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Climate-Responsive Approach in the Vernacular Settlements
(Case Study: Indonesia's Equatorial Rainforest Climate Zone)

A Thesis submitted in the Partial Fulfilment for the Requirement of the Double Degree of Master of Science in Integrated Urbanism and Sustainable Design

by
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(31 July 2022)

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Cheers!
Melvina

Abstract

Climate change is a notorious phenomenon in current civilization, especially in fast-growing development, including Indonesia. Indonesia is inside a tropical equatorial climate zone that mainly has a moderate temperature without extreme climate challenges such as cold winter and hot summer. Indonesia as a developing country has a significant demand for housing both in rural, new urban, and urban areas. The current trend of the residential typology in Indonesia is dominated by single-family detached houses. Modern development influences generic design solutions even in different cultural, environmental, and climate contexts. Meanwhile, a long time ago before the industrial era, past civilizations had survived to build a settlement called “vernacular” that tends to respond to the climate context in the limited architectural knowledge and technology appliances then, it is still sustained until now in Indonesia. It can be assumed that vernacular settlements are a successful sample of a sustainable design invention based on local people’s experience. The objective of the research is to determine the climate-responsive design solution from the vernacular settlement that is practically applicable for modern residential development contextual to Indonesia’s Equatorial Rainforest climate zone. The research methodology conducts through an analytical analysis of statistical weather data to define the climate characteristics of the cases, a thematic analysis to investigate the inventory of climate-responsive solutions in the vernacular settlements, and qualitative-quantitative analysis to evaluate the shared principles among case studies through computational simulation. The expected outcomes of the research are a set of list climate-responsive design parameters for settlement development considering passive design strategies and finding the inventory of climate-responsive design solutions based on practice from the vernacular settlements that are applicable for modern settlement development.

Keywords: Climate-responsive, Vernacular, Settlement, Bioclimatic, Equatorial Climate

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List of Abbreviation

MSL	: Mean Sea Level
PMV	: Predicted Mean Vote
CFD	: Computational Fluid Dynamic
CBE	: Centre for the Built Environment
ERA5	: Fifth generation of ECMWF atmospheric reanalyses

Chapter 1: Introduction

The first chapter will explain the research background considering the prominent study of climate-responsive design in Indonesia's cases of vernacular settlement. Five sub-chapters present the problem statement, research hypothesis, objective, and questions.

1.1 Preface

Climate is a prominent factor that has formed the characteristics of our planet in terms of ecological context and indirectly shaped our socio-culture life. Climate has persuaded people's decisions through body signals such as sweating when in a high temperature or high humidity space, then continuing to take decisions for cooling down the body, such as finding a wind. Furthermore, many studies mentioned that our ancestors dealt with climatology to survive in their specific climate challenges before the science of climatology was invented. They considered climate the environmental element for their lifestyle through crop system, living space, culinary, clothing, Etc. In addition, the relationship between people and climate has been expressed this way. Indigenous people contemplated specific climate challenges through the concept of vernacular settlement for sedentary community groups and shelter for nomadic community groups. F.L.Wright mentioned how indigenous people were responsive to actual needs and fitted into the environment where the folk building was growing or currently called vernacular. In addition, an analytical study of the traditional building provides a holistic understanding of the relationship between culture, climate, and building (Hyde, 1998). The limited technology when vernacular settlements built was indicates how the design solution at the time succeeded without a mechanical system. It leads to a passive design strategy with less energy consumption. Moreover, it is an heir of knowledge from the past. It has an opportunity for the future society to develop a sustainable design in more efficient along with the current invention of technology.

1.2. Problem Statement

Many studies in the world mention that climate change has affected to environmental degradation of our planet due to human civilization. The challenge of energy consumption and climate change risk is troublesome for sustainable development based on energy efficiency. The climate-responsive approach can significantly reduce the energy demand of buildings while still considering modern living needs (Bodach et al., 2014). The study of the climate-responsive practice is an idea to formulate sustainable design solutions for specific climate contexts rather than against the nature of the environmental context.

1.2.1. Climate and Settlement Development

Settlement is a product of human civilization to provide a living space through spatial pattern configuration. Human society is constantly growing, but it should be paid off by at least avoiding and reducing environmental degradation. In nature, people always seek comfortable environments, both indoor and outdoor spaces, to thrive in their life. In the context of this research, the idea of enclaved space, latter will be called a building is to provide a shelter in the way permanently or temporarily with thermal and visual indoor comfort for its occupants. However, the comfort level in a building depends on how the designer adapts to the outdoor climate. Adapting to climate context is understandable as passive action from the human response. Human psychological experiences of climate comfort influence it, which is called thermal comfort. At the same time, the answering response can be identified as the active action of humans to tackle the nature of the climate and manifest it into their enclave space or building. In addition, the impact of climate conditions influenced environmental degradation in outdoor spaces, such as urban heat island phenomena, flooding, Etc. In the modern era, the settlement terms have been associated with residential terminology consisting of housing and supporting tangible infrastructure for people inside the community, such as streets, open spaces, drainage systems, Etc. Meanwhile, our ancestors had the richness of knowledge to survive tackling specific climate contexts in complex ways such as integrating the housing with working space, distance to get water resources, Etc (Motealleh et al., 2018). At the time, native communities built their settlement had been linked to energy efficiency for achieving comfort because of their adaptation to climate and location (Pozas et al. 2016).

The common characteristic of vernacular settlement is built by their community for themself (Wijaya et al., 2021). It would be argued that the vernacular settlement was purely built to answer their needs and not a mass commercial real estate production. Modern settlements or residential areas are built mainly by institutions, either by public or private companies. Many have less interest in the critical parameter of design that should gain sustainability benefits for the environment and community. The modern industrial invention has also influenced construction systems in a generic solution due to time efficiency, while local resources consider ecological context as part of the design decision. Consequently, vernacular settlements are getting to disappear, and the knowledge is slowly forgotten.

1.2.2. Climate-responsive and the manifesto of Indonesia's vernacular settlement

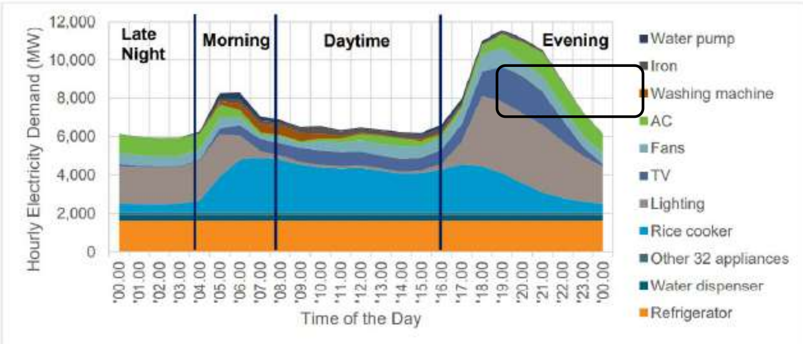
Indonesia is an archipelago country inside a tropical or warm - humid climate region. It has only two seasons per year, either a dry or a wet season. There is no extreme climate challenge compared to other climate zones. The country has hundreds of tribes separated by a natural boundary such as an ocean or river. The diversity of the Indonesian ethnic groups has a wide variety of traditional houses and settlements based on their cultural history, which is a prosperity of research cases (Scefold et al., 2004). However, Indonesian native tribes tended to inherit their knowledge of vernacular construction through storytelling within their groups or inheritance. Predictably, the regeneration of vernacular knowledge in Indonesia has been in a challenging situation. Even though it does not mean to duplicate the past vernacular knowledge into current civilization but at least consider the principle of how vernacular houses and settlements are responsive to climate and environmental context.

A study mentioned that "vernacular architecture is architecture without an architect," but it is oriented to local needs by utilizing the potential of nature and existing context (Rudofsky, 1987). Vernacular settlement is the outcome of the past human civilization process of optimization resources to provide a comfortable local community neighborhood in a local climate using local materials and a known native construction without mechanical which use passive solar measurement to achieve thermal comfort condition (Bodach et al., 2014). Besides that, a study also found that the local climate and geomorphology approach had been implemented into vernacular dwellings to accommodate the comfort needs of the occupants, then the principle of vernacular construction has a lot to inspire contemporary architects and engineers in terms of environmentally responsive design (Philokyprou et al., 2017).

1.2.3. The fundamental climate-responsive approach for residential development in Indonesia

Indonesia is in a fast-growing development because of rapid urbanization as an impact of population growth. The demand for housing is increasing yearly based on the World Bank Group report 2019 found that during five years from 2015 to 2019 has doubled from 0,60 million units to 1,25 million units of housing built. Detached single-family housing type has been favorable, especially for residential development in the satellite city or rural areas. The argument has been supported by data from the Indonesia Ministry of housing and infrastructure that the construction of detached-land single-owner housing is higher than apartment or multi-stories sharing ownership housing types; in 2017, Indonesia had built 519.485 detached-land housing and only 349 multi-stories housing. Moreover, the plan of relocating the new capital city in Borneo Island is targeted to convert around 28.000 Ha for new settlement development in the rural context (BAPPENAS, 2019), which is part of Indonesia's equatorial rainforest climate zone.

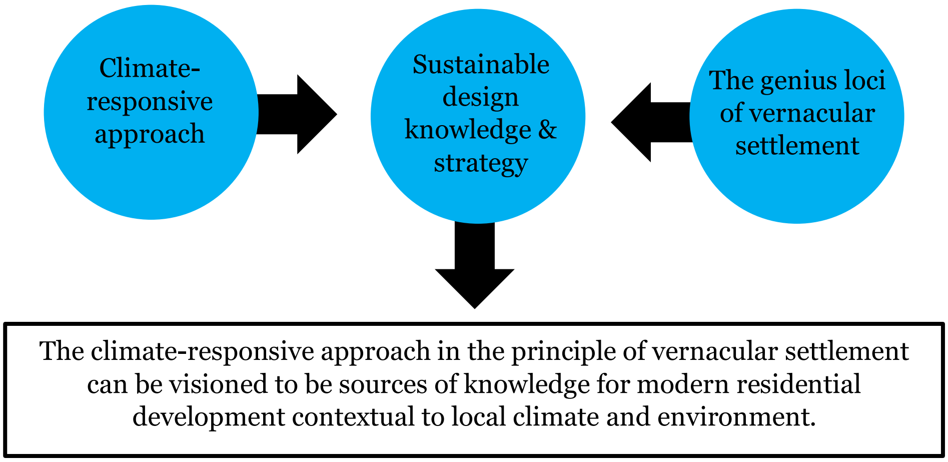
Observing the current residential trend in Indonesia related to electricity consumption, based on CLASP report 2020, the hourly electricity consumption of air conditioning and fan has been in the third position. The peak duration of activating an air conditioning system is during the evening, around 10 hours per day which consumes approximately 8000 MW per hour (CLASP, 2020, Indonesia Residential End-Use Survey).



(Fig 1.1) Hourly electricity consumption trends for the 42 electricity appliances
Source: CLASP, 2020, Indonesia Residential End-Use Survey

Higher energy consumption during night-time is questionable for a region without extreme climates such as cold winter and hot summer, in which theoretically complex heating and cooling system are less important for achieving thermal comfort. It means the opportunity to limit energy consumption for achieving thermal comfort in a household is conceivable through optimization sources of climate such as sunlight, wind, humidity, airspeed, etc. Hence, the master thesis research vision wants to contribute to the realization of sustainable design in the scale of settlement development, especially for the equatorial climate zone where the plan for Indonesian capital city relocation will be in the same climate zone.

1.3 Hypothesis



(Fig.1.2) Research Hypothesis
Source: Author

The research assumes that utilization of a climate-responsive approach has been implemented in vernacular settlement through passive design strategy both indoors and outdoors without neglecting environmental context. Then, the native civilization has provided with practical knowledge-based experience manifested in the vernacular settlement and reflected in different solutions of a small-controlled environment within a natural setting, which is the potential to be adopted for current, and future detached landed residential in Indonesia.

1.4 Objective

The objective of the research is to determine the climate-responsive design solution from the vernacular settlement that is practically applicable for modern residential development contextual to Indonesia's Equatorial Rainforest climate zone. For achieving the research objective, it is prominent to identify the factors that influence passive design solutions for achieving thermal comfort in settlement development, investigate the knowledge of settlement typology adapting to climate context, and evaluate the performance of climate-responsive design strategy. Accordingly, the performance measurement of climate-responsive design findings from the vernacular settlement knowledge is expected to inspire further research to develop more efficient, detailed solutions for enhancing sustainable design practice.

1.5 Research Question

The research questions are presented to guide the development of this thesis research based on the selected approach considering the research problems and objective:

What is the potential climate-responsive design solution in the vernacular settlement that is applicable for modern settlement development contextual to the local climate?

For answering the main research question, three supporting questions are necessary to identify as the foundation of this research.

- What are the climate challenges and characteristics in the equatorial rainforest of Indonesia?
- Are those vernacular settlements designed responsively to climate?
- How do Indonesian tribes' communities respond to the climate context in which the vernacular settlement typologies in the equatorial rainforest region tackle climate challenges?

Chapter 2
Theoretical Framework

The theoretical framework chapter aims to give a general understanding of climate-responsive for achieving thermal comfort and relevant aspect related to sustainable design practice. It will begin with a fundamental understanding of the climate element influencing design decisions, the benefit of climate-responsive implementation for sustainable design practices, and the understanding of indigenous people responding to climate context.

2.1. Definition

The logic of building design is necessary to respond to climate, as well as that the fabric should respond to the laws of statistics. On our topic, the laws of statics can determine by the law of science of thermodynamics. The climate-responsive approach is considered the building form and structure that moderates the climate for human good and well-being (Hyde, 2000). The idea of climate-responsive design is an integral part of the environmental framework to reduce environmental impacts. Emphasizing the principle of climate-responsive design is a process of understanding the climate parameter where the building or design approach is situated. Furthermore, climate-responsive can be determined as a result of both analytical and synthesis skills to maximize the relationship between the site, climate, and requirements (Hyde, 2000). Hence, the climate-responsive approach is a contextual-based design solution based on climate parameters which intercorrelated to human knowledge and behavior to the local climate.

The exploration process of the site opportunity, both in terms of macro and microclimate, is a prominent phase for resulting building forms. The meaning of "forms" is explained, including the building elements and materials associated with the landscaping of the surrounding environment. The role of landscaping can be a feature as an additional climate modifier for the building envelope. Theoretically, the practice of a climate-responsive approach should cover an integrated landscape and building response as a holistic. Its relationship can be seen in settlement configuration, which considers not only a single building but the formation within its landscape.

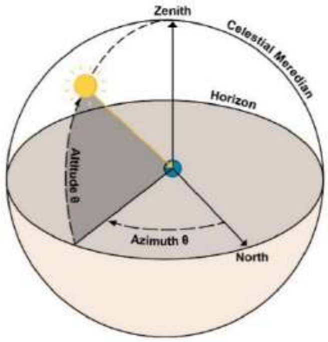
2.2. Climate Elements

Climate is a meteorological pattern to a specific region, influenced by geographical position and the interrelation to nature patterns. Warm climate areas are laid down along the Equator. The seasonal variation has slightly seasonal change and moderate temperatures with dense rainfall throughout the year. The climate context is defined by the patterns of some elements and their variable. The climate elements that are considered directly to influence human comfort and settlement design are solar radiation, longwave radiation, air temperature, wind, humidity, and precipitation (rain or snow).

2.2.1 The Sun

Thermal energy from the sun has penetrated the earth by radiation. The sun is a dominant factor influencing climate (Gut, 1993). The climate parameter as an effect of the earth's orbital to the sun is divided into sun path, solar radiation, and shadow effect. However, seasonal clouds in the sky are also affecting the amount of solar radiation.

a) Sun Path

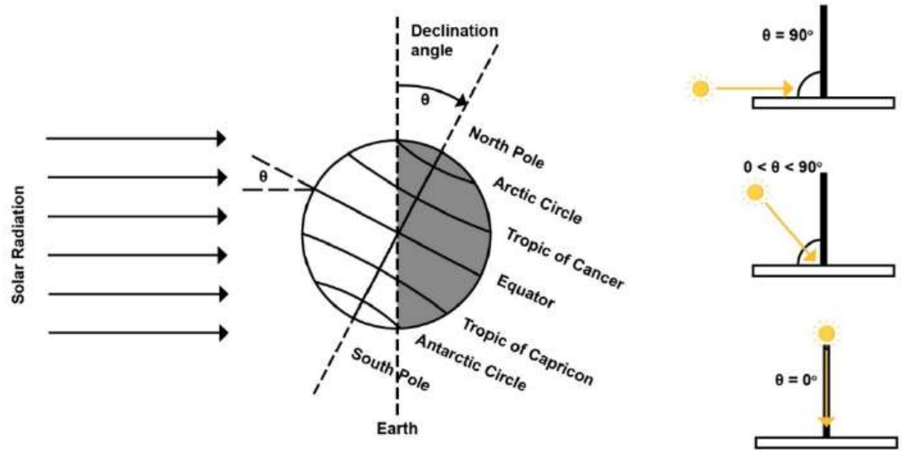


(Fig.2. 1) Earth-Sunar Geometry
Source: Gut,1993

The sun path data is determined by geographical location (latitude) where the earth's position orbit the sun (Fig.2.1). The sun path is a definite pattern that controls the time of year (season) and time of day (hour). The sun's maximum altitude is in the tropic region, lowering towards the north and south poles. The sunlight duration is increased in summer and reduced in winter, depending on latitude, while equatorial latitude has an almost equal duration of sun throughout the year (Fig.2.2). Based on Givoni's study, if the building configuration considers the sun's orbit in the tropic region, it is necessary to orient the building massing configuration perpendicular to the axis of the overheated period (west-east) for the smallest surface.

b) Solar Radiation

Solar radiation energy received to the earth's surface varied over time, depending on the angle of incidence of the sun, the sky clearance concerning clouds, and the purity of the air considering the possibility of dust, carbon dioxide, water vapor, etc. (Hyde, 2000). Solar radiation is an electromagnetic wave of radiation penetrating from the sun into the earth's surface (Givoni, 1998). The wavelength-covered solar spectrum ranges from about 0.2 to 2.0 microns on the earth's surface. The solar spectrum generally is divided into three components: the ultra-violet, the visible, and the infrared-red. Solar radiation is partially absorbed in the atmosphere depending on wavelength. Meanwhile, the pattern of diurnal and annual solar radiation on a given region of the earth's surface depends on the intensity and duration of irradiation by the sun.



(Fig.2. 2) Solar Radiation and geographical location
Source: Goswami D.Yogi,kreith, 2015

Figure 2.2 describe the impact of the sun angle on the earth's surface considering direct solar radiation. For the location in the equator line the sun angle is higher compared to northern and southern locations.

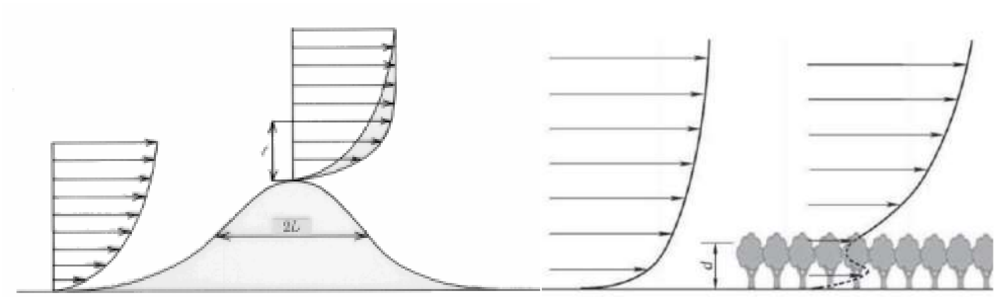
2.2.2 Wind

a) Winds velocity

The seasonal global air pressure, the earth's rotation, the region altitude, and its surrounding physical barrier are influenced the distribution and the characteristic of wind over a region. Air masses flow from high pressure towards the low-pressure area. The mass of the air is classified as "Polar" or "Tropical" and as "Continental" or "Maritime" (Givoni, 1976). Global wind patterns based on geographical location are divided into three classifications in each hemisphere: trade winds, westerlies winds, and polar winds. Meanwhile, the monsoon wind system is influenced by the annual difference in heating of land and ocean area. Different land altitudes influence wind velocity. For instance, when the air is pushed up a mountain, it blows from a higher to a lower pressure region, then cooling the lower area. Contrastingly, when an air mass descends, it has compressed and heated. It is known as the adiabatic cooling and heating process. The rate of temperature change is about 1 degree C per 100metres in altitude (Givoni, 1976).

(Tabel.2.1) Wind characteristic
Source: Givoni, 1976

Wind characteristic	Originate	Wind distribution
The trade winds	Sub-tropical	Flow to the south-west in the northern hemisphere & to the north-west in the southern hemisphere
The westerlies	Sub-tropical	Flow towards the sub-artic region
The polar winds	Polar & arctic	To the south-west in the northern hemisphere & the north-west in the southern hemisphere
The monsoon winds	Winter land winds and summer sea winds	The flow from central Asia to Australia, in a south-west direction over Southern Asia and change at the equator until a south-eastern direction is followed at the north-west coast of Australia (January) The flow from Australia to Indian Peninsula, in a north-west direction over Australia and north-east on reaching South Asia (June)
Land and Sea Breezes	Sea and land surfaces on the similar latitude	Warmer air rises and colder sea airflow to inland reversed process at night.
Mountain and Valley winds	The air over the slopes and the air at the same altitude over the valley with different temperature	Winds are generated in large mountain valleys, blowing up-valley in the daytime and down into the valley at night



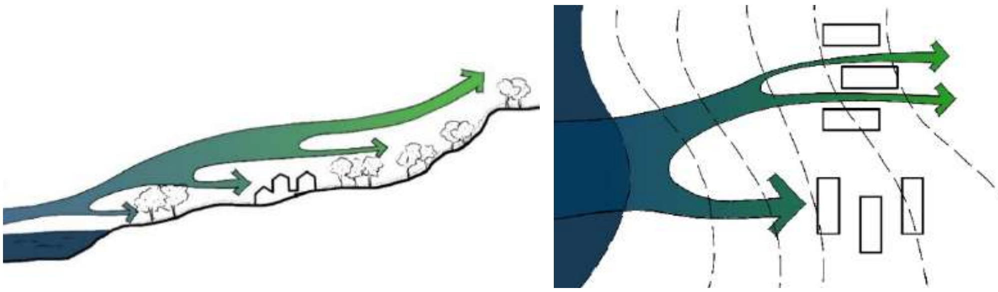
(Fig.2. 3) (a)Wind gradient related to altitude (a)Wind gradient related to landscape
Source: (a) Gryning, 2007 and (b) T. Wallbank, 2008

Airflow modification should be assessed regarding the level of exposure to breeze and summer cooling. Elevation and orientation are two prominent factors in the selected location and site planning (Fig.2.3). Outdoor poor ventilation condition associated with air pollution has a high possibility occurred in a flat valley surrounded by mountains. Winds can be channeled elements of topography and increase and decrease accordingly. Landscape features such as trees can modify and reduce the velocity as barriers or breakers. Furthermore, the effect of airspeed on comfort is influenced by air temperature and humidity. Givoni outlined that at air temperatures below 33° C, escalating air velocity reduces the heat sensation because of the higher convective heat loss from the body and decreasing the skin temperature.

In contrast, at a temperature between around 33° – 37° C, increasing wind velocity does not create a significant thermal sensation; however, it has possibility effect on thermal discomfort from excessive skin wetness, depending on the humidity level and human adaptation to the type of clothing. On the other hand, at a temperature above around 37° C, improving wind velocity would increase the thermal sensation of heat.

b) Winds direction

The topography condition might directly affect the wind velocity for the local climate, with higher elevation resulting in higher wind velocity . Windward slopes a hill accelerate the wind speed from the valley or lower area (Fig.2. 4). For a warm and humid region that may be rather low wind velocity, a narrow valley facing the wind concertation is a desirable location for inhabitants where natural ventilation is essential throughout the year. In mountain or high-altitude areas, the temperature is lower compared to low land areas because of acceleration wind velocity.



(Fig.2. 4) Effect of wind and terrain
Source: Author adopted from Carmona 1984

2.2.3. Precipitation

Based on Man, Climate, and Architecture book by Givoni, there are three types of precipitation which are conventional precipitation because of ascending humid air masses heated by contact with a hot surface, orographic precipitation emerges from air mass with pressure gradients over mountain slopes which its rains might start before any abrupt in the land surface, and lastly, convergent precipitation happened by raising air expands, cools and condense the moisture into the cloud and the precipitates. When the condensation decreases the rate of cooling with elevation and speeds up the ascent, this conventional precipitation happens in the tropical region, especially during the afternoon of the hot season. The rainfall is dense on the windward side of the mountain and deficient beyond the ridge. In the tropical regions, airstreams have similar characteristics, and their simultaneous ascent is rapid, which results in heavy shower rains. At the same time, the gentle slow ascent results in an extensive and long duration of rains.

2.2.4. Air Temperature

There is a complex of physical, chemical, and biological elements to determine the air temperature, such as the intensity of solar radiation, wind, or atmosphere pressure, sea breezes, etc. In 1592, the tools to measure air temperature were first invented by Galileo and developed more for the scale of measurement by Anders Celsius, Daniel G Fahrenheit, and Lord Kelvin. Commonly for climate engineering practice, either Celsius or Fahrenheit scales are used. However, the climate parameter of air temperature is not common to measure for our ancestors, but the consideration of temperature intuitively has known well, such as fire is hot, and snow is cold.

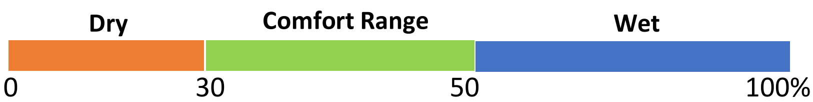
The earth's surface temperature is commonly colder than the air at night and during winter, so the net heat exchange is reversed, resulting in the air in contact with the ground being cooled. The covering earth's surface material has significantly influenced air temperature. The direct contact of the air layer with the warm ground increases the air temperature by conduction. Alters the air temperature has also strongly correlated with a change in altitude. Before sunrise, theoretically, air temperature is at its minimum in both the outdoor air and indoor surface of buildings. After sunrise, the outdoor temperature rises, reaching its maximum around the afternoon (2 pm) depending on latitude and longitude position.

The building envelope's surface position and ground determine the intensity of incident solar radiation, resulting from different temperature patterns for the local climate. Air temperature can be adjusted by local conditions on situated sites such as topography and vegetation. Hilly topography can influence local katabatic cooling. In stable conditions, cold air to the hollows generates cool pools and lower temperatures than on the peak of the hillside. Large water landscaping, such as a river role as a cooling zone, breezes will be flushing the river and penetrating inland.

2.2.5 Humidity

The absolute humidity, specific humidity, vapor pressure, and relative humidity are several terminologies to describe the atmosphere's moisture content. Absolute humidity is the weight of water vapor per unit volume of the air (g/m3). Specific humidity is the weight of water vapor per unit weight of air (g/kg). Vapour pressure of the air is a cumulative atmosphere pressure. Then, relative humidity is the ratio of the actual absolute humidity to the maximum moisture wight of the air at its temperature.

While the vapor pressure of the air is the most common parameter to express humidity condition-related physiological point of view because the rate of evaporation from the body is proportional to vapor pressure, both the vapor pressure and relative humidity are significantly varied with the geographical location and time condition. The moisture distribution over the earth is not uniform but gets highest in the equatorial and lowers towards the poles.



(Fig.2. 5) Humidity classification
Source: Lstiburek, 2002

The relative humidity influences the behavior and durability of building materials. Figure 2.5 classify the relative humidity and perception of the environment. Relative humidity between 30% and 50% is identified as comfort and does not influence material damage due to humidity conditions. Even tough to define thermal comfort is also necessary to consider air temperature conditions. Relative humidity below 30% can be defined as uncomfortably dry. It can affect human health, such as eye and skin irritation. Moreover, cracking building material has a high possibility in low humidity conditions. On the other hand, more than 50% of relative humidity is defined as uncomfortable wet when people have a sweating sensation on the skin. The high relative humidity is also a challenge for building materials such as corrosion and weathering. Relative humidity of more than 80% can influence mold growth in building material depending on ambient temperature, exposure time, and surface condition of materials (Viitanen, 2003). The floors and lower parts of walls have high exposure to high humidity, which lead to being degraded by the potential biodeterioration process (Paajanen et al. 1989).

(Tabel.2.2) Organisms involving damage and defects of building material
Source: Viitanen et al, 2003

Humidity range (%)	Temperature range (° C)	Type of organism growth	Effects
RH > 97%	Ca. -5 to +60	bacteria	Bio corrosion both organic and industrial construction materials, smell, health problem
RH > 75%	Ca. 0 to +50	Mould fungi	Surface growth on different materials, smell, and health problems
RH > 95%	Ca. 0 to +45	Blue-stain fungi	Blue-stain of wood permeability change of wood
RH > 65%	Ca. 5 to +50	Insects	Different type of damage in organic materials, surface failures or strength loss

Table 2.2 is explained the relative humidity of more than 65% has a high possibility of damaging building materials and impacting human health. However, material construction assembly would influence the material durability from humidity exposure, such as an elevated floor slab from the ground is recommended to extend the durability of construction materials.

2.3 Climate Responsive Approach and Sustainability

The significance of the climate-responsive approach comes from the rising concern amongst the design decision for the environment considering the local sources which are influenced by climate. Such as the availability of some organic or local material construction that supports zero carbon-embodied from material distribution and waste chemical production. In addition, climate-responsive has also complemented other environmental goals such as the effect of the building or built environment on human health and phycological benefit by creating a comfortable environment in terms of thermal comfort or sufficient daylight.

Climate-responsive design belongs to an environmental approach to building development called ecologically sustainable design (ESD) (Hyde, 2000). The climate-responsive approach has a role as a subset of environmental solutions which examines the comprehensive relationship between the building and the surrounding environment. Some factors that consider climate challenges and opportunities for ecological aspects such as efficient use of material by scheduling local or organic material collecting at a specific time when the material is in the optimal condition, which can expand material durability. Hence, the practice of ESD in implementation should be considered the local biodiversity of natural flora and fauna on-site and the building design to be integrated with the site. Hyde mention in his book with title Climate-Responsive Design that there are four design criteria for the climate-responsive framework:

1. The geography and the extent of the local landscape aspect have been modified to consider the building.
2. The competency approach in which building fabric has overcharged carbon embodied might be considered using alternative construction systems, including selecting recycled material.
3. Local climate and operational energy demands
4. The optimization for using local or recycling material.

Based on the framework above, the local environment elements such as topography or the availability of water bodies is a key issue to identify that indirectly affect microclimate and the energy used to optimize the site in terms of a sustainable environment. From the perspective of environmental design, the climate-responsive approach is a convenient way of providing for the well-being of users through thermal comfort, air quality, daylight optimization, etc., with a minimum of environmental degradation.

2.4 Climate Responsive and Passive Design Theory

The strategy of climate-responsive design is complex theoretical knowledge depending on the specific climate challenge that it wants to address. There are many supported theories related to climate-responsive that are applicable for a passive and active design solution but contextual to the context of research for residential development in developing countries which tends to be a low-cost solution and less maintenance. Hence, bioclimatic theories are adopted as theoretical background for investigating the climate-responsive design solution in the vernacular settlement.

2.4.1 Bioclimatic Design

Bioclimatic design is formulated based on "biology" and "climate" that an approach to the design of building and surrounding built environment based on responding to climate context (Watson, 2013). "Bioclimatic" terminology is described as an implementation of a passive design strategy that utilizes the optimization of natural energy resources (Visitsak, 2016). Bioclimatic comfort determines optimum climate conditions in which people receive thermal comfort. The bioclimatic approach is a quantitative indicator of climate-responsive design that is designated based on the meteorological database. The bioclimatic design had been implemented as practical knowledge of indigenous people adapting to climate context throughout the historical period, including early modern architecture (Watson, 2013). The design strategy of bioclimatic design is optimizing natural sources of energy on climate (solar radiation, rain precipitation, wind, air temperature, geothermal temperature, etc.) through classic strategies of applied science such as conduction, radiation, evaporation, thermal storage, etc. (Watson and lab, 2013). The implementation of bioclimatic design can be for outdoor and indoor spaces that measure comfort indicators.

a) Outdoor Area (Settlement)

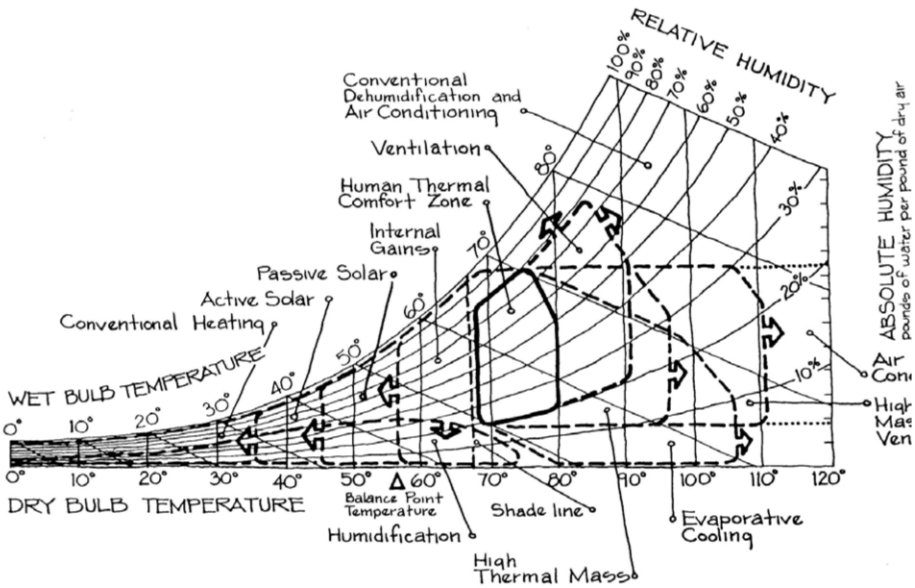
People experiencing outdoor space are adapting their level of physical activity to the ambient thermal conditions, which satisfies thermal comfort conditions, contributes to a healthier environment, improves the intensity of outdoor activities in the neighborhood, and generates social interactions (Barbulescu, 2016). Reflection on the COVID pandemic, providing comfortable outdoor spaces can improve the quality of life and create a healthier environment. Figure. 2.5 summarizes the climate and environmental elements that influence outdoor thermal comfort. The specific climate challenge is necessary to define for evaluating outdoor thermal comfort. There are seven major parameters that influence outdoor comfort which are direct and diffuse solar radiation, humidity, air temperature, the surface temperature of the surrounding context, wind velocity, user metabolism, etc. The literature review method generates relevant examples of bioclimatic design strategy for outdoor space that considers the strategy and specific climate challenge to achieve thermal comfort (Table.2.5).

