Study of vertical solar irradiance and local scale climate to assess passive cooling potential in Tangerang of Indonesia

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Abstract. Solar radiation information is very important in green building design, namely for the daylighting, solar heat gain prevention as well for solar energy utilization. This study uses solar radiation data from six pyranometer sensors for measuring the horizontal component (global horizontal irradiance (GHI) and infrared irradiance) and the vertical component (pyranometer sensors to the north, south, east, and west) located in Tangerang, Indonesia. Measurements have been filtered for one year from January 2021 to December 2021. The solar radiation observation is complemented with other measurement of climate elements, such as wind speed and direction, dew point temperature, relative humidity, and air temperature. The diurnal and seasonal patterns of solar irradiance and other climatic elements have been observed using the visualization technique of heat maps. The results show that sensors pointing north experience an increase in solar intensity in May, June, July, and August. Meanwhile, sensors that point to the south experience the increases in solar intensity in November, December, January, and February. The increase in radiation intensity towards the east occurs from 07.00 to 10.00 local time (LT), while the increase in sensor intensity towards the west occurs from 14.00 to 16.00 LT. The results of solar radiation analysis in horizontal and vertical surfaces are combined with other climate elements to create a bio-climatic design guideline suitable for buildings in the hot and humid climate.

1 Introduction

Humans' activities in buildings need comfortable thermal conditions. As a solution when excessive heat in a room leads to uncomfortable conditions, active cooling systems have been used extensively to satisfy the thermal comfort. Meanwhile, the use of active cooling which is sourced from fossil energy had been identified as the major source of global warming and other environmental issues. Since the main source of heat in buildings is solar radiation, the solar heat gain has contributed for almost half of the total cooling load in buildings [1]. Therefore, when a building is exposed to higher solar radiation, it will lead to more cooling demands in the room [2].

The understanding of solar radiation is critical for designing energy-efficient buildings. For instance, the solar radiation data on the building envelope is important in determining the building orientation, façade design, selection of glass material, solar shading, etc. [3]. Moreover, the solar radiation is divided into several components which can be used to assess and design the heat prevention techniques [4]. For example, direct and diffuse radiation data are very important to determine the amount of solar heat gain entering the building [5]. Horizontal solar radiation data can be used to design building elements on horizontal surfaces, such as skylights, roof, etc. Moreover, the solar radiation on vertical surface can be used to design the building's façade for reducing the solar heat gain in order to meet such desirable condition. In addition, the solar radiation is also critical to determine the outdoor micro-climate, which is useful in designing greeneries and public spaces around buildings [6].

Nevertheless, in Indonesia, the solar radiation data and other climate variables are not well utilized in the current green building design guideline. For instance, the existing calculation method for Overall Thermal Transfer Value (OTTV) uses the solar radiation on vertical surface which are generated by mathematical model, not from observation data. The model itself was generated using the weather observation in Singapore [7], which may not suitable in the context of Indonesia cities. Moreover, the Indonesian green building guideline have not

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emphasized the importance of natural ventilation. For example, there is no such guideline to recommend desirable indoor air speed to achieve thermal comfort through natural ventilation although the elevated can increase the acceptability limit in the adaptive thermal comfort (ASHRAE-55). Meanwhile, several recent studies have used passive cooling techniques to cool down the temperature in the room, such as using natural ventilation [8] and night ventilation [9]. Those passive cooling techniques depend strongly on the understanding of the weather data such as outdoor wind speed and direction, for instance.

Indonesia is the fourth-most populous country situated in the tropical zone near the equator. Considering the promising economic growth, rapid urbanization as well as the construction of a new capital city, it is important for Indonesia to design their buildings to be sustainable by taking into account the local climate condition. Meanwhile, the climatic phenomenons ranging from global-, regional- to local-scales [10] affect the climate condition in Indonesia. For instance, the land-sea breeze affects the diurnal cycle [11], the monsoons affect the seasonal cycles [12] and el-nino influences the annual cycles [13], respectively. Therefore, it is important to understand the local climate for proposing a suitable green building guideline.

This research is a preliminary study that aims to investigate the pattern of solar radiation intensity in the daytime as well as the seasonal cycles of solar radiation in two horizontal raditation components and four vertical radiation components, respectively. Local-scale climate assessment was also carried out to see the variability and range of climate on a diurnal and seasonal basis so that the boundaries for determining the boundaries of the thermal comfort zone can be identified. In addition, the assement on the potential of two passive cooling technique methods, namely daytime comfort ventilation and night ventilation, was also carried out.

2 Methodology

The observation data in the Tangerang city of Indonesia with the location coordinates of 6°13'6"S and 106°34'46"E is used as case study. The weather station and station environmental conditions can be seen in Figure 1.

