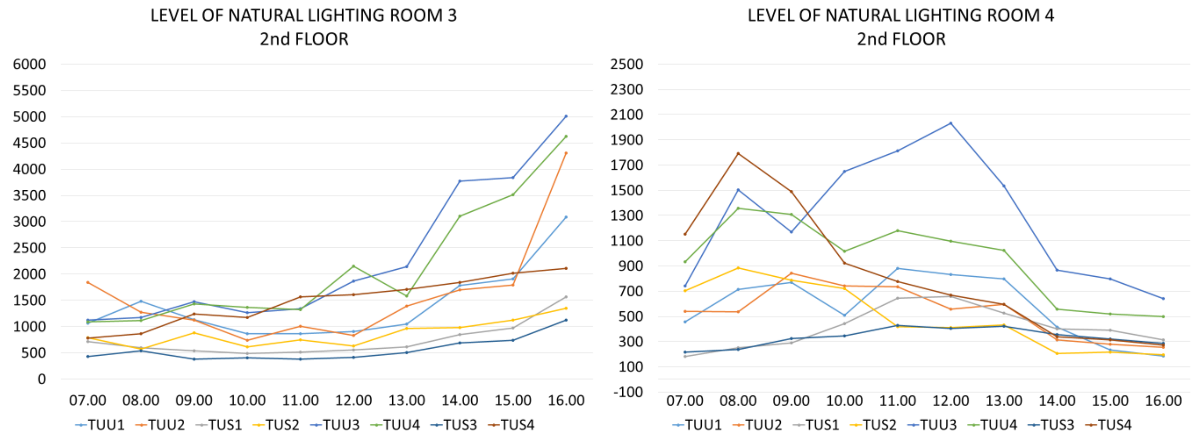


Figure 7. Room 3 and room 4 of natural lighting charts.

Room 1 and Room 3 has the same opening but different altitude, this situation causes some difference in natural lighting level because the opening on Room 3 did not get obstacle from buildings and plants around it, this allows sunlight to enter the room to the maximum. This situation also occurs in Room 2 and Room 4, where Room 4 has a higher level of natural lighting because it lacks obstacle.

4. Discussion

4.1. The effective temperature analysis

Thermal comfort for the tropics can be divided into cool comfortable between 20.50C ~ 22.80C TE, optimal comfort between effective temperature 22.80C ~ 25.80C TE, and warm comfortable between 25.80C ~ 27.10C TE [3]. For a room to be considered comfortable, the room must be included in Mom-Weiseborn category, if it is not included in the category then there needs to be a change in the facade design or additional mechanical assistance.

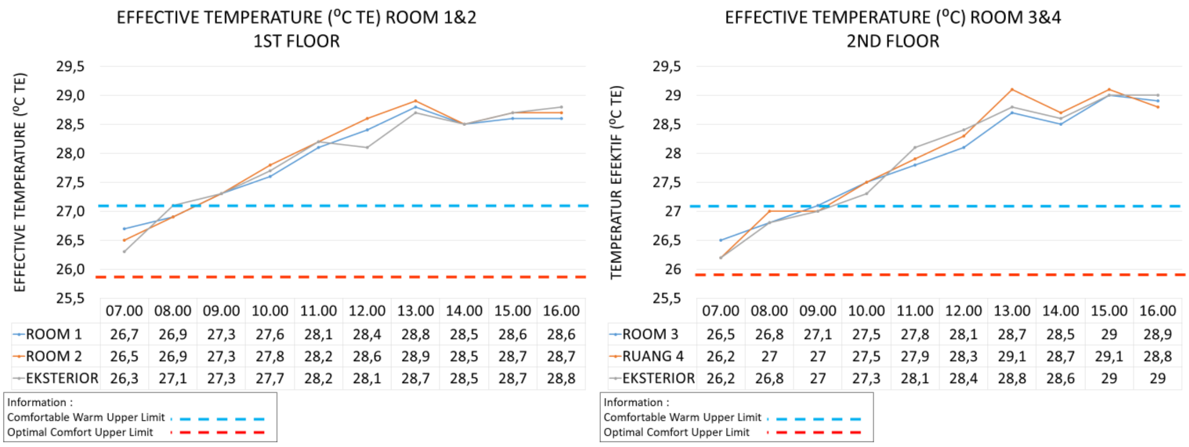
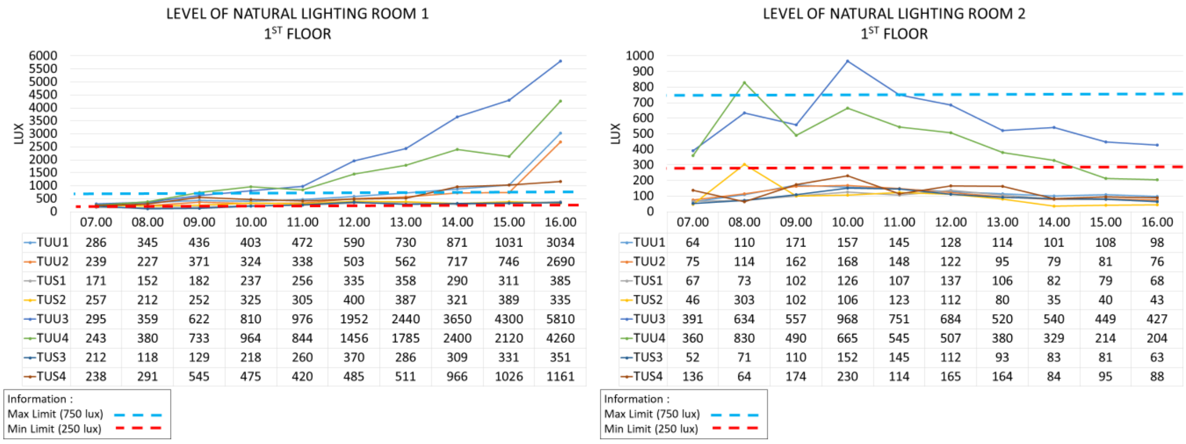