(Tabel.2.3) Outdoor Bioclimatic Strategy Summaries
Source: Author

Outdoor Strategy	Definition	Climate challenge
Outdoor shading	Reconditioning outdoor space with supporting geometry that can block direct solar radiation	For high air temperature (heat stress)
Outdoor passive heating	Recondition the optimization of sun exposure for outdoor space	For low air temperature (cold stress)
Water evaporation	Reconditioning outdoor space with water bodies such as pool, river etc.	For low humidity (dry environment)
Outdoor wind ventilation	Reconditioning geometry configuration for improving air velocity	For low-speed wind velocity in moderate humidity and moderate air temperature.
Outdoor wind barrier	Reconditioning the geometry context to block damaging wind velocity such as tree, canopy etc.	For high wind velocity in heat stress and cold stress conditions
Land surface material	Reconditioning the surface material that can conditioning thermal comfort such as grass material for absorbing heat stress.	For high solar radiation (heat stress)

b) Indoor Area (Building)

The indoor area means the area which has physical boundary and creating a micro-climate because of people interventions. The approach of bioclimatic comfort indicators for defining indoor comfort conditions had firstly developed by Givoni (1976). The climate-design approach consider the form of building and its design strategy as respond to outdoor climate conditions for enhancing the thermal comfort in indoor space where people sheltered. The selection of passive design strategy related for indoor thermal comfort at this case is based on air temperature and relative humidity conditions data set plotting to psychometric chart.



(Fig.2. 6) Bioclimatic Psychometric chart
Source: Givoni (1976)

There are ten passive strategies based on the bioclimatic psychometric chart of weather data plotting which are conventional active heating, passive heating, internal gains, conventional air conditioning or dehumidification, ventilation, humidification, thermal mass, and evaporative cooling. The definition of low air temperature is the air temperature below the balanced point of comfort air temperature in vice versa, and the definition of low humidity refers to the humidity below the comfort zone. The weather data cases need to be plotted into the psychometric chart to calculate the distribution of time in the climate case for achieving thermal comfort. Table 2.4 consist of the bioclimatic strategy for building level and corresponding to the specific climate challenge.

(Tabel.2.4) Indoor Bioclimatic Strategy Summaries
Source: Author

Bioclimatic strategy	Definition	Climate challenge
Conventional active heating	Reconditioning an active heating system such as fireplace	Low air temperature and low humidity
Passive heating	Reconditioning to minimize heat thermal loss of the building such as	Low air temperature and low humidity
Natural Ventilation	Reconditioning air movement inside the building	Moderate to high air temperature and high humidity
Evaporative cooling	Reconditioning the building for evaporating moisture into air stream	High air temperature and low humidity
Dehumidification/ Conventional air conditioning	Reconditioning the air to condensate the moisture using chilled water	High air temperature and high humidity
Humidification	Reconditioning the air to condensate the moisture using water	Low humidity
Thermal mass	Reconditioning of building material to delay heating load	High air temperature
Internal heat gains	Reconditioning of building material to delay cooling load	Low air temperature and moderate humidity

The recommendation strategy is defined based on the interpolar of dry and wet bulb temperature into humidity conditions for achieving indoor thermal comfort. The bioclimatic passive design strategy is the only main approach to climate-responsive; the design solution can be in more ways. The chart can be a preliminary study to define bioclimatic strategy relevant to specific climate conditions. However, the chart cannot evaluate the performance of the design solution even though the strategy is already applied or planned. Hence, the thermal index is necessary as an indicator to measure the performance of the bioclimatic strategy for achieving thermal comfort.

2.5 Climate Responsive Indicators for human comfort

The practice of climate-responsive is not limited only to achieving comfort for humans. However, the practice related to reducing energy consumption from thermal conditioning mechanical systems is relevant to the phenomenon in Indonesia that AC and fans are two of higher electricity consumption even tough at night-time. Hence, thermal comfort and wind comfort indicators will be used to evaluate the finding of climate-responsive design solutions from vernacular settlements. The thermal comfort standard determines human satisfaction with thermal environmental conditions. ASHRAE-55 is a thermal comfort standard developed by American National Standard, which takes the case in various climate conditions (ANSI, 2020). The standard is determined by adaptive and PMV (Predicted Mean Vote) indicators.

2.5.1 Thermal comfort Indicators

Thermal comfort is determined by the state of mind human experiencing satisfaction in a thermal environment (Olesen,2000). The thermal environment parameters include the climate condition (air temperature, humidity, wind speed, etc.) and human metabolism (activity, sex, clothing, etc.). The main context of thermal comfort is the climate. It has an influence on the building design of inhabitants. Reconditioning a thermal comfort environment leads to creating a healthy, comfortable, and energy-friendly environment (Lichtenbelt, 2017).

The thermal comfort index is useful to measure the performance of climate-responsive design solutions for achieving thermal comfort. PMV model can project the thermal sensation as a function of activity, clothing, and four climate elements (air temperature, mean radiant temperature, air velocity, and humidity). Furthermore, the PMV model has been tested in climate studies with Asian subjects (Dear, 1991). The extension of the PMV model for non-air-conditioned buildings in a warm climate confirms the actual votes well (Fanger, 2002). Table 2.5 identify the classification of PMV index into thermal perception. For a room with PMV between -0,5 to 0,5 can be classified as Neutral perception which is the condition when human experiencing thermal comfort.

(Tabel.2.5) PMV Index
Source: Fanger, 2002

PMV	Thermal Perception
-3	Very Cold
-2	Cold
-1	Slightly Cold
-0,5	Neutral
0	Neutral
0,5	Neutral
1	Slightly Warm
2	Warm
3	Hot

2.5.2 Wind Comfort Indicator

a) Outdoor wind comfort

Wind comfort indicator can be defined as an impact of wind conditions on human sensation and effect on the environment. The Beaufort wind scale defines the relation of wind speed to the physical appearance of the sea surface and the effect on the land. The effect on land is explained by damages and the destruction of trees, homes, and utilities. Based on the wind scale, the scale of 0 - 5 is acceptable to influence outdoor comfort, more than it will affect uncomfortable and damage the building structure. Table 2.2 corresponds to the effect of wind velocity on the outdoor area. The Beaufort wind scale can be used as preliminary identification of outdoor wind effects related outdoor environment.

(Tabel.2.6) Beaufort wind scale

Source: Beaufort wind scale (WMO, 1970)

Beaufort Scale	Description	Wind velocity at 1.75 m height (m/s)	Effect on land
0	Calm	0.0 – 0.2	Still, smoke rises vertically
1	Light Air	0.3 – 1.5	Smoke drifts, vanes remain motionless
2	Light breeze	1.6 – 3.3	Leaves rustle, vanes move, wind can be felt on face.
3	Gentle breeze	3.4 – 5.4	With the constant movement of leaves and small twigs, flags begin to stream
4	Moderate breeze	5.5 – 7.9	Dust and lose paper are lifted, thin branches move
5	Fresh breeze	8.0 – 10.7	Small trees in leaves begin to sway
6	Strong breeze	10.8 – 13.8	Large branches move, power lines whistle, stop lights sway, umbrellas difficult to control
7	Moderate gale	13.9 – 17.1	Entire trees sway, some resistance to walkers, the car feels the force of the wind
8	Fresh gale	17.2 – 20.7	Twigs break off trees, difficult walking against the wind
9	Strong gale	20.8 – 24.4	Roof tiles are lifted off, windows may be blown in, trees may topple
10	Whole gale	24.5 – 28.4	Trees uprooted considerable structural damage to some buildings
11	Storm	28.5 – 32.7	Widespread damage, extensive flooding in low lying areas if the wind is directed onshore
12	Hurricane	>32.7	Severe structural damage to buildings, widespread devastation, and flooding

b) Indoor wind comfort

The building has conditioned a microclimate from outdoor conditions. Wind influences thermal comfort that leads to cooling or heating of the human body (Hou,2018). If the wind speed is the consideration for environmental comfort, wind velocity determines human comfort. The wind index is applied when the apparent temperature is lower than the air temperature. The wind index has adjusted for a calm wind environment in 2001 by scientists from the Joint Action Group for Temperature Indices. Esfahankalateh mentioned in her paper that the equivalent wind chill temperature ($t_{eq,wc}$) is an appropriate indicator for evaluating wind comfort that had taken the case in a clam wind criteria (6.4 km/h or 1.8 m/sec) approved by meteorologists. The equivalent WCI (Wind Chill Index) formula is the actual combination of air temperature and wind velocity. Table 2.7 summarize the occupant's reactions to the various conditions of wind velocity based on the equivalent.

(Table 2.7) – The equivalent Wind Chill Index
Source: Esfahankalateh1 (2020)

Air velocity at body level (1.5m)	Human sensation	Occupant evaluation
0 - 0.05	Stagnant air	Complain about stagnant air
0.05 – 0.254	Favorable	Generally favorable (manufacture of air outlet device, e.g. base performance on 50 fpm air velocity in an occupied zone)
0.25 – 0.51	Comfortable	Awareness of air motion but can be comfortable (e.g. some retail shops and stores) when the temperature of moving air is above room air temperature.
0.5 – 1.02	Acceptable	Constance awareness of air motion but can be acceptable (e.g. some factories) if air supply is intermittent and above air room temperature
1.02 - 1.5	Disruptive activities	Increasingly drafty conditions with complaints about 'wind' in disrupting a task, activity, etc.
1.5 ≤	Discomfort	Chaotic domestic activity

2.6. Local Knowledge and Vernacular Settlement

The past civilization recognized that regional climate adaptation was an essential architectural design decision to survive (Olgyay, 2015). Climate, terrain, and culture are the vast spectrum of various vernacular architecture. It has also consisted of inherent unwritten information about the optimization of the energy performance of building at low cost using current technology inventions (Zhai, 2009). The general forms of native habitants were born of the environment with their current technology inventions, which mostly without mechanical systems. As considered a fewer technology availability of our ancestors for tackling climate challenges, vernacular houses are mainly designed to enhance the use of natural resources such as the sun and wind, which are persistent and continuous efforts for more efficient and impeccable solutions (Dili et al., 2012).

Climate-responsive building design in traditional practice has a significant role in decreasing the energy demand of building without contradicting the modern living standard (Motealleh, 2016). Many studies have mentioned that vernacular architecture has achieved better thermal performance through passive and practical design solutions (Borong, 2004).

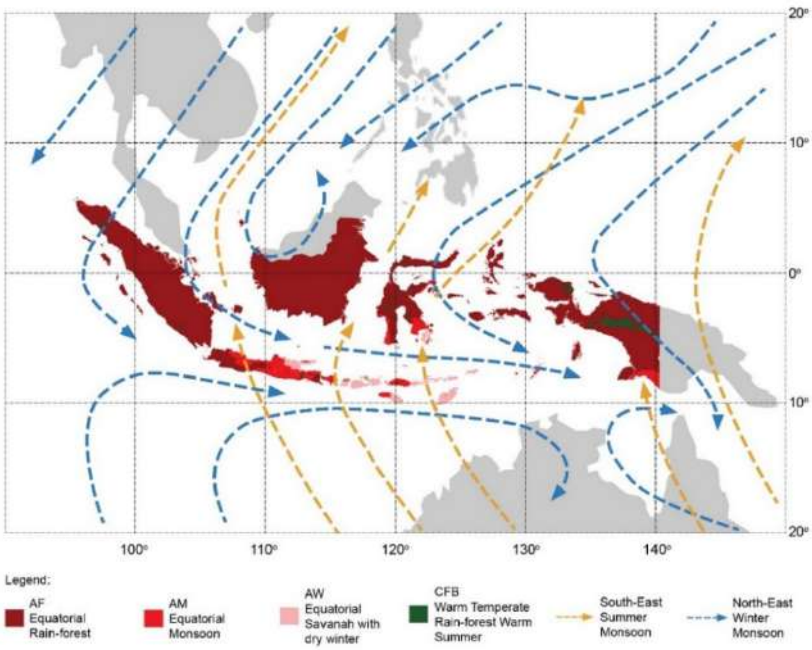
Furthermore, traditional buildings incorporate rich practical knowledge that should not be abandoned and fully replaced by modern general energy-intensive building practices (Bodach et al., 2014). The value of local knowledge in relation to climate adaptation has increasingly been a concern in the past decade, and the practical solution based on environmental context is the reason behind it. Passive design strategies are important for conservating efforts and sustainable design, and the implementation of passive design strategy has already applied in the traditional building, which can be seen how the building respond to local climate and enhancing indoor thermal comfort (Huang, 2020).

Chapter 3
The Context

The third chapter explains the context of the research in terms of the climate context of the equatorial rainforest, the context of location related to land elevation in Indonesia, and the context of residential development trends in Indonesia, focusing on the government's housing products, and the case study context.

3.1 Climate Context

Indonesian archipelago lies in the center of the equatorial within 6°08' N to 11°15' S latitude and from 94°45' E to 141°05' E longitude (Indonesia Ministry of Foreign Affairs,2018). It has two seasons: the dry season from April to September and the rainy season from October to February. In between the season, it has a period of transition season which is identified to influence some diseases such as dengue, influenza, arthritis, and chikunga. It results from the rapid change of weather patterns during the transitional season. Based on environmental characteristics, Indonesia can be defined as a tropical marine climate where the ocean is connected among those islands. Theoretically, the average monthly temperature range is considered constant with a little change during daytime and nighttime. High temperature and rainfall climate patterns are generally identical to the equatorial region, but the wind pattern shows specific characteristics due to the monsoon wind. In July, the Southeast monsoon comes from Australia to the North, while in January, the Northeast monsoon wind flushes Indonesia from the North towards the south. During those two monsoon seasonal periods, the amount of rainfall can be reinforced.

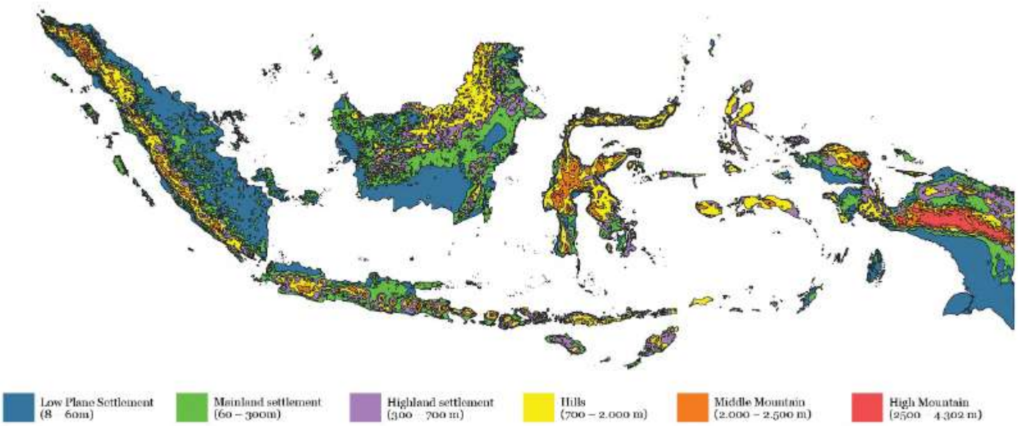


(Fig 3.1) Indonesia Climate Classification based on Köppen classification
Source: Author based on Köppen classification map

Based on the Köppen climate classification, Indonesia is divided into four climate zones: equatorial rainforest, equatorial monsoon, equatorial savannah, and warm temperate rainforest (Figure 1). In addition to geographical position, land altitude has also influenced local climate. In some parts of Indonesia, especially in high mountains such as Jayawijaya mountain, Papua, snow mountain has been challenging in tropical latitudes. The land area mainly lies in the equatorial rainforest climate region, which is 86% compared to other climate types. From East to West, Papua Island, Maluku Island, Sulawesi Island, Kalimantan Island, a partial area of southwest side Java Island, and Sumatera Island are inside the equatorial rainforest climate zone. Equatorial rainforest climate has warm, humid characteristics defined based on on-air temperature and humidity conditions.

3.2 Location Context

Indonesia is an archipelago country consisting of 17,508 islands with five big islands: Sumatra, Java, Kalimantan (Borneo), Sulawesi, and Papua. Stretched out on the equator, it has a total land area of 1,919,443 square kilometers and a total sea area of 3,000,000 square Kilometers. The country is divided into three-time zone areas which is GMT+7 for Sumatera, Java, and West & Central Kalimantan; GMT+8 for Bali, Nusa Tenggara, South & East Kalimantan, and Sulawesi; and GMT+9 for Irian Jaya and Maluku archipelago.



(Fig 3.2) Indonesia Physiographic Region
Source: Author based on GIS database

According to administration regulations, the country is divided into 34 provinces. From the independence until the 20th century period, the concentration of development had focused on Java Island and resulted in a high-density phenomenon as a record in 2020 which 56% of the total 271,066 population are living in Java province (BAPPENAS, 2020).

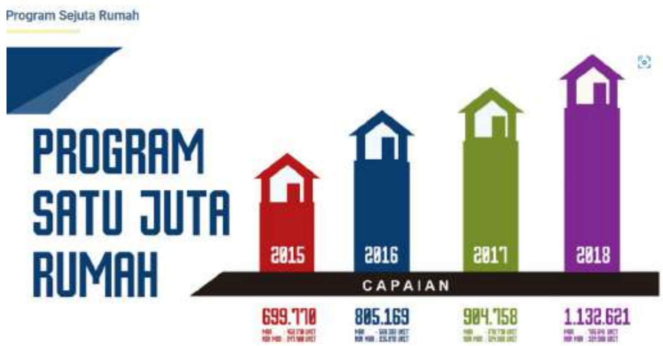
Based on GIS database (see figure 3.2), Indonesia's land altitude is between 8 msl to 4.302 msl. It is divided into six classifications based on altitude data which are low plane settlement, mainland settlement, highland settlement, hills, middle mountain, and high mountain.

(Table 3.1) The Settlement Classification based Altitude
Source: Author

Physiographic Characteristic	Elevation	Settlement Availability	Vegetation Character	Local Material Resources for Construction
High mountain	2.500 – 4.302 msl	No	Coniferous Forest	Mountain stone, Timber
Middle mountain	2.000 – 2.500 msl	No	Deciduous Broadleaf Forest	Mountain Stone, Timber
Hills	700 – 2.000 msl	Yes, limited	Evergreen Tropical Forest	Mountain Stone, Timber, Coconut Husk/Sirap
High land settlement	300 – 700 msl	Yes	Subequatorial Rainforest	River Stone, Timber, Coconut Husk/Sirap
Mainland settlement	60 – 700 msl	Yes	Subequatorial Rainforest	Red Brick, Timber, Coconut Husk/Sirap, Rattan, River Stone
Low plan settlement	8 – 60 m	Yes	Subequatorial Rainforest	Red Brick, Bamboo, Timber, Coconut Husk/Sirap, Rattan

Altitude diversity has influenced the biodiversity source of local material (table 3.1) for construction, which influenced the vernacular settlement style. The low land settlement area in the 8 – 60m altitude is a place of subequatorial rainforest vegetation types such as bamboo, timber, and coconut husk for building material. In middle land settlement area around 60 – 70 m altitude above sea level, the natural sources have almost similar material to the low land area, but rattan has also been invented for construction material beside river stone. Meanwhile, red brick is not used as a local building material for high-land settlements due to the unsuitable soil mineral composition for pug milling and kilning the soil to brick. It has a possibility to get brick from the middle land area, but it was not efficient in terms of material distribution at that time. In the hills area at around 700 – 2.000 m altitude, there is limited vernacular settlement due to the geographical challenge of building in the hilly area. The domination of evergreen tropical forest vegetation type unequivocally influenced building material for the settlement, which was mainly within close proximity to local source timber and coconut husk. Even though almost all the settlements in the different geographical regions use timber as the main local material, the type of timber is diverse. However, the close similarity in colors could be seen with dark brown wood fiber, although biologically different.

3.3. Context of Residential Development in Indonesia



(Fig 3.3) One million housing program
Source: Indonesia Ministry of Housing Development

The idea of giving an overview of residential trends in Indonesia is to understand the common trend of Indonesia's housing preferences, especially for international readers of this research. In a context related to housing demands, Indonesia is a developing country with a vast area and skyrocketing population growth which undoubtedly increases housing needs. The demand for new residential development is considerably high. In 2018, more than 1 million new housing was built. Starting from 2015 until now that Indonesia's president has a program of one million housing units (Seribu Rumah), targeting to build a million affordable housing for the majority of middle- and lower-class income (figure 3.3). Significant development of housing is also in line with increasing energy consumption of household activity.

Table 3.2 indicates the distribution of housing development in Indonesia; based on the Ministry of Housing Indonesia database, the trends of detached landed housing (*Rumah Tapak*) is favorable compared to multi-stories housing or apartment (*Rumah Susun*). Indonesia has 519.485 detached landed housing have been built by the government, which spread out in both rural and semi-urban areas. Sumatera Island, Java Island, and Kalimantan Island have a higher number of detached housing development. The building housing size in Indonesia is commonly in the range of areas of 21 m2, 36 m2, 45m2, 54m2, 60m2, and more than 60m2 as a special size. Figure 3.5 illustrates the common housing development in Indonesia, especially in semi-urban and rural areas that are still surrounded by a natural environment.

(Table 3.2) Residential development trend between landed housing & apartment
Source: Ministry of Housing and Infrastructure, 2019

Provinsi	Rumah Tapak	Rumah Susun	Total
Aceh	2.290	4	2.294
Sumatera Utara	33.499	5	33.504
Sumatera Barat	7.371	0	7.371
Riau	31.034	2	31.036
Jambi	15.327	0	15.327
Sumatera Selatan	30.404	2	30.406
Bengkulu	6.334	0	6.334
Lampung	7.368	0	7.368
Kepulauan Bangka Belitung	4.334	0	4.334
Kepulauan Riau	13.328	8	13.336
DKI Jakarta	12	383	395
Jawa Barat	220.159	69	220.228
Jawa Tengah	31.442	0	31.442
D.I. Yogyakarta	1.490	0	1.490
Jawa Timur	39.524	0	39.524
Banten	60.438	0	60.438
Bali	1.782	0	1.782
Nusa Tenggara Barat	3.983	0	3.983
Nusa Tenggara Timur	3.262	1	3.263
Kalimantan Barat	24.027	-1	24.026
Kalimantan Tengah	10.900	0	10.900
Kalimantan Selatan	37.233	-6	37.227
Kalimantan Timur	3.370	22	3.392
Kalimantan Utara	218	0	218
Sulawesi Utara	10.267	0	10.267

Sulawesi Tengah	4.621	0	4.621
Sulawesi Selatan	20.927	0	20.927
Sulawesi Tenggara	7.810	0	7.810
Gorontalo	2.631	0	2.631
Sulawesi Barat	2.999	-1	2.998
Maluku	81	0	81
Maluku Utara	312	0	312
PapuaBarat	6.077	0	6.077
Papua	6.697	1	6.698
Indonesia	**651.551**	**489**	**652.040**

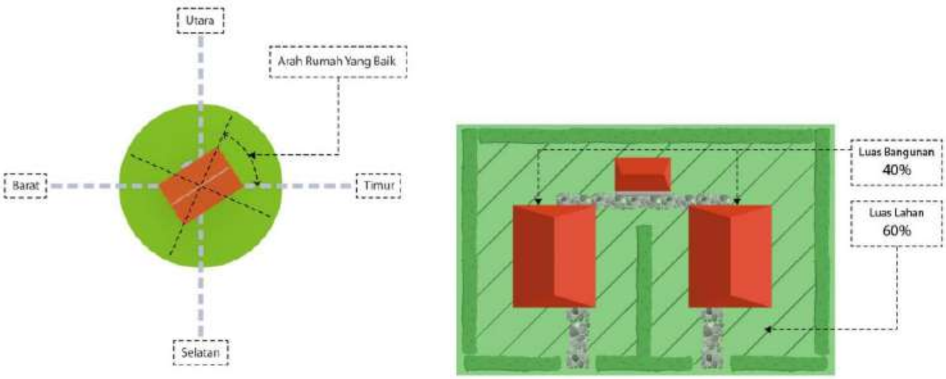
In addition, learned from previous modern settlement development, refers to figure 1.1 page.5 illustrates energy consumption for housing in Indonesia based on the CLASP study in 2020. The survey was conducted both in urban and rural districts of Indonesia's 34 provinces. The survey points out that the consumption of electricity for air conditioning (Fan and AC) is higher, up to 10.000 MV per day which interestingly happens in the evening time operational.

3.3.1. Government's residential guideline *"Rumah Sehat"*

The new development of the residential area in Indonesia is commonly developed by both private and government. Focusing on the government residential project is mainly targeted to create inclusive development of affordable housing for Indonesia's citizens. In common, the new residential development areas, especially from government subsidies placed in rural areas which in some cases are very remote and have inadequate accessibility. Interestingly, the housing design was very identical regardless of location, which makes the development less contextual and occurs multi-layered problems, mainly environmental issues. Figure 3.4 is an illustration of the government's housing products on Kalimantan Island. The housing type is a detached single-family house. It was built in a rural area of Kalimantan.

(Fig 3.4) Example of Government Landed Housing in Kalimantan Island
Source: Indonesia Ministry of Housing, 2021

One of the housing guidelines for new residential development in Indonesia is "*Rumah Sehat*," translated in English as Healthy Housing. The main concept is to create a healthy environment for housing development. Figure 5.3 illustrate the guideline of "*Rumah Sehat*," but it is not limited to the building size and architectural style. Based on the guidelines, it mentioned that the preferable building orientation should be towards East and West direction as considered to sun path orbital from East to West. Based on the guideline, the buildable area for single housing should be a maximum of 40% of the land area



(Fig 3.5) Massing configuration of "Rumah Sehat" guideline
Source: Ministry of housing (2016) P.10

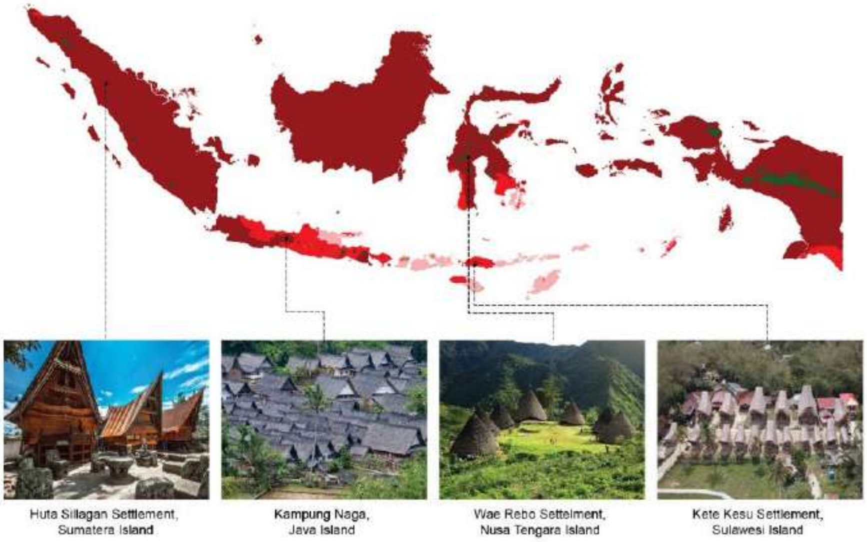
There are minimum requirements for rooms of "Rumah Sehat," which are two bedrooms, a bathroom, a living room, and a kitchen. Figure 3.6 describes the building layouts and sections. Based on the illustration, it is shown that each of the building sides is required windows, and the floor plate has a minimum elevated 75cm above the ground.

(Fig 3.6) Building layouts of "Rumah Sehat" guideline
Source: Ministry of housing (2016) P.11

Based on the regulation, the idea of "*Rumah Sehat*" does not have a specific size, it can be adjusted to user requirements related to housing size. The selection of material is also can be adjusted with budget and material availability on project locations.

3.4 Case Study Context

This research will select several representative case studies related to the implementation of climate-responsive in the vernacular settlement. It aims to gain knowledge from the past and from the traditional settlers with antiquity knowledge that is renowned for their way of life and responsive approach to the climate in a practical solution. The case study selection is taken in the vernacular settlement in the majority climate classification, which is in the equatorial rainforest. Those selected case studies are Huta Siallagan vernacular settlement in North Sumatera Island, Kampung Naga vernacular settlement in West Java Island, and Wae Rebo vernacular settlement in East Nusa Tenggara, and Kete Kesu vernacular settlement in West Sulawesi Island (figure 3.7).



(Fig 3.7) Case Study Locations
Source: Author

Contextual to the location and user activity, in general, the perception of vernacular housing and settlement in Indonesia when it is built is a place for resting. They are mostly using the space during nighttime because most indigenous people's daily activity is in outdoor spaces such as farming, animal hunting, etc. (Hariyanto, 2021). The following part will explain the environmental condition of the case study.

3.4.1 Huta Siallagan

Huta Siallagan settlement is located on the Northern side of Samosir island, an island that lies in the center of Toba Lake, North Sumatra, at 910 MSL above sea level. For the house inside the Huta, the locals called it Rumah Bolon or, in English words, Bolon house. Originally, the settlement consisted of 8 houses, but four new houses were built for tourism purposes in 2019. The community group itself is still living inside the settlement. Himasari mentioned that the building configuration of the Huta Siallagan settlement followed natural symbolic elements that strongly appear in the building orientation toward water element (Toba Lake) and mountain (hilly side). Figure 3.8 illustrate the site location and the visualization of Huta Siallagan land conditions.

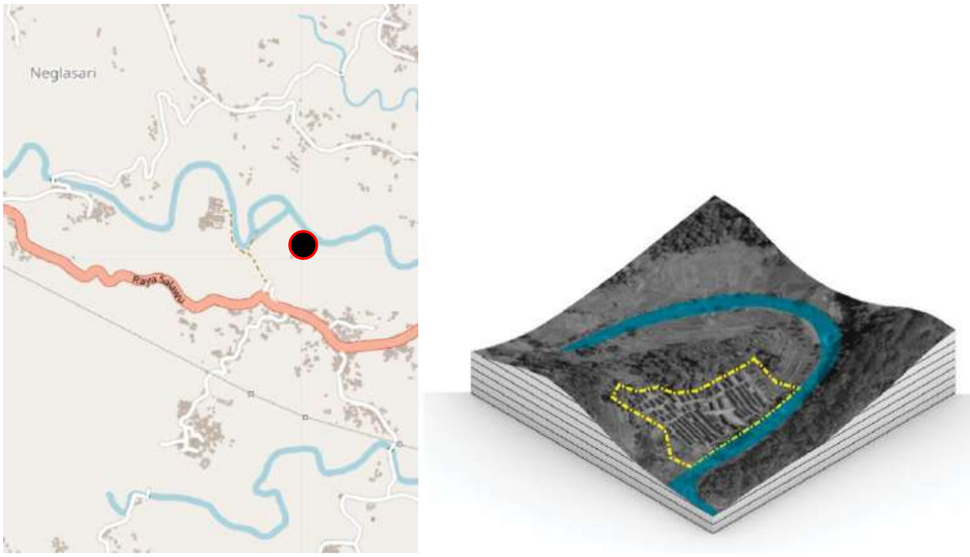
(Fig 3.8) Huta Siallagancontext location and land condition

Source: Author

3.4.2 Kampung Naga

Kampung Naga, or in English Naga settlement, was built by people who inherited in Sundanese race, which most inhabitants in the western part of Java Island. The settlement is located in the rural area of Tasikmalaya, West Java, at 600 MSL above sea level. The settlement consisted of 112 vernacular housing, which were built on 1.5 hectares of the settlement area. The settlement was bordered by forest and river as natural boundaries prevented it from expanding beyond the natural border. Located on a slope facing towards the east, which receives more morning sunlight, it makes the location an ideal area for both residential and agricultural fertile land (Damayanti, 2018). Figure 3.9 illustrate the site location and the visualization of Kampung Naga land conditions.

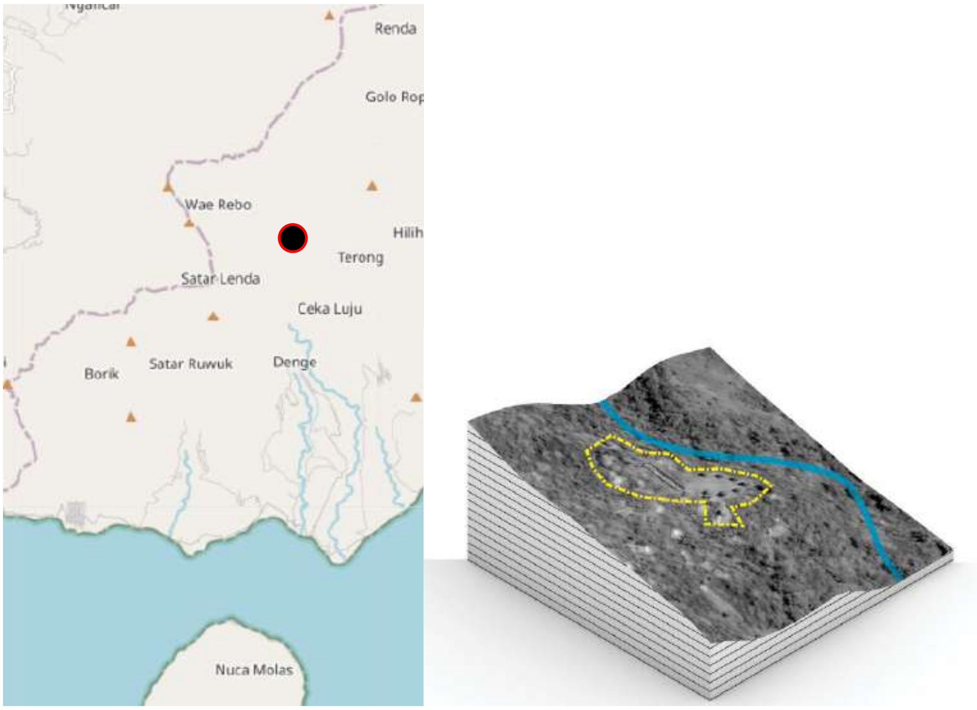
In kampung Naga, the number of housings inside the settlement was fixed, which the concept of balancing human needs and natural resources for a thriving life. Hence, the Sundanese people who live in the settlement are only the oldest generation in the family clan. The settlement is an agricultural community whose most members of the community work as farmers.



(Fig 3.9) Kampung Naga context location and land condition
Source: Author

3.4.3 Wae Rebo

Wae Rebo is the tribe's settlement located on the plateau of Manggarai Regency, East Nusa Tenggara Island, at 1.109 MSL above sea level. The settlement is surrounded by hills and dense tropical forests with a water tributary on the northern side of the settlement. The settlement's land use consists of housing or Mbaru Niang as local called outdoor public space, and a local cemetery. It has seven houses as co-living housing that was built by local knowledge. The house adopted a co-habitation or co-living system with several multi-family from the same clan living under the roof. Figure 3.10 illustrate the site location and the visualization of Wae Rebo land conditions.



(Fig 3.10) Wae Rebo context location and land condition
Source: Author

3.4.4 Kete Kesu

Kete Kesu settlement is located in Toraja district, part of South Sulawesi regency at 769 MSL above sea level. The settlement had been built by the ancestor of the Toraja tribe based on cultural group regulation which is called Aluk Todolo. The Aluk Todolo folklore described that the roof parts of Tongkongan houses (vernacular housing terms inside the Kate Kesu) have an important role in social symbols to be oriented to North where the place of Puang Matua, the sun god. Even though the sun's path direction from East to West, Manurung mentioned that in the view of the sky toward the North direction, we can see the sun's orbital from sunrise time to dusk from the same position. Hence, all the Tongkongan buildings must be oriented to the North. Figure 3.9 illustrate the site location and the visualization of Kete Kesu land conditions.