Figure 1. Weather station in Tangerang

Tangerang city experiences the monsoonal climate which has relatively hot temperatures during the day throughout the year and has wind directions that vary seasonally with wind speeds in the weak category.
This study employs historical solar radiation data from horizontal and vertical components, respectively. The horizontal components consist of the global horizontal irradiance (GHI) and infrared irradiance. Meanwhile, vertical components are the north-, south-, west- and east-facing vertical surface irradiances. All components of solar radiation are measured using six pyranometer sensors (Kipp and Zonen CMP21). Meanwhile, other climate elements such as air temperature, surface wind speed, relative humidity, dew point from were also measured using the Automatic Weather Station which has been filtered for one year starting from January 2021 to December 2021. The temporal resolution of irradiation observations is every 10 seconds, while Automatic Weather Station is in one minute interval. In order to deal with the time interval differences, the analysis employed hourly resolution using the averaging method within the one-hour period. The solar radiation data was taken from 05:00 to 19:00 local time (LT). Solar radiation analysis at night-time was not carried out because the irradiance level at is zero. Meanwhile, the other climate variables were investigated using the data observed in both day and night-time (24 hours).

The flow of data processing from this research is first to compare the radiation intensity of the four vertical components, namely north, south, east, and west. The second analyzes the intensity of solar radiation by averaging the month and the same hour so that daytime and seasonal information is obtained for each component. The third is to analyze climate elements including temperature, relative humidity, dew point, and wind speed by averaging the month and the same hour so that diurnal and seasonal information is obtained for each climate element. Furthermore, an analysis of the direction frequency and wind speed in four different sub-seasons is December to February (DJF), March to May (MAM), June to August (JJA), and September to November (SON). The last is to calculate the potential of passive cooling techniques for daytime comfort ventilation and night ventilation. The calculation of the daytime comfort ventilation method is carried out to see the hourly probability starting from 06.00 – 18.00 by assuming the minimum wind speed limit is 2 m/s, so when the wind speed rises above 2 m/s it is considered the potential for the daytime comfort ventilation method. Calculation of the night ventilation method is carried out to see the minimum hourly temperature starting from 19.00 - 06.00 by assuming the minimum temperature limit is 26ºC, so when the minimum temperature drops below 26ºC it is considered the potential for night ventilation. The daytime comfort ventilation and night ventilation methods are carried out every month from January 2021 to December 2021.

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3 Results and discussion

3.1 Global Horizontal and Infrared irradiance analysis

Most of the solar radiation is emitted at visible and infrared wavelengths. Incoming solar radiation is a key factor affecting architectural design because solar radiation causes an increase in temperature inside buildings due to heat transfer [2]. Global horizontal irradiance is the total amount of short wave radiation that reaches the earth by way of the horizontal surface to the surface of the object [14]. Figure 2 shows that global horizontal irradiance measurements have a high intensity throughout the year in Tangerang. On a diurnal basis, the intensity of the sun reaches its maximum at around 11.00 LT to around 14.00 LT. seasonally, the global horizontal irradiance increases in March-April and September-October, which are the equinoxes. The intensity of solar radiation varies as a function of geographic location, calendar days, and hours of day. Therefore, measurements without a scale are needed to compare results, regardless of location, date, and time [15].

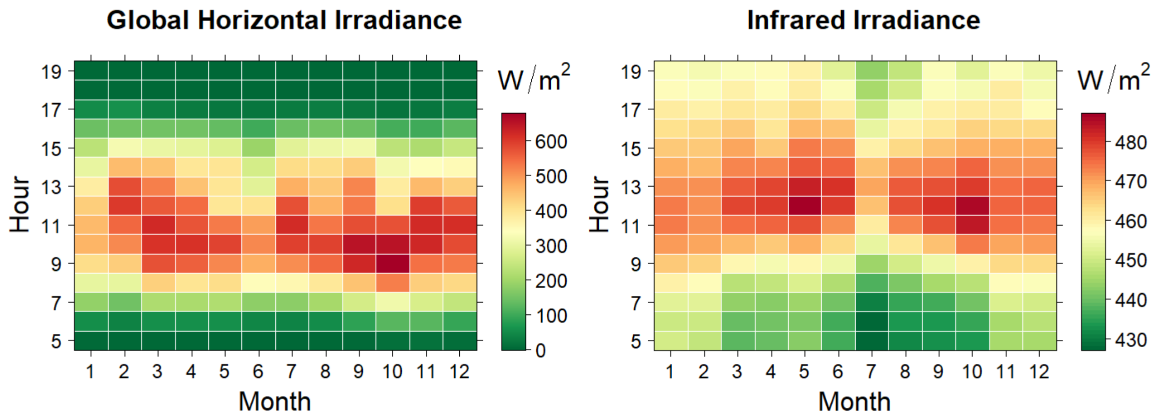

Figure 2. Heatmap for global horizontal irradiance and infrared irradiance

In addition to global horizontal irradiance, the study of infrared irradiance intensity is an important approach to increase the efficiency of solar energy utilization, which has practical scientific value and application significance [16]. Global infrared radiation can be obtained from several existing measurement stations or by building radiation modeling methods [4]. Based on heatmap analysis month by month from 05.00 LT to 19.00 LT, the average hourly infrared irradiance intensity ranges from 396 w/m^2 to 500 w/m^2, the infrared irradiance intensity reaches its maximum value around 12.00 LT. seasonally the lowest infrared intensity occurs in July while the maximum occurs in May and September during 2021 in Tangerang.

