Redesigning space layout by considering thermal comfort and prevention of COVID-19 transmission in campus building

Wenny Arminda*, Widi Dwi Satria, Maqbul Kamaruddin, M. Shoful Ulum
Department of Architecture, Institut Teknologi Sumatera, 35365 Lampung Selatan, Indonesia

*Email: wenny.arminda@ar.itera.ac.id

Abstract. Lecture building is one of the important facilities in supporting the success of the teaching and learning process. The lecture room should be thermally comfortable and has a low risk of disease transmission. In adapting to the Covid-19 pandemic, attention to prevent disease transmission is necessary to the safety of students and lecturers while staying on campus. This study aims to propose a new concept design related to the arrangement of indoor layouts that minimize the crowds and reducing indoor air temperatures due to exposure to solar radiation on the east-west side of the building. The research was conducted by observing human movement patterns and measuring indoor air temperature and surface façade temperature adjacent to the outside environment. The results obtained that the average indoor air temperature was in the range between 28.8 - 33.2 °C, with a surface temperature on the east-west side, reaching 39.1 °C. The new design proposed the concept of one-way access by separating vertical and horizontal circulation, additional corridors, and rearranging the layout of lecture rooms to distinguish in-out access to minimize contact physical contact between building users.

1. Introduction
Building in the tropics region received a large amount of solar radiation through the building envelopes and penetrating through windows, hence, increasing indoor air temperature. The building envelope materials absorb solar radiation, keep the heat and transfer the warmth into the building [1]. Excessive solar radiation affects the indoor thermal environment in two ways, i.e. through direct radiation and absorption by building materials and also through penetration from aperture [2]. The high indoor air temperature of the buildings leads to the utilization of air conditioning systems. However, during the current Covid-19 pandemic, the use of air conditioning systems is considered a risk in disease transmission. The “Coronavirus disease 2019” (COVID-19) pandemic is caused by the emerging infectious agent termed as “Severe Acute Respiratory Coronavirus type 2” (SARS-CoV-2) [3]. A recent review of SARS studies applied a snowball strategy to investigate airborne transmission through air conditioning systems and reported that the spread of viral particles through air conditioning systems was suspected and supported by computer simulation [3].

During the Covid-19 pandemic, many countries worldwide have declared a so-called “social distance” of about 1.5m, 2m or 6ft (values depend on the country) to be kept between individuals [4] to anticipate the spread of the disease, where this must also be applied during the new normal period [5]. All sectors feel the impact of the Covid-19 virus, one of which is the education sector. Currently,
Indonesian education has to manage all activities according to applicable regulations regarding applying health protocols to overcome and prevent the spread of the Covid-19. Institut Teknologi Sumatera (ITERA) is one of the universities in Indonesia that follows the regulation from the government regarding the implementation of health protocols on campus.

Currently, the educational system of Indonesia implements online learning where this system requires students to interact online to minimize physical contact [6]. However, during the post-pandemic period, arranging several places in the campus environment is necessary, especially the lecture hall. The Covid-19 pandemic situation requires a lecture room design that can adapt to the needs of health protocols to break the chain of virus spread [7]. Since the covid-19 is a virus variant that can spread through the air, hence it is necessary to pay attention to air circulation and suitable ventilation so that the air quality in the room remains healthy [8]. Based on all the existing issues, currently, ITERA needs to make adjustments regarding the design of the space in the lecture building so that all building users can feel safe and comfortable during the new normal period.

This study aimed to evaluate the existing condition of the lecture building in terms of thermal condition and user movement in the building. This study will propose recommendations regarding an optimal spatial arrangement in lecture buildings in increasing thermal comfort and the same time, preventing disease transmission of Covid-19.

2. Method
This research is qualitative research which was conducted on a case study, an educational building located in Lampung, Indonesia. The first step of this study was the initial observation of the building, to have a direct experience regarding the real condition of the case study. The observation was conducted with direct visitation to the building, construction drawing to see the zoning area and movement pattern and field measurement to investigate the indoor air temperature in the lecture hall and the inner surface temperature of the envelope (glazing) which directly receives solar radiation under actual hot and humid climate condition.

2.1 Case study
2.1.1 Site description
The case study of this research is a building located in the Institut Teknologi Sumatera (ITERA), South Lampung, Indonesia (5°21'36.3"S and 105°18'55.5"E) as shown in Figure 1a. Since located in the hot and humid tropical climate region, this building receives large solar radiation with long periods of sunny days throughout the years. The average annual temperature in this area is around 27 °C [9].