(Fig 3.11) Kete Kesu context location and land condition
Source: Author

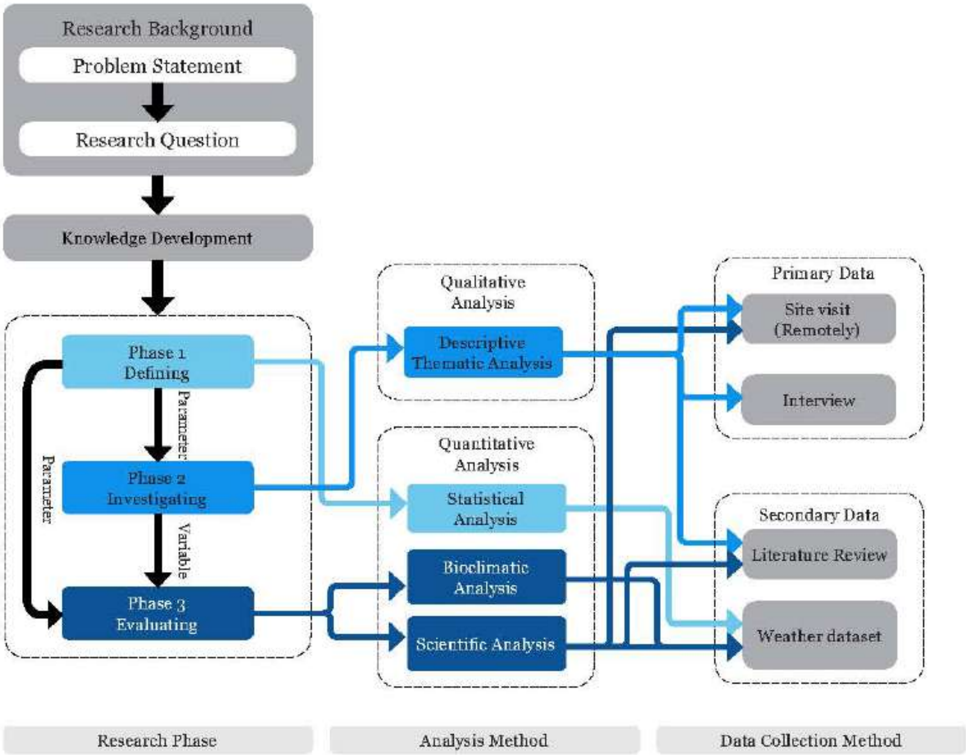
Chapter 4: Methodology

Chapter four is explained about the methodology for this master thesis research. It includes the structure of the research methodology and detailed method for each phase of the research.

4.1 Research Methodology

The methodology is established for answering the research question. The research methodology is divided into three phases: defining, investigating, and evaluating. Both qualitative and quantitative analysis methods will be conducted comprehensively. The qualitative analysis method will be applied for investigating phase, which focuses on investigating the relevant knowledge of climate-responsive design in the vernacular settlement. The source of data is collected from primary and secondary sources. Due to the COVID-19 pandemic and international travel limitations at the time of this research, the primary data were collected remotely by comprehensive teleconference with dedicated research assistants based on proximity to the selected case locations.

On the other hand, the quantitative analysis method will be applied in defining and evaluating phases. The defining phase is targeted to define the significant climate characteristics and challenges in the Equatorial Rainforest region of Indonesia based on weather data statistics. Furthermore, the evaluation phase is expected to evaluate the performance of climate-responsive design solutions based on finding from the investigation phase, which will be evaluated through computational climate simulation.



(Fig.4.1) Structure of Research Methodology
Source: Author

Figure 4.1 illustrates the research methodology in the structured diagram. The research structure in the figure has described the connection of research background into research phases and follows into analysis method that is suitable for each phase. For data collection gathering some method in the last diagram is prepared. Further details of research tools and research phases are explained in the following pages.

4.2 Research Phasing

Phase 1 - Defining

The Method

The first phase in the research methodology is to define climate challenges in the selected equatorial rainforest climate zone within the Indonesian archipelago. It is conducted by an analytical method for analyzing statistical weather data. The first phase aims to understand the climate characteristic in the equatorial rainforest based on weather data analysis.

Data Collection

The climate data was collected from ERA 5 database with a preliminary data study conducted by analyzing weather data from the earliest year range of data (1980,1981,1982) until the latest year range of data (2019,2020,2021) (see appendix). Based on the preliminary weather database, the research found a slightly different between the earliest and latest year ranges of the data set; thus, further analysis will be used of the weather database recorded by 2021, considering an updated current data set.

The research considers the climate data regarding the sun path, direct solar radiation, wind velocity, wind speed, rain precipitation, relative humidity, and 2-meter air temperature. Furthermore, literature reviews have also been conducted to find ecological aspects that influence the development of vernacular settlements, such as geographic diversity and local material availability. The expected result of the first phase will be used as a parameter for the second phase (Investigation).

The Tools

1. Ms. Excel

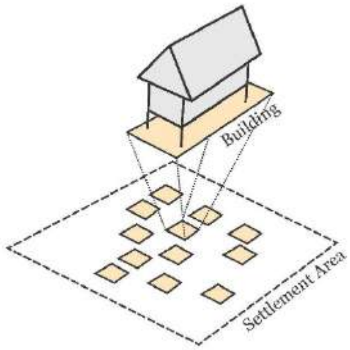
   Computational spreadsheet calculation software is used for calculating main trends such as average, mean, peak, and lowest number.

2. Climate studio

   Computational climate data visualization software is utilized to visualize climate data overlay with analysis objects (Figure 3.2). The EPW weather data is required to generate climate analysis. For this research, the climate analysis is limited to the sun path and wind rose diagram.

Phase 2 - Investigating

The thematic descriptive analysis will be divided into two scales: settlement configuration and building mass (Figure 4.2). The study investigates the shared design principle in vernacular settlement and building concerning climate context.



(Fig.4.2) Scope of analysis
Source: Author

The Method

The second phase will investigate the inventory knowledge of the vernacular settlement. The analysis will be conducted through a descriptive thematic analysis method which aims to identify common themes – topics, ideas, and shared patterns of how the Indonesian tribe communities respond to climate and ecological aspects through vernacular settlement design knowledge.

The Data Collection

The primary data is collected by a remote site survey with dedicated research assistants had been delegated to collect primary data on-site based on the research subject in the selected case location (see appendix for research assistant proof of data validation). Re-measurement of the dimension of analysis content is conducted in three locations, Huta Siallagan, Kampung Naga, and Kete Kesu. Meanwhile, limited accessibility for the Wae Rebo case cannot be accessible for delegating research assistants to the location. Hence interviews with residents are conducted to validate the secondary data.

The secondary data will be collected from previous research manuscripts. A set of syntheses of existing research is targeted from secondary data. The inventory study result will be used as a variable for quantitative evaluation in the last phase of this research.

<u>The tools</u>

1) Digital documentation

Photo documentation is collected from a digital camera as the primary data

2) Desktop data collection

The research manuscripts are collected from online and offline publications.

2) Sketch illustration

Re-visualization of architectural components based on manuscript data and on-site survey. Structured interviews were conducted to validate the data collection related to the dimension, material, story behind the design decision, etc.

4) Tabulation

Data grouping based on thematic analysis topic.

Phase 3 - Evaluating

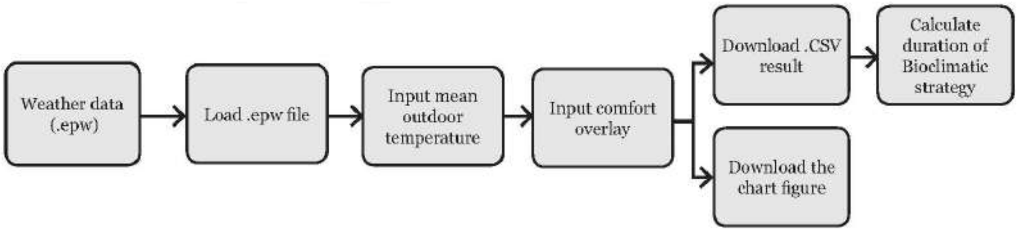
<u>The Method</u>

A quantitative method utilizing computational analysis will be conducted for the last phase in the research methodology. It aims to evaluate the performance of vernacular settlements responsively to their climate context. The research result from the first phase will be used as the analysis parameter and the research result from the second phase has a role as the analysis variable. A set of an indicator is defined to measure the climate responsive performance considering the context of the climate challenge. The idea of evaluating the method wants to prove whether or not the climate-responsive design solution in the vernacular settlement works, then look for possible adoption or improvement of knowledge.

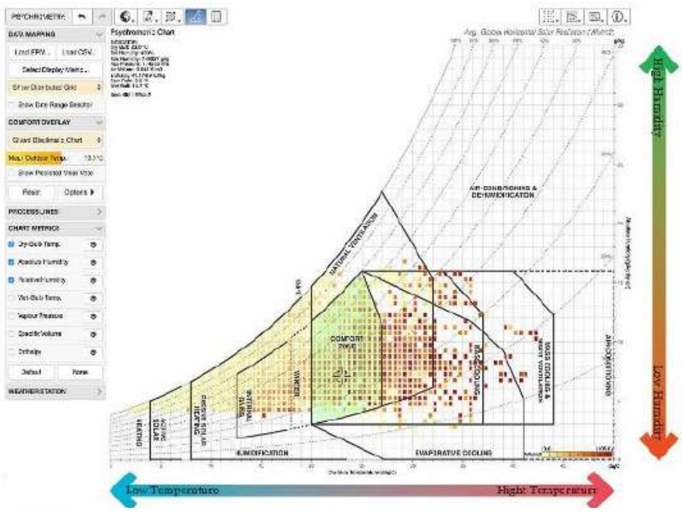
The Tools

1) Psychometric chart - Bioclimatic comfort standard

The psychometric chart is a graph of the thermodynamic parameters of moist air at constant pressure. The dry-bulb temperature and humidity data are plotted in hourly format. The chart is generated on the andrewmarsh web application (http://andrewmarsh.com/software/psychro-chart-web/).



(Fig 4.3) - The bioclimatic psychometric chart step
Source: Author

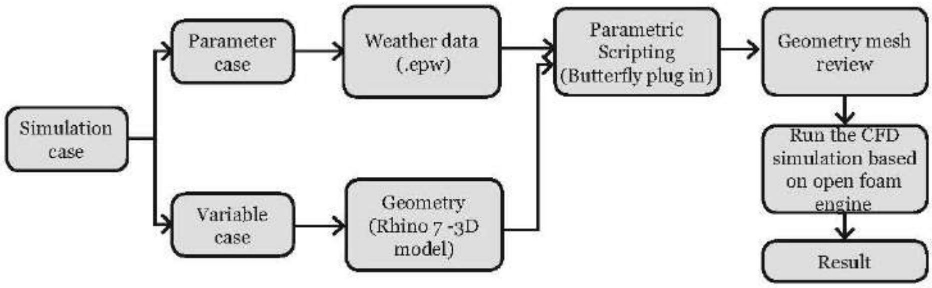


(Fig 4.4) - Psychometric Chart
Source: https://drajmarsh.bitbucket.io/psychro-chart2d.html accessed 10.03.2022

2) A set of tools for the CFD (Computational Fluid Dynamic)

The CFD is a computational simulation that aims to evaluate wind-driven. This type of parametric computational analysis will be utilized in this research to analyze specific challenges in the equatorial rainforest climate region. The CFD simulation scripting and method are proven and validated based on Sakiyama's (2021) research titled "Using CFD to Evaluate Natural Ventilation through a 3D

Parametric Modelling Approach". The CFD simulation will conduct in Rhino 7 with support by butterfly plug on grasshopper scripting. The CFD open-source code Field operates and calculates automatically in OpenFOAM software. Figure 4.5 illustrates the step of the CFD simulation and the script for the simulation is attached in the appendix.

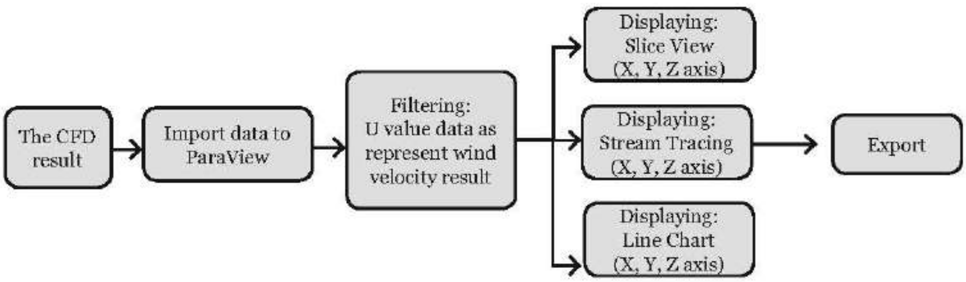


(Fig 4.5) - The CFD simulation steps
Source: Author adapted from Sakimaya, 2021

3) ParaView - Post Processing

The ParaView application is used used in post-processing. It is an open-source, multi-platform for computational data analysis and visualization. For simulation result visualization, a sliced view and stream tracing are utilized.

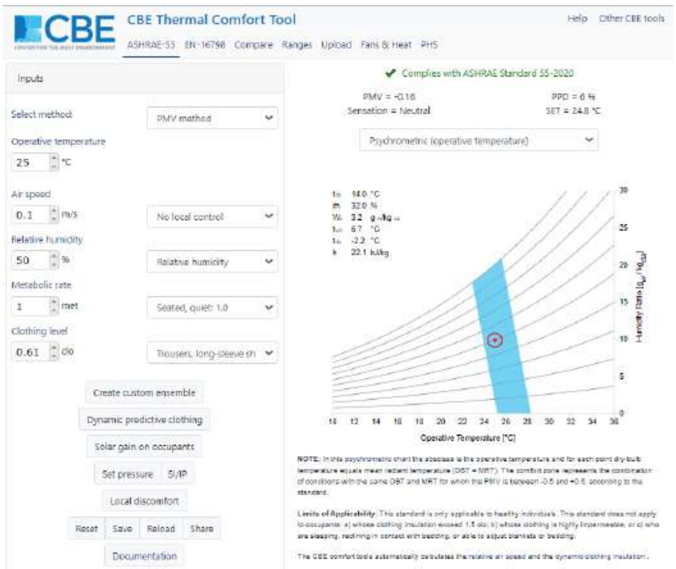
A sliced view is a visualization type of render view representing a representative result. Stream tracing is a filter to generate streamlines for vector fields. It can produce wind flow as the representative coordinate of our selection. Line Chart is a numeric plotting for slice view results.



(Fig 4.6) – Post-Processing Steps
Source: Author adapted from ParaViewUsersGuide - 10.04.2022

4) The CBE thermal comfort tools

The CBE (Center for the Built Environment) tool is a no-cost tool for measuring thermal comfort and casualisations corresponding with the ASHRAE 55-2017, ISO 7730:2005, and EN 16798-1:2019 thermal comfort standards (Tartarini, 2020). Specific for this research, the ASHRAE-55 thermal comfort standard is applied, a set of data input for evaluating thermal comfort, including operative temperature, air speed (input based on the CFD simulation result), relative humidity, metabolic rate, and clothing level. Figure 4.7 is the interface of CBE thermal comfort tools.



(Fig 4.7) – The CBE Thermal Comfort Tool

Source: Tartarini, (2020)

5) ms. Excel

The result of the CBE tool is plotted in a tabular format to evaluate the percentage of the sampling that has received thermal comfort (PMV -0,5 until 0,5). The sampling is tested at a critical time during the year of weather data which is the hottest day in the case study.

Chapter 5
Data and Analysis

Chapter five consists of data and analysis of two research phases: phase 1 for defining equatorial rainforest climate characteristics and phase two for investigating climate-responsive design solutions in the vernacular settlements.

5.1. Defining Equatorial Rainforest Climate Characteristics

Understanding the annual weather data aims to define the climate pattern or characteristic for those selected case study locations. The finding of climate characteristics will be used as parameters to evaluate the climate-responsive design in the selected case studies. In this section, the analysis will focus on the local climate aspect, which probably had an interrelation with the design solution in Indonesia's vernacular settlements.

The analysis will utilize sets of weather data collected from the ERA 5 in 2021. Before conducting the 2021 weather data analysis, the preliminary climate data analysis has done by the researcher. The climate analysis will explain in the following pages based on each climate elements.

(Table.5.1-a) Weather Data 2021 for Huta Siallagan and Kampung Naga locations
Source: Author based on ERA5 database – weather data 2021

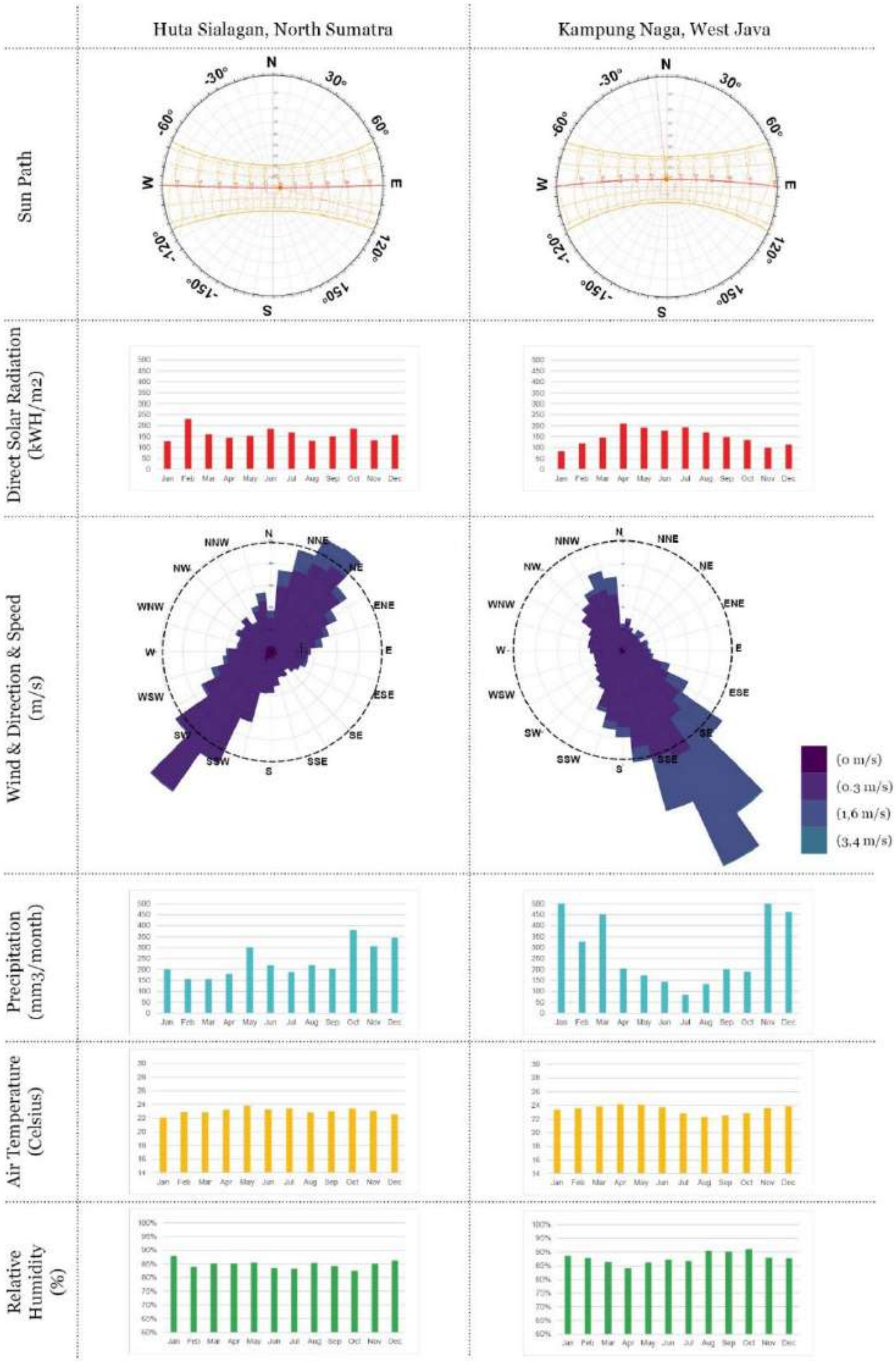


Table.5.1-b) Weather Data 2021 for Huta Siallagan and Kampung Naga locations

Source: Author based on ERA5 database – weather data 2021

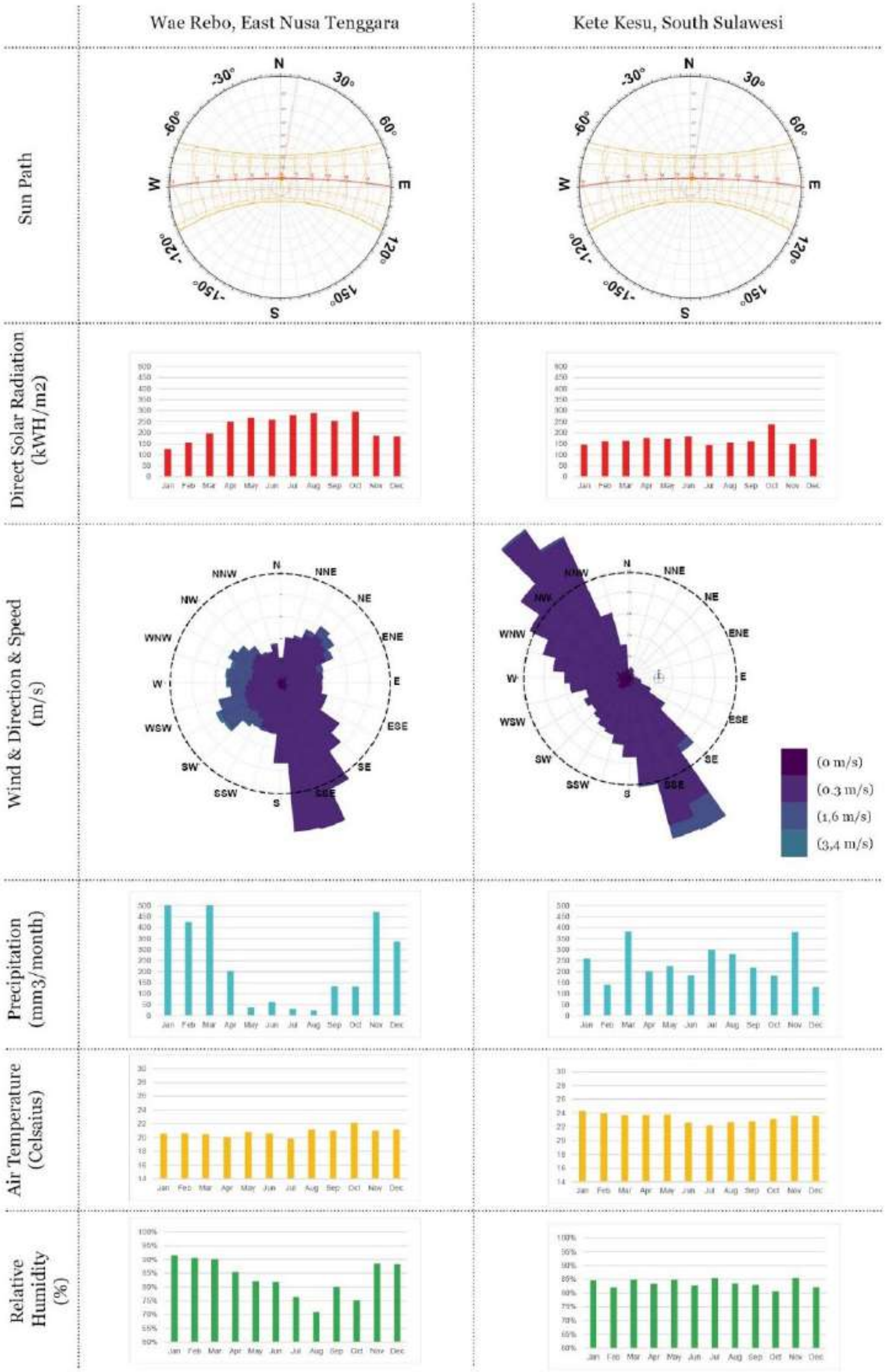


Table 5.1 a and b summarizes the statistical formed monthly average of weather data. All the data was formed in the hourly format and analyzed by the statistical method in the aforementioned selected case location. The calibration was conducted as consideration of different elevations between weather data and site elevation, which only the impact can be seen in the air temperature data. Based on the rule of thumb, the temperature is decreased by 6.5° C per 1.000 m altitude higher.

5.1.1 Sun path analysis

Regionally, all the selected case studies lay in the equatorial line. The daytime and night-time are almost equal in duration, approximately 12 hours each day. The sun's position projected from earth has three patterns: the most northern, in the middle / in the equinox, and on the most southern. Table 5.2, 5.3, and 5.4 record the peak of sun altitude of the day for three representative time which are at the most northern (June), at the equinox line (March) and at the most southern (December)

(Table.5.2)- The most northern sun position of selected case studies
Source: Author based on ERA5 database – weather data 2021

Case study	Date	Time	Sun Altitude
Huta Sillagan (2.679003, 98.836527)	21 Jun	11:58	69.25°
Kampung Naga (-7.361018, 107.991982)	15 Jun	11:45	59.32°
Wae Rebo (-8.769360, 120.283831)	21 Jun	12:05	57.97°
Kete Kesu (-2.996398, 119.910241)	17Jun	12:05	63.63°

(Table.5.3) - The middle/equinox sun position of selected case studies
Source: Author based on ERA5 database – weather data 2021

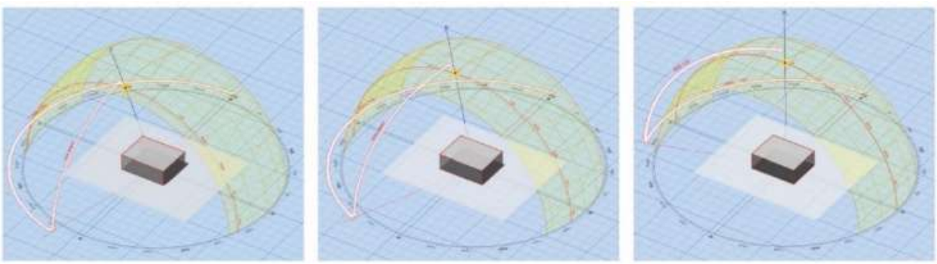
Case study	Date	Time	Sun Altitude
Huta Sillagan (2.679003, 98.836527)	29 Mar/ 21 Sep	12:30	89.21°
Kampung Naga (-7.361018, 107.991982)	22 Mar/ 21 Sep	11:55	81.93°
Wae Rebo (-8.769360, 120.283831)	22 Mar/ 21 Sep	12:05	80.67°
Kete Kesu (-2.996398, 119.910241)	22Mar/ 21Sep	12:20	86.35°

(Table.5.4) - The most southern sun position of selected case studies
Source. Author based on ERA5 database – weather data 2021

Case study	Date	Time	Sun Altitude
Huta Sillagan (2.679003, 98.836527)	21 Dec	12:02	63.89^{o}
Kampung Naga (-7.361018, 107.991982)	20 Dec	11:40	73.88^{o}
Wae Rebo (-8.769360, 120.283831)	21 Dec	12:00	75.16^{o}
Kete Kesu (-2.996398, 119.910241)	17 Dec	12:00	69.65^{o}

The peak of the sun position from the most northern position is around mid-June with sun altitude between 50^{o} - 70^{o}, which in the particular context of case location, Huta Siallagan located on the most northern geographical location among selected case locations, has the peak of sun position by 69.25^{o} at 11:58 Am in 21 of June. Meanwhile, the peak of sun position from the most southern is around mid-December with sun altitude between 60^{o} - 75^{o} and most eastern geographical location of selected case study such as Wae Rebo in Nusa Tenggara Island has the peak sun position by 75.16^{o} at noon on 21 December.

The highest sun altitude in the equatorial regions occurs in March and September at around more than 80^{o} (see table 5.3). In detail, there are slightly different sun altitude positions in those case studies which are 89.21^{o}, 81.93^{o}, 80.67^{o}, and 86.35^{o} respectively of Huta Sillagan, Kampung Naga, Wae Rebo, and Kete Kesu. At the time, there is a short shadow projection caused by the perpendicular sun's altitude position to the earth. (Figure 5.1). Meanwhile, in summer (June) or winter (December) time, the sun’s altitude is lower and identical, which is around 70^{o} (table 5.2 & 5.4).

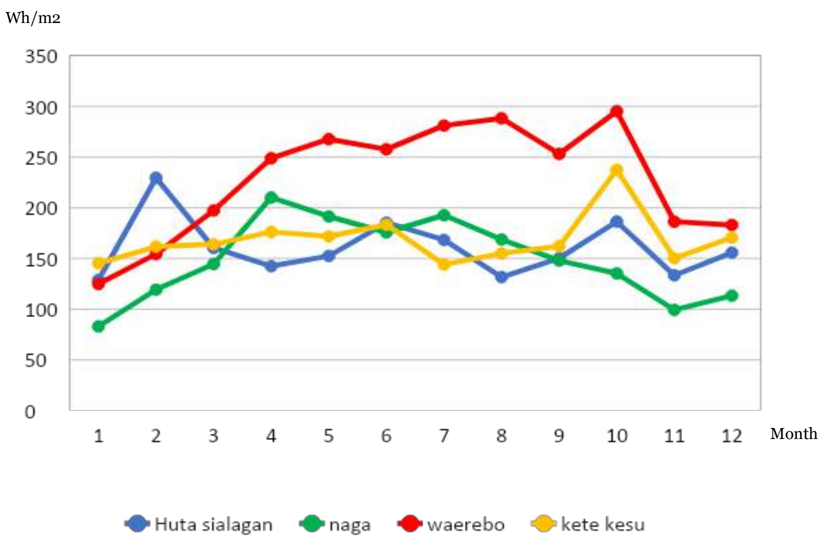


(Fig.5.1) - Shadow projection in different sun altitudes for 70^{o}, 80^{o}, and 90^{o} (left to the right image)
Source: Author

Overall, it would be argued that the critical time related to the direct sun angle position is in the equinox position. In the equatorial context, this period happened twice a year. When the sun is positioned at almost perpendicular 90o to earth, the settlement element such as a tree or the building itself would have a limited or short distance of shadow at the time which has a possibility of direct radiation into the building or ground surface. A long period of direct radiation can increase air temperature or damage an electrical appliance. However, due to the high angle of the sun, the vertical surface of the building envelope such as the wall surfaces in several orientations is unquestionably covered by shadow, in contrast, the horizontal surface of the settlement element such as the roof and the ground surface has penetrated by the direct solar radiation (Figure 5.1).

5.1.2 Global solar radiation

Global solar radiation represented in figure 5.2 indicates that the equatorial rainforest region received average solar radiation approximately around 140 – 230Wh/m2/month. In the period of April until August, the intensity of solar radiation plummeted compared to other months.



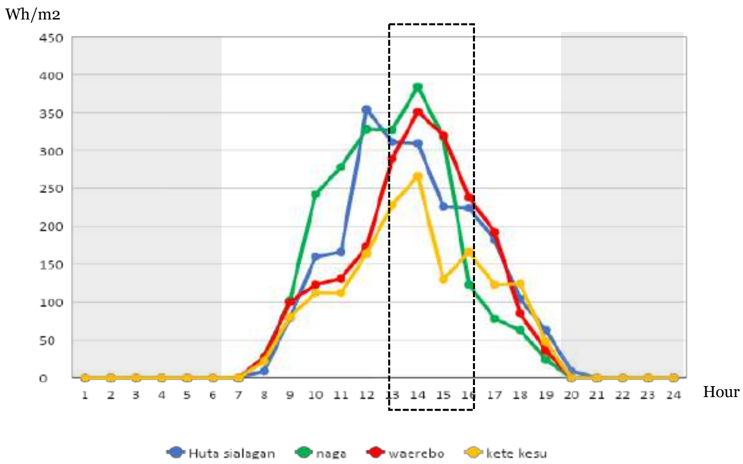
(Fig.5.2) – Graph of annual average solar radiation in all locations
Source: Author based on ERA5 database – weather data 2021

(Table.5.5) – Summary of annual solar radiation during daytime (6 am – 6 pm)
Source. Author based on ERA5 database – weather data 2021

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Max (Wh/m2)	997	928	971	937
Min (Wh/m2)	1.69	1.69	1.69	1.69
Average (Wh/m2)	160.13	148.60	228.58	168.50

Table 5.5 summarised the annual weather data in selected case studies which the amount of solar radiation indicated a similarity reached the peak up to 970 Wh/m2 and less than 1.69 Wh/m2 at the lowest. The relation between land elevation and high solar radiation was founded in Wae Rebo at 1.109 sml which received the highest amount of solar radiation with an average annual solar radiation of 228.59 Wh/m2. Otherwise, Kampung Naga located at 600 sml altitude has the lowest solar radiation at 148.60 Wh/m2.

Hourly Direct Solar Radiation



(Fig.5.3) – Graph of Hourly Global Solar Radiation on March 22
Source: Author based on ERA5 database – weather data 2021

22 of March is decided as an example of weather data in those selected cases to investigate the solar radiation during the daytime because at the time the sun's position is almost in the equatorial line which can be a representative case.

Based on figure 5.3, the peak of solar radiation in the equatorial rainforest is around 12 pm – 2 pm. Huta Siallagan received the highest solar radiation at 12 pm as much as 354 Wh/m2. Meanwhile, Kampung Naga, Wae Rebo, and Kete Kesu have the peak of direct solar radiation at 2 pm, as amounts of 384 Wh/m2, 351 Wh/m2, and 266 Wh/m2 respectively.

5.1.3 Wind velocity and direction

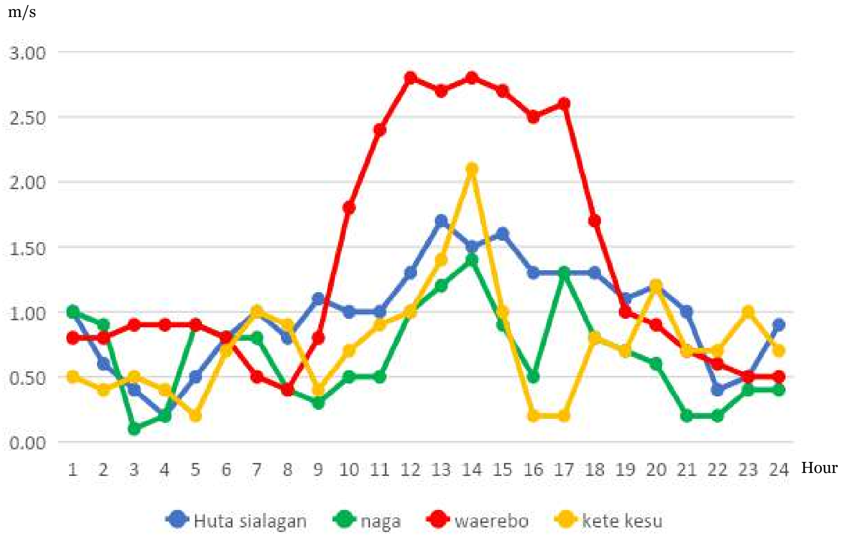
In this analysis, the research focused on identified wind aspects in the selected locations. The weather data taken from ERA5 database (table 5.1) shows that all the locations in the Equatorial Rainforest climate zone have varied wind angles. The wind direction diagram is described in table 5.1. Every location has a different dominant wind direction, as recorded Southwest, and Northeast direction (Huta Siallagan); South-Southeast direction (Kampung Naga); Northwest and South-Southeast direction (Kete Kesu). Meanwhile, Wae Rebo mainly receives wind from the South-Southeast direction but the highest velocity comes from West0Southwest and Northeast.