3.2 Vertical surface irradiance analysis

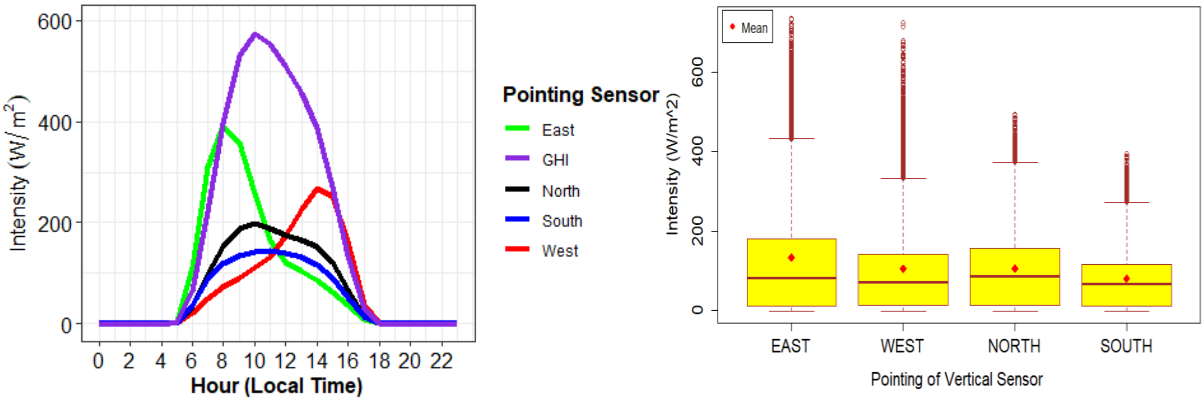

Figure 3. Comparison of the intensity of the four directions of the vertical pyranometer

Solar radiation especially on vertical surfaces from north, south, east, and west is very important for the design of energy efficient buildings and natural lighting schemes. for active solar energy applications such as building-integrated photovoltaics and passive energy-efficient building designs a vertical global component is also required. Due to several things that have been mentioned solar irradiation measurements need to be carried out for the global vertical component [17]. Figure 3 shows the boxplot of the four-directions vertical surface pyranometer comparison from 05.00 LT to 19.00 LT in Tangerang. Based on the four vertical directions, it was found that the vertical radiation from the east direction showed the highest intensity, namely an average of 133.4 w/m^2 and a maximum value of 736.1 w/m^2. the vertical intensity from the west is influenced by local climate conditions, namely the condition of few clouds with clear skies in the morning. for the radiation value from the west direction the average is 104.2 w/m^2 with a maximum value of 725.3 w/m^2 this is smaller than when compared to the vertical from the east due to more cloud cover occurring during the day to night [18]. Vertical irradiance from the south direction is the lowest with a maximum value of 393.6 w/m^2 and an average of 79.0 w/m^2 compared to the north direction, the lowest vertical surface irradiance intensity from the south is due to the geographical location of Tangerang which is south of the equator [15]. for solar radiation from the north direction the maximum value is 493.4 w/m^2 with a mean value of 105.5 w/m^2.