Figure 8. 1st and 2nd floor thermal comfort charts.

From the results of field measurements, it can be seen in figure 8 that only at 07.00 WIB, both at the measuring point on the 1st and 2nd floors, is in the warm comfortable category. Meanwhile, from 08.00 to 16.00 WIB, it is not included in the comfortable category. Due to the condition of the room that only relies on openings in the form of windows as effective temperature controllers in the classroom, the temperature outside the room which tends to be above comfort level, greatly affects the effective temperature in the room. The direction and strength of the wind, also the elevation of the façade opening greatly affect the amount of wind that enters the room. This event can be seen from Room 1 on the 1st floor that has an average effective temperature slightly higher than Room 3 on the 2nd floor. In room 1, the east side is blocked by plants, and the west side is blocked by a building while both openings in Room 3 are not blocked by buildings or plants. This causes that the wind to enter Room 3 effectively and lower the effective temperature in the room [7].This temperature difference also occurs in Room 2 on the 1st floor which is hotter than Room 4 which is on the 2nd Floor. From the results of this field analysis, it can be concluded that the humidity and dry temperature outside are very influential on the effective temperature in the room especially when using natural ventilation. To increase the thermal comfort of the room, it is necessary to increase air velocity with the help of mechanics such as fans or by applying cross ventilation with changing the design opening of the façade to increase wind for outside to enter effectively, another method including blocking direct sunlight coming into the room to minimize the heat that occurs from solar radiation using solar shading device both fixed such as vertical louver or movable such as a curtain [8,9,10].

4.2. Natural lighting analysis

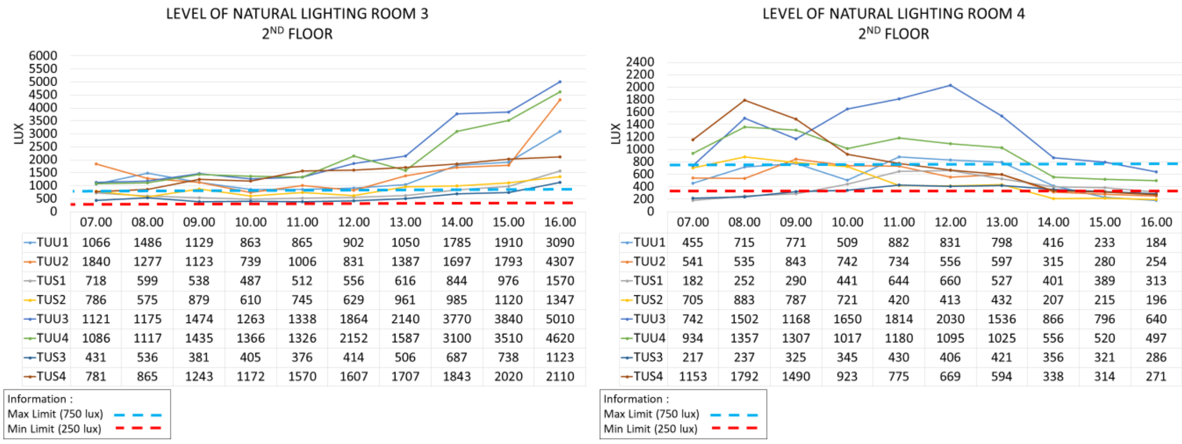
The measuring point in Room 1 on the 1st floor tends to be above the minimum level of classroom lighting, as described in figure 9. This is because the window openings in Room 1 face east and west so that they get good natural lighting from sunlight. However, it can be seen that in the afternoon the lighting level tends to exceed the maximum limit of 750 lux that has been set and it is not ideal for students' activities. This condition happened because the opening on the west side receives direct sunlight without being blocked by buildings and plants. The geometric shape of the window that spans the length of the room with an overhang type canopy also has a significant impact on performance concerning daylight penetration, because it can not prevent the entry of direct sunlight into the room [11]. This can result in glare thereby reducing visual comfort in the classroom. In Room 2 on the 1st floor, the lighting level of the classroom tends to be below standard. This is because the window openings in this room face north and south. On the south side, the opening faces a canopied hallway and a garden full of trees so that it blocks the entry of sunlight into the room. On the north side, the opening in Room 2 on the 1st floor is opposite to a 1-story building opposite. This condition blocked the sunlight from entering the room.