(Table.5.6) – Annual summary of wind velocity at 10 above ground
Source. Author based on ERA5 database – weather data 2021

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Max (m/s)	3.60	4.00	4.50	2.30
Min (m/s)	0.10	0.10	0.10	0.10
Average (m/s)	0.91	1.20	1.02	0.78

The average wind velocity within the equatorial rain forest based on Beaufort's wind scale classified in the light air category (0.3 – 1,5). In open space without any wind-blocking, the wind condition influences land as Smoke drifts and vanes remain motionless. In the relation to high elevation and wind velocity, figure 5.4 describes the example condition on March 22 in which in Wae Rebo location, the wind speed is flushing up to 2.7 m/s while in other case locations the daily wind speed is no more than 1,5 m/s.

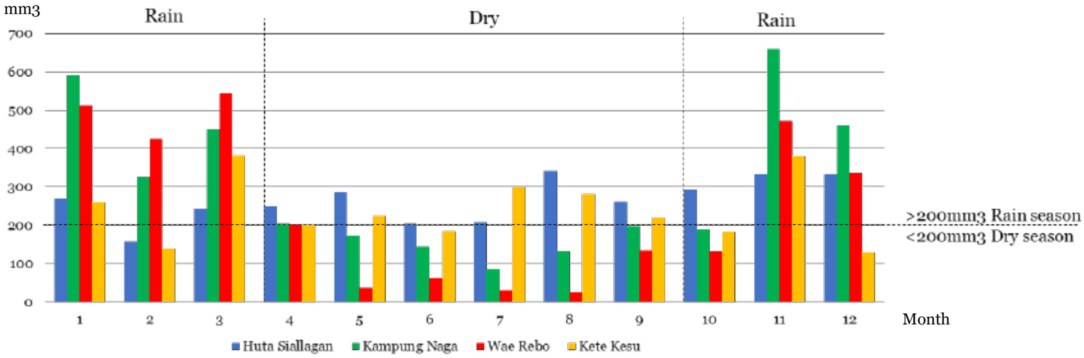
Hourly Wind Velocity



(Fig.5.4) – Graph of Hourly Wind Velocity on March 22
Source: Author based on ERA5 database – weather data 2021

5.1.4 Precipitation

The precipitation analysis aims to see the rain precipitation pattern. Figure 5.5 describes rain precipitation among the selected case location. The monthly total of rain precipitation has a peak from August until March in all case study locations. Based on Carl Mahoney's theory, all the case study locations identify as high rain precipitation, which is counted to receive more than 200 mm^3/month.



(Fig.5.5) – Graph of Annual Rain Precipitation Per Month (mm3/Month)
Source: Author based on ERA5 database – weather data 2021

In detail, table 5.7 summarize the number of rain precipitation in all cases. The monthly rain precipitation in Huta Silagan lies within 158 mm3/month until the peak at 341 mm3/month in August. In Kampung Naga, the monthly rain precipitation is around 85mm3/month up to 660 mm3/month and the highest amount of precipitation occurs in October. The settlement lies adjacent to a river which plays an important role as a rainwater run-off area during the rainy season. Meanwhile, Wae Rebo and Kete Kese are identical which both reached up to 544 mm3/month and 381 mm3/month respectively in the dense rain season in March. Based on the interview conducted on-site, the settlement has abundant freshwater sources as well as consuming groundwater springs.

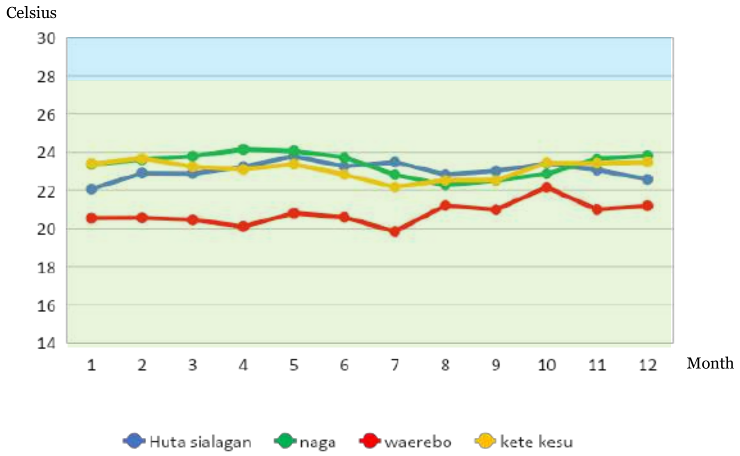
(Table.5.7) – Annual summary of rain precipitation
Source. Author based on ERA5 database – weather data 2021

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Peak (mm3/month)	341 (August)	660 (October)	544 (March)	381 (March)
Lowest (mm3/month)	158 (February)	85 (July)	25 (August)	130 (December)
Average (mm3)	265	301	242	240
Total (mm3/year)	3.449	3.913	3.152	3.122

In summary, high precipitation has been one of the climate challenges in the equatorial rainforest region related to building resistance and weathering problems. On another side, it potentially becomes an opportunity for settlement in terms of accessibility to getting freshwater sources if the planner can optimize water and rainwater management.

5.1.5 Air Temperature

Air temperature has been one of the aspects of climate elements that identify heat or cold conditions in the air. This research uses the Celsius unit to represent air temperature analysis. Figure 5.5 describes the air temperature pattern in those selected locations as representing locations for the equatorial rainforest climate region in Indonesia. The monthly average outdoor temperature in Indonesia's equatorial rainforests land lies in the range of 19^{o} C to 24^{o} C (figure 5.5). In Huta Siallagan, Sumatra Island, the lowest average monthly air temperature occurs in January at 22.070C and the highest air temperature is in May at 23.78^{o} C. In Kampung Naga, West Java is also indicated as a little range of monthly average air temperature (3^{o} C), the lowest temperature is in August at 22.27^{o} C and the highest air temperature is in February at the amount of 24.15^{o} C. Wae Rebo has the lowest monthly of air temperature in July, which is similar to Kete Kesu, at about 19,85^{o} C and 22,17^{o} C respectively. The highest temperature occurred in October for Wae Rebo (22,16^{o} C) and in February for Kete Kesu (23.68^{o} C). It has a similar pattern with rain precipitation that in the middle of the year has the lowest rain precipitations. So, it can be concluded, that the dried season has lower air temperature than the rain season.



(Fig.5.6) – Graph of annual average air temperature (Celsius)
Source: Author based on ERA5 database – weather data 2021

Table 5.8 is the calculation result of mean temperature for all locations. The monthly average air temperature indicates quite similar for location in the high land settlement classification as around 23^{o} Celsius, while Wae Rebo in hills land is considerably lower air temperature.

(Table.5.8) –Annual mean air temperature
Source: Author based on ERA5 database – weather data 2021

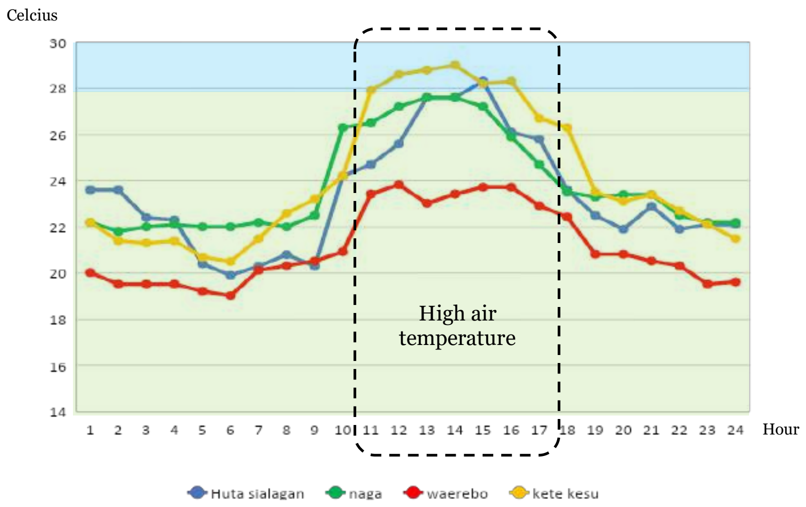
	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Land elevation	769 sml	600 sml	1.109 sml	800 sml
Average (Celsius)	23.04	23.39	20.79	23.10

Hourly 2-meter air temperature

To understand the air temperature change between daytime and night time, hourly data of air temperature has been studied respectively on this research. Based on figure 5.6, the delta air temperature range in the equatorial rainforest stated around 5 - 9°C. It is considerably less shocking of daily air temperature change.

(Table.5.9) –Daily air temperature range
Source: Author based on ERA5 database – weather data 2021

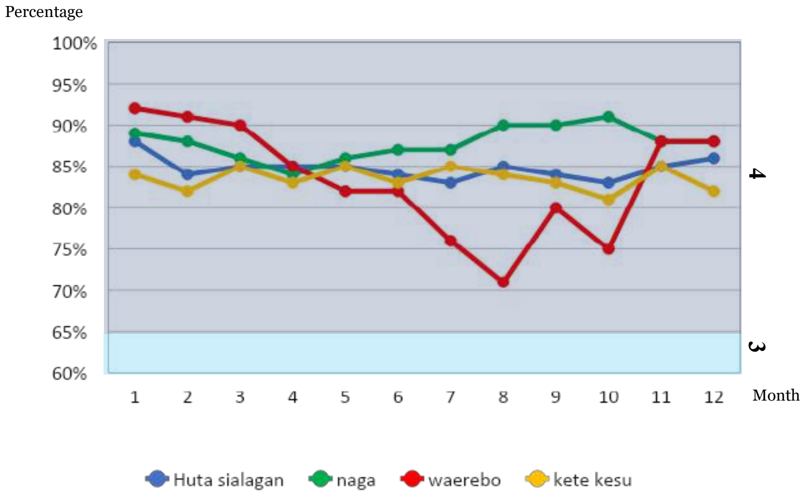
	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Highest (Celsius)	19.90	21.80	19.02	20.50
Lowest (Celsius)	28.30	27.60	23.82	29.00
ΔT air temperature (K)	8	6	5	9



(Fig.5.7) – Graph of hourly 2-meter Air Temperature on March 22
Source: Author based on ERA5 database – weather data 2021

5.1.6 Humidity

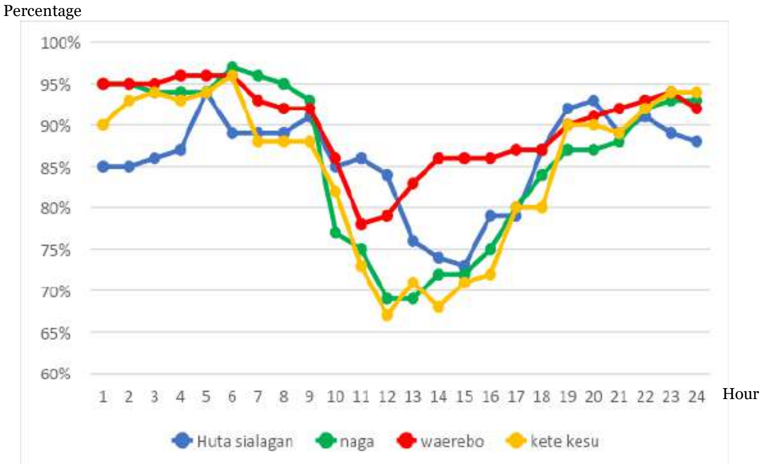
The equatorial rainforest has had constant high humidity over the years. Figure 5.8 shows that the average monthly humidity for all case locations is constantly between 75% - 100%. It can be defined as group 4 based on Mahoney classification (very humid). In detail, the monthly average relative humidity in Huta Siallagan is between 88% - 91%. Kampung Naga received monthly average relative humidity of about 87% - 92%, Wae Rebo receive 75%-90% of relative humidity, and lastly, Kete Kesu received 88%-91% of monthly average relative humidity.



(Fig.5.8) – Graph of annual average relative humidity
Source: Author based on ERA5 database – weather data 2021

Hourly humidity data has been studied to define the daily pattern of climate challenge in the equatorial rainforest, which describes in figure 5.9. Based on the analytical analysis, it has a correlation pattern between relative humidity and air temperature. When the relative humidity is lower, the air temperature is getting higher for the cases in the equatorial rainforest. Relative humidity around 12-14 pm indicates a decreasing pattern for all cases.

Hourly Relative Humidity



(Fig.5.9) – Graph of hourly relative humidity at March 22
Source: Author based on ERA5 database – weather data 2021

5.2. Investigating Climate-Responsive Design Solution

The descriptive thematic analysis method was conducted to investigate the knowledge of vernacular settlements responsive to climate context. The primary data from a remote on-site survey and the secondary data from the literature review are combined and analyzed in a thematic topic. The finding of the inventory study on vernacular settlements is divided into six thematics. The investigation aims to find the implementation and principle of climate responsive design solutions from the based practice of vernacular settlement. The theoretical framework is used as the base of knowledge for analysis.

5.2.1 Building Configuration and Orientation

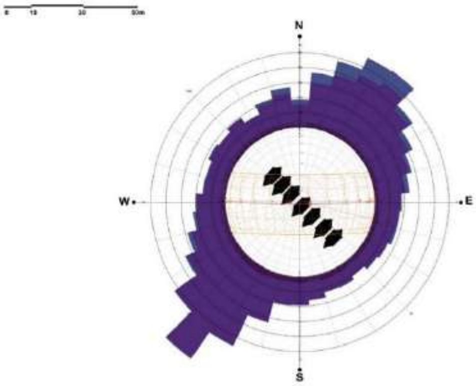
The settlement environment condition is in low-density areas considerably rural and semi-rural area. The case study has an ordered building configuration either linear, grid, or radial. Table 5.10 is summarized the finding the of the investigation phase.

(Table.5.10) – Settlement Environment Classification
Source: Author

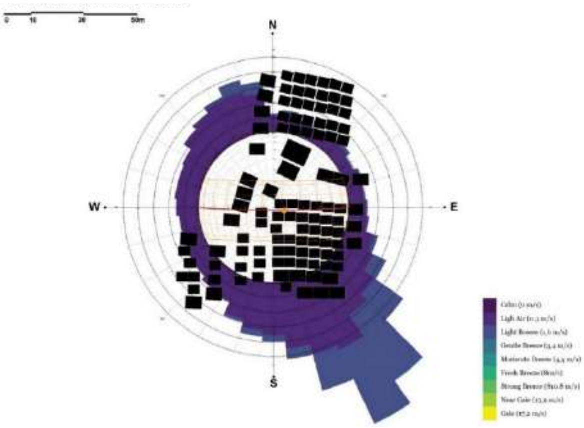
	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Environment condition	Semi-rural	Semi-rural	rural	Semi-rural
Settlement pattern	Dense in small scale	Compact in order	Detached in order	Dense in small scale
Building configuration	Linear	Grid	radial	Linear
Building type	Single-family house	Single-family house	Co-living house	Single-family house

To investigate how responsive the settlement configuration to the climate conditions, figures 5.10 and 5.11 illustrate superimposed the climate data and settlement site plan.

a) Huta Siallagan, Sumatera Island

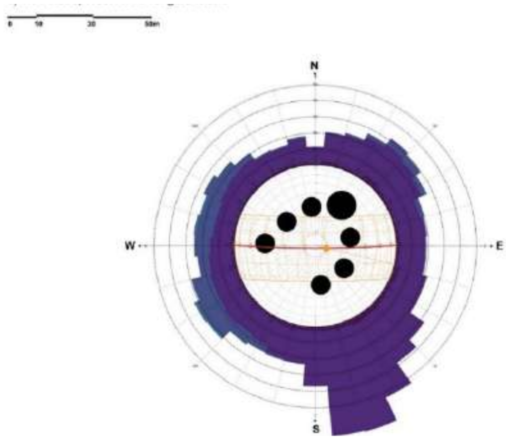


b) Kampung Naga, West Java Island

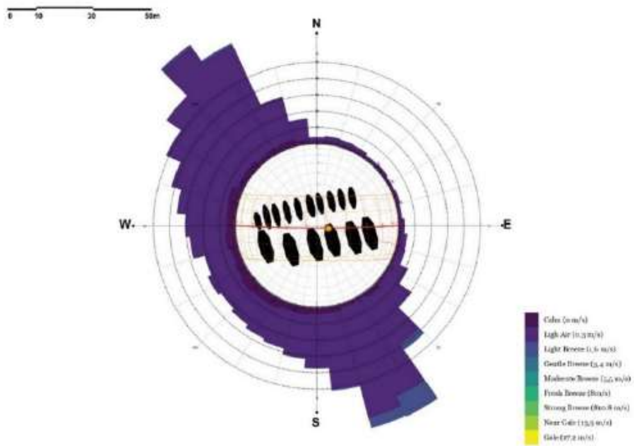


(Fig.5.10) – Building configuration and climate data overlaid. a) Huta Siallagan b) Kampung Naga
Source: Author

a) Wae Rebo, West Nusa Tengara Island



b) Kete Kesu, Sulawesi Island



(Fig.5.11) – Building configuration and climate data overlaid a) Wae Rebo b) Kete Kesu
Source: Author

Based on the overlay of climate data and settlement configuration in figures 5.10 and 5.11, it is indicated that the building configurations orientation towards the wind direction rather than to sun path. Huta Siallagan and Kete Kesu settlements are arranged in a linear and the street canyon is perpendicular to the wind direction. For Huta Siallagan, the building configuration towards a Southwest to Northeast direction (fig 5.10-a), while Kete Kesu's building direction is oriented Northwest to Southeast (fig 5.11-b).

On the other hand, houses in Kampung Naga have arranged in grid composition and street orientation towards the south to east direction, as a response to the sloping direction (fig 5.10-b). However, based on the theory, the wind direction is influenced by land topography. The arrangement of the houses in Kampung Naga can optimize outdoor airflow by contextual to terrain conditions. Kampung Naga's building configuration is oriented on the short surface in an East-West direction meanwhile the other settlements configuration tends to order the length of building surface towards sunrise and sunset direction. However, as explained in the first subchapter that in the equatorial rainforest the sun angle position is almost perpendicular to 90°, which means any vertical surface (wall) of the building has lower radiation compared to the horizontal surface (roof). It would be argued that any building direction would receive almost similar exposure to solar radiation throughout a year for constant cloud intensity.

In the last case of vernacular settlement inside the equatorial rainforest, Wae Rebo has radial patterns and an identical to a half-circle for building configurations (fig 5.11-b). Nevertheless, the building configuration creates a wind barrier for the open space in the center of the settlement from the southwest to northwest wind direction.

In conclusion, the shared principle of building configuration in the vernacular settlement case studies is highly responsive to wind conditions rather than the sun path positions. The building orientations are almost perpendicular to most of the wind direction. Considering humidity in the climate context, accelerating the wind speed rather than blocking the wind is obviously responsive to climate context in achieving comfortable conditions.

5.2.2 Building Layouts & Section

This analysis part of vernacular building layouts and sections are considered the behavior of climate elements for housing. The theoretical framework in chapter two is a foundation of knowledge to investigate the implementation of climate-responsive at the building level through descriptive qualitative analysis. The data in table 5.11 and table 5.12 illustrate the building data and overlay of climate impact on the building based on qualitative analysis with a supporting theoretical framework. It has three parameters to be overlaid which are solar angle, wind movement, and rainwater.

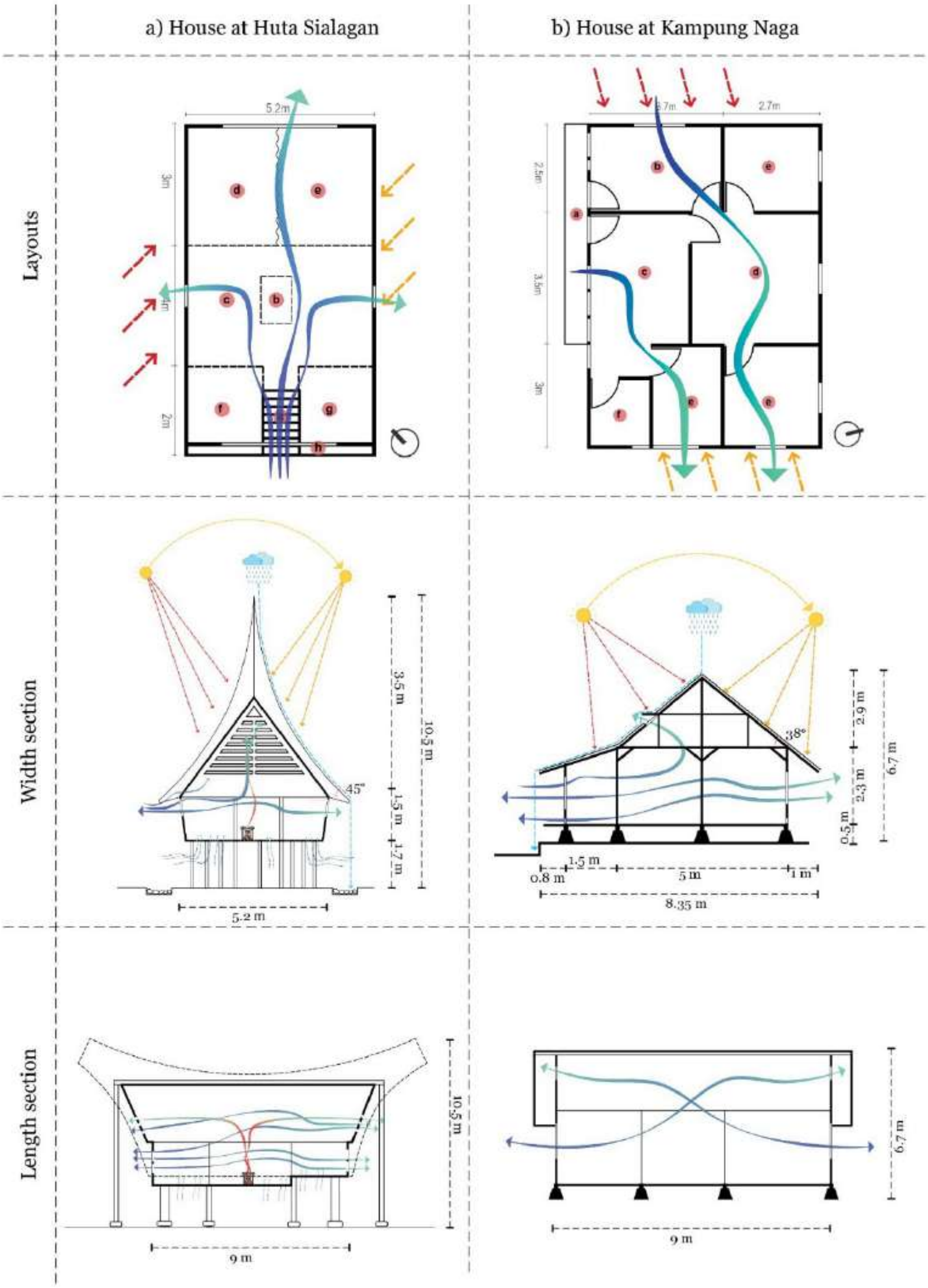
(Table.5.11) – Building layout characteristic
Source: Author

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Layout size	46,8 m2	57.6 m2	201 m2	32 m2
Layout form	Rectangular	Rectangular	Circle	Rectangular
Capacity	Single-family	Single-family	Multifamily	Single-family
Number of floors	1	1	4	2
Building layout ratio (Width - Length)	1 : 1.7	1:1,4	1:1	1: 2.5
Layout proportion	Symmetrical	Symmetrical	Symmetrical	Symmetrical
Building structure component	Lower – main - upper	Lower – main - upper	Lower – joined main and upper	Lower – main - upper

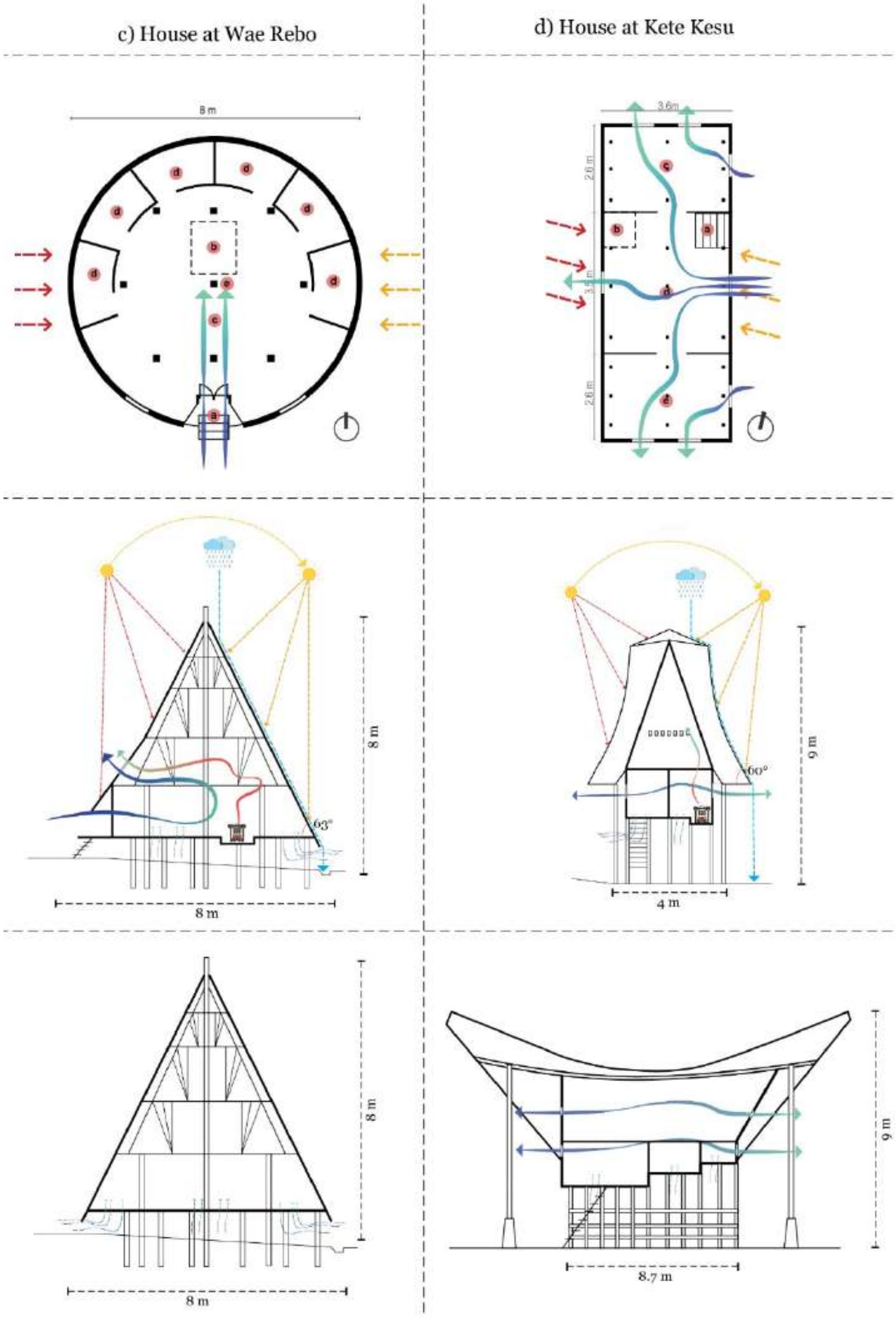
To be contextual between the building layout as responding to user needed at the time, the context of the user activity for the vernacular housing explained in the third chapter. All the vernacular building has symmetrical proportion, but three vernacular housing has a rectangular layout with different rations; Huta Siallagan, Kampung Naga, and Kete Kesu, while Wae Rebo has a circular floor plan.

As the focus of the analysis is the frame of climate-responsive, the items of the analysis will consider how the building layouts are responsive to climate challenges in the equatorial rainforest context. Rectangular building layouts and a semi-open plan layout can optimize the air circulation in the room, especially for locations with low wind velocity and desirable air temperature conditions which is the climate character of equatorial rainforest based on defining climate characteristic analysis parts. In another hand, to get a comprehensive analysis, the building section needs to be investigated to understand the flow of air flushing to the indoor spec.

(Table.5.12) – Building plan and section interrelated with climate element a) Huta Siallagan b) Kampung Naga
Source: a) Rambe,2019 b) Sudarwani, 2016 modified by author



(Table.5.13) – Building plan and section interrelated with climate element c) Wae Rebo c) Kete Kesu
Source: c) Antar, 2018 d) Manurung, 2017 modified by author



Three of the settlement house study have openings as windows and air
ventilation on the four sides of the façade with various proportions that can

optimize natural ventilation for the building, while Wae Rebo's house only provides small openings on the same side of the building entrance without any opening on the upside. It would be argued that the principle of cross ventilation is not found in the Wae Rebo's building.

In relation to dense rain precipitation in the equatorial rainforest region, the gamble roof shape with a roof angle of more than 30 degrees is an advantage to avoiding water traps in the upper structure. Table 5.13 for the width and length section confirms the roof angle in the case studies helps to avoid rainwater accumulation on the roof.

5.2.3 Building (housing) envelope

This part of the analysis focused on the building envelope analysis in the vernacular settlement. As described in figure 5.13 below, the visualization of building envelopes by 3d modeling for vernacular housing in a selected case location.

The analysis investigates three vernacular housing (Huta Siallagan, Kampung Naga, and Kete Kesu) have identical building envelopes which formed in a rectangular form. Meanwhile, Wae Rebo's house has a cone building form in a symmetrical proportion which differs from the other vernacular house. Considering the high level of sun altitude in the equatorial rainforest region, the rectangular box building envelope theoretically is a strategy to reduce direct solar radiation only if the direction of the bigger roof surface is oriented towards the North-South direction. In practice, only in Kampung Naga house is found and applied. The other buildings in Huta Siallagan and Kete Kesu are oriented their large surface of the roof towards East-West direction. Furthermore, it would be argued that Wae Rebo is optimizing direct solar radiation on the roof by cone building form.

a) Building Form of Vernacular House at Huta Sialagan
Source : Author

b) Building Form of Vernacular House at Kampung Naga
Source : Author

c) Building Form of Vernacular House at Wae Rebo
Source: Author , right photo: https://img.itinari.com/page/content/original/ea78e51f-eb06-48d6-b3f0-6504cfdf6d04-img_6213.JPG?ch=DPR&dpr=1.2000000476837158&w=994&s=5582f162a8e8bf1bb157b2924305e8e0, accessed 2022

d) Building Form of Vernacular House at Kete Kesu
Source : Author

(Fig.5.12) – Building envelope. a)Huta Siallagan b)Kampung Naga c) Wae Rebo c) Kete Kesu
Source: Author

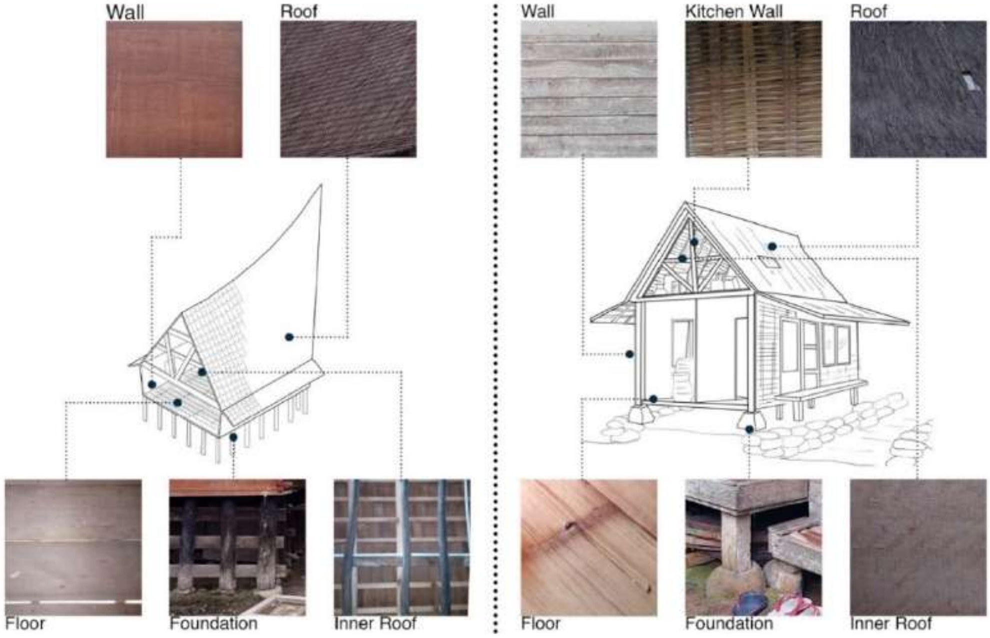
(Table.5.14) – Building envelope characteristic
Source: Author

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Building form	Rectangular form	Rectangular form	Cone	Rectangular form
Building type	Detached house single family	Detached house single family	Detached house multi-family	Detached house single family
Building proportion	symmetrical	symmetrical	symmetrical	symmetrical

In summary, the building envelope for three of those case studies are inviting direct solar radiation to the roof surface rather than avoiding it. Otherwise, Kampung Naga building envelope is considered to arrange the largest roof surfaces in the North-South direction, which theoretically can reduce heat from direct solar radiation. Furthermore, to evaluate the finding of building envelope based on objective measurement, the computational analysis will perform in chapter 6 to understand the design decision in those vernacular settlement case studies from a climate-responsive point of view.