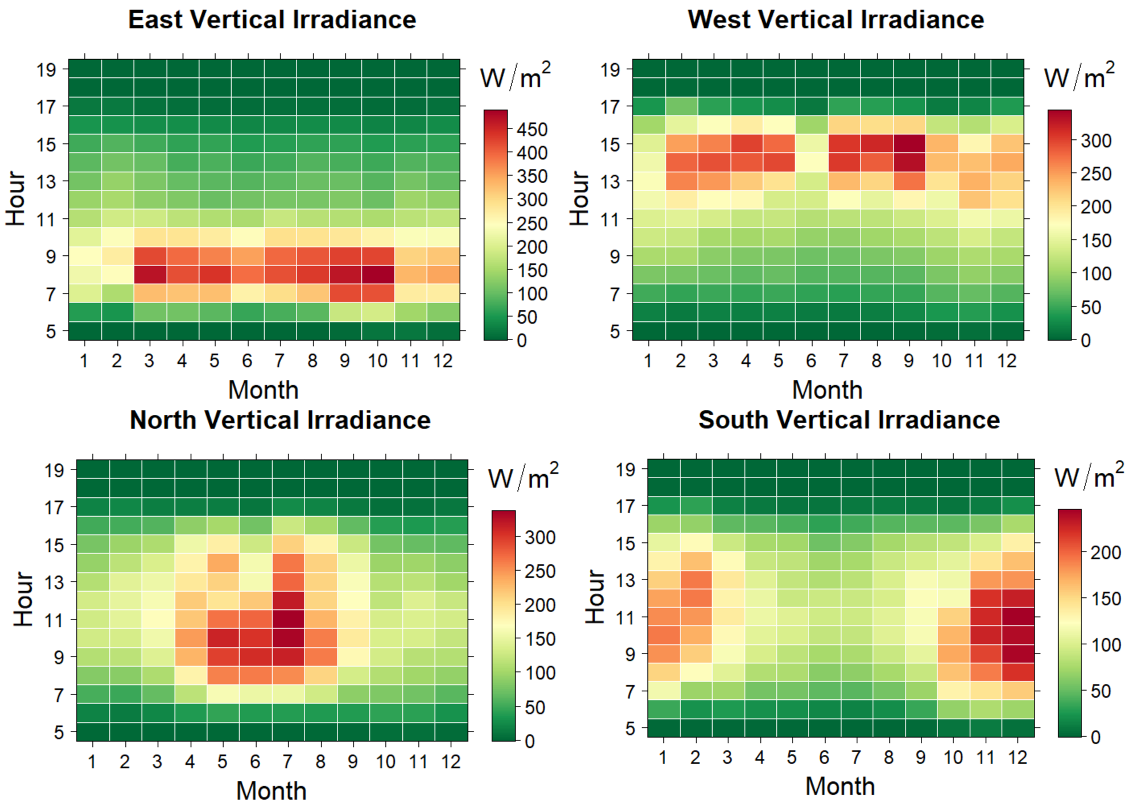

Figure 4. Heatmap comparison of four directions of vertical surface irradiance

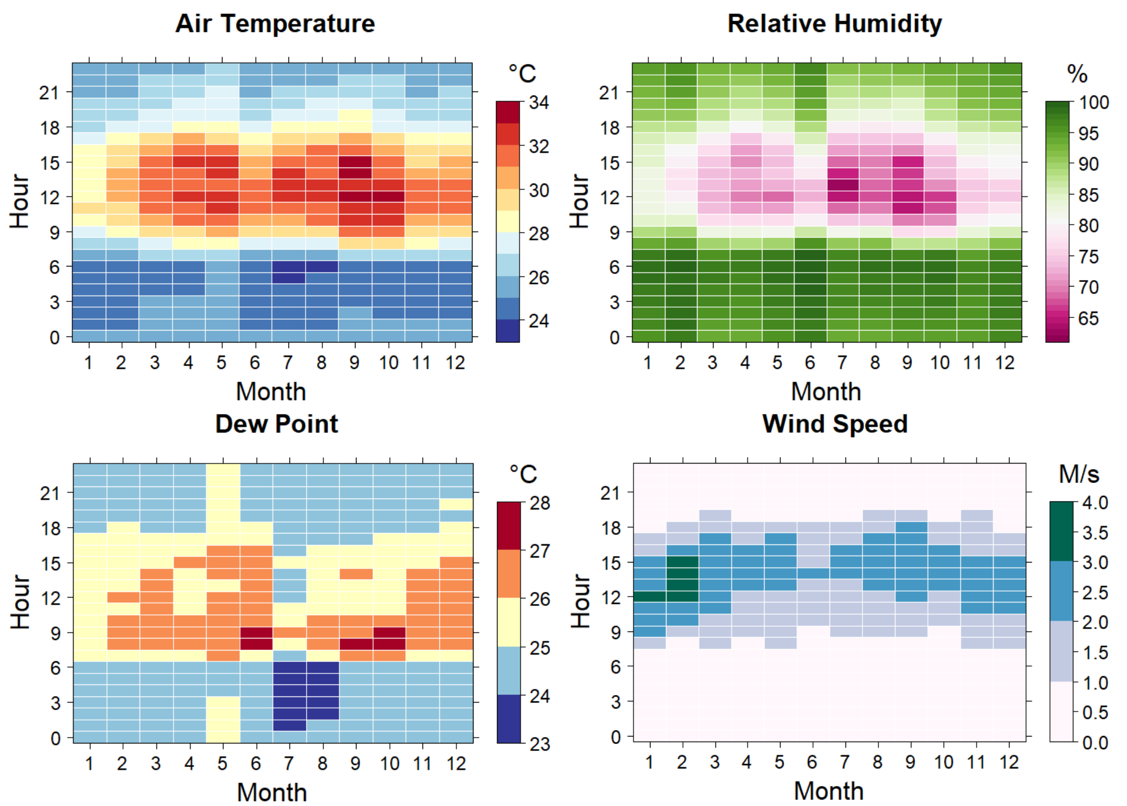

Figure 5. Heatmap of diurnal and seasonal local climate scale averages

Figure 4 shows a comparison of the daytime and seasonal patterns of vertical surface irradiance from the four directions, namely north, south, east, and west. The vertical irradiance pattern from the north and south shows that the annual movement of the sun from the equator/equinox to 23.5 north latitude and 23.5 south latitude has affected the intensity in both vertical directions [19]. The pyranometer sensor towards the north recorded an increase in radiation intensity from March to September. The pyranometer sensor towards the south recorded an increase in radiation intensity from October to March. The vertical irradiance pattern from the east and west shows that the diurnal movement of the sun has affected the intensity in both vertical directions. In general, the eastward pyranometer sensor records an increase in radiation intensity from sunrise around 06.00 LT to around 12.00 LT. while the pyranometer sensor to the west recorded an increase in radiation intensity at around 12.00 LT until sunset at around 18.00 LT. seasonally, there is a decrease in intensity on the east and west sensors from November to February due to the rainy season and the large number of clouds in this region [20]. cloud conditions can affect global horizontal irradiance depending on the reach and position of the clouds relative to the sun [21].