![Figure 1. Location of the case study (a), Façade of lecture building (b).](image)

2.1.2 Building Structure
This lecture building has three floors above the ground and one level of semi-basement. The L-shaped form makes this building has two orientations, the east-west oriented part of the building is mostly used for lecture halls, while the north-south oriented part is used for offices, meeting rooms and library. Each of the rooms is divided by removable non-permanent walls. The entire side of the room facing
out is made of the metal-framed single clear-glazing window with a 100% window-to-wall ratio (WWR), only a few parts of the window can be opened (Figure 2). The clear glass is 6 mm thick with a U-value of 6.0 W/m²K [10]. Some of the windows are covered with the glass coating film, but some of the coating films have been cracked in some places. The surrounding of this building is grass-covered, there is no building or vegetation which can be used as solar shading around this building. Most of the rooms have a split air-conditioning system placed on the glazing area.

2.2 Measurement
The indoor air temperature of each room in this building was taken using a handle wind meter WeatherHawk WindMate (WM-300), while the surface temperature was measured using a thermal imaging camera FLIR C2. The measurement was taken for a one-hour interval from 8.00 am to 5.00 pm (working hours) on 16-18 April 2021, which categorized one of the months with the highest annual average temperatures [9]. Figure 3 shows the solar path on the testing day. The elongated plane of the glass-dominated structure is directly exposed to the sun. The surface area facing west in the simulation is 1,511.35 m², with the sun rising at an altitude of 56.41° and azimuth of -63.85° on 18 April 2021. Nevertheless, the test days were randomly chosen, given that global warming and the current climate change had raised global temperatures and intense heat waves. The data was recorded manually and analyzed using descriptive methods by explaining existing conditions through supporting graphics and pictures.

3. Results And Discussions

3.1 Thermal condition
The lecture building which has an east-west orientation with a wide clear glazing facade without any sun shading makes this building receives a lot of solar exposure, causing problems in terms of the high
air temperature which leads to thermal discomfort in the lecture room, especially during the day. Even though some of the windows have glass coating film, the field measurement and observation found that it was not effective in inhibiting the penetration of sunlight into the room. Moreover, the effectiveness of the coating film on the glass window has decreased over time. Figure 4a shows the condition of the glazing window with the damaged coating film, while Figure 4b shows the window still needs to be covered with paper even though the coating film is still in good condition.

![Figure 4. Indoor condition of lecture room.](image)

The result of the air temperature measurement shows that the average air temperature of the lecture rooms was ranging from around 28.8 °C at 8 am to 33.2 °C at the apex point at 2 pm and decrease to around 30.1°C at 5 pm, but still above the standard of thermal comfort temperature in the tropics, which is in the ranges between 27.1°C to 29.3°C [11]. The high indoor air temperature is caused by direct exposure to solar radiation, which penetrates through the glass envelope especially on the east-west sides. Meanwhile, the air temperature in the corridor of this building is lower because there are openings at the two farthest ends (north-south wing) that allow the wind to flow in. Figure 5 illustrated the surface temperature measurement of the glass window on April 2021 at 2 pm. The red marked areas illustrated the hot condition of the lecture room, while the yellow marked area is the only corridor provided.
Figure 5. Existing building layout (a), Façade surface temperature measurement at apex point 2pm (b).

From the figure, it can be seen that the surface temperature of the glass window was higher than 30 °C. Rooms A located in the east wing received a surface temperature of 33.3 °C, lower than room B (35.4 °C) and C (39.1 °C) which are located in the west wing. This is rational considering at 2 pm, the sun is in a position that is more to the west. From the data taken, it can also be seen that even though the room B and C are next to each other and both are on the west side, respectively, the facade temperature of room C is much higher due to the window glass coating film is no longer functioning optimally. Building designs that do not have shading on parts that get maximum sun exposure will impact the increasing room temperature [12]. During the day, the room temperature will be higher and decreasing comfortable of occupants [13], meanwhile, the classrooms are required to provide a sense of comfort to the users. Comfort, in this case, emphasizes a cleanroom condition and has a low room temperature [14].

The air conditioning system installed in the window area was not capable to reduce the indoor temperature. Even though the air conditioning system is sufficient in reducing indoor air temperature, it needs to be noticed that the airborne transmission through air conditioning systems was suspected to spread contagious agents such as the virus [3]-[15]-[16]. In this outbreak, droplet transmission was prompted by air-conditioned ventilation. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has acknowledged the potential for aerosol transmission of SARS-CoV-2 and states that facilities of all types should follow, as a minimum, the latest published standards and guidelines and good engineering practice [17].

To reduce exposure and risk of COVID-19 disease, Blocken et al., [4] suggested improving the indoor air quality (IAQ) and indoor air environments by providing ventilation systems, especially displacement ventilation in all indoor environments. In displacement ventilation, the outside air is usually supplied at low speed from diffusers near floor level and is extracted above the occupied zone, near or on the ceiling.