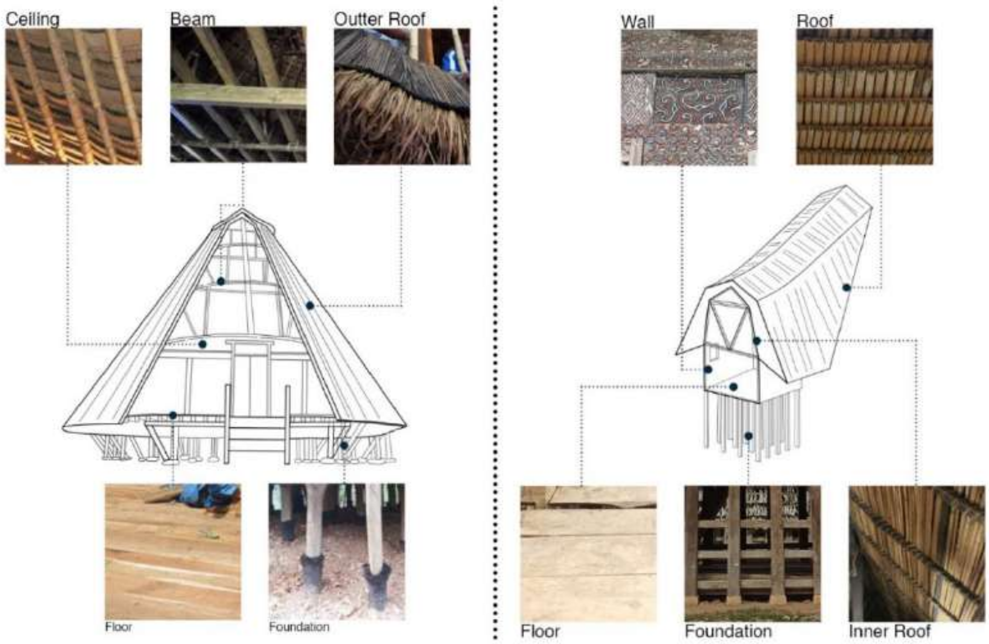
5.2.4 Building Materials

Located in a tropical region with abundant natural resources and vegetation types, many vernacular housings and traditional tribes settlement in Indonesia build from local material sources. Also, it would be argued that varied altitude has influenced the diversity of local construction materials. The investigation of building materials in the vernacular settlement is summarized in figure 5.14 which the explanation of the building material is divided into building material as surface (floor, wall, roof, and window) and structure (foundation, columns, and beam).



a. Bolon house, Huta Siallagan b. Vernacular house, Kampung Naga

(Fig.5.13) – Building material. a)Huta Siallagan b)Kampung Naga
Source: Author sketch and data collection from research assistants



c. Mbaru Niang house, Wae Rebo d. Toraja house, Kete Kesu

(Fig.5.14) – Building material c) Wae Rebo d) Kete Kesu
Source: Author sketch and data collection from research assistants

Materials for Roof

The roof analysis aims to investigate the materiality of the roof surface in the selected vernacular house. Based on the 5.15 figure, the roof material for Mbaru Niang house and Toraja house have multi-layered roof materials and relatively closed arrangements. Mbaru Niang house used dried weeds and coconut husk roof weaving while Toraja house has a bamboo interlocking system. The multi-layered bamboo interlocking system has a unique roof system that allowed space for air flushing in thick roof layers. Bolon house in Huta Siallagan and vernacular house in Kampung Naga had used coconut husk for the roof cover. The material is contained high lignin which becomes durable and resistant to rotting especially in high humid climate regions (Gaspar, 2020).

(Table.5.15) – Building material for roof
Source: Author

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Material	Palm Fiber	Palm Fiber	Dried weeds & Palm Fiber	Bamboo
Vegetation Species for the material	Leaf of Metroxylon sagu	Leaf of *Eurih* and *Tapus*) Local name	Leaf of Borassus flabellifer &	Stem of Bambusa multiplex
Number of layered	Single layered roof	Multi-layered roof	Multi-layered roof	Multi-layered roof
Material character	Water resistance & air cavity material	Water resistance & air cavity material	Water resistance & air cavity material	Water resistance & air cavity material
Roof angle	45°	38 °	63 °	60 °

Materials for Wall

The walls of vernacular houses at Huta Siallagan, Kampung Naga, and Kete Kesu are light and without insulation. The wall material is commonly using wooden panels, but in Kampung Naga, bamboo strips that are loosely woven into meshes are used only for the wall adjacent to the kitchen. The bamboo woven walls provide pores ventilation that is beneficial to flush hot air temperature from kitchen activity. In another hand, Wea Rebo's house does not have a wall as the building surface, the roof is covered from the top building envelope to the floor.

(Table.5.16) – Building material for wall
Source: Author

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Material	Single wooden board without insulation	Single wooden board without insulation	No wall	Single wood board without insulation
Thickness	±4cm	±4cm		±3cm
Material character	Cavity material	Cavity material		Cavity material

<u>Materials for Floor</u>

An elevated floor plate from the ground is commonly implemented in all case studies of vernacular settlements inside the equatorial rainforest climate zone. Based on an interview with residents in Kampung Naga and Kete Kesu, high precipitation and material weathering have been the main reasons for them to build the ground floor of the house above soil level. In addition, an elevated floor system is also beneficial for avoiding water flow blocking by building construction and expanding organic-made construction material lifespan.

For the materiality, the wood panel is a common local material for floors in all cases locations, but the types of wooden panels varies in each location. Especially for Kampung Naga and Wae Rebo, the local communities have preserved an area adjacent to the settlement for wood production internally as a source of building material regeneration. In addition, an elevated floor system is also beneficial for avoiding water flow blocking by building construction and expanding organic construction material lifespan.

(Table.5.17) – Building material for floor
Source: Author

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Material	Wooden panel & 170cm elevated from the ground.	Wooden panel & 50cm elevated from the ground.	Wooden panel & 120cm elevated from ground.	Wooden panel & 170cm elevated from the ground.
Thickness	4cm	4cm	4-6cm	3cm
Material character	Water resistance & air cavity material	Water resistance & air cavity material	Water-resistance & air cavity material	Water resistance & air cavity material

Materials for Structure

The component of the building structure investigates in this research consists of the foundation, column, and beam for low-rise building scale (table 00). The settlement in the high land altitude lower than 900 sml are used river stone as the lower structure of the pedestal foundation. Meanwhile, for Wae Rebo building in 1.109 sml, timber is mainly used for building a foundation covered by palm fiber and nailed to the ground. All of those construction types from the vernacular house with limiting direct contact of the timber building structure to the ground with stone and palm fiber helps to lengthen building material from weathering in high humid and high precipitation climate regions.

(Table.5.18) – Building structure data
Source: Author

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Foundation	Stone - wood foundation above the ground	Stone pedestal foundation above the ground	Wood covered coconut husk foundation partially beneath the ground	Stone wood foundation above the ground
Beam	Timber (±10 X 10 CM)	Timber (±4 X 10 CM)	Bamboo	Timber (±4 X 8CM)
Column	Timber (±20 X 20 Cm)	Timber (±12 X 12 Cm)	Main Colom: Timber (30x30cm)	Timber (±20 X 20 Cm)

5.2.5 Opening and air ventilation

In this part, the investigation focuses on three types of building openings (door, window, and dedicated air ventilation) that are commonly used for housing. Table 5.19 is summarizing the finding of the building opening at the case studies.

The building opening has a function to optimize air movement, daylighting, and climate control for a room (Cremers, 2011). Based on the investigation phase, it found that window opening is mainly for air movement purposes rather than for optimizing daylight, as consider user activity during daytime is outside the house. In addition to circulation purposes, the door has also an opening element that brings impact to the indoor climate. In the case of Huta Siallagan and Kete Kesu house, the entrance is based on vertical access with stairs and the main entrance door is oriented faced to the ground. Meanwhile, Wae Rebo and Kampung Naga have the common types of main doors in the front façade. The door is covered by the long eaves of its roof. Interestingly, at Kampung Naga, the building has two doors in front facades, which are for access to the main living room and to the kitchen. the door to the kitchen is covered with bamboo woven with pores which optimize hot air circulation from cooking activity.

(Table.5.19) – Building opening and ventilation data
Source: Author

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Door	 View of entrance from inside  View of entrance from outside  Door to veranda Wooden panel, 4cm thickness, oriented to ground	 Left: kitchen door Size: 70x200cm Material: Bamboo and wood Right: Kitchen door Size: 70x200cm Material: Wood	 Main entrance Size: Door material: wooden panel Oriented to outdoor space	 View of entrance from inside  View of entrance from outside Wooden panel, 4cm thickness, oriented to ground

Window	 Wooden panel, size: 55x35x3 cm, window at 2 sides of a building oriented to NW and SE	 Original window  Transformation window only for living room	 Wooden board covered with palm fibber Size:40cm x 40 cm	 Material: Wooden panel, size: 40x40x3 cm, window at 4 sides of the building
Gabel ventilation	  Ventilation on the upper roof oriented NE and SW	  Ventilation on the upper roof oriented to East and West		 Ventilation holes (trails)

Three of the case studies have windows on four sides of the facades while only in Wae Rebo house that windows are only found on the front of the façade. The Wae Rebo's housing has only two small windows on the front façade of the building and the ratio of the window compared to all building surfaces are only 8,7%. Contextual to the wind velocity condition in equatorial rainforest identically with light breeze wind (0,9 – 1.5 m/s), the limitation of air ventilation can reduce wind velocity inside the building. On the other hand, Huta Siallagan, Kampung Naga and Kete Kesu have dedicated ventilation in the upper wall. Theoretically, it can accelerate wind velocity in indoor space, especially in compact settlement building configurations.

To conclude, the building opening in three case studies (Huta Siallagan, Kampung Naga, and Kete Kesu) have to implement natural ventilation with additional ventilation in upper side of the wall, meanwhile, Wae Rebo house has limited opening ventilation.

5.2.6 Air Conditioning (Heating System)

Cooking activities such as boiling water can increase air temperature. All the kitchens in the case studies are inside the house. For Huta Siallagan, Wae Rebo, and Kete Kesu, the kitchen with a fireplace is in the centre of the living room, and functions as a heater. But, Kampung Naga has a dedicated room for a kitchen and is separated from other rooms.

(Fig.5.15) – Conventional cooking place a)Huta Siallagan b)Kampung Naga c) Wae Rebo d) Kete Kesu
Source: Author c) Dinilit 2018

Chapter 6
Evaluation and Simulation of Climate-Responsive Design

Chapter six aims to evaluate and simulate the previous chapter's findings concerning how the vernacular settlement overcome the main climate challenge in the equatorial rainforest climate. Considering the complexity of climate responsive practice, the discussion focused on the wind performance as the previous analysis finding shows low wind velocity in the climate zone area for achieving neutral thermal comfort.

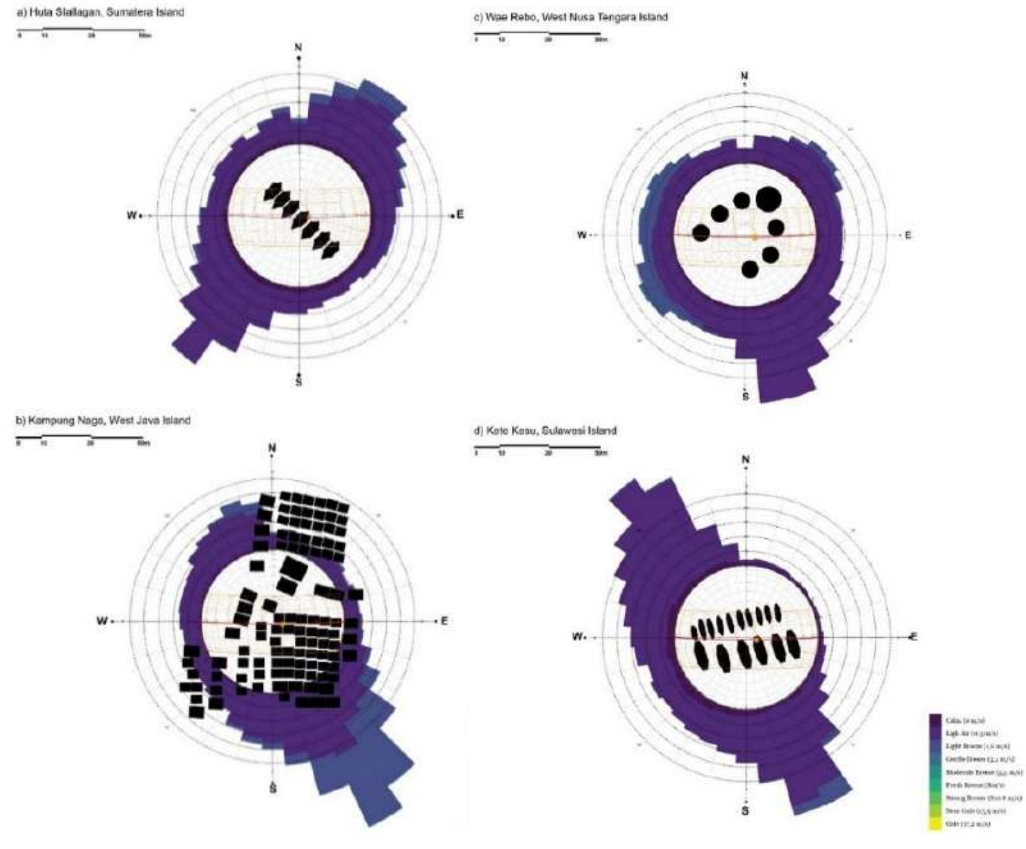
6.1 Climate-Responsive Evaluation for Outdoor Space

This subchapter aims to evaluate the configuration of vernacular buildings in settlement configuration that responds to specific climate characteristics particularly to wind velocity parameters. Based on theoretical reviews to create a healthy outdoor space, utilizing the CFD (Computational Fluid Dynamic) climate analysis running together with the Butterfly plugin in Grasshopper tools aims to simulate the impact of building configuration to wind comfort. The CFD computational process will be based on scripting which describes in previous chapter 4 and the analysis variables of indoor and outdoor data from chapter 5 analysis. The analysis criteria for evaluating the performance of climate design solution adopted from the report of urban climate map and Standard for wind environment by CUHK university, which considering report has a similar context location in a calm wind environment in 80% of relative humidity.

6.2.1 Outdoor Wind evaluation

The CFD simulation is a high-level wind flow simulation, that aims to test the performance of climate-responsive in the vernacular settlement in terms of outdoor wind comfort based on the quantitative analysis that found the Equatorial Rainforest responsive to organize the building configuration considering most of the wind direction.

a) Analysis Variable



(Fig.6.1) – Building configuration. a) Huta Siallagan b) Kampung Naga c) Wae Rebo d) Kete Kesu
Source: Author

Figure 6.1 describes the case of simulation and variables such as wind angle, building dimension, and building distance Based on chapter 5 analysis. In qualitative analysis, the building orientation is more responsively to wind conditions rather than sun orientation.

b) Analysis Criteria

In the below 6.1 table, the wind comfort parameters are adopted from the urban climate map and Standard for wind environment report by CUHK university. The wind comfort criteria are adaptable measurements with the equatorial rainforest conditions with similarity in wind velocity average (1.3 m/s); 80% of relative humidity; 27,9° Celsius of air temperature; 0,3 of clothing coefficient; and 1 (people standing) of metabolism rate for achieving PET neutral or comfortable thermal sensation* (18,1° – 23° Celsius) with research case location.

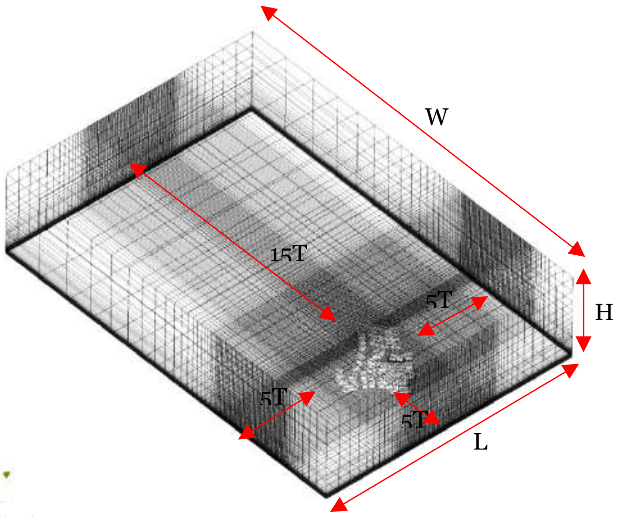
(Table 6.1) - Outdoor Wind Comfort Evaluation Criteria for Moderate Temperature in High Humidity
Source: Liu et al (2019) and urban climate map and standard for wind environment (2018)

Wind Speed	Human sensation
$V \leq 0.3$	No wind with terrible thermal comfort
$0.3 \leq V \leq 0.6$	Unbearable with poor thermal comfort adjustment people's clothing
$0.6 \leq V \leq 1.0$	Tolerant
$1.0 \leq V \leq 1.3$	Somewhat satisfied
$1.3 \leq V$	Comfortable and no damaging environment

c) Simulation Environment

The simulation case is the geometry of the simulation object and simulation environment. The simulation object consists of 3D massing of vernacular settlement buildings and the simulation environment creates a wind tunnel as a virtual climate environment. The wind tunnel size is adopted from Sakiyama's research. Figure 6.2 represented the wind tunnel example case for the outdoor wind CFD simulation, the proportion of wind tunnels is adopted by AIJ guidelines for the practical application of CFD (Tominiga et al, 2008). The computational case dimension was determined: windward, height, and lateral side= 5X, and leeward= 15X to allow flow redevelopment, for which T is the building height.

Simulation case:



(Fig.6.2) – Wind tunnel visualization
Source: Author

Simulation input:

(Table 6.2) – The CFD simulation input for outdoor wind simulation
Source: Author

Component	Input Data			
	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Wind Velocity	0.9	1.2	1.0	0.78
Wind direction	45° from South	45° from East	75° from East	60° from East
Landscape coefficient	Type 3	Type 3	Type 4	Type 3
Case dimension	5.2 x 64 x 10.5 m	129 x 144 x 6.7 m	57 x 100 x 8 m	38 x 72 x 9m
Wind tunnel size (W x L x H)	(168 x 52,5 x 215.2)	196 x 278 x 33.5	137 x 260 x 40	128 x 252 x 45

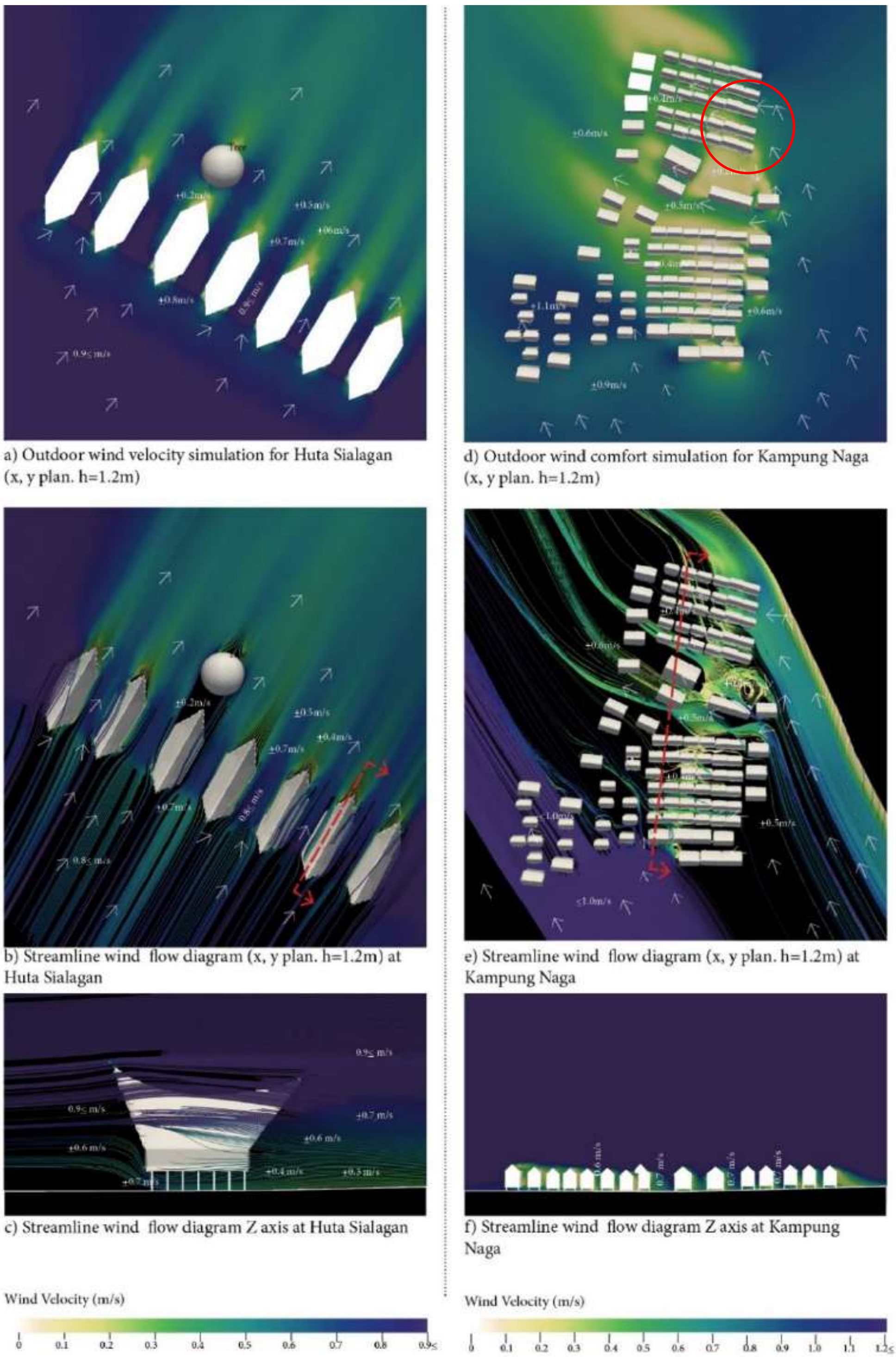
Note: Landscape coefficient
Type 3: coefficient 0.10 (roughly open, cultivated, or natural area with low corps with occasional obstacles
Type 4: coefficient 0.25 (rough, cultivated area with high crops or varying crops and scattered obstacles at relative distances

d) Outdoor Wind Simulation Result

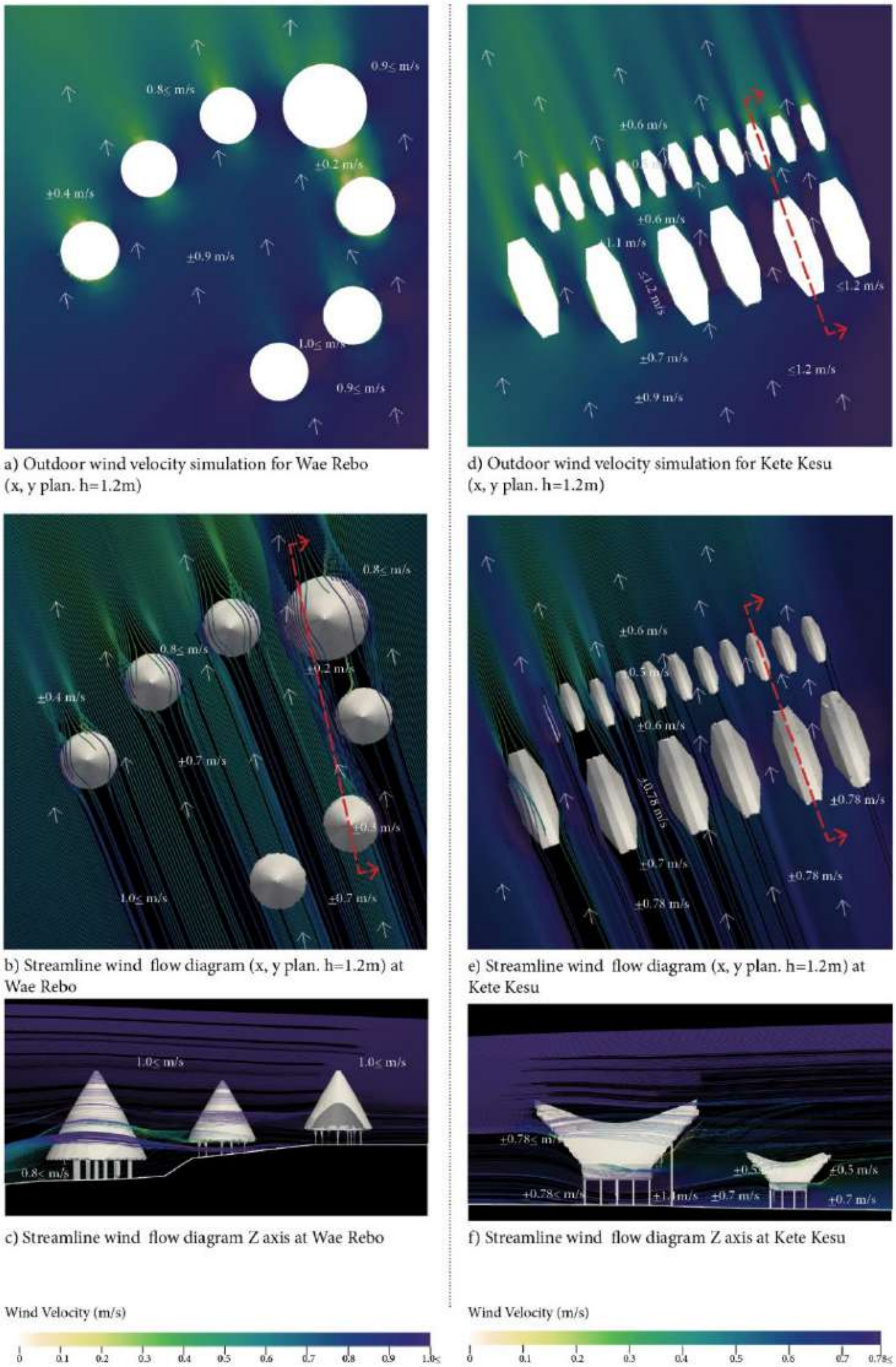
The result of outdoor wind simulation for vernacular settlement configurations (Figures 6.3 and 6.4) illustrates the wind flow distribution for the most wind direction in each case study. The analysis result is visualized based on the horizontal and vertical axis. The arrow represents the direction of the wind, and the colour intensity represents the visualization of wind velocity at the level of 1.2m above the ground. The meaning of colour in the wind simulation is noted in the legend in which the lighter colour is represented lower wind velocity, and the darkest colour is represented the highest wind velocity.

In the case of Huta Siallagan and Kete Kesu settlement, it has an identical principle that building orientation perpendicular to the most of wind direction even though two of the cases have a different majority of wind direction (Huta Siallagan = 450 from South, and Kete Kesu = 600 from East). Based on the CFD simulation result, the design decision can slightly decrease wind velocity by less than 0.2 m/s. Considering the indicator of wind comfort in a high humidity climate, the building configuration in those two case studies are increasing outdoor wind velocity. Huta Siallagan outdoor area receives + 0.6 m/s of wind velocity (fig.6.6-b), and Kete Kesu outdoor area receives + 0.6 m/s (fig.6.7-e) of wind velocity, which considerably tolerant feelings of wind comfort.

In addition to building forms, the elevated floor plate has an important role in conditioning the wind flow at the human body level (1.2m) to be less deceleration (fig.6.3-c and fig.6.4-f). Those two buildings (Huta Siallagan and Kete Kesu) elevated the floor as high as 1,6m above the ground, which allows better air movement at the human level (1,2 – 1,8m). Based on wind simulation, the gap space between the building can accelerate wind velocity significantly. In the case of Huta Siallagan, wind velocity increase more than 0.9 m/s at the gap space, which means the gap can function as an outdoor ventilation channel.

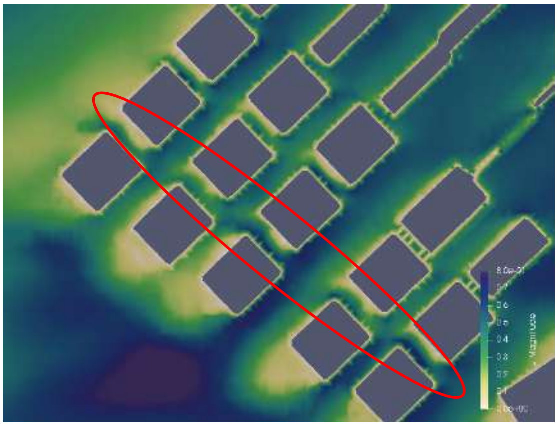


(Fig.6.3) – Outdoor wind simulation result for Huta Siallagan and Kampung Naga
Source: Author



(Fig.6.4) – Outdoor wind simulation result for Waerebo and Kete Kesu
Source: Author

In another case, the Kampung Naga settlement lies on a sloping landscape orientation from the East (lower) to the West (higher) axis while the majority wind direction flushing 450 from the East caused by hilly landscape perpendicular to the East. It would be argued that the design decision in the sloping landscape has limitations in optimizing the building orientation to avoid blocking wind velocity. However, fortuitously air movement between gaps of buildings increased air circulation along the major walking path, which increased the chance of air circulation penetrating the interior of the building, while the main cause of the connection path mainly for accessibility purposes without concerning directly to wind direction. It could be asserted that the existing settlement configurations with detached houses caused gaps between buildings creating a venturi effect which helps to accelerate wind velocity in outdoor space from 0.4 m/s to 0.8 m/s.



(Fig.6.5) – Zoom-in wind velocity simulation result at Kampung Naga
Source: Author

In the case of location without dominant wind direction, the Wae Rebo settlement had organized the building configuration in radial, and the center area was dedicated to public space. Moreover, the building envelope with a cone shape helps overcome any wind direction. The outdoor open space in Wae Rebo receives around 0.8 m/s wind velocity. It has a 0.2 m/s reduction speed from the simulation parameter input for an inlet wind velocity of 1.0 m/s (fig 6.7-b).
In summary, the vernacular settlements are responsive to the wind pattern as considered to tackle the climate challenge in the Equatorial Rainforest. However,

environmental conditions such as terrain or natural barrier also influence the local climate.

6.2 Climate-Responsive Evaluation for Indoor Space

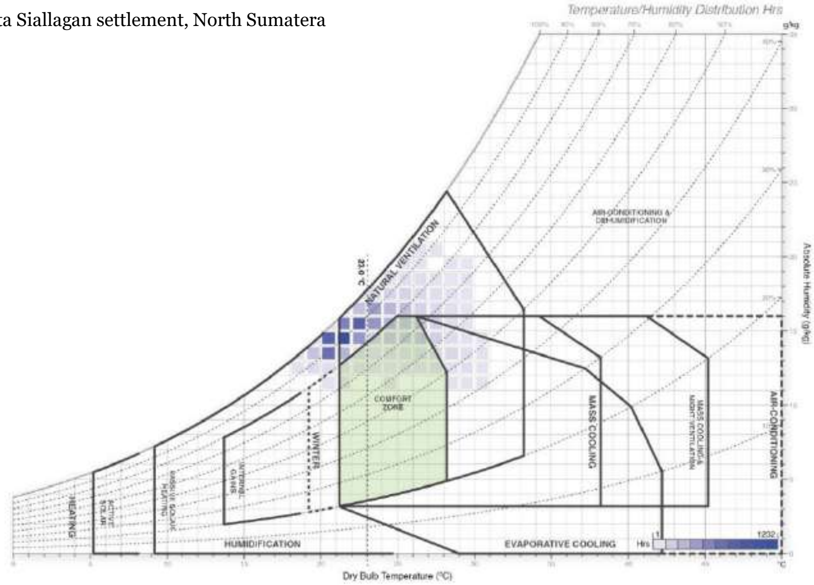
Based on the theoretical framework understanding, the practice of climate responsiveness for low-rise building scales can be achieved through a passive design strategy; then, Bioclimatic psychometric charts are generated as an indicator to find a shared principle of climate responsiveness in the building scale, contextual to the local climate.

6.2.1 Bioclimatic design strategy evaluation

The Givoni-Milne psychometric chart required dry bulb temperature, wet bulb temperature, absolute humidity, and relative humidity data as variables of measurement. The chart is commonly used for residential buildings (Santy et all, 2017). To generate the charts, mean temperature data need to define as a baseline. The calculation method is explained in the previous methodology chapter.

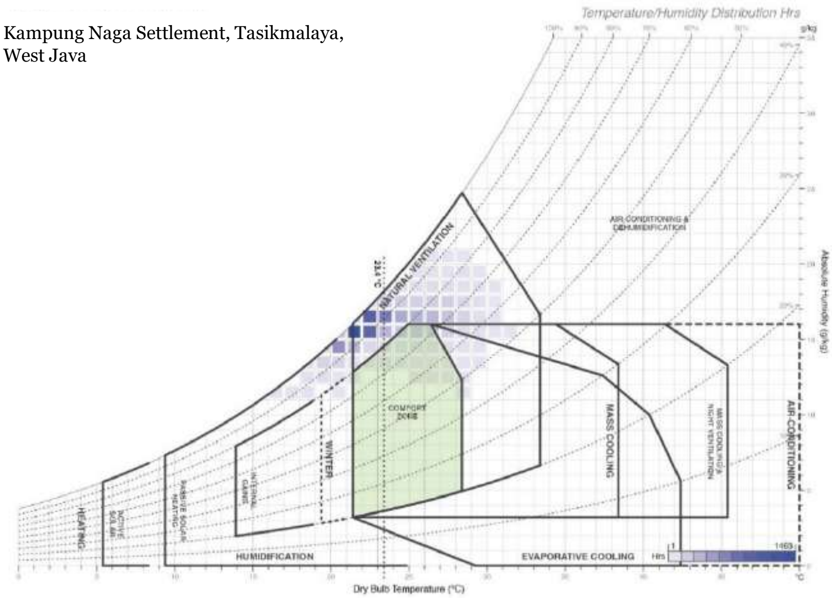
The psychometric chart at figures 6.6, 6.7, 6.8, and 6.9 visualize the interrelation of dry bulb temperature and relative humidity data to identify indoor thermal comfort based on the Givoni comfort standard. The colored grid square indicates the duration of a similar climate condition in a year calculated in hours. The X-axis represents the amount of dry bulb temperature (o Celsius) and The Y-axis represents the amount of absolute humidity (g/kg).

a) Huta Siallagan settlement, North Sumatera



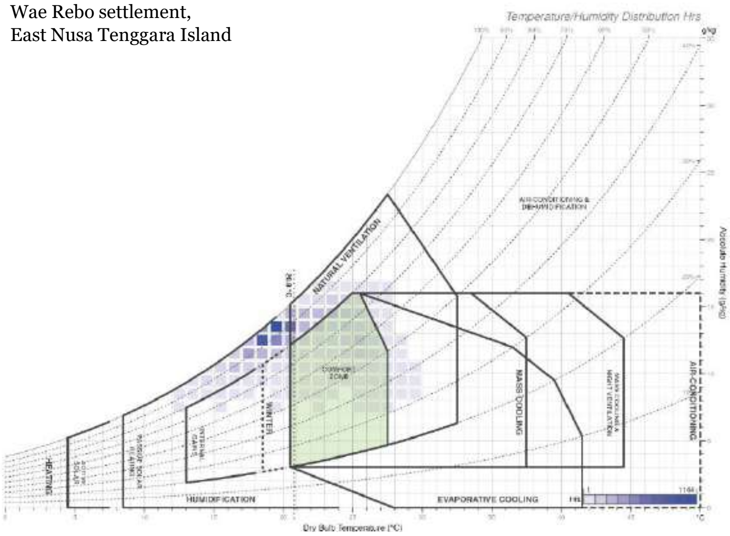
(Fig.6.6) - Bioclimatic psychrometric chart for Huta Siallagan local climate
Source: Author

b) Kampung Naga Settlement, Tasikmalaya, West Java



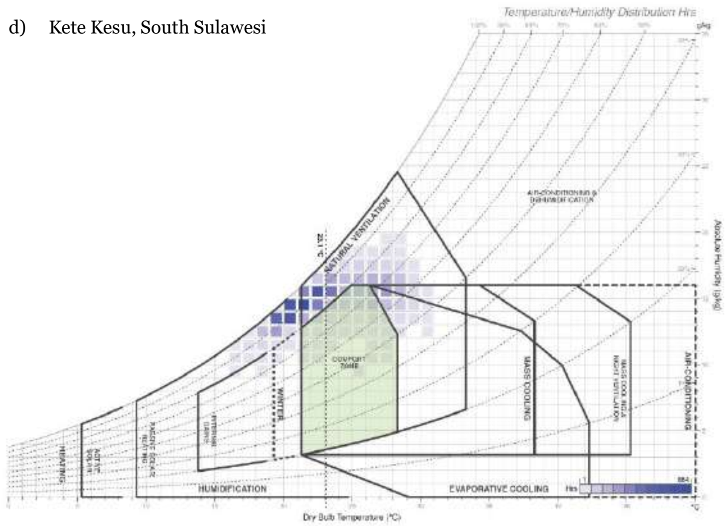
(Fig.6.7) - Bioclimatic psychrometric chart for Kampung Naga local climate
Source: Author

d) Wae Rebo settlement,
East Nusa Tenggara Island



(Fig.6.8) - Bioclimatic psychrometric chart for Wae Rebo local climate
Source: Author

d) Kete Kesu, South Sulawesi



(Fig.6.9) - Bioclimatic psychrometric chart for Kete Kesu local climate
Source: Author

Table 6.3 below summarizes the distribution of bioclimatic design strategies for those selected case studies. The yellow mark on the table informs the highest percentage of suitable climate responsive strategies for the climate conditions. In the case of the equatorial rainforest, the climate has naturally conditioned the building into three classifications: comfortable without conditioning, required natural ventilation, and passive solar heating. Huta Siallagan climate context is equal to requiring natural ventilation and already in comfort. Two case studies in high-land settlements (Kampung Naga and Kete Kesu) are necessary to provide more natural ventilation as considered 75% of the time in a year of Kampung Naga and 61%of time in Kete Kesu settlement. Meanwhile, Wae Rebo has another condition that passive solar heating is more crucial as 61% of the time in a year to have passive solar heating systems.