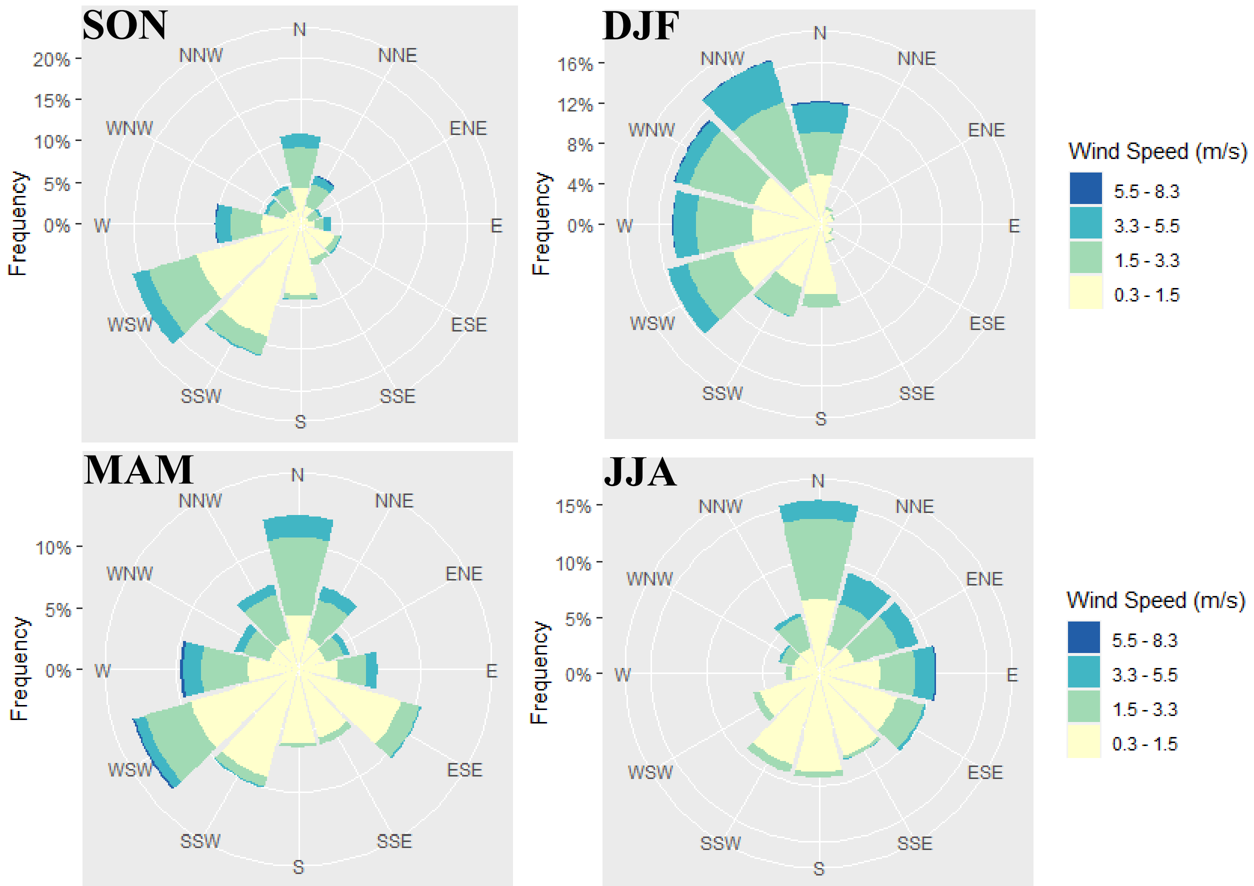

Figure 6. Frequency of wind direction and speed; (SON) Sep-Nov, (DJF) Dec-Feb, (MAM) Mar-May, (JJA) Jul-Aug.

3.3 Analysis of local climate scale

Figure 5 shows that the Tangerang area is a hot area during the day throughout the year with an average maximum of 33.5°C and slightly decreases at night with a minimum average diurnal temperature of 23.7°C. The pattern of the sun's annual movement has affected the pattern of seasonal temperature, this can be seen from the increase in temperature around March and September when at that time the position of the sun is above the equator. Relative humidity conditions decrease during the day and increase at night throughout the year. The seasons of July, August, September, and October are the seasons with the lowest RH conditions. The average minimum RH is 62.6% and the average maximum RH is 99.6% [22]. The dew point can be defined as the temperature below which water droplets start to condense and form dew. Or it is the temperature to which air must be cooled in order to be saturated with water and water vapor. When cooled further, the water vapor condenses on the water. Figure 5 shows that the dew point condition recorded an increase during the day to reach a maximum of 27.3°C and decreased at night to reach a minimum of 23.3°C. in a diurnal pattern, the wind speed increases during the day, ranging from 1 m/s to a maximum average wind speed of 3.5 m/s. the wind speed tends to decrease (calm) at night throughout the year. Seasonally, the highest wind speeds occur in the seasons of December, January, and February [10].