Room 1	07.00	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
TUU1	286	345	436	403	472	590	730	871	1031	3034
TUU2	239	227	371	324	338	503	562	717	746	2690
TUS1	171	152	182	237	256	335	358	290	311	385
TUS2	257	212	252	325	305	400	387	321	389	335
TUU3	295	359	622	810	976	1952	2440	3650	4300	5810
TUU4	243	380	733	964	844	1456	1785	2400	2120	4260
TUS3	212	118	129	218	260	370	286	309	331	351
TUS4	238	291	545	475	420	485	511	966	1026	1161

Room 2	07.00	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
TUU1	64	110	171	157	145	128	114	101	108	98
TUU2	75	114	162	168	148	122	95	79	81	76
TUS1	67	73	102	126	107	137	106	82	79	68
TUS2	46	303	102	106	123	112	80	35	40	43
TUU3	391	634	557	968	751	684	520	540	449	427
TUU4	360	830	490	665	545	507	380	329	214	204
TUS3	52	71	110	152	145	112	93	83	81	63
TUS4	136	64	174	230	114	165	164	84	95	88

Figure 9. Graph of natural lighting levels for room 1 and room 2 on 1st floor.



Room 3	07.00	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
TUU1	1066	1486	1129	863	865	902	1050	1785	1910	3090
TUU2	1840	1277	1123	739	1006	831	1387	1697	1793	4307
TUS1	718	599	538	487	512	556	616	844	976	1570
TUS2	786	575	879	610	745	629	961	985	1120	1347
TUU3	1121	1175	1474	1263	1338	1864	2140	3770	3840	5010
TUU4	1086	1117	1435	1366	1326	2152	1587	3100	3510	4620
TUS3	431	536	381	405	376	414	506	687	738	1123
TUS4	781	865	1243	1172	1570	1607	1707	1843	2020	2110

Room 4	07.00	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00
TUU1	455	715	771	509	882	831	798	416	233	184
TUU2	541	535	843	742	734	556	597	315	280	254
TUS1	182	252	290	441	644	660	527	401	389	313
TUS2	705	883	787	721	420	413	432	207	215	196
TUU3	742	1502	1168	1650	1814	2030	1536	866	796	640
TUU4	934	1357	1307	1017	1180	1095	1025	556	520	497
TUS3	217	237	325	345	430	406	421	356	321	286
TUS4	1153	1792	1490	923	775	669	594	338	314	271

Figure 10. Graph of natural lighting levels for room 3 and room 4 on 2nd floor.

Figure 10 shows the measuring point in Room 3 tends to be stable and all of them are above the minimum limit of 250 lux until 12.00 WIB then increase drastically until late afternoon. This is due to the fact that the window openings in Room 3 face east and west without being blocked by buildings or surrounding trees so that they get natural lighting from sunlight all day long. However, it can be seen that the measuring points TUU1, TUU2, TUU3, and TUU4, figure2, which are located in the middle of the room tend to be far above the maximum limit of 750lux that has been set. At this point, it even tends to be very high and can cause glare thereby reducing visual comfort in the classroom. Windows that are not optimally protected by shading devices barely meet the acceptance criteria and thus require additional control devices such as vertical louver canopy or curtains [12]. Room 1 on the 1st floor and Room 3 on the 2nd floor have the same direction of openings but the level of natural lighting in Room 3 on the 2nd floor tends to be higher than Room 1 on the 1st floor. This is because the eastern opening of Room 1 faces the hallway and garden so that the morning sun tends to be blocked by trees.

