THE PREDICTED PERFORMANCE OF NATURAL VENTILATION STRATEGIES IN ISLAMIC BOARDING SCHOOL DESIGN IN MAGELANG

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ABSTRAK

Isu penting dalam menyediakan kualitas udara dalam ruangan yang nyaman bertentangan dengan penggunaan energi untuk pendinginan mekanis di wilayah tropis seperti Indonesia. Ventilasi alami dianggap sebagai potensi untuk menyediakan kenyamanan melalui perubahan udara di dalam dan di luar ruangan. Ventilasi alami menjadi strategi untuk mencapai ketahanan bangunan terhadap perubahan iklim karena tidak memerlukan konsumsi energi. Oleh karena itu, penelitian ini bertujuan untuk membenarkan desain ventilasi alami di Rumah Tahfidz bagi masyarakat berpenghasilan rendah di Magelang menggunakan simulasi keadaan tetap. Hasil penelitian menunjukkan bahwa di antara tiga strategi ventilasi yang disimulasikan dalam penelitian ini, dapat disimpulkan bahwa stack effect diprediksi akan menghasilkan aliran udara yang lebih tinggi yang menghasilkan prediksi kenyamanan adaptif yang nyaman.

Kata kunci : ventilasi alami, tropis, resiliensi bangunan, pendinginan, udara segar

ABSTRACT

The importance issue in providing comfortable indoor air quality conflicts with the use of energy for mechanical cooling in tropics region such as Indonesia. Natural ventilation is seen as a potential to provide comfort through the change of air within the inside and outside of the space. Natural ventilation becomes a strategy to achieve building resilience towards climate change because it requires no energy consumption. Therefore, this research aims to justify the design of natural ventilation of low-income Islamic Boarding School in Magelang using steady state simulation. The results indicated that among three ventilation strategies simulated in this study, it can be concluded that stack effect is predicted to produce higher air flow rate which results to comfortable predicted observation on adaptive comfort.

Keywords : natural ventilation, tropics, building resilience, cooling, fresh air

1. INTRODUCTION

One of the key issue to provide suitable indoor air quality is the process of replacing stale indoor air by fresh outdoor air, which is named ventilation (Chenari, Dias Carrilho, and Gameiro Da Silva 2016). Naturally ventilated buildings can provide a major role in reducing the risk of climate change due to the low energy consumption and produced CO_2 emission compared to mechanically-ventilated building (Lomas and Ji 2009). Many parts of Southeast Asia, including Indonesia, have been reported experiencing high temperature at the end of 2016 (Imada et al. 2018). Several studies concluded that heat waves have become more frequent over the global land area because of human-induced global warming (Christidis and Stott 2014; Jones, Stott, and Christidis 2008; Shiogama et al. 2014). This condition becomes worse in the tropical region, such as Indonesia, because it has high temperature and humidity levels and with the effect of climate change it is highly likely to become higher (Guo et al. 2018; Pramitasari, Harjanto, and Iqbal 2020). This condition can lead to the increasing exposure to heat stress conditions in household and heatwave-related mortality (Guo et al. 2018). A climate model has calculated that the tropical region, which has warmed by 0.7-0.80C over the las century, is predicted to have an inclining of temperature by 1-2^{0}C by 2050 and 1-4^{0}C by 2100 (James Cook University 2014).

Tropic regions, such as Indonesia, experience high solar altitudes and seasonal rainfalls (Jamei et al. 2020). People who live in this area must cope with the combination of high temperatures and high humidity (Balling and

Brazel 1987; Chow and Roth 2006; Saaroni et al. 2000). The combination of heat stress and high humidity causes discomfort for human and can lead to the increasing morbidity and mortality (Fischer, Oleson, and Lawrence 2012). Additionally, heat stress is strongly correlated with the increasing CO2 concretations therefore the tropics experience the greates increasing number of high-heat-stress nights (Fischer et al. 2012).