3.4 Sub-seasonal analysis for wind speed and direction

Figure 6 shows the frequency of wind direction and speed analysed on a sub-seasonal basis. Basically, the wind direction and wind speed can change diurnally and seasonally depending on the strength of the influence of climatic phenomena. Based on the climate zone, the city of Tangerang is in the monsoon season zone, which means that in this area there are seasonal changes in wind direction [22]. Based on the wind rose frequency chart, it can be seen that the dominant wind from the Dec-Feb season comes from the west (WSW to N) which indicates that the air mass originates from the Asian continent [13].

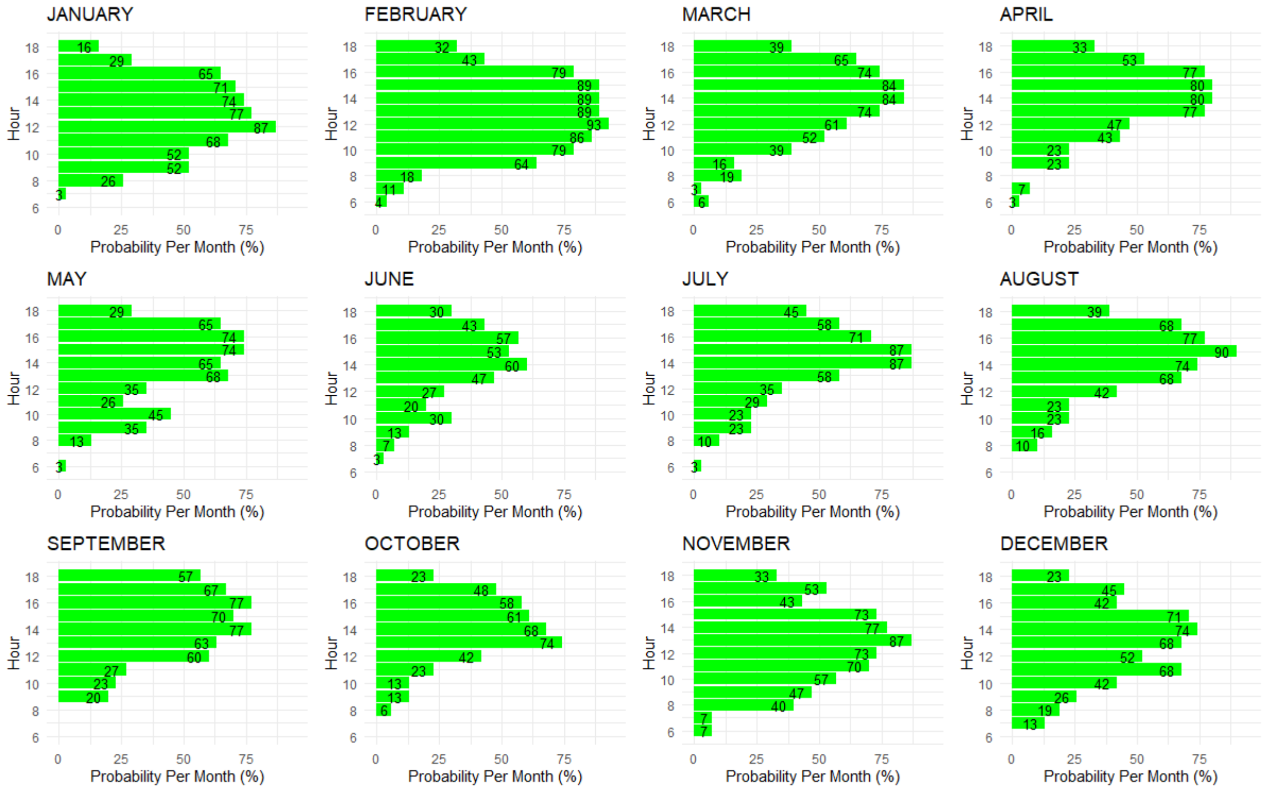

Figure 7. Daytime comfort ventilation potential

While the July-August season the dominant wind comes from the east (N-SSE), which means the wind comes from Australia [23]. The Sep-Nov period is the transition season I, showing the dominant wind comes from WSW which is the wind direction transition period I. The Mar-May period is the II transition season, showing wind directions that vary from SSW to ESE which is the wind direction transition period II. Based on information from wind speed and direction analysis to maximize air flow into the building, the window design should be made to face east, north, and west.

3.5 Daytime comfort ventilation potential

Daytime comfort ventilation is affected by wind speed conditions during the day [24]. This study assumes that the wind speed is 2 m/s as a limitation for airflow to enter and be ventilated through the window, so that when the wind speed reaches above 2 m/s there is a potential that can flow through the window as comfort ventilation. Figure 7 shows an hourly graph of the probability of daytime comfort ventilation starting at 06.00 LT to 18.00 LT. The monthly chart shows that all months during the day there is potential and suitable for comfort ventilation techniques. If viewed every hour during daytime, there is a potential for a slow rise from 08.00 LT and the potential with the highest probability occurs between 12.00 LT to 16.00 LT. After 16.00 LT the potential for daytime comfort ventilation decreases slowly.