(Table 6.3) - Distribution duration of bioclimatic design strategy
Source: Author

	Huta Siallagan		Kampung Naga		Wae Rebo		Kete Kesu	
	Hours	%	Hours	%	Hours	%	Hours	%
Comfort	3,700	42%	622	7%	2379	27%	1,024	12%
Natural Ventilation	3,398	39%	6,611	75%	1449	17%	5,348	61%
Passive Solar Heating	1,662	19%	1,526	17%	4931	56%	2,388	27%

Based on bioclimatic psychometric weather data plotting, it found that three of case studies required more natural ventilation for achieving comfort while the Wae Rebo case is preferable to utilize passive solar heating. It can be concluded that the elevation of the site influences the design strategy of climate responsive even tough in a similar climate region.

The matrix assessment of the implementation of the passive design strategy is based on bioclimatic psychometric chart plotting results. The idea of matrix assessment is to find the shared principle of climate-responsive knowledge as the source of the analysis variable to be tested in the discussion. Chapter five's descriptive thematic research analysis is a significant source of relevant knowledge to validate in the matrix. Table 6.4 below summarizes the implementation of climate-responsive design solutions at the building level of those vernacular settlements tackling climate challenges based on bioclimatic strategy.

(Table 6.4) – Matrix assessment of the implementation of bioclimatic design strategy for building
Source: Author

Climate Responsive Design Strategy	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Natural Ventilation	**(+)** • Window on three sides of the building facade. • Permanent ventilation at two gable sides	**(+)** • Window on four sides of the building facade. • Permanent ventilation at gable sides of façade. • Permanent ventilation above the door • Perforated door (cavity material)	**(±)** • Small window ratio	**(+)** • Window on four sides of the building facade. • Permanent ventilation at two gable sides
Passive solar heating	**(±)** • Natural heating convection at roof surface (gable roof shape-oriented to East-West) • Fireplace	**(±)** • Lower natural heating convection at roof surface (gable roof shape-oriented to North-South)	**(+)** • Compact building envelope for minimizing heat loss • Natural heating convection by optimizing roof exposure to direct solar radiation (cone roof form without wall) • Fireplace	**(±)** • Natural heating convection at roof surface (gable roof shape-oriented to East-West) • Fireplace

Classification: (+): applied (-): not applied (±): partially applied

Overall, three of the case studies are necessary to have natural ventilation. Those have similar principles of natural ventilation, windows on a minimum of three sides of the building, and gable ventilation. For the case of Wae Rebo, based on plotting weather data into the bioclimatic psychometric chart, natural ventilation is not a dominant requirement to achieve thermal comfort. It is relevant to the finding from chapter five that Wae Rebo houses have two small proportions of windows, and the roof surface is the most prominent building envelope part for receiving direct solar radiation.

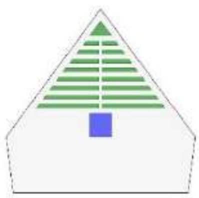
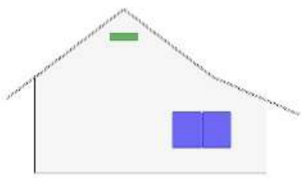
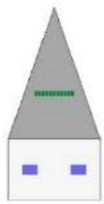
6.2.2 Indoor wind evaluation

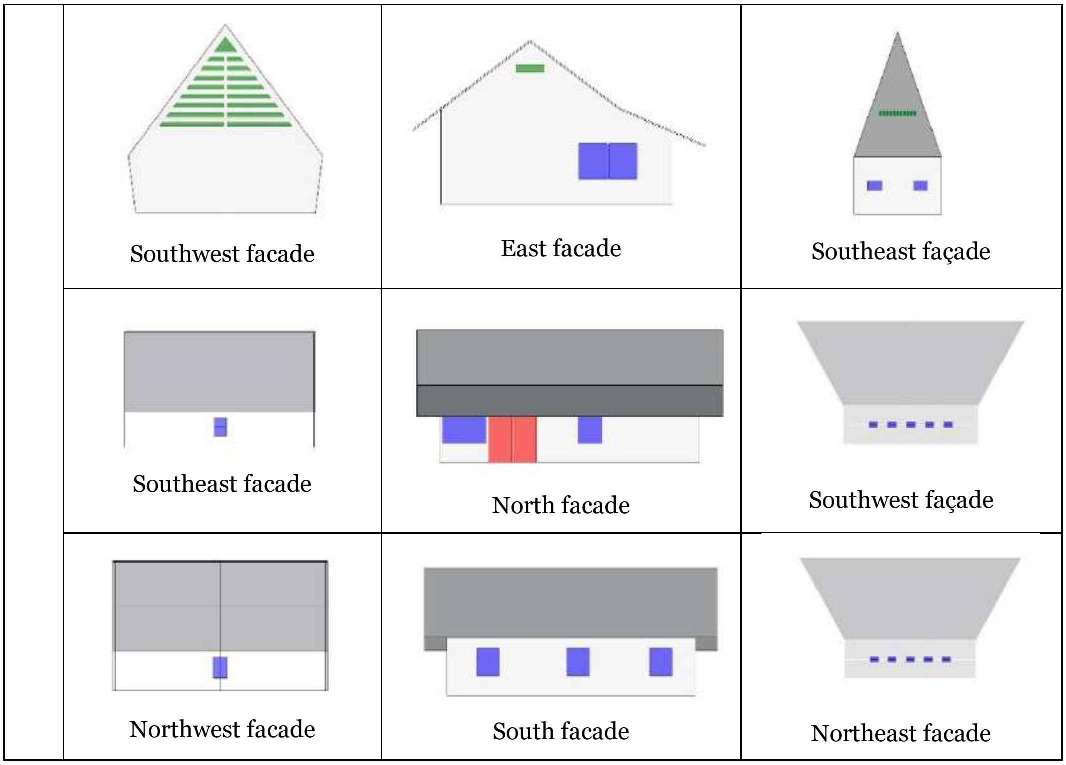
Despite the equatorial rainforest receiving low-speed air velocity (average 1.2 m/s) in high humidity conditions (average above 80%) and moderate temperature (an average 21° C), the bioclimatic psychrometric chart does not consider the variable of wind velocity but indoor air velocity in buildings is influencing to gain of thermal comfort (Esfahankalateh, 2020). Hence, the discussion part focuses on evaluating the implementation of natural ventilation in a climate context that requires a more dominant natural ventilation. The CFD simulation will conduct to evaluate the performance of the natural ventilation system for those case studies.

a) Analysis variable

Analysis variables are a set of findings from the investigation phase that indicates climate responsive design solution in qualitative analysis. Table 6.5 summarize those variables that will be tested through computational simulation. There are three variables: the window system, gable ventilation system, and both combinations. The blue color on the image represents the window's geometry, and the green color represents gable ventilation. The Detailed dimension is attached in the appendix.

(Table 6.5) –Geometry of ventilation and facade
Source: Author based on literature review and remote site survey

	Huta Siallagan	Kampung Naga	Kete Kesu
Opening-to-wall	 Northeast facade	 West façade	 Northwest façade



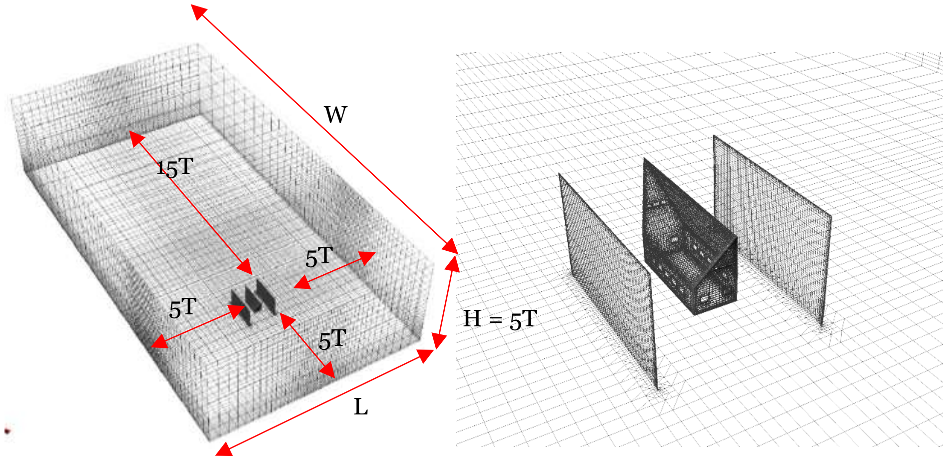
b) Analysis Criteria

For evaluating indoor wind comfort in the natural ventilation systems on the vernacular housing, the PMV index is used as a measurement. -0.5 and +0.5 PMV indexes are classified as achieving sufficient thermal comfort. The CBE tool is used to evaluate thermal comfort based on ASHARE 55 standards, considering the ventilation system in the vernacular building. Detailed thermal comfort standard was explained in chapter two.

c) Simulation Environment

The model for indoor wind simulation is simplified such as the context of the surrounding building represents as a single surface for simulation time efficiency reasons. Figure 6.10 illustrates the simulation environment for indoor wind simulation.

Simulation case for indoors:



(Fig.6.10) – a) Visualization mesh of wind tunnel environment b) Visualization mesh of analysis object
Source: Author

Simulation input:

(Table 6.6) – The CFD simulation input for indoor wind simulation
Source: Author

Component	Input Data		
	Huta Siallagan	Kampung Naga	Kete Kesu
Wind Velocity input	0.9	1.2	1.0
Wind direction	45° from South	45° from East	60° from East
Landscape coefficient	Type 3	Type 3	Type 3
Building dimension	10.5 x 5.2 x 9	6.7 x 8.35 x 9	9 x 4 x 8.7
Wind tunnel size (W x L x H)	52.5 x 110.2 x 166.5	33.5 x 113.35 x 166.5	45 x 109 x 166.2

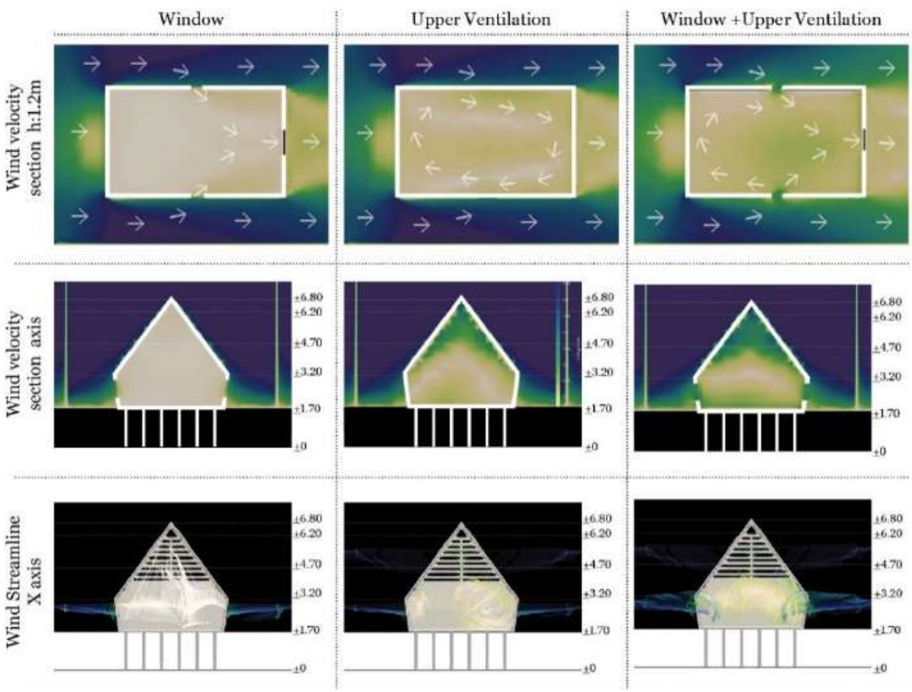
Note: Landscape Type 3: coefficient 0.10 (roughly open, cultivated, or natural area with low corps with occasional obstacles

d) Indoor Wind Simulation Result

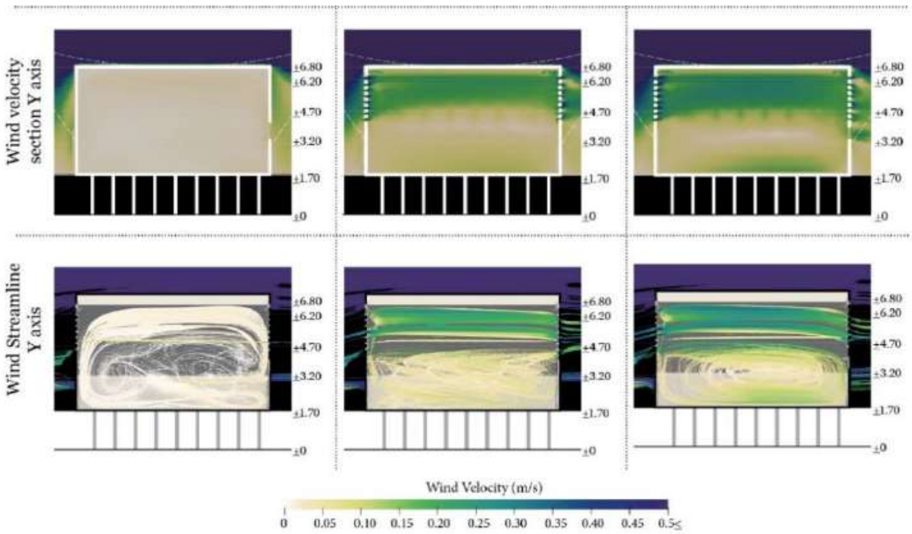
The reading guideline and representative result value for CFD wind simulation are explained in chapter 4 (methodology). For the simulation color and legend, the lighter color represents lower speed wind velocity (min=0 m/s), and the darker color represents higher wind velocity. The legend is adjusted based on the maximum wind velocity value for indoor space. Three case studies indicate unique and similar principles of ventilation systems in Huta Siallagan, Kampung Naga, and Kete Kesu. Meanwhile, Wae Rebo provides a small percentage of openings (less than 1%), so the CFD simulation did not conduct for the Wae Rebo building as predicted; the air velocity inside the building might not be countable.

1) The CFD indoor for the Huta Siallagan case.

The strategy of natural ventilation in the Kampung Naga building was implemented into two design solutions which are windows and gable ventilation. The window is positioned at a human level of 0.8 m above the floor, and the gable ventilation is placed 2m above the floor without clap. Furthermore, the position of gable ventilation is perpendicular to the major wind direction at the location. Considering the operational time of natural ventilation, the user can adjust the window operation, while gable ventilation is a fixed system.

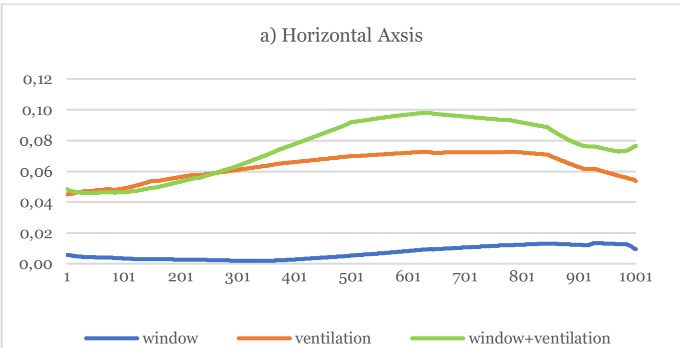


(Fig.6.11) –Indoor wind simulation result for Huta Siallagan
Source: Author

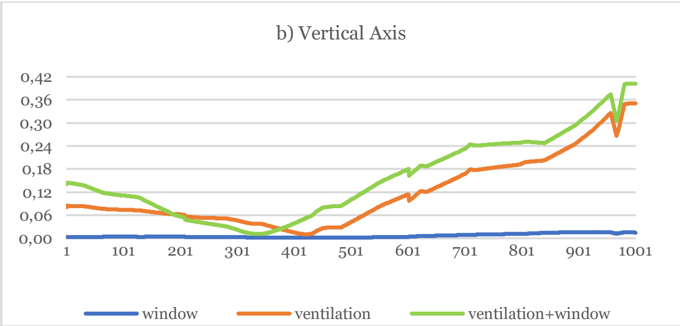


(Fig.6.11) –Indoor wind simulation result for Huta Siallagan
Source: Author

Figure 6.11 describes the visualization of CFD simulation on a representative grid at the human body level due to the wind being filled a volume geometry and figure 6.12 a & b show the calculation result of average wind speed on the example grid. Based on the CFD simulation those windows with a 3% proportion of envelope surface do not result in significant air movement in indoor space at average only 0.0068 m/s. Even though a higher level of buildings receives faster wind velocity (0.3 m/s) compared to a lower level (0.1 m/s), gable ventilation helps to improve greater wind velocity.



(Fig.6.12-a) – Graph of indoor wind velocity value for Huta Siallagan a) Horizontal axis
Source: Author



(Fig.6.12-b) – Graph of indoor wind velocity value for Huta Siallagan b) Vertical axis
Source: Author

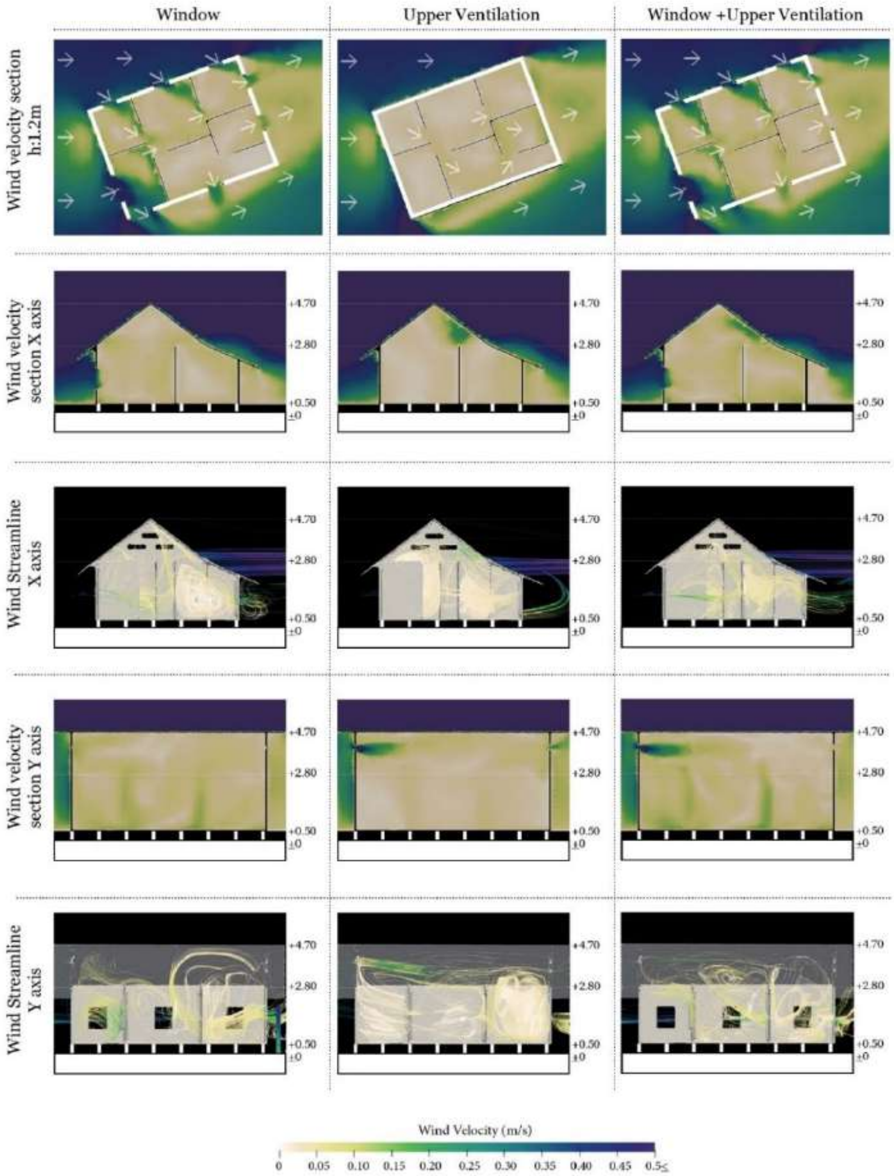
(Table.6.7) – Average indoor wind velocity plotting value for Huta Siallagan
Source: Author

	Window	Gable Ventilation	Ventilation + Window
Opening ratio to façade surface area	3%	4%	7%
Horizontal axis (h=1.5m)	0,006848	0,063364	0,075528
Vertical axis	0,006494	0,1174	0,154774

The design strategy combining windows and gable openings has conditioning better and stable air movement in Huta Siallagan's building. During nighttime when windows are possibly closed due to privacy and security reasons, gable natural ventilation improves air circulation in indoor spaces with natural ventilation.

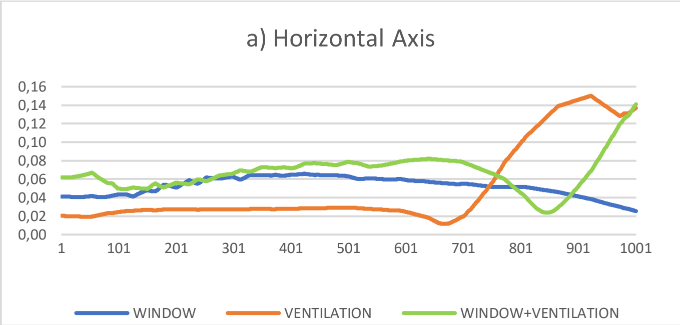
2) The CFD indoor wind simulation with natural ventilation system for the Kampung Naga case

The strategy of natural ventilation in the Kampung Naga building was implemented into two design solutions which are windows on four sides of the building envelope and gable ventilation. The window is positioned at a human level of 0.8 m above the floor and the gable ventilation is placed 2.4m above the floor without clap. Furthermore, the position of gable ventilation is perpendicular to the major wind direction at the location. Considering the operational time of natural ventilation, the user can adjust the window operation while e ventilation is a fixed system.

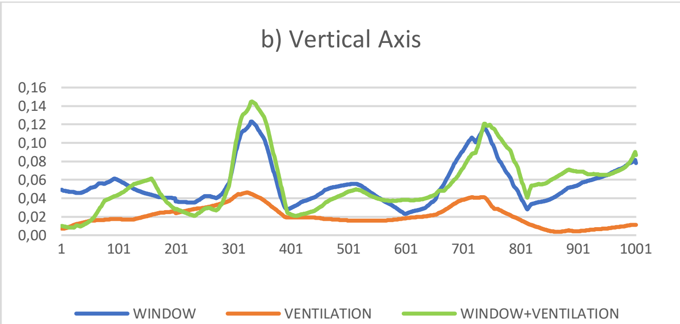


(Fig.6.13) – Indoor wind simulation result for Kampung Naga
Source: Author

Figure 6.13 illustrates the CFD simulation result of a representative grid at the human body level and figure 6.18 shows the calculation results in a graph format on the example grid. Based on the CFD simulation, those windows with a 14% proportion of envelope surface indicate slightly general favorable criteria of wind comfort as the average of only +0,055 m/s at horizontal and 0,052 m/s at the vertical axis.



(Fig.6.14-a) – Indoor wind velocity plotting value for Kampung Naga a) at horizontal axis
Source: Author



(Fig.6.14-b) – Indoor wind velocity plotting value for Kampung Naga b) at the vertical axis
Source: Author

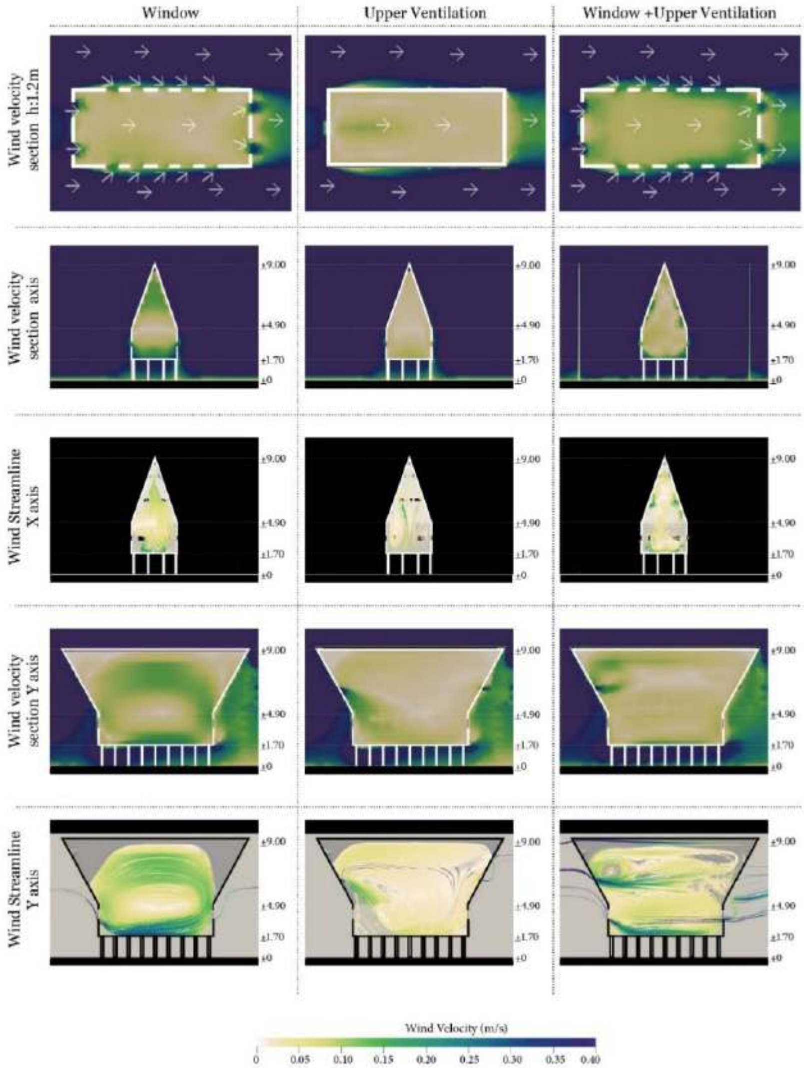
(Table.6.8) – Average indoor wind velocity plotting value for Kampung Naga
Source: Author

	Window	Ventilation	Ventilation + Window
Opening ratio to façade surface area	14%	2%	16%
Horizontal axis (h=1.5m)	0,055497	0,020675	0,055242
Vertical axis	0,052471	0,050083	0,067092

The design strategy of combination windows and gable openings has conditioning slightly better and stable air movement in the Huta Callaghan. However, the inner wall of the building can influence indoor air movement.

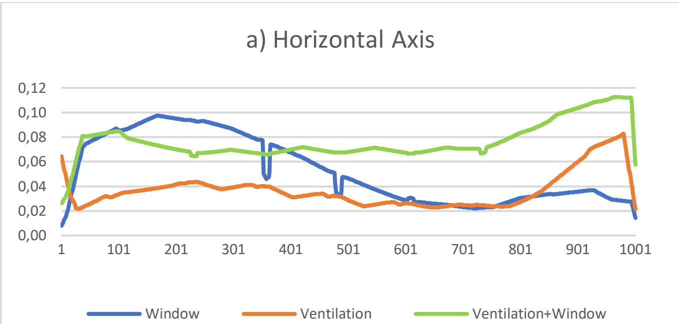
3) The CFD indoor wind simulation for the Kete Kesu case

The strategy of natural ventilation in the Kete Kesu building was implemented in two design solutions which are windows on four sides of the building envelope and gable ventilation perpendicular to the major wind direction at the location. The windows are positioned at a human level of 0.8 m above the floor and the gable ventilation is placed 3.2 m above the floor without clap. Considering the operational time of natural ventilation, the user can adjust the window operation while gable ventilation is a fixed system.

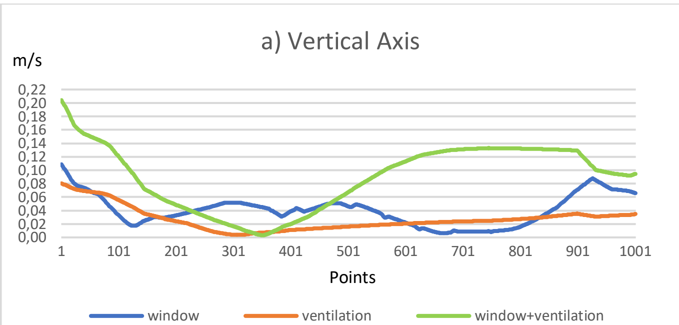


(Fig.6.15) – Indoor wind simulation result for Kete Kesu
Source: Author

Figure 6.15 describes the CFD simulation result of a representative grid at the human body level due to the wind-filled volume geometry. The graph shows that window ventilation creates better air velocity in lower levels due to wind whirl distributing inside the building volume. While the combination of window and upper ventilation or gable helps to distribute air conversion from outdoor space. Figure 6.16 shows the calculation result of the average wind speed on the example grid. Based on the CFD simulation in figure xx illustrate the windows configuration in the building's accelerating wind velocity, especially in the area closer to the window opening. Since the proportion of gable ventilation is only 1% of the building surface, the system helps to improve air velocity by 0,036525 m/s. Compared to the window system, 5% of the window opening is resulting 0,052859 m/s indoor wind velocity. It means, that 1% of gable ventilation is 30% higher improving indoor air velocity than 1% of window ventilation.



(Fig.6.16-a) – Indoor wind velocity plotting value for Kete Kesu a) at horizontal axis
Source: Author



(Fig.6.16-b) – Indoor wind velocity plotting value for Kete Kesu b) at the vertical axis
Source: Author

(Table.6.9) – Average indoor wind velocity plotting value for Kete Kesu
Source: Author

	Window	Gable ventilation	Ventilation + Window
Opening ratio to façade surface area	4%	1%	5%
Horizontal axis (h=1.5m)	0,052859	0,036525	0,076494
Vertical axis	0,040067	0,026837	0,08965

The design strategy of combination windows and gable openings has conditioning better and stable air movement in the Kete Kese building and small holes as gable ventilation helps to stabilize the distribution of overall air movement in indoor space.

6.2.3 Indoor Thermal Comfort - PMV Index calculation

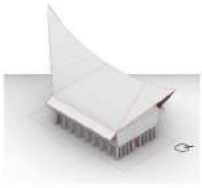
The thermal comfort evaluations are taken in sampling day as a representative of when the sun is positioned in the equinox. The idea for evaluating indoor thermal comfort is for finding the best practice of climate-responsive solutions in the vernacular settlement cases as sources of knowledge for modern residential development in Indonesia. To evaluate the climate design solution in the vernacular building, the wind velocity result from the CFD simulation has been inputted into the CBE tool. It has conditions adjustment of metabolism and clothing level for daytime and nighttime considering common human activity.

Table 6.10, 6.11; 6.12; and 6.13 are PMV index calculation result in tabular format. It indicates more than 70% time a day of three case studies in satisfying indoor thermal comfort based on ASHRAE-55 standard except Wae Rebo building. In the case of the Huta Siallagan building, 88% of the time a day is predicted to achieve neutral thermal comfort. It has almost similar to two other cases in that 75% of the time a day in the Kampung Naga building and 83% of the time a day in Kete Kesu is quantitatively proofing for achieving neutral thermal comfort. In another hand, 63% of the time a day in the Wae Rebo building received a slightly cold PMV condition, which means in line with the findings of the bioclimatic psychometric chart that the location is required a more passive heating strategy than natural ventilation (page.91).