One of the most critical challenges that the building industry needs to deal in the coming decades is avoiding excessive temperaures induced by overheating (Gupta, Barnfield, and Gregg 2017; Kjellstrom, Holmer, and Lemke 2009). The need for resilient building design and construction to anticipate climate change and disruptions caused by weather extremes, increasing carbon emissions and depletion of resources is highly crucial (Shady 2018). Therefore, resilient cooling solutions is needed to keep comfort in building despite extreme weather events due to climate change (Attia et al. 2022) and reducing the fuel intensive mechanical cooling to slow climate change (IEA 2018). The use of AC needs to be reduced because it is predicted that GHG (Greenhouse Gas) emissions from building AC based on 2018 levels stand at around 210-460 gigatonees of carbon dioxide equivalent over the next four decades (IEA 2020).

Resilient cooling is defined as the use of low-energy and low-carbon cooling solutions to strengthen the ability of individuals and community as a whole to prevent and withstand the thermal and other impacts of climate change in global and local scale, specifically concerning the increasing outdoor temperature and frequency and severity of heat waves (Burman, Kimpian, and Mumovic 2014). It was claimed that during the design phases, naturally-ventilated building takes a higher complication than mechanically ventilated building because of different principles of natural ventilation that needs to be taken into account (Kleiven 2003). Therefore, this paper aims to justify the design of natural ventilation of low-income Islamic Boarding School in Magelang using steady state simulation.

This study concerns the condition of the proposed Islamic boarding school which is designed for low-income children. Due to limited funding and resources the design requires the ability to use natural ventilation as the first strategy to deal with thermal condition inside the room to cope with the inability of purchasing mechanical cooling. Hence, simulation is used as methodology of this research to investigate the configuration during the design proses to measure the predicted performance of the natural ventilation without using mechanical ventilation. The limitation of this study is the ability of the tools selected which can only predict one specific room. Therefore, it could not give the holistic finding of natural ventilation for the whole design. The main contribution of this study is to inform the practitioners how the natural ventilation works in regards of air flow rate to determine the next step which affect the overall design of the building.

2. LITERATURE REVIEW

Natural ventilation works under the principle of the air motion as a result of different temperature and pressure between indoor and outdoor environment (Chenari et al. 2016). Natural ventilation can provide significant energy saving by using wind driven or buoyancy driven forces (Chenari et al. 2016). A study to review the performance of various ventilation methods was conducted by Cao et al. (2014) which pointed out that the effectiveness of the ventilation depends on the purpose of the system such as air distribution, air exchange rate, pollutant removal, heat removal and exposure (Cao et al. 2014). The purpose of ventilation for a space with outdoor fresh air serves the following (Awbi 2004):

- to provide oxygen for human respiration,
- to dilute contaminated gasess to achieve short-term exposure limits to odours, vapours and harmful chemical compounds,
- to control the aerosols inside the building by utilising filtered lower aerosol concentration from outdoor air,
- to control indoor humidity because normally outside has lower moisture content,
- to promote comfort and healthy environment for the occupants through properly distributed air.

2.1. Principle of Natural Ventilation

As natural ventilation is the result of exchanging proses of air between indoor and outdoor environment without using mechanical systems, there are two natural driving forces for natural ventilation, mainly based on buoyancy or wind (Chenari et al. 2016). When the density difference between indoor and outdoor air occurs as a consequence of temperature differences, the force of the natural ventilation is based on buoyancy (Chenari et al. 2016). Meanwhile the wind driven ventilation is the result of pressure differences in the building facades that can be inward or outward depending on the opening position and location (Chenari et al. 2016).

Researchers became interested in flows driven by air temperature differences due to problems with interior heat gains. These temperature disparities lead to buoyancy forces that either create a turbulent plume, mixing the air within the space, or a displacement flow where cooler outside air falls to the floor while pushing warm air up and out through upper openings in the façade (Chenari et al. 2016). An experimental study had been concluded that in buoyancy driven a well-defined stratified flow of air is established and become the predominant feature in flows driven by temperature differences where no outdoor wind exists (Heiselberg, Svidt, and Nielsen 2001). In situations where wind and buoyancy act together, the incident wind can potentially enhance ventilation rates by creating a pressure difference between windward and leeward openings (Hunt and Linden 2001). However, when wind and buoyancy forces oppose each other, this increase in ventilation rates is not always observed (Hunt and Linden 2001). The domination of temperature difference (buoyancy effect) or wind speed in natural ventilation process relies upon the ratio between forces and wind direction (Larsen and Heiselberg 2008).