3.2 Indoor circulation path

The lecture building is a double-loaded corridor type where this type of corridor is commonly found in office buildings or hotels. This type of corridor requires its users to access the space in the building through one path, which if the conditions are crowded, will cause a density of activity in the corridor [18], while crowd density plays a major factor in the higher risk of spreading disease [19]. The yellow marked area is the corridor, the only way connected the north and south of the building (see Figure 5a). During the present day, it is quite risky to use this method of movement pattern considering the current
pandemic situation because there will be direct contact and less dynamic air circulation. Therefore, it is necessary to regulate the movement pattern of building users in the corridor.

The lecture building has two vertical accesses to each floor located at the north and south wing of the building. Before the pandemic, building users were free to choose from any direction, whether using stairs or elevator. After the pandemic, it is necessary to manage the human movement pattern (vertical and horizontal) to minimize contact and pass each other. The occupant must be directed regarding which area can be used to go up or down.

3.3 Design Concept

Based on the analysis conducted both from the thermal discomfort point of view and the Covid-19 spread prevention, several concepts are proposed which can be applied to respond to all issues in the lecture building. The main concept is redesigning the layout of this lecture building by adding a one-meter wide corridor on both sides of the building adjoining to the outside environment facing east-west. The width of the corridor is following fire safety standards in buildings. The addition of the corridor on the east-west side is expected to reduce the air temperature in the lecture hall because sunlight does not penetrate directly into the room. The newly corridor area aims to increase the circulation path for users and act as a barrier between the classroom area and the building surface. Moving the layout position is possible because the existing lecture rooms are divided by removable non-permanent partition walls. Moreover, the corridors on both sides can circulate air from the open sections on both north-south sides, also creating air circulation through corridors.

Figure 6 shows 3D visualization of the new layout of the lecture building. The new classrooms layout are designed using non-permanent partition walls. The walls on the elongated side of the building are equipped with louvre windows. On the wall adjacent to the middle corridor, the louvre window is placed in the lower area near the floor, while on the wall adjacent to the outer corridor (towards the facade), the louvre window is placed at the top near the ceiling. The louvre window can be opened and acts as cross ventilation for natural ventilation. And when an air conditioning system is needed, the louvre windows can be closed easily. The vents located at the bottom of the wall adjacent to the middle corridor is related to consideration of the existing conditions, where the middle aisle have a higher air pressure from the open sides at both ends of the building. This pressure difference is expected to leave clean air in the lower zone while the contaminated air is in the upper zone.

![Figure 6](image_url)

**Figure 6.** New layout design and 3D visualization, (a) corridor between façade and classroom (a), layout of the room in the lecture building (b), air flow from the cross ventilations
To prevent disease transmission, this concept providing one-way circulation, which possible for managing human movement to not pass each other and reduce crowds. Managing the circulation inside the building is possible because the building already has separated vertical transportation systems. The stairs are located at the north-south wing, respectively, while a lift is placed near the staircase on the north wing. Figure 7 illustrated the proposed circulation concept of lecture building. The stair and lift located on the east wing serve as the access to go up (green marked area), while area marked in blue is planned to be a special access point for users who want to go down from the top floor. The doors are placed diagonally to divide people who enter and leave the room so as not to pass each other. For this circulation pattern to be applied and easy to understand, it will be marked at every point in the building.

![Figure 7. Circulation concept](image)

4. Conclusions
This study was objected to investigate the existing condition of the lecture building located in ITERA. From the field observation and measurement of indoor air temperature, it was found that most of the lecture rooms located on the east-west wings are a bit higher than the standard. Hence, to make a better quality of the learning process, this study proposed a new concept design of the space layout. The redesigned layout of the space in the lecture building was created with consideration on thermal comfort and prevention of disease transmission of Covid-19 by implementing social distancing. Additional corridor designed to separate the room from the east-west envelope to reduce solar radiation. The concept also creating a one-way circulation path arrangement as a method of adapting to the new normal after the covid-19 pandemic.

Considerations are made to provide harmony between the entire campus academic community and their environment. Physical restrictions applied in the lecture building area which paying more attention to health and hygiene factors will become mandatory to support the health and safety of all users in it. It is hoped that this new design recommendations can guide ITERA and other universities with similar building types when re-implementing lectures on their respective campuses.

The future study will be conducted to investigate the effectiveness of the new design concept on reducing indoor air temperature and air circulation using Computational Fluid Dynamic (CFD) software simulation.
Acknowledgement
The authors gratefully acknowledge the Institut Teknologi Sumatera (ITERA) and Sustainable Infrastructure Research & Innovation Centre for providing financial support to complete this research through HIBAH PENELITIAN ITERA 2021 Ref. No. B/499/IT9.C/PT.01.03/2021.

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