Indoor Thermal Comfort Evaluation

Conditional:

Time	1-6	7-8	9-17	18-24
Clothing Level	0,96	0,60	0,60	0,96
Metabolism Rate	1,0	1,8	1,2	1,0



Huta Siallagan House

Time		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Air Temperature		22,1	21,5	21,5	21,5	21,2	21,8	19,2	19,4	20,2	20,7	23,2	23,6	24,1	25,9	27,1	27	26,6	25,8	21,4	21,7	22,1	22,3	21,9	21,8
Humidity		88	90	91	93	95	87	94	97	95	94	86	86	80	77	75	77	78	81	100	95	89	88	89	88
V= 0,006 m/s	PMV-a	-0,08	-0,35	-0,34	-0,23	-0,3	-0,18	-0,03	0,08	-0,1	-0,02	-0,34	-0,35	-0,21	0,44	0,83	0,85	0,55	0,43	-0,21	-0,15	-0,07	-0,02	-0,13	-0,17
V = 0,063 m/s	PMV-b	-0,08	-0,35	-0,34	-0,23	-0,3	-0,18	-0,07	-0,02	-0,12	-0,01	0,3	-0,35	-0,21	0,44	0,83	0,85	0,52	0,43	-0,21	-0,15	-0,07	-0,02	-0,13	-0,17
V=0,0755 m/s	PMV-c	-0,08	-0,35	-0,34	-0,23	-0,3	-0,18	-0,09	-0,04	-0,12	-0,01	0,3	-0,35	-0,21	0,44	0,83	0,85	0,52	0,43	-0,21	-0,15	-0,07	-0,02	-0,13	-0,17
Condition		Neutral														Slightly Warm			Neutral						

88% Neutral PMV

(Table) PMV calculation for Kampung Naga house in a day example (March 22)
Source: Author

(Table 6.10) – Result of indoor thermal comfort calculation (PMV Index) for Huta SIallagan

Source: Author

Kampung Naga House

Time		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Humidity		22,20	21,60	21,40	21,40	21,30	20,80	21,00	21,00	21,50	22,50	26,80	27,70	28,10	28,60	28,90	27,50	26,70	25,90	24,30	24,00	23,80	23,40	23,30	23,00
Air Temperature		93	95	95	94	95	95	94	94	94	91	71	66	63	66	68	71	75	78	82	85	87	89	92	93
V=0,055 m/s	PMV-a	-0,01	-0,18	-0,24	-0,25	-0,27	-0,42	-0,26	-0,26	-0,46	-0,17	0,72	1,00	0,97	1,2	1,33	0,81	0,53	0,44	-0,12	0,47	0,42	0,32	0,31	0,23
V= 0,020 m/s	PMV-b	-0,01	-0,18	-0,24	-0,25	-0,27	-0,42	-0,26	-0,26	-0,46	-0,17	0,72	1,00	0,97	1,2	1,33	0,81	0,53	0,44	-0,12	0,47	0,42	0,32	0,31	0,23
V=0,055 m/s	PMV-c	-0,01	-0,18	-0,24	-0,25	-0,27	-0,42	-0,26	-0,26	-0,46	-0,17	0,72	1,00	0,97	1,2	1,33	0,81	0,53	0,44	-0,12	0,47	0,42	0,32	0,31	0,23
Condition		Neutral										Slightly Warm							Neutral						

75% Neutral PMV

(Table) PMV calculation for Kampung Naga house in a day example (March 22)
Source: Author

Note: A)Window b)Gable ventilation c)Windows + Gable ventilation

(Table 6.11) – Result of indoor thermal comfort calculation (PMV Index) for Kampung Naga

Source: Author

Indoor Thermal Comfort Evaluation

Conditional:

Time	1-6	7-8	9-17	18-24
Clothing Level	0,96	0,60	0,60	0,96
Metabolism Rate	1,0	1,8	1,2	1,0

Kete Kesu

Time		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Air Temperature		21,2	20,9	20,7	20,9	20,6	20,4	21,2	21,9	23,2	24,6	28	28,5	28	27,6	26,3	26,6	24,7	24,3	23,5	22,9	22,8	22,9	22,4	22
Humidity		92	92	91	89	89	89	87	87	83	73	63	60	62	67	73	74	81	84	88	89	88	87	88	89
V=0,052 m/s	PMV-a	-0,32	-0,41	-0,48	-0,43	-0,52	-0,58	-0,24	-0,1	-0,03	0,3	1,06	1,23	1,07	0,81	0,35	0,48	0,4	0,31	0,34	0,17	0,13	0,15	0,01	-0,1
V=0,036m/s	PMV-b	-0,32	-0,41	-0,48	-0,43	-0,42	-0,48	-0,22	-0,06	-0,02	0,32	1,08	1,23	1,07	0,81	0,35	0,48	0,4	0,31	0,34	0,17	0,13	0,15	0,01	-0,1
V=0,076m/s	PMV-c	-0,32	-0,41	-0,48	-0,43	-0,52	-0,58	-0,29	-0,14	-0,03	0,3	1,06	1,21	1,05	0,81	0,35	0,48	0,39	0,29	0,34	0,17	0,13	0,15	0,01	-0,1
Condition		Neutral										Slightly Warm				Neutral									

83% Neutral PMV

(Table) PMV calculation for Kete Kesu house in a day example (March 22)
Source: Author

(Table 6.12) – Result of indoor thermal comfort calculation (PMV Index) for Kete Kesu

Source: Author

Wae Rebo*

Time		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Humidity		19,62	19,32	18,36	18,92	18,62	18,62	18,72	19,22	20,02	20,72	21,22	24,92	25,12	24,22	23,42	23,42	24,22	21,82	21,42	20,12	19,72	19,62	19,62	19,22
Air Temperature		92	91	96	96	97	97	96	93	92	87	83	70	68	75	83	81	81	89	89	92	95	95	96	97
V= 0,00 m/s	PMV	-0,79	-0,88	-1,14	-0,98	-1,06	-1,06	-0,04	0,04	-0,92	-0,73	-0,6	0,42	0,47	0,25	0,06	0,04	-0,29	-0,39	-0,28	-0,65	-0,75	-0,78	-0,77	-0,88
Condition		Slightly Cold						Neutral		Slightly Cold			Neutral								Slightly Cold				

*Wind Velocity = 0 m/s due to there is no cross-ventilation system & limited opening at the building

37% Neutral PMV

(Table) PMV calculation for Wae Rebo house in a day example (March 22)
Source: Author

Note: A)Window b)Gable ventilation c)Windows + Gable ventilation

(Table 6.13) – Result of indoor thermal comfort calculation (PMV Index) for Wae Rebo

Source: Author

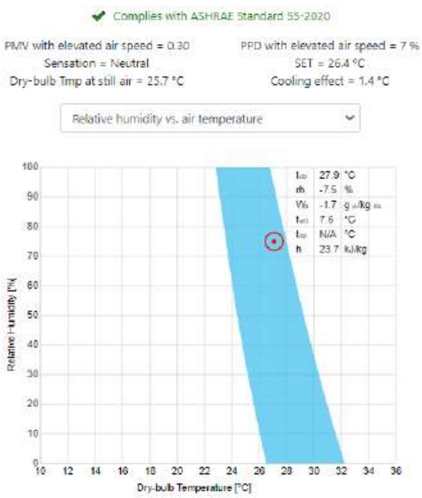
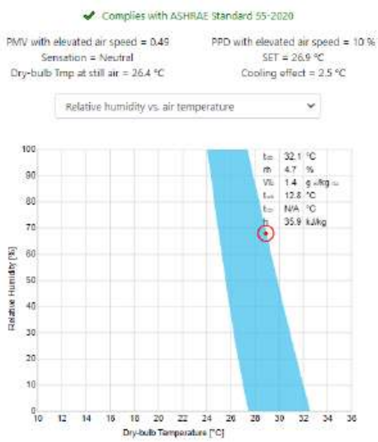
Based on the plotting of indoor thermal comfort (PMV Index) in the above table, it indicates that the ventilation systems which influence indoor wind velocity in the building are conditioned to be neutral PMV (-0,5 – 0,5) during morning and nighttime. At particular times, mostly afternoon and in the afternoon, the indoor space is experienced as slightly warm. In the case of the Huta Siallagan building, when the air temperature reached more than 26,60° C and relative humidity above 78%, it is resulting to achieve PMV of more than 0,81 which means a slightly warm experiencing thermal sensation. For the Kampung Naga building, the air temperature above 26,70° C and relative humidity above 75% create a PMV index of more than 0,53 as considered a slightly warm thermal sensation. And lastly, for the building with a similar principle of natural ventilation, the user in the Kete Kesu building achieves a slightly warm thermal experience when the air temperature reached 27,6 ° C and the relative humidity is 67%. In another hand, the Wae Rebo building creates a neutral PMV thermal condition mostly during the daytime and the rest of the night in a slightly cold thermal sensation which is solid proof that weather data plotting on bioclimatic chart require more passive solar heating of climate responsive design strategy than natural ventilation for achieving thermal comfort.

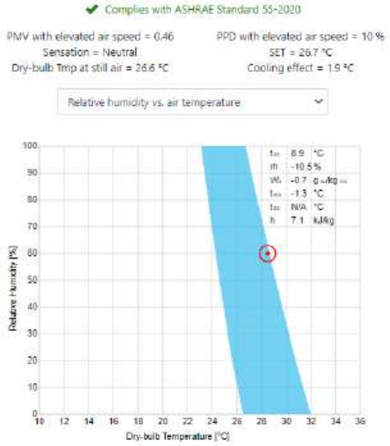
6.2.4 The Improvement

The improvement section is limited to the location that is required most of the time to achieve comfort with natural ventilation. As considered the micro-climate for indoor space is not always achieved neutral thermal comfort, the idea of climate-responsive is how to respond to the climate conditions to achieve our comfort target (PMV neutral) both daytime and nighttime. Focusing on the improvement of wind velocity for indoor space in the given climate condition, the idea of improving thermal comfort in indoor space through accelerating wind velocity in indoor space. The CBE tool is used to calculate how much indoor wind velocity needs to accelerate. The calculation sampling is only for the highest PMV index in each case that summarized in table 6.14.

(Table 6.14) – Indoor thermal comfort calculation for targeting PMV neutral

Source: Author

<table>
<tr><th>PMV on existing ventilation</th><th>PMV calculation
Targeted PMV Neutral</th><th>Wind velocity adjustment
Targeted PMV neutral</th></tr>
<tr><td>Case: Huta Siallagan
PMV Index: 0.83
Operative Temperature: 27,1º C
Relative Humidity: 75%
Wind Velocity: 0,075 m/s</td><td>
</td><td>Accelerating wind velocity at an amount of 0,3 m/s can create a cooling effect at an amount of 1,4 º C that results in a neutral PMV index (0.30) for cases of building in similar climate conditions to Huta Siallagan location.</td></tr>
<tr><td>Case: Kampung Naga
PMV Index: 1,33
Operative Temperature: 28,9º C
Relative Humidity: 68%
Wind Velocity: 0,055 m/s</td><td>
</td><td>Accelerating wind velocity at an amount of 0,6 m/s can create a cooling effect at an amount of 2,5º C that results in a neutral PMV Index (0.49) for cases of building in similar climate conditions to Kampung Naga location.</td></tr>
</table>

Case: Kete Kesu • PMV Index: 1,21 • Operative Temperature: 28,5° C • Relative Humidity: 60% • Wind Velocity: 0,076 m/s		Accelerating wind velocity at an amount of 0,4 m/s can create a cooling effect at an amount of 1,9° C that results in a neutral PMV Index (0.46) for cases of building in similar climate conditions to Kete Kesu location.

Accelerating wind velocity in indoor space can create a cooling effect which leads to achieving a neutral PMV index. The climate-responsive design solution can be through conditioning the size ratio of ventilation opening to building envelope volume targeted as the amount of higher wind velocity. As considered, the slightly warm thermal condition has happened during the daytime, and there is not founded in the nighttime, it is preferable to widen the window opening dimension because of its operational flexibility.

Specific to climate conditions in equatorial rainforests based on the calculation summary in table 6.14, a climate-responsive design solution is recommended to condition indoor wind velocity to at least reach a minimum of 0,3 m/s for a location near Huta Siallagan (North Sumatera), 0,6 m/s minimum of indoor wind velocity for a location nearby Kampung Naga (West Java) and 0,4 m/s minimum of wind velocity for a location nearby Kete Kesu (South Sulawesi).

Chapter 7
Conclusion

"If we knew what we were doing, it would not be called research, would it?"

- Albert Einstein

This chapter will summarize several points that are analyzed and discussed in the previous chapter. In addition, this final chapter also aims to emphasize the answer to the research question based on the findings with emphasis on the knowledge adoption of climate-responsive design potentially adapted in current residential buildings, reflection on methods and case studies, and potential further research areas.

7. 1 Research Questions Follow up

Three supporting research questions are raised in the introduction section as considered preliminary research with the objective of the question is to achieve a specific understanding of the settlement development challenge from a climate perspective. Based on the theoretical review, the climate-responsive approach is to promote a sustainable practice of improving a balanced environment with human-made development in many aspects such as energy consumption, avoiding biodiversity loss by climate change, etc. Hence, the practice of climate-responsive is necessary to be based on environmental contextuality.

The first question objective is to understand specific climate characteristics in the equatorial rainforest where four case studies in different locations within similar climate regions were analyzed along with a weather statistic database. Based on preliminary research by comparing the weather data, the 2021 weather data was decided as a reference corresponding to the similar pattern of the data and the research vision for current and future climate-responsive design solutions.

- **What** are the climate challenges and characteristics in the equatorial rainforest of Indonesia?

Based on defining phase of six climate elements, it can be concluded that the climate challenge to achieve environment comfort in the equatorial rainforest would be influenced by low wind velocity in high humidity conditions since air temperature is preferable in moderate comfortable. Constant and equal duration of daytime and night-time throughout a year occur because of the equatorial locations influences high sun angle resulting in almost equal shadow effect during daytime. Furthermore, high rain precipitation is also the main characteristic of the equatorial rainforest climate region. Table 7.1 is summarized in tabular format the climate challenge and characteristics of Indonesia's Equatorial Rainforest climate region.

(Table.7.1) – Equatorial Rainforest Climate Characteristic Summary
Source: Author's

Climate Element	Climate Characteristic
Sun path	High angle sun path (70° – 90°), equal daytime & nighttime (12 hours)
Solar Radiation	Constant daily solar radiation (0 – ±900 Wh/m²), the daily average is 200 Wh/m².
Wind	Light air wind classification (in averagely: 0.91 (Huta Siallagan), 1,2 (Kampung Naga), 1,02 (Kampung Naga), and 0,78 m/s (Kete Kesu)

Rain precipitation	- Varied seasonal period of rain and dry season, peak rain precipitation in August – October for Huta Siallagan and Kampung Naga location and on March for Wae Rebo and Kete Kesu. - Dense rain precipitation in average 265 mm/3 month (Huta Siallagan), 301 mm3/month (Kampung Naga), 242 mm3/month (Wae Rebo) and 240 mmm3/month (Kete Kesu)
Air Temperature	- Constant air temperature pattern contextual to elevation level of the cases 19,90-28,300 C (Huta Siallagan) , 21,80-27,600 C (Kampung Naga), 19,02-23,820 C (Wae Rebo) and 20,50-29,000 C (Kete Kesu) - A narrow range of daily air temperature (5-90 C)
Humidity	Constant high humidity (80% - 100%)

To answer the second research question, the investigation phase was conducted. Literature review, remote site survey by delegating research assistants and data validation to previous researchers were conducted. The descriptive thematic analysis method was conducted to answer the second research question.

- **Are** those vernacular settlements designed responsively to climate?

It succeeds to answer based on finding from qualitative analysis corresponding to theoretical support and quantitative evaluation refers to computational simulation. It can be concluded that vernacular settlements in all case studies are unconsciously responsive to climate challenges even though the weather database was not founded at the time the settlement had built and does not refer to climate consideration. The finding of climate responsive design solution in the vernacular settlement is reliable with the principle of passive design strategy in which no supporting mechanical system that led to energy consumption. Furthermore, the selection of building materials is also contextual to climate conditions, and the complexity of local craftsmanship pieces of knowledge are precious sources for sustainable local-based materials systems which further generation needs to preserve this antiquity knowledge for future development. Table 7.2 is summarized of climate-responsive design solution based on qualitative analysis.

(Table.7.2) – Summarized design solutions for the vernacular settlement

Source: Author

	Huta Siallagan	Kampung Naga	Wae Rebo	Kete Kesu
Building Configuration	Linear ordered perpendicular to the majority wind direction	Grid compact ordered	Radial loose ordered, blocking wind to main open space	Linear ordered perpendicular to the majority wind direction
Building layout	Rectangular	Rectangular	Circle	Rectangular
Building envelope	Symmetrical	Symmetrical	Symmetrical	Symmetrical
Building Material	Local material	Local material	Local material	Local material
Roof	Single layered, roof sloped 45°	Single layered, roof sloped 38°	Double layered, roof sloped 63°	Double layered, roof sloped 60°
Wall	Wooden panel	Wooden panel	No wall	Wooden panel
Floor	Elevated floor plan: as respond to not blocking water flow in high precipitation climate region, allowing air movement below the floor can avoid humidity stuck.	Elevated floor plan: as respond to not blocking water flow in high precipitation climate region, allowing air movement below the floor can avoid humidity stuck.	Elevated floor plan: as respond to not blocking water flow in high precipitation climate region, allowing air movement below the floor can avoid humidity stuck.	Elevated floor plan: as respond to not blocking water flow in high precipitation climate region, allowing air movement below the floor can avoid humidity stuck.
Structure	Pedestal foundation above the ground	Pedestal foundation above the ground	Timber foundation nailed to the ground covered with palm fiber	Pedestal foundation above the ground
Opening and ventilation	Windows at the human level in front and length side, air ventilation holes at the upper wall for optimizing building airflows.	Windows on four sides of buildings and air ventilation holes at the upper wall for optimizing building airflows.	Small ventilation of the building to keep heat inside the room	Windows at the human level in front and length side, air ventilation holes at the upper wall for optimizing building airflows.
Air conditioning (Heating System)	Open kitchen with fireplace at the center of the house	No	Open kitchen with fireplace at the center of the house	Open kitchen with fireplace at the center of the house

In conclusion, the investigation of climate-responsive design solutions in Indonesia's vernacular settlement found that there are shared principles of the vernacular settlement responsive to climate context. The consideration of how the knowledge of vernacular settlement achieves comfortable conditions explained in the summary pointed below.

- In the settlement scale, , the building configuration in all case studies is responsive towards most wind directions rather than the sun path. It can be identified in the building configuration in Huta Siallagan, Kampung Naga, and Kete Kesu which are perpendicular to the major wind direction while in Wae Rebo settlement, the building configuration is blocking the wind direction to the main open space in the center of the settlement.
- Related to responsively to wind condition, this research found that despite having a window, gable natural ventilation is applied in three case vernacular building. Meanwhile, the Wae Rebo building has a limited opening which responds to the low temperature in the area and to keep heath and the interior temperature warm.

Furthermore, another knowledge related to the climate-responsive approach to the challenge of high precipitation has also been utilized in the building level, such as the elevated floor plan design decision which can optimize water flow during the dense rainy season (up to 400mm2/month) and optimize air circulation underneath the floor. Based on the theory, the long exposure to high humidity can impact in destruction and wearable of organic building materials unless air circulation can re-circulate high humidity in the air to keep organic-made materials in optimal condition. Moreover, the street design in Kampung Naga also considers the shifting function street as drainage during rain. In relation to sunlight exposure for indoor space, optimization of daylight through building opening is not founded due to most of the user time activities in outdoor space during daytime.

The last question can be answered based on accumulative analysis and tested in the computational simulation for measuring the performance of climate-responsive design solutions.

- **How** do Indonesian tribes' communities respond to the climate context in which the vernacular settlement typologies in the equatorial rainforest region tackle climate challenges?

The third research question answer confirms that Indonesian tribes in the equatorial rainforest are more responsible for wind conditions. It can be seen from the building configuration at Huta Siallagan, Kampung Naga and Kete Kesu which are perpendicular to most wind direction considering the location which only has two perpendicular wind directions in limited velocity (average 0.8mm/s). Furthermore, bioclimatic strategy evaluation based on a psychometric chart generates the main strategy to achieve comfort in three case locations that have the necessity to provide natural ventilation. The ventilation system, window, and gable ventilation in all case studies have good performance in improving air velocity in indoor space based on the CFD simulation results.

On the other hand, the relevance of the lack of major wind direction in the location and the building envelope form adaptation found in Wae Rebo house in which a cone-formed building envelope does not tackle wind challenges but instead absorbs wind that coming from all directions. In addition, the small proportion of opening ration in its building envelops unequivocally respond to climate context in which to avoid thermal loss as stated in bioclimatic evaluation that the settlement location needs a passive heating strategy.

7.2 The knowledge adoption and adaptation

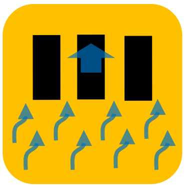
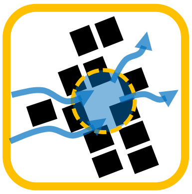
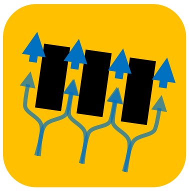
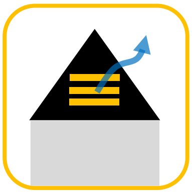
The practice of climate responsive design is a complex approach and a comprehensive understanding of defining the climate challenge contextuality which is necessary to define since the beginning of development. It aims to optimize settlement performance by implementing a passive design strategy based on a climate-responsive approach which leads toward sustainability practice. This section is considered to answer the main research question.

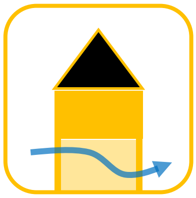
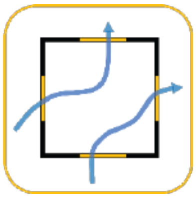
What are the potential climate-responsive design solutions in the vernacular settlement that is applicable for modern settlement development contextual to local climate and the local environment?

In this research summary, adoption terminology refers to taking the finding of climate design principles stated in the previous chapter while adaptation terminology refers to the process of implementing the adopted principles in the new development. The knowledge adoption aims to generate climate-responsive design principles for residential development in Indonesia where most of the development target locations are in rural and semi-urban areas to achieve inclusive development plans. Based on the context of equatorial rainforest climate in Indonesia, the knowledge adoption focused on climate-responsive principles related to the wind velocity in the region, humidity, and climate characteristics stated in chapter six.

These design principles aim to be adopted in the design development process without limiting designer creativity and enhancing indoor and outdoor wind comfort performance for a better living environment. However, to be contextual to the local climate context, the climate design principle summarized in table 7.3 only works for the location with required more natural ventilation as a climate-responsive design strategy based on plotting weather data into a bioclimatic psychometric chart.

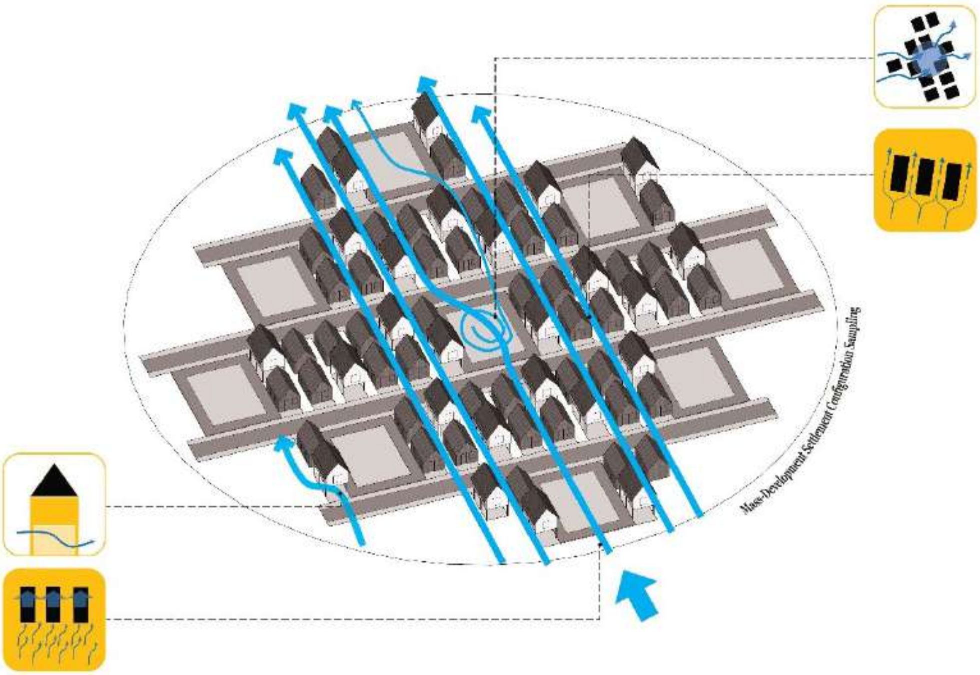
(Table.7.3) – The list of potential climate-responsive design principles for residential development in the Equatorial rainforest
Source: Author

Climate responsive design knowledge adoption	Scale of implement ation	Benefit	Adaptation process	Constrain
 Massing configuration perpendicular to major wind direction	Land Use Plan	• Minimizing wind velocity deceleration • Improving outdoor ventilation for creating a healthier outdoor environment.	• Identify major wind direction and wind velocity for deciding the main orientation • Identify context barriers to the site • Terrain study	• Settlement site geometry • Site terrain • Housing unit's targets
 Outdoor void	Land Use Plan	• Conditioning an outdoor comfort meeting point leads to generating social connections in the neighborhood.	• Identify wind direction and wind velocity • Identify settlement density for allocating equal outdoor void distribution • Terrain study	• Settlement site geometry • Site terrain • Land proportion target of buildable area
 Outdoor air ventilation channel	Land use and Building Plan	• Accelerating wind velocity on the pedestrian level to help improve outdoor air movement by providing an outdoor wind channel	• Identify wind direction and wind velocity condition • Building distance ration	• Housing land plot geometry
 Gable air ventilation	Building Plan	• Reconditioning a stable air movement • low-cost construction • Easy maintenance. • Minimize air stack in high humidity with a small ratio of opening to the wall but significant	• Identify major wind direction for determining the appropriate direction of gable ventilation • Ventilation to facade and building volume study • Identify wind barrier in the	• No ceiling building • Service accessibility for cleaning

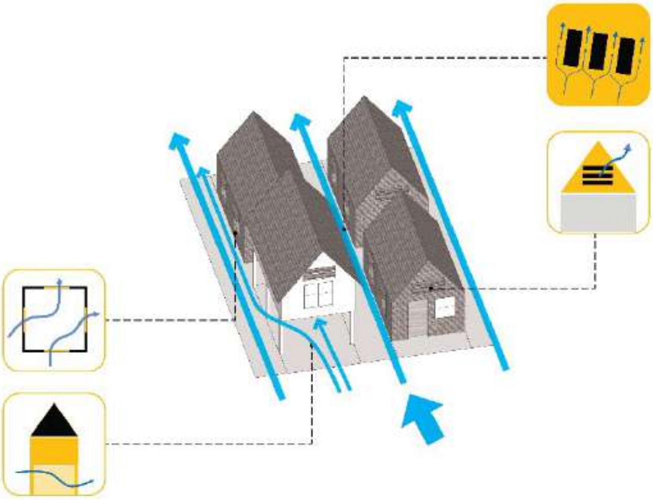
		improvement (1% ratio of gable opening impact to +0.03 m/s wind velocity)	context of location	
 Lifting-up building massing at pedestrian level	Building Plan	• Avoiding blocking outdoor and indoor air movement by allowing better air velocity on the pedestrian level	• Identify geometry context • Identify context density • Identify wind barrier in the context of location	• Density of domestic appliances in the lifting area • Human behavior related to public and private space
 4-sided façade with natural ventilation opening	Building Plan	• Micro-scale optimization in capturing wind and enhancing indoor cross-natural air ventilation. • Specific to equatorial rainforest climate conditions, conditioning wind velocity with a minimum of 0.3 m/s can achieve neutral thermal comfort.	• Shifting design paradigm from attached housing into detached housing with open area perimeter. • Window opening size ratio to building volume	• Distance between the building should be cleared, so there is no distraction of air movement from outdoor to indoor space.

Based on table 7.3, the design principle can be simulated in forming a new possibility of landed settlement configurations. The simulation below (Figures 7.1, 7.2, and 7.3) is not contextual to specific location and intended only to show the possibility of the adaptation of design principles in a new development settlement. The simulation will be limited only to the typical settlement configuration. It is required further research on contextually based local environmental conditions such as land topography, source of water body, major wind direction, etc.

Based on the finding of climate-responsive design solutions from the vernacular settlement, the adaptation of the knowledge into the modern settlement is explained in this part. At the settlement scale, building configurations should optimize air movement and avoid humidity stacked on the air. The main strategy is illustrated in figure 7.1, the building configurations should be perpendicular to major wind direction which allowed outdoor natural ventilation to work. Rectangular building massing is preferable rather than square which can optimize space between the building as an air channel. The existence of a square has a role in conditioning an outdoor comfort meeting point and leads to generating social connections in the neighborhood. A detailed of the illustration is described in figure 7.2

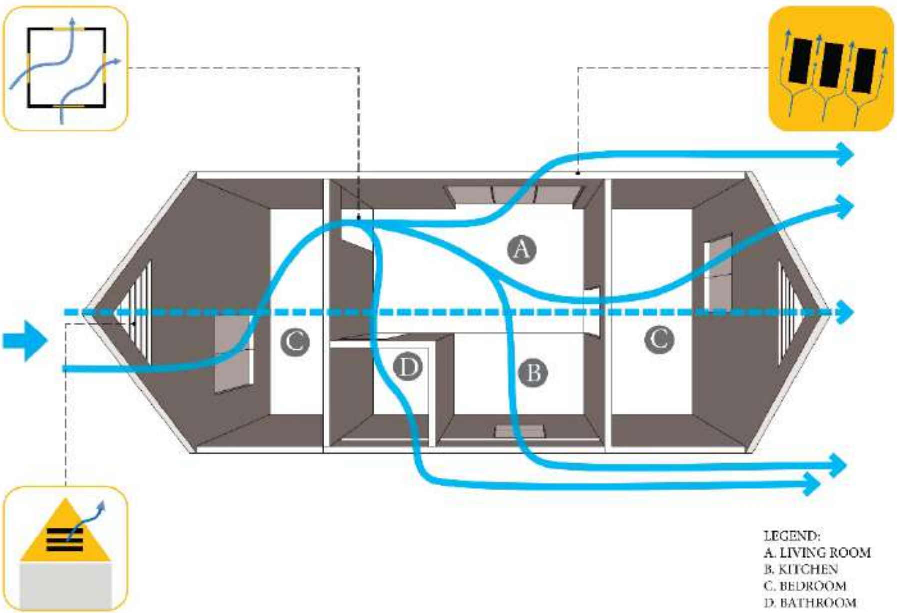


(Fig.7.1) Conceptual adaptation for masterplan scale
Source: Author



(Fig.7.2) Conceptual adaptation for building configuration scale
Source: Author

For the building level, the adaptation of the knowledge into the modern settlement is illustrated in figure 7.3. The illustration is only to visualize the possibility implementation of climate-responsive knowledge without limited architect design exploration.



(Fig.7.3) Conceptual adaptation for building layouts plan
Source: Author

Natural ventilation is a key for achieving thermal comfort in the equatorial rainforest region elevation below 1.000 msl. However, for making the natural ventilation working properly, design decision needs to consider the major direction of wind at the location is supposed to be perpendicular with length side of the building. Furthermore, building layouts and the position of building opening (window, doors, and ventilation holes) should be consider the principle of crossing ventilation and ensuring the building parameter has an outdoor gap for optimalization air movement.

7.3 Reflection of methodology

In summary, the research methodology is acceptable to reach the knowledge of a climate-responsive approach starting from understanding the climate context based on specific climate regions and framing the practices from local experience contextual to the regions. However, the topic of climate-responsive is challenging in the evaluation phase. Hence, after defining the climate challenge in the case study location, the researcher decides to discuss it from one perspective which is climate-responsive related to wind conditions. The computational simulation helps to evaluate the finding in quantitative measurement, and the literature review method is relevant to justify qualitative analysis. The consideration points of the research methodology are stated below:

- Statistical weather data analysis based on sampling weather data is an efficient method with an objective manner for defining the climate characteristics and challenges.
- The limitation of accessibility during the COVID-19 pandemic was not a fundamental boundary to doing research remotely for the case study in remote areas. The current communication technology invention of teleconference allows researchers to do a remote site survey. The preparation list of research contents for research assistants was the prominent key for data collection and needs to be prepared after the preliminary research phase. Also, consent of previous researchers in the same study location is a method to validating the data collection

- Thematic analysis method can be a strategy for framing the content of the investigation analysis based on the theme of contents.
- Climate computational simulation can be an efficient tool in terms of cost and duration for evaluating the performance of climate-responsive design solutions in an objective way. Despite the computational simulation having accuracy issues, it helps to generate a past and prognosis evaluation. Since the focus of research is not focused on validating the computational simulation only, this research adopts the CFD simulations method that is already validated by Sakiyama, 2021.

7.4 Reflection of Case Study

Four case study locations inside similar climate regions give an understanding that even though the location is in a similar climate region; the probability to have different climate behaviors such as different patterns of wind direction will be possible. Besides the tangible parameters, the vernacular settlement design decision in eastern oriental society was also influenced by intangible cultural requirements that are stated in the context of case studies which is totally different from mass residential development requirements. Even though, the source of climate-responsive knowledge from the vernacular settlement contains a practical conventional solution without energy consumption and less maintenance, not all practical climate-responsive can be found such as in the aspect of daylighting due to the evolution of human activity in space.

7.5 The Conclusion

This research conclusion will point to several points as stated below:

- To define climate characteristics, the research needs to be contextual with the environmental condition. It shows in the research findings that the influence of topography on the wind direction tends to bend and generates wind velocity and the relation of air temperature with land elevation. Hence, even though the region is claimed inside a similar climate region, the practice of climate-responsive cannot be generalized.

- For achieving neutral thermal comfort, the given climate conditions in Indonesia's equatorial rainforest region with an elevation below 1.000 msl can be achieved with proper natural ventilation installation and accelerating wind velocity both indoor and outdoor, which mechanical air conditioning is not urgent. Meanwhile, the same climate region with an elevation above 1.000 msl should be considered passive heating strategies to achieve neutral thermal comfort.
- The air temperature for Equatorial Rainforest climate region is considerably constant and has short delta air temperature between daytime and night-time.
- Based on weather data study, the air temperature and humidity are strongly correlated, when the humidity is lower it helps to reduce body sweating but the air temperature increases in vice versa.
- The indigenous people in Indonesia are considered to achieve environmental comfort for survival in a contextual approach with the implementation of a passive design strategy.
- The aspect of daylighting design knowledge is not founded in the vernacular settlement case study, as to consider housing mainly used during night-time.
- Based on qualitative analysis as considered with high rain precipitation, the roof eaves and steep roof slope are beneficial for optimizing rainwater flow and reducing building watering rather than for shading purposes since the high altitude of sun position (80^o – 90^o) influences the short length of shading (Figure 5.1, p.54).
- For achieving a low-cost passive design strategy in the Equatorial Rainforest, optimization of natural ventilation for the outdoor and indoor areas is crucial, especially in a location that has low wind velocity (averagely 0.8 m/s – 1.2 m/s).
- 0,3 m/s wind velocity is a minimum of wind speed that is preferable for achieving neutral thermal comfort by combination of wind and gable ventilation holes since the climate region does not have extreme cold conditions.

- The methodology of this research; starting from defining climate characteristics and measuring the performance of design decisions from the climate-responsive point of view, can be used as a reference to develop a climate-responsive design approach for remote cases on the preliminary design.

7.6 Limitation

After the process of theoretical review is done, the researcher realizes the topic of climate-responsive is a complex study to be done in a holistic way during a period of the master thesis. The topic is a complex understanding of climate elements and how humans respond based on their needs, hence this research ends up focusing on one climate-responsive approach for optimizing wind comfort as considered based on defining phase, low wind velocity is one of the challenges. In targeting the climate-responsive approach for the residential user, this research has a limitation of collecting the current user needs and the challenge from the developer side due to time investment mainly for weather data analysis, data gathering redrawing, and computational simulation.

7.7 Further Research

The research finding and results are the potential to become a foundation for further research or built environment project on particular topics related to climate responsive design which is stated below:

- Based on findings of climate-responsive design solutions in the vernacular settlement, it can be a foundation of research in relation to finding residential users' and developers' challenges for implementing climate-responsive principles in Indonesia.
- The further research related to the optimization of natural ventilation for building in equatorial rainforest climate regions. The optimization terminology related to the ratio between ventilation and building envelop, type and position of ventilation, the position of ventilation, constrain of natural ventilation typology etc.

- The further research method of building configurations for vernacular settlement in this research can be a source of reference for further research related to urban block configuration and relation to block massing density for achieving outdoor comfort.
- The phenomenon of high precipitation leads to develop a research topic about sustainable water management in the Equatorial Rainforest and the climate analysis from this research can be used as the foundation of knowledge.
- The practical climate responsive design solution from the vernacular settlement is potential research for the transformation of climate responsive design strategy for current and future construction technology.
- The climate responsive design principles also potentially to developed in the development of the new cities in the future equatorial region project, especially in the context of the new Indonesia capital city on Borneo Island which lies on the same climate characteristic as the research case study.