2.2. Type of Natural Ventilation

There are three main types of natural ventilation such as, single-sided, cross and stack (Chenari et al. 2016). Figure 1 illustrated the three main types of natural ventilation. Single-sided ventilation occurs when the location of the opening is only on one side of the ventilated space façade resulting in a lower ventilation rate and less airflow penetration compared to other types of natural ventilation (Chenari et al. 2016). The efficiency of single-sided ventilation with buoyancy driven can be increased by exploring the transient features of the initial flow rather than prolong the opening window period (Heiselberg and Perino 2010). When the windows are open, the air temperature quickly drops until it stabilizes at a quasi-steady state, typically representing the average between indoor and outdoor temperatures (Heiselberg and Perino 2010). The floor level experiences the highest air velocities, indicating that the primary risk of discomfort from cold drafts occurs at this level (Heiselberg and Perino 2010). Heiselberg and Perino (2010) concluded that the optimum utilisation of buoyancy-driven ventilation windows should be in a relative short opening time and high opening frequencies.

A rule of thumb is used to determine the effectiveness of cross ventilation. The rule suggests that the building length (L) should be less than five times of the ceiling height (H) (Chenari et al. 2016). The reason behind the rule of thumb is because of the smaller pressure difference of windward and leeward facades and the internal friction (Chu and Chiang 2014). They also highlighted that the significant increasing performance of cross ventilation depends on the location of the inlet and outlet. Cross ventilation does not always outperform single-sided ventilation which depends on the outdoor temperature (Gratia, Bruyère, and De Herde 2004). Lastly, stack ventilation occurs when the airflows come through openings located on different facades and escape through a high level outlet such as chimney (Zhai, Song, and Wang 2011).

Building orientation, which contributes to the heat absorbtion from the sun, and winward or leeward orientation are the relevant issues in designing natural ventilation (Fordham 2000). However, some experimental studies have found means to optimise or increase the air flow rate in natural ventilation. Creating different openings height with greater vertical size can increase the airflow rate and the penetration length (Gratia et al. 2004). A higher location of the inlet air supply has been reported providing a better thermal comfort (Wildeboer and Fitzner 2002).

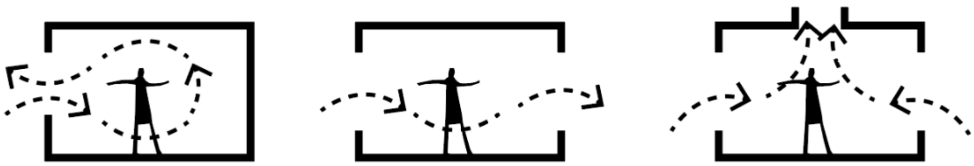

Figure. 1
Type of natural ventilation
Source: Chenari et al., 2016

3. RESEARCH METHODS

The methodology of this study is simulation which uses quantitative data to generate findings. The design proposal is simplified and simulated in an open source online natural ventilation tool named *Optivent 2.1*. The tool is selected due to the stages of the design, which was in the preliminary process, to determine the size of the opening for the proposed design. Although the tool can only predict the performance of one specific room and not connected into other room, this tool help to investigate the effect of buoyancy and wind on each natural ventilation proposed by the design. This is beneficial to expect the worst-case scenario for the designer in deciding the upcoming formal exploration. Additionally, the meteorological data is acquired from *Meteoblu*e to determine the time of simulated condition.

Figure 2 and Figure 3 illustrates the design proposal of the Islamic boarding school. There are three rooms that was investigated to find the air flow rate and predicted adaptive comfort which is bedroom (Room 1), bedroom (Room 2) and multipurpose room (Room 3). Each bedroom is designed to fit for six students who sleep and do their activity on the floor. Meanwhile, the multipurpose room is used by 12 students and 3 teachers for learning Quran, doing social activities and eating.