3.6 Night ventilation potential

Night cool storage potential is affected by the minimum temperature at night [25]. Figure 8 shows a graph of the hourly cool storage potential starting at 19.00 until 06.00 LT with temperature (T) set at 26°C. This study assumes that a temperature of 26°C as a limit for building structures can store cold capacity, so when the temperature drops below 26°C is the potential for cold that can be stored in building structures [9]. Based on the monthly analysis, it can be seen that throughout the year (every month from January to December) there is potential for cool storage with relatively slightly different values every hour. The monthly graph shows an increase in potential starting at 19.00 LT and reaching its peak at 06.00 LT.

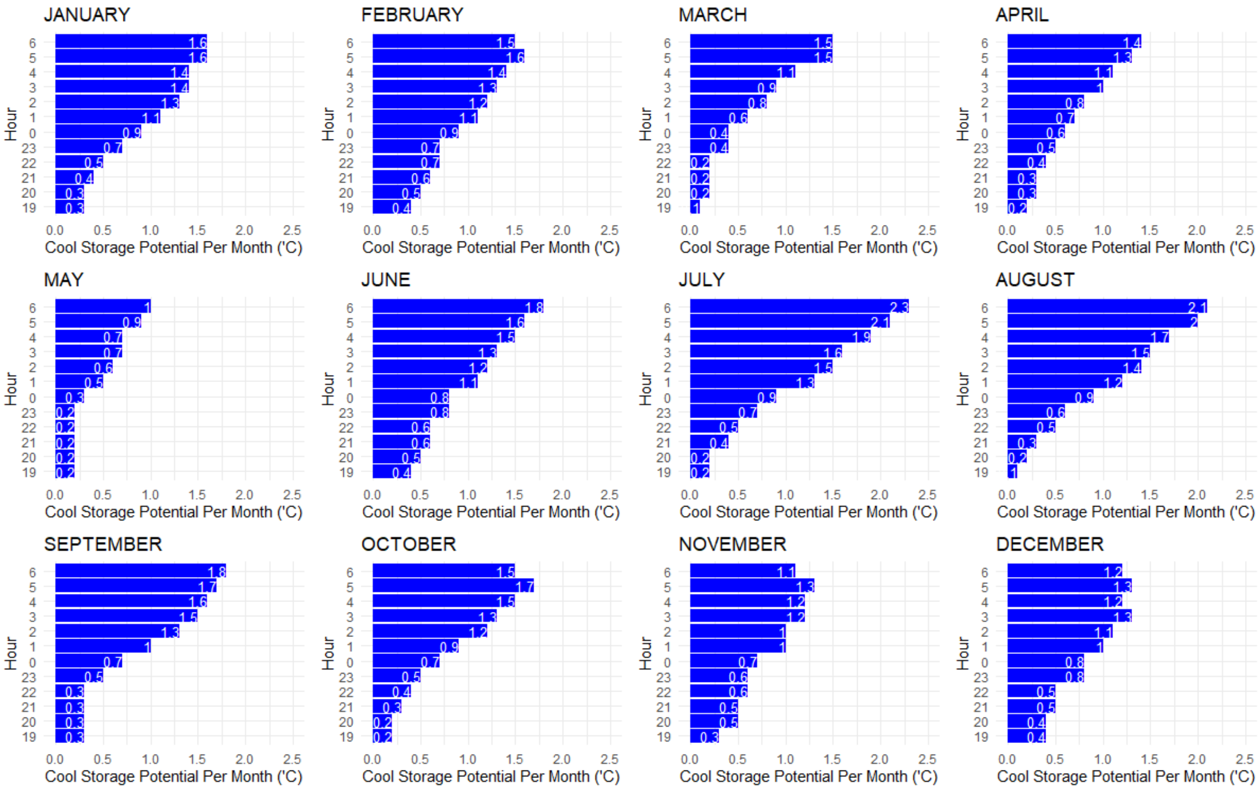

Figure 8. Night ventilation potential

4 Conclusion

Based on an analysis of solar radiation, local scale climate, and passive cooling potential in Tangerang during 2021 several points can be concluded as follows:

The intensity of global horizontal irradiance has a high intensity throughout the year with the maximum diurnal intensity occurring between 12.00 and 13.00 LT. The highest vertical surface irradiance intensity was recorded from a sensor facing east and the lowest intensity from a sensor facing south. The intensity of the vertical surface irradiance has a clear seasonal pattern that follows the diurnal pattern of the sun and the apparent seasonal movement of the sun from the equinoxes to 23.5 latitudes and 23.5 latitudes. The vertical surface irradiance from the south has a maximum increase in intensity during the DJF season, while the vertical surface irradiance from the north has a maximum increase in intensity during the JJA season.

In terms of local scale climate, Tangerang is a monsoonal climate zone with strong seasonal variations in wind direction. namely the Dec-Feb season, the dominant wind comes from the west (WSW to N) which shows the air mass coming from the Asian continent. While the July-August season the dominant wind comes from the east (N-SSE), which means the wind comes from Australia. On a diurnal basis, the wind speed increases during the day and calms down at night. Daily temperature conditions have an average maximum of 33.5°C with a minimum RH of 62.6% during the day, an average minimum temperature of 23.7°C and an average maximum RH of 99.6% at night.

In optimizing the creation of a passive building design, several things need to be considered, namely, daytime comfort ventilation has good potential throughout the year. According to the direction frequency and wind speed, windows will be effective if they face west, north, and east to maximize wind flow into the building through the windows during the day. Night ventilation has good potential when the building structure is set to retain cold when the temperature drops below 26°C.