Infield measurements Room 4, the lighting level of the classroom tends to be high in the morning and down in the afternoon. The lighting level, in general, has exceeded the minimum limit of 250 lux, this is because the window openings facing north and south are not blocked by buildings or trees so that the room can receive sunlight well. With the condition of openings facing north and south that I not obstructed, the lighting level tends to be within the 250-750 lux range so that the level of visual comfort is better than Room 2 on the 1st floor which has the same direction of opening. Meanwhile, for field measurements in Room 2 on the 1st floor, the natural lighting level of the classroom tends to be below standard [4]. On the south side, the opening faces a canopied hallway and a garden full of trees so that it blocks the entry of sunlight into the room. To assist in increasing visual comfort, Room 2 needs to be assisted with artificial lights or redesigned by using larger windows. Even though it helps increase the level of natural luminance, direct sunlight should always be avoided because it brings heat into the building that can reduce the thermal comfort in the classroom [10]. The amount of illumination in each zone based on the required light level needs to be controlled to improve occupant visual comfort and also reduce lighting energy consumption. Natural lighting strategies must be able to reduce and control the level of solar radiation, especially from side and top lighting, to overcome the problem of heat distribution by providing shading and adjusting the size and location of windows to get indirect sunlight and also prevent exposure from east or west. In the building area facing East-West, new shading devices should be applied to reduce solar radiation such as egg crate and vertical louver [13].

5. Conclusions

Based on the discussion above, it can be concluded that with the current opening and facade design, all selected classrooms do not fit the comfortable criteria according to the Mom-Wiesebron standard. Different designs are needed in the form of larger openings with cross ventilation models, different canopy designs from existing conditions, and mechanical assistance to help maximize air movement. In addition, with the current situation, the selected classrooms did not meet the criteria of visual comfort according to Indonesia National Standard with east-west openings tend to experience glare while openings with a south-north direction are less than optimal in receiving natural lighting. In redesigning the facade, it is necessary to design according to the need to let natural light enter the room but also protect it from solar radiation heat so visual and thermal comfort can be achieved.

6. References

[1] Olgyay V 1963 *Design With Climate* (Princeton: Princeton University Press)
[2] Mangunwijaya Y 1997 *Pengantar Fisika Bangunan* (Jakarta: Djambatan)
[3] Soegijanto 1998 *Bangunan di Indonesia dengan Iklim Tropis Lembab Ditinjau dari Aspek Fisika Bangunan* (Jakarta: Departemen Pendidikan dan Kebudayaan)
[4] Standar Nasional Indonesia 2000 Konservasi energi pada sistem pencahayaan *SNI 03-6197-2000* p 17
[5] Standar Nasional Indonesia 2001 Tata cara perancangan sistem pencahayaan alami pada bangunan gedung *SNI 03-2396-2001*
[6] Standar Nasional Indonesia 2001 Tata cara perancangan sistem ventilasi dan pengkondisian udara pada bangunan gedung *SNI 03-6572-2001* pp 1–55
[7] Lippsmeier G 1994 *Bangunan Tropis* (Jakarta: Erlangga)
[8] Ching F D K 1997 *Arsitektur Bentuk, Ruang, dan Susunannya* (Jakarta: Erlangga)
[9] Reza F and Kojima S 2020 Thermal comfort investigation based design considerations for the tropical studio type classroom *Int. J. Sustain. Dev. Plan.* vol 15 no 8 pp 1179–1185
[10] Szoklay S V 1980 *Environmental Science Hand Book for Architect and Builders* (London: The Construction Press Lancaster)
[11] Ochoa C E, Aries M B C, Loenen E J van and Hensen J L M 2012 Considerations on design optimization criteria for windows providing low energy consumption and high visual comfort *Appl. Energy* vol 95 pp 238–245
[12] Teitelbaum E *et al* 2020 Membrane-assisted radiant cooling for expanding thermal comfort zones globally without air conditioning *Proc. Natl. Acad. Sci. U. S. A.* vol 117 no 35 pp 21162–21169
[13] Egan M D 1975 *Concept in Thermal Comfort* (Engelwood Cliffs: New Jersey: Prentice Hall Inc)

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