This study focuses on three types of natural ventilation including cross ventilation in Room 1, single-sided ventilation in Room 2 and stack effect in Room 3 (see Figure 4). The simulation calculated the predicted air flow rate in two scenarios: buoyancy driven and buoyancy + wind driven. Due to the nature of steady state simulation, two critical days were selected to determine the performance of the selected rooms: the hottest day (October) and the coldest day (February). The selection is based on the analysis of monthly temperature profile in Magelang in 2022 derived from Meteoblue. It determines the assumption for the simulation as the following:

- Latitude: 7 S
- Hottest month: October with the temperature of 29^0C and wind speed of 4.5 mph
- Coldest month: February with the temperature of 27.5^0C wind speed of 6 mph
- Simulation time: 12.00 pm

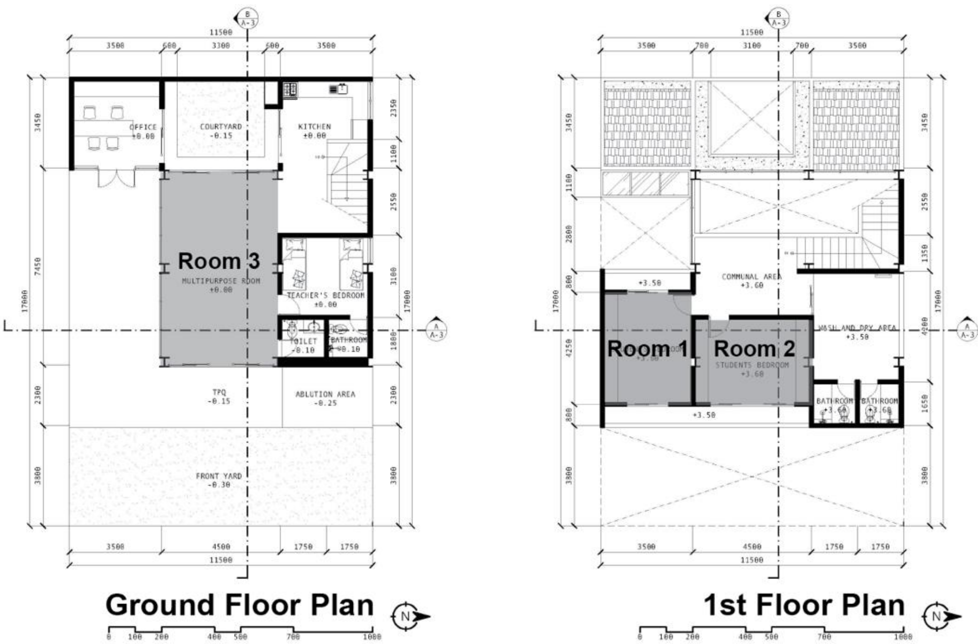

Figure. 2
Plans of the Islamic boarding school design
Source: Author

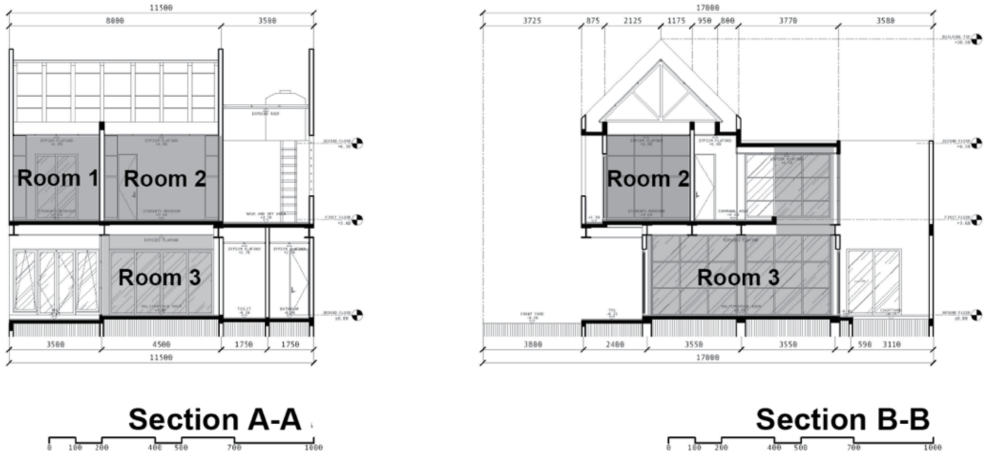

Figure. 3
Sections of the Islamic boarding school design
Source: Author

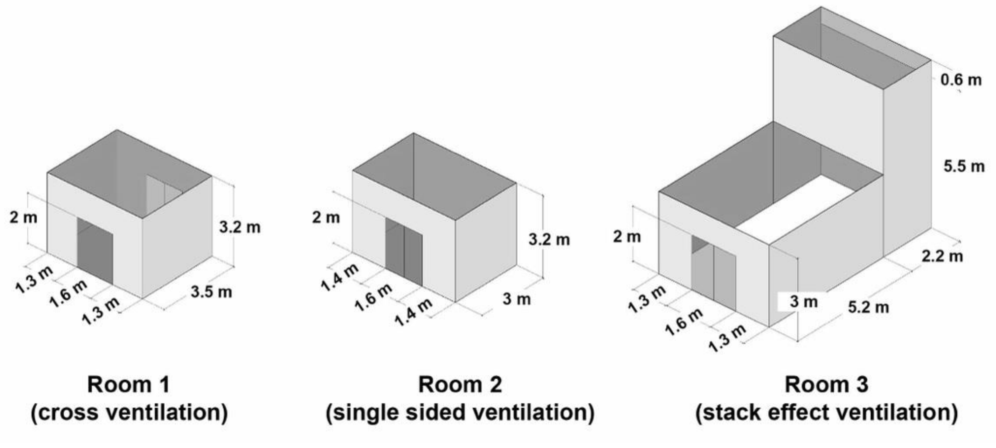

Figure. 4
Simplified models for simulation
Source: Author

4. RESULTS AND DISCUSSION

As shown in Figure 5 left side, in the hottest day scenario when the temperature is 29^{0}C, Room 1 can surpass the requirement for fresh air and cooling in the combination of buoyancy and wind driven mode with the cross ventilation. In this scenario, Room 1 requires minimum air flow rate of 0.06m^3/s for fresh air and 0.73 m^3/s for cooling. The buoyancy and wind driven generate 2.61 m^3/s air flow rate in Room 1 in the hottest day scenario and 3.47 m^3/s in the coldest day scenario. However, Figure 5 left side illustrates that with buoyancy driven only can only fulfil the requirement for fresh air and fail to reach the minimum requirement for cooling. Although Room 1 utilises cross ventilation during hottest and coldest day, the buoyancy of the room can produce 0.24 m^3/s air flow rate which is below the cooling requirement (0.73 m^3/s).