References

1. D.H.W. Li, J.C. Lam, C.C.S. Lau, A new approach for predicting vertical global solar irradiance, Renew. Energy. **25** (2002)
2. D.S. Lee, J.H. Jo, Application of simple sky and building models for the evaluation of solar irradiance distribution at indoor locations in buildings, Build. Environ. **197** (2021)
3. W.A. Friess, K. Rakhshan, A review of passive envelope measures for improved building energy efficiency in the UAE, Renew. Sustain. Energy Rev. **72** (2017)
4. Q. Mao, L. Luo, Experimental research of solar infrared spectral radiation in Wuhan, China, Infrared Phys. Technol. **125** (2022)
5. D. Tschopp, A.R. Jensen, J. Dragsted, P. Ohnewein, S. Furbo, Measurement and modeling of diffuse irradiance masking on tilted planes for solar engineering applications, Sol. Energy. **231** (2022)
6. Y. Ji, J. Song, P. Shen, A review of studies and modelling of solar radiation on human thermal comfort in outdoor environment, Build. Environ.

214 (2022)
7. I. Paryudi, S. Fenz, A.M. Tjoa, Study on Indonesian Overall Thermal Transfer Value (OTTV) Standard, Int. J. Therm. Environ. Eng. **06** (2013)
8. E.M. Saber, I. Chaer, A. Gillich, B.G. Ekpeti, Review of intelligent control systems for natural ventilation as passive cooling strategy for UK buildings and similar climatic conditions, Energies. **14** (2021)
9. T. Kubota, D.T.H. Chyee, S. Ahmad, The effects of night ventilation technique on indoor thermal environment for residential buildings in hot-humid climate of Malaysia, Energy Build. **41** (2009)
10. M.D. Yamanaka, Physical climatology of Indonesian maritime continent: An outline to comprehend observational studies, Atmos. Res. **178–179** (2016)
11. J.H. Qian, Why precipitation is mostly concentrated over islands in the maritime continent, J. Atmos. Sci. **65** (2008)
12. V. Moron, A.W. Robertson, J.H. Qian, M. Ghil, Weather types across the Maritime Continent: From the diurnal cycle to interannual variations, Front. Environ. Sci. **2** (2015)
13. J.H. Qian, A.W. Robertson, V. Moron, Interactions among ENSO, the Monsoon, and Diurnal Cycle in Rainfall Variability over Java, Indonesia, J. Atmos. Sci. **67** (2010)
14. N.B. Mohamad, A.C. Lai, B.H. Lim, A case study in the tropical region to evaluate univariate imputation methods for solar irradiance data with different weather types, Sustain. Energy Technol. Assessments. **50** (2022)
15. H. Morf, A validation frame for deterministic solar irradiance forecasts, Renew. Energy. **180** (2021)
16. N. Lindsay, Q. Libois, J. Badosa, A. Migan-Dubois, V. Bourdin, Errors in PV power modelling due to the lack of spectral and angular details of solar irradiance inputs, Sol. Energy. **197** (2020)
17. D.H.W. Li, N.T.C. Chau, K.K.W. Wan, Predicting daylight illuminance and solar irradiance on vertical surfaces based on classified standard skies, Energy. **53** (2013)
18. I.D. Gede, A. Pandawana, T. Tanaka, T. Osawa, A.R. As-syakur, M. Sudiana, Characteristics of Diurnal Rainfall Cycle Over Java as seen by the TRMM Precipitation Radar, **3** (2019)
19. S. Luo, H. Li, Y. Mao, C. Yang, Experimental research on a novel sun shading & solar energy collecting coupling device for inpatient building in hot summer and cold winter climate zone in China, Appl. Therm. Eng. **142** (2018)
20. S. Lestari, A. King, C. Vincent, D. Karoly, A. Protat, Seasonal dependence of rainfall extremes in and around Jakarta, Indonesia, Weather Clim. Extrem. **24** (2019)
21. C.A. Gueymard, J.M. Bright, D. Lingfors, A. Habte, M. Sengupta, A posteriori clear-sky identification methods in solar irradiance time series: Review and preliminary validation using sky imagers, Renew. Sustain. Energy Rev. **109** (2019)
22. I.D.G.A. Putra, H. Nimiya, A. Sopaheluwakan, T. Kubota, H.S. Lee, R.P. Pradana, M.N.F. Alfata, R.B. Perdana, D.S. Permana, N.F. Riama, Development of climate zones for passive cooling techniques in the hot and humid climate of Indonesia, Build. Environ. **226** (2022)
23. V. Moron, A.W. Robertson, R. Boer, Spatial coherence and seasonal predictability of monsoon onset over Indonesia, J. Clim. **22** (2009)
24. A.M. Omer, Renewable building energy systems and passive human comfort solutions, Renew. Sustain. Energy Rev. **12** (2008)
25. N. Artmann, H. Manz, P. Heiselberg, Climatic potential for passive cooling of buildings by night-time ventilation in Europe, Appl. Energy. **84** (2007)