Simulation result for Room 2 (Figure 5 middle), which situated to utilise single sided ventilation, demonstrate the same pattern with cross ventilation in Room 1 result. As illustrated in Figure 5 middle the combination of buoyancy and wind driven outperform the buoyancy driven only. With single sided ventilation in Room 2, the room configuration requires 0.06 m^3/s air flow for fresh air and 0.57 m^3/s for cooling. The simulation predicted that with the buoyancy and wind driven, Room 2 can achieve 0.59 m^3/s in the hottest day and 0.77 m^3/s in the coldest day. Meanwhile, Room 2 can only achieve 0,14 m^3/s in the hottest day and 0.14 m^3/s in the coldest day with buoyancy driven which is although it surpasses the minimum requirement of fresh air (0.06 m^3/s), it can not satisfy the requirement for cooling (0.57 m^3/s).

A consistent pattern also can be depicted from the simulation result of Room 3 (Figure 5 right side) which adopted the stack effect ventilation. The room configuration in Room 3 requires 0.14 m^3/s of air flow for fresh air and 1.63 m^3/s of air flow for cooling. Figure 5 right side demonstrates that the buoyancy and wind driven simulation result exceeds the requirement for fresh air and cooling in the hottest day with 3.21 m^3/s of air flow rate and in the coldest day with 4.22 m^3/s of air flow rate whereas it only produces 0.83 m^3/s of air flow with buoyancy driven. The buoyancy driven can not fulfil the requirement for cooling (1.63 m^3/s) although it provides fresh air by surpassing the minimum required fresh air which is 0.14 m^3/s.

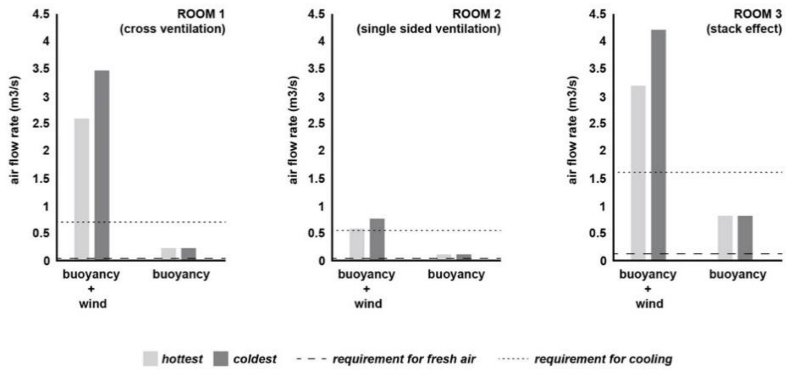

Figure. 5
Air flow rate of simulated natural ventilation
Source: Author

Comparing three strategies of natural ventilation, the simulation results indicated that with the same inlet and orientation of natural ventilation, stack effect produces the highest air flow rate and single sided ventilation. It also resonates with the predicted observation on the adaptive comfort solution in Figure 6. In the hottest day the buoyancy driven of Room 1 (cross ventilation) is too warm in 90% acceptability limits and Room 2 (single sided ventilation) is too warm both on the 80% and 90% acceptability limits. Although the buoyancy driven air flow rates in Room 3 (stack effect) can not satisfy the minimum requirement for cooling either in the hottest and coldest day, stack effect in Room 3 is predicted to maintain comfortable condition on both 80% and 90% acceptability limits.

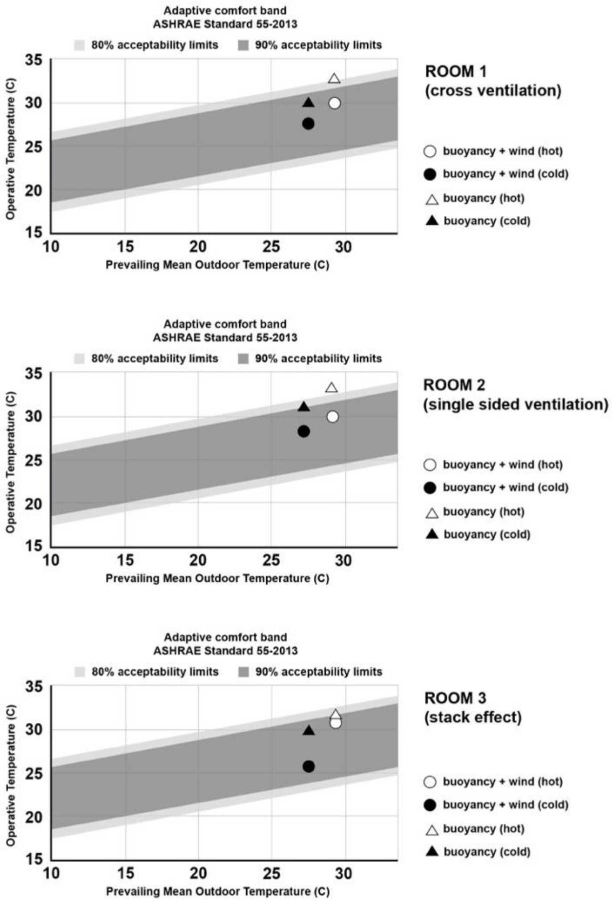

Figure. 6
Predicted operative temperature on the adaptive comfort band
Source: Author

The air flow rate data and the general predicted operative temperature on the adaptive comfort band inform that wind has a significant role in each natural ventilation strategy. It shows that relying on buoyancy driven can not help all the natural ventilation to be able to provide cooling for the room. Therefore, the designer needs to consider providing mechanical fan to substitute the absence of wind to help the cooling process of the room. This is the most affordable solution considering the limitation of the building operation. Mechanical fan is expected to be able to generate air movement during the non windy siuation to help the natural ventilation perform better.

5. CONCLUSION

Based on simulation results of three strategies of natural ventilation (cross ventilation, single sided ventilation and stack effect ventilation), it shows that buoyancy driven only can not provide cooling effect either in the hottest day or coldest day when the outdoor temperature is 29^0C and 27^0C respectively. However, the simulation results also inform that the combination of buoyancy and wind can perform better not only to provide fresh air but also as cooling. Among three ventilation strategies simulated in this study, it can be concluded that stack effect is predicted to produce higher air flow rate which results to comfortable predicted observation on adaptive comfort in 80% and 90% acceptability limits for both hottest and coldest day as well as buoyancy-wind driven and buoyancy driven. This result can be used as a guideline to determine the most effective natural ventilation for similar building type or configuration in hot and humid area, such as Indonesia.

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