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Appendix

List of Interview Sources

Interviewer	Case	Credibility	Interview Date	Method Interview
Faiz Hamdi Supratmant	Wae Rebo	Lecturer & book author of “Pesan dari Waerebo”	10.03.22	Video call
Benny	Wae Rebo	Local Resident	10.03.22	Video Call
Parmonangan Manurung	Kete Kesu	Lecturer & Tongkonan in Toraja	13.03.22	Video Call
Lina	Huta Sialagan	Local Resident	15.03.22	Video Call
Sanda	Kete Kesu	Local Resident	18.03.22	Video Call
Anarisman	Kampung Naga	Local Resident	20.03.22	Phone call
Himasari Hanan	Huta Sialagan	Researcher for Huta Sialagan	24.03.22	Video call

List of Remote Survey

Research Title:

Climate-Responsive based Experience

An inventory study of Indonesia vernacular settlement typology

Researcher : Melvina Pramadya Puspahati

Fieldwork schedule : March 2022 (+ 1 month)

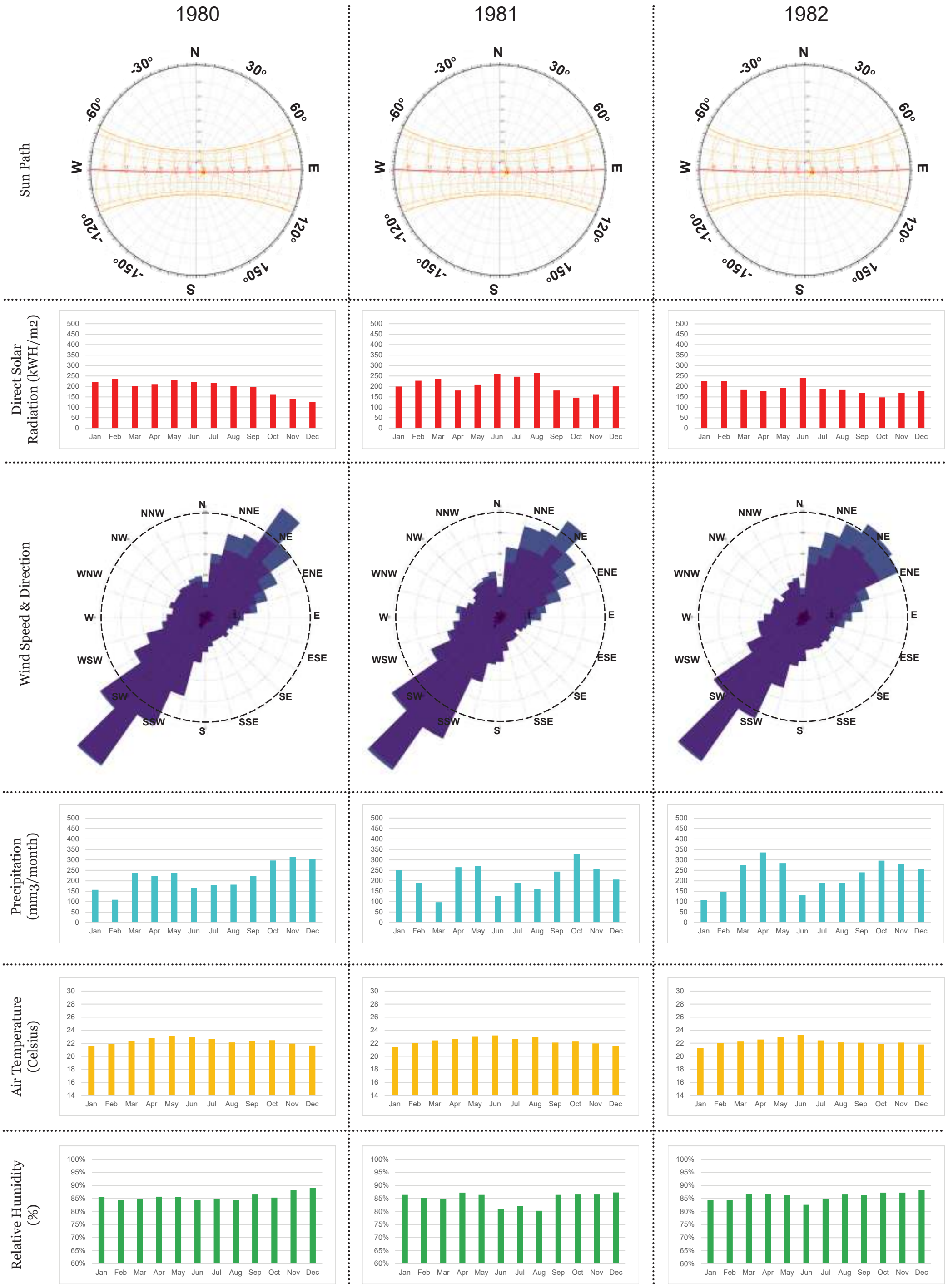
Field Work Target Data Collection

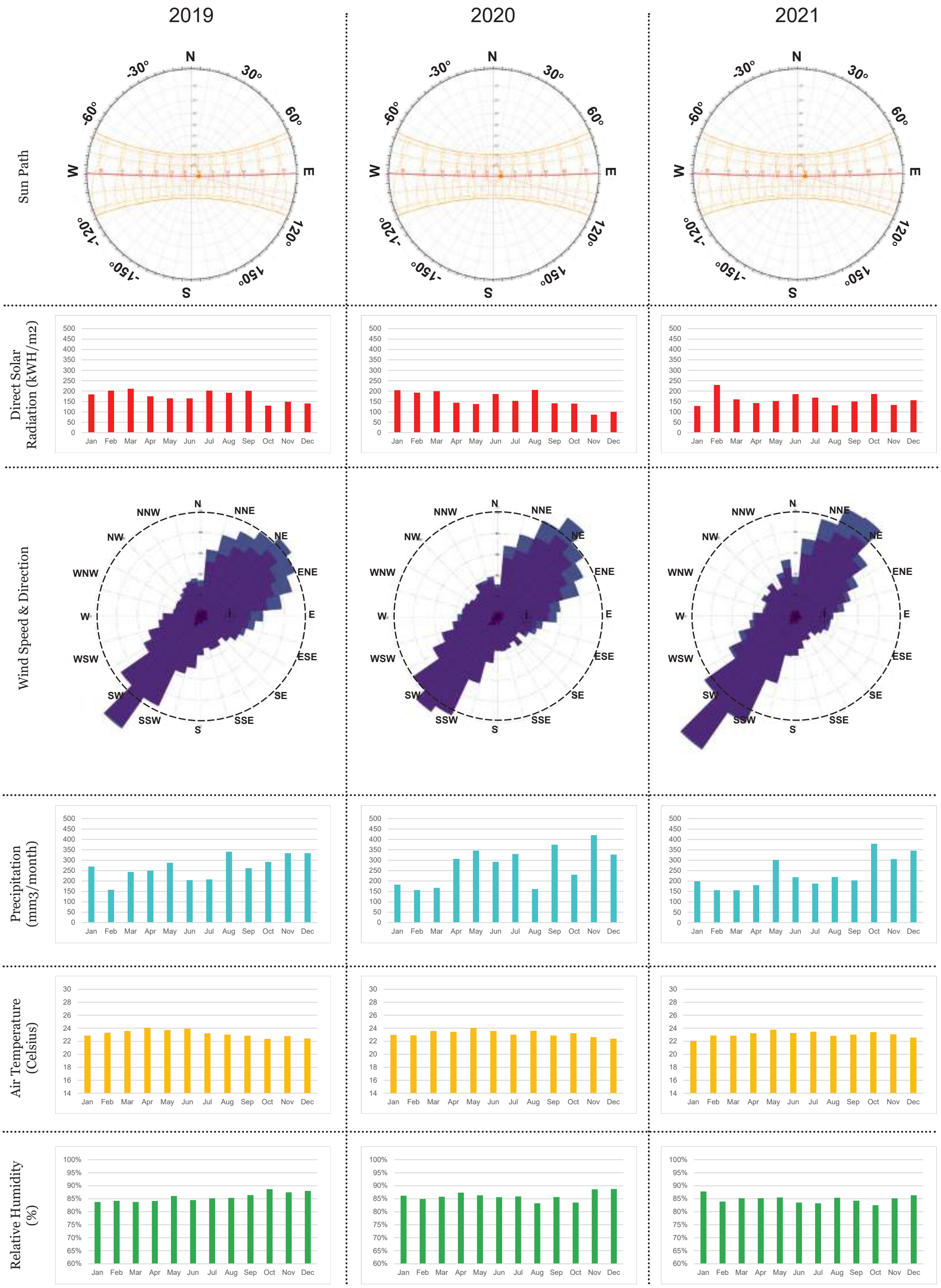
Data requirement for each case study:

No	List of Data	Data Type	Source	Data gathering	Checklist
1	**Weather Data**	**Secondary**	**https://www.ladybug.tools/epwmap/**	**EPW file**	
1	**Settlement area spatial configuration**				
A	Site selection	Secondary	Literature	Topographic data	
		Primary	Interview	The reason for selecting the location	
B	Town Structure	Secondary	Literature	Masterplan data	
		Primary	Survey	Land cover material	
C	Public Space	Secondary	Literature	Masterplan data	
D	Landscape configuration	Primary	Survey	Vegetation Mapping Vegetation Type & size Water source location	
2	**Building spatial configuration**				
A	House Type	Secondary	Literature	Type of housing	
B	General Arrangement	Secondary	Literature	Distance between building Distance between building to vegetation	
C	Plan	Secondary	Literature	Site plan data	
D	Form & Volume	Secondary	Literature	Site plan data Building Section Building Facade	
E	Orientation	Secondary	Remote	Site plan data	
F	Interior	Secondary	Literature	Site plan data	
		Primary	Survey	Interior building documentation Partition configuration	
G	Color	Primary	Survey	Building color	
3	**Building Element**				
A	Opening & Window	Primary	Survey	Opening type, position, and size	
B	Walls	Secondary	Literature	Wall Position	
		Primary	Survey	Wall thickness	
C	Roof	Secondary	Literature	Roof forms, angle, and size	
		Primary	Survey	Roof layer components	
D	Material	Primary	Survey	Roof material for building	
E	Shading Device	Primary	Survey	Shading type and position in the building Shading length and angle	
F	Foundation	Primary	Survey	Building foundation	
G	Mechanical Equipment	Primary	Survey	Conventional for heating or cooling system	
4	**Intangible information**				
A	The process of local tribes built their settlement	Primary	Online interview		
B	The information about how local tribe respond to climate or to ecological context for forming a settlment	Primary	Online interview		
C	The perception of settlement from a local perspective	Primary	Online interview		

HUTA SIALAGAN, SAMOSIR, WEATHER DATA

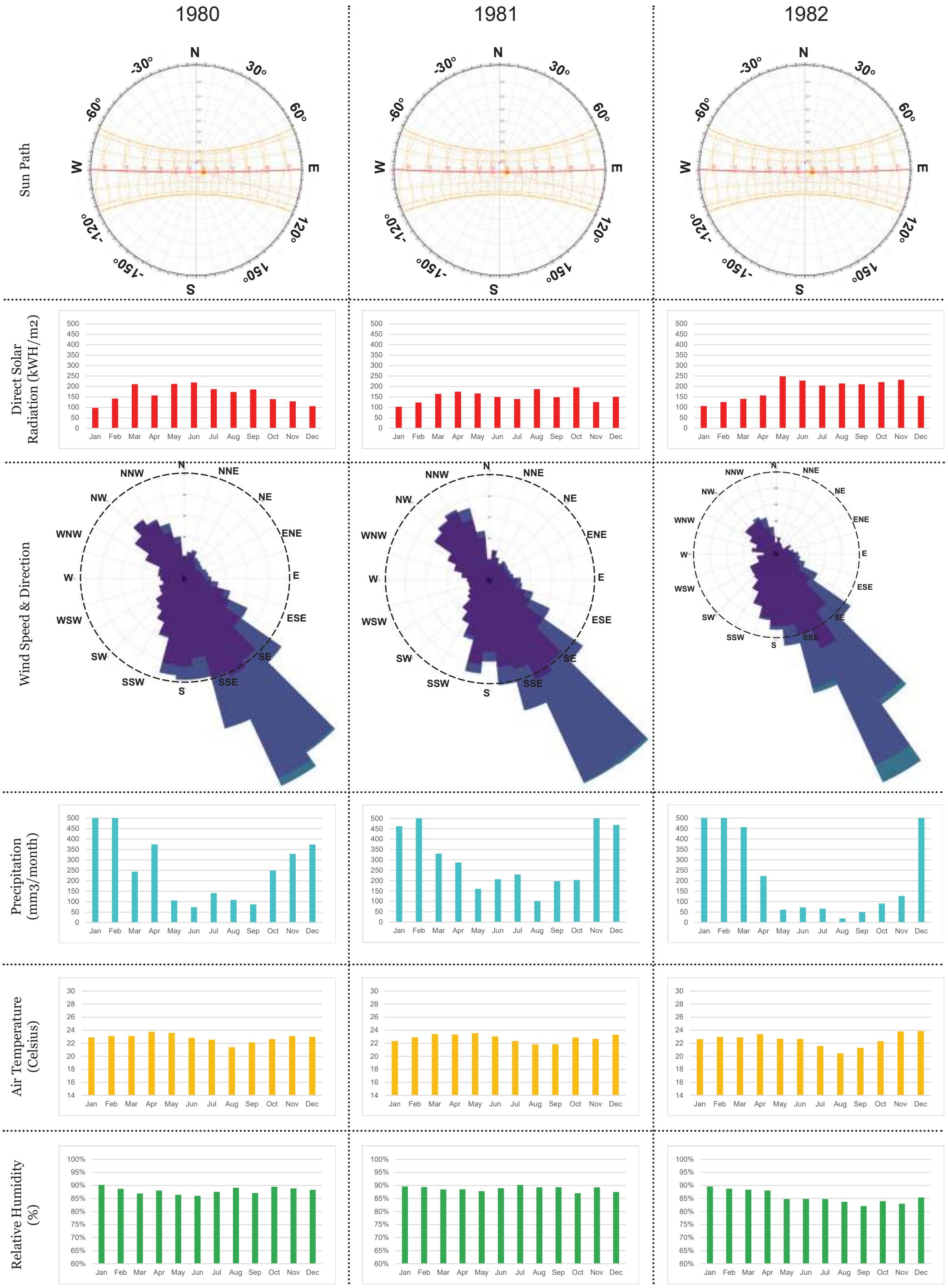
Weather Data Huta Sialagan
(1980, 1981, 1982, 2019, 2020, and 2021)
Source: Authore based On ERA5 database

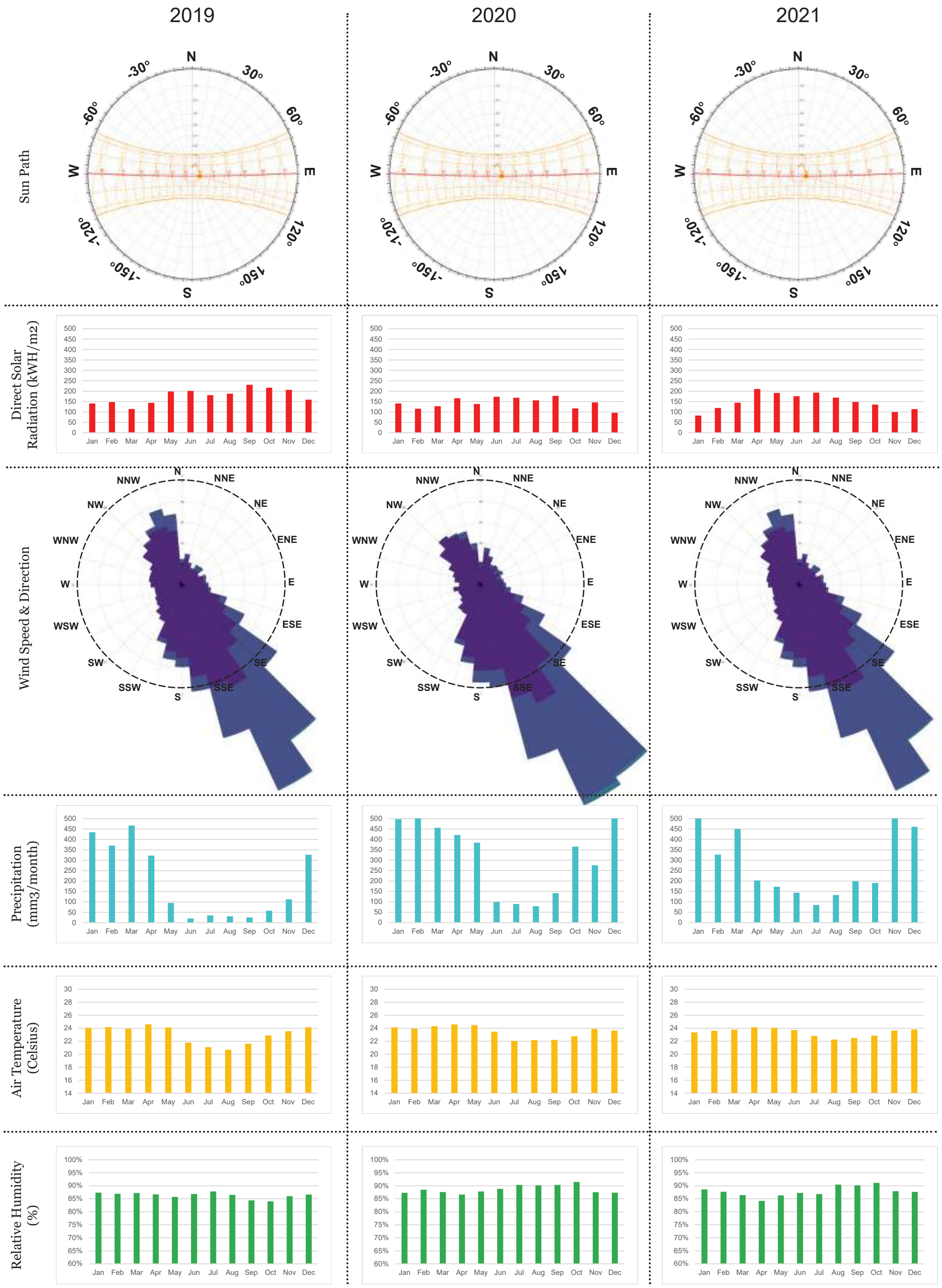



2019
2020
2021
Sun Path
Direct Solar Radiation (kWH/m2)
Wind Speed & Direction
Precipitation (mm3/month)
Air Temperature (Celsius)
Relative Humidity (%)
N
S
E
W
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
NNW NNE NW NE WNW ENE WSW ESE SW SE SSW SSE

KAMPUNG NAGA, TASIKMALAYA WEATHER DATA

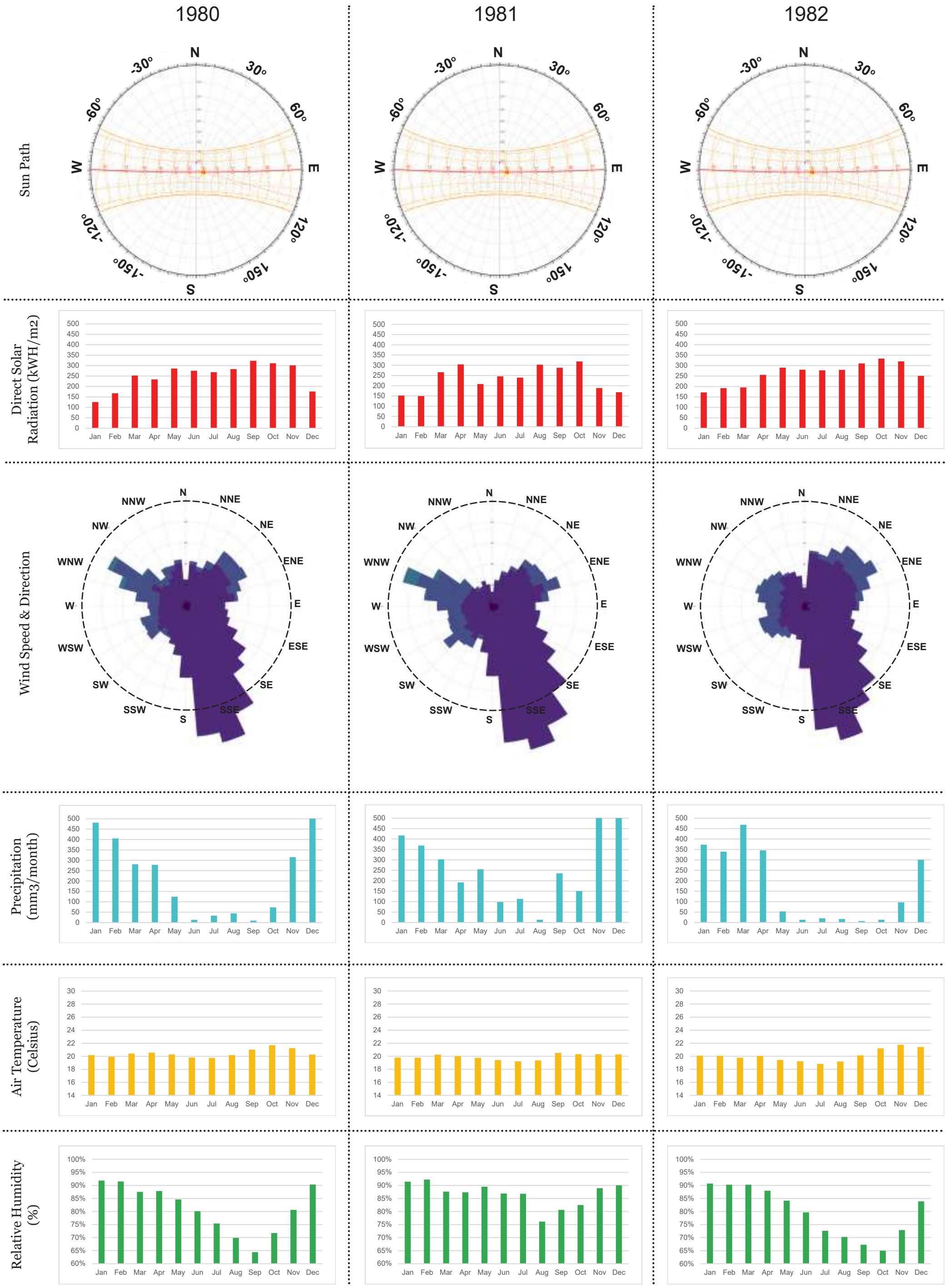
Weather Data Huta Sialagan
(1980, 1981, 1982, 2019, 2020, and 2021)
Source: Authore based On ERA5 database

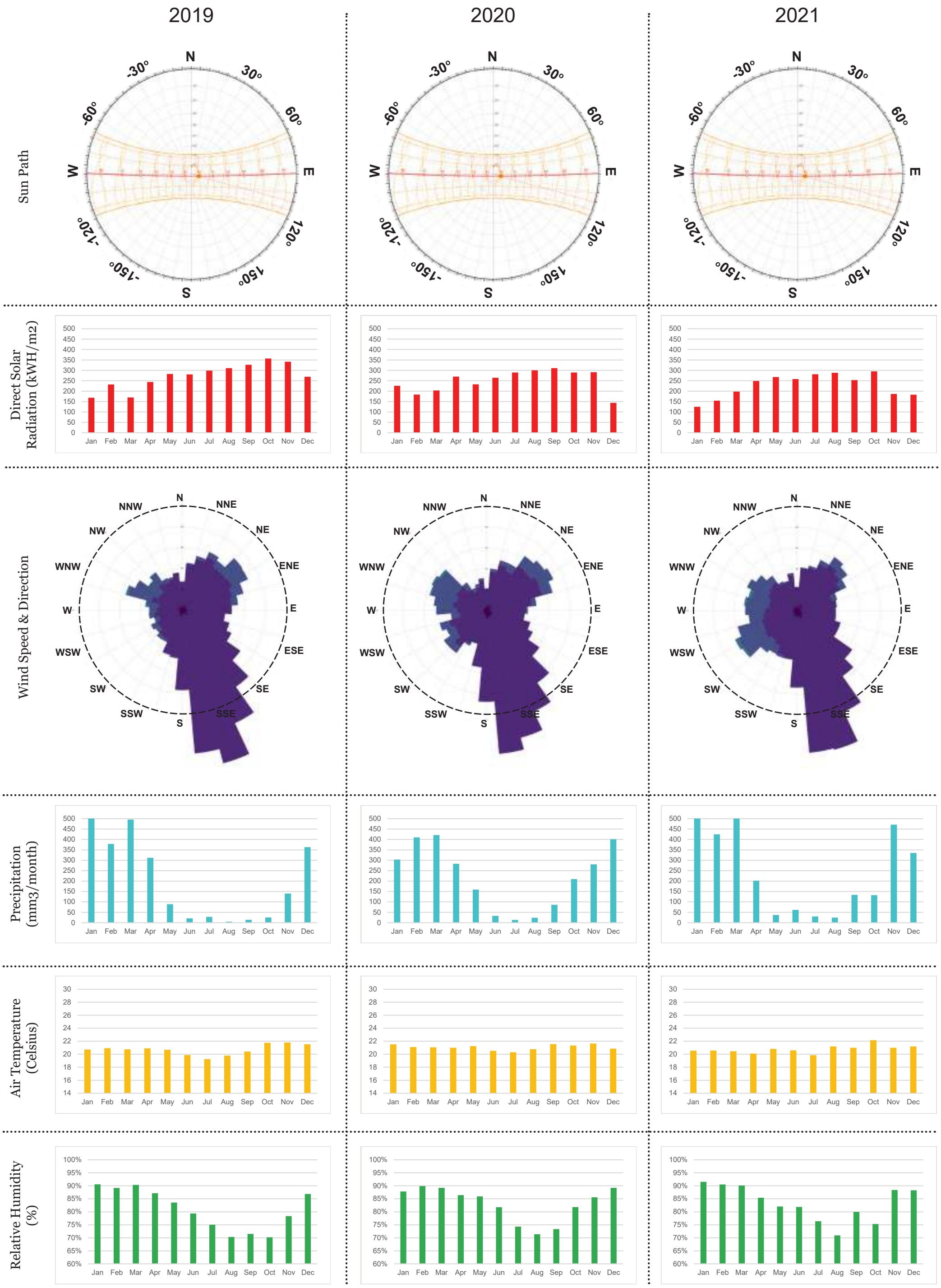



2019
2020
2021
Sun Path
Direct Solar Radiation (kWH/m2)
Wind Speed & Direction
Precipitation (mm3/month)
Air Temperature (Celsius)
Relative Humidity (%)
N
S
E
W
30°
60°
120°
150°
-30°
-60°
-120°
-150°
NNE
NE
ENE
ESE
SE
SSE
SSW
SW
WSW
WNW
NW
NNW
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

WAE REBO WEATHER DATA

Weather Data Huta Sialagan
(1980, 1981, 1982, 2019, 2020, and 2021)
Source: Authore based On ERA5 database




2019
2020
2021
Sun Path
N
S
E
W
30°
60°
120°
150°
-30°
-60°
-120°
-150°
Direct Solar Radiation (kWH/m2)
Wind Speed & Direction
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
Precipitation (mm3/month)
Air Temperature (Celsius)
Relative Humidity (%)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Research Assistant

Ain Shams University
Egypt

University of Stuttgart
Germany

Research Assistant Confirmation Letter

On behalf of my role as a research assistant,

Name : Rio Agung Nugroho
Location Survey : Kampung Naga, Tasikmalaya, West Java
Date of survey : 13 – 16 March 2022
Contact person : rioagungars@gmail.com

I would like to confirm that I conducted a site survey for Melvina's master thesis research with the title of **Climate Responsive Approach in Vernacular Settlements**, a case study of Indonesia's vernacular settlements inside the equatorial rainforest climate region. I declare my statement that all the data collection is correct.

Please do not hesitate to contact me if you have any further questions

Yours sincerely,
Bandung, 22.04. 2022

Rio Agung Nugroho

Ain Shams University
Egypt

University of Stuttgart
Germany

Research Assistant Confirmation Letter

On behalf of my role as a research assistant,

Name	: Sanda Paluta
Location Survey	: Ke'te Kesu', North Toraja, South Sulawesi
Date of survey	: 28 February – 7 March 2022
Contact person	: sandapaluta@gmail.com

I would like to confirm that I conducted a site survey for Melvina's master thesis research with the title of **Climate Responsive Approach in Vernacular Settlements**, a case study of Indonesia's vernacular settlements inside the equatorial rainforest climate region. I declare my statement that all the data collection is correct.

Please do not hesitate to contact me if you have any further questions

Yours sincerely,
North Toraja, 09 June 2022

(Sanda Paluta)

Ain Shams University
Egypt

University of Stuttgart
Germany

Research Assistant Confirmation Letter

On behalf of my role as a research assistant,

Name	: HERLINA SINAGA
Location Survey	: HUTA SIALLAGAN , SAMOSIR
Date of survey	: 03 MARCH 2022
Contact person	: +62-87876882764

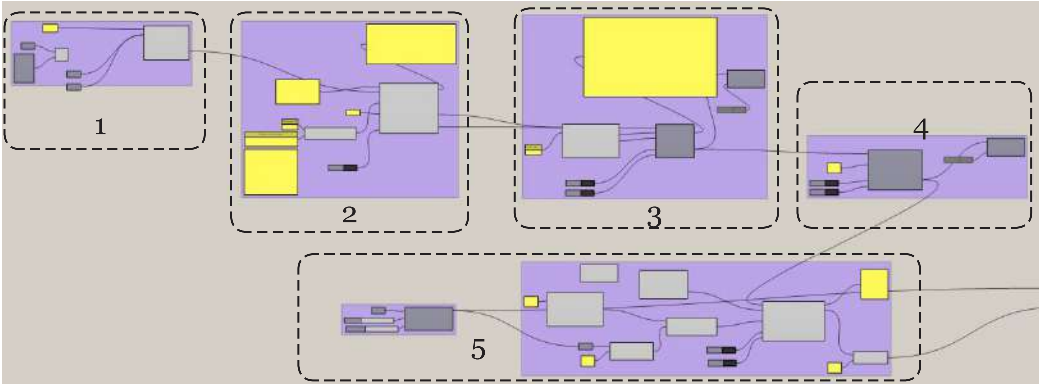
I would like to confirm that I conducted a site survey for Melvina's master thesis research with the title of **Climate Responsive Approach in Vernacular Settlements**, a case study of Indonesia's vernacular settlements inside the equatorial rainforest climate region. I declare my statement that all the data collection is correct.

Please do not hesitate to contact me if you have any further questions

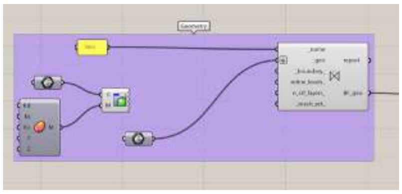
Yours sincerely,
SAMOSIR, 6-8-2022

(HERLINA SINAGA)

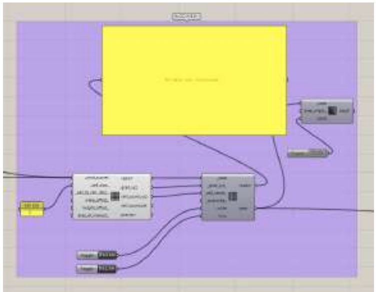
CFD wind simulation scripting



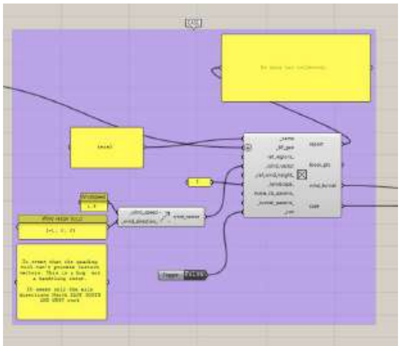
1. Geometry input



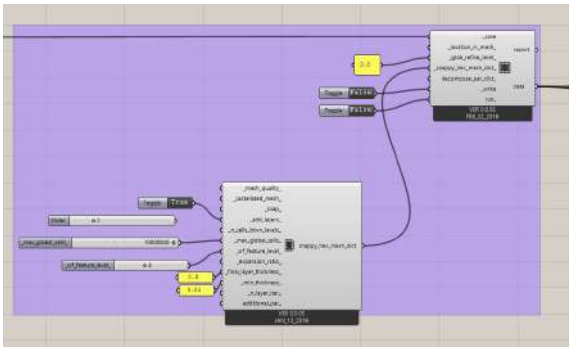
3. Create block mesh



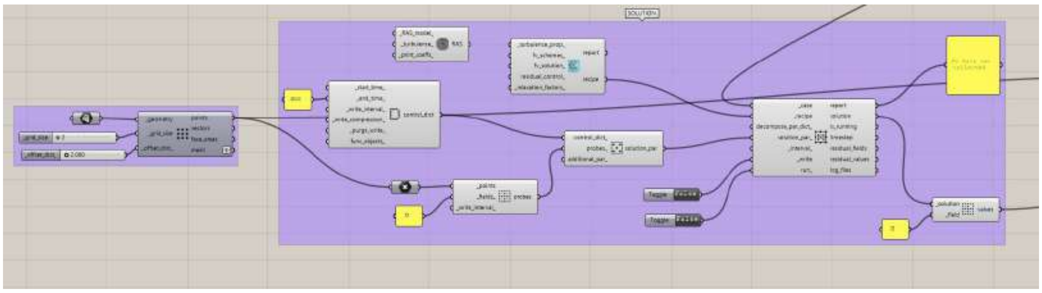
2. Wind tunnel set up



4. Create hex mesh



5. Run simulation solution



(Fig 4.6) - the CFD simulation scripting
Source: Author adapted from Sakimaya, 2021

مجرد:

إن تغير المناخ ظاهرة سيئة السمعة في الحضارة الحالية، ولا سيما في التنمية السريعة النمو، بما في ذلك إندونيسيا .تقع إندونيسيا داخل منطقة مناخية استوائية تتمتع بشكل أساسي بدرجة حرارة معتدلة دون تحديات مناخية شديدة مثل الشتاء البارد والصيف الحار إندونيسيا كبلد نام لديها طلب كبير على الإسكان في كل من المناطق الريفية والحضرية والحضرية الجديدة .يهيمن على الاتجاه الحالي لتصنيف المساكن في إندونيسيا منازل منفصلة لأسرة واحدة . تؤثر التنمية الحديثة على حلول التصميم العامة حتى في السياقات الثقافية والبيئية والمناخية المختلفة .في غضون ذلك، قبل فترة طويلة من العصر الصناعي، نجت الحضارات السابقة لبناء مستوطنة تسمى »اللغة العامية «تميل إلى الاستجابة للسياق المناخي في المعرفة المعمارية المحدودة والأجهزة التكنولوجية في ذلك الوقت، ولا تزال مستمرة حتى الآن في إندونيسيا. يمكن افتراض أن المستوطنات العامية هي عينة ناجحة من اختراع التصميم المستدام بناءً على تجربة السكان المحليين. الهدف من البحث هو تحديد حل التصميم المستجيب للمناخ من المستوطنة العامية التي تنطبق عمليًا على التطوير السكني الحديث في سياق منطقة مناخ الغابات الاستوائية المطيرة في إندونيسيا .وتجري منهجية البحث من خلال تحليل تحليلي لبيانات الطقس الإحصائية لتحديد الخصائص المناخية للحالات، وتحليل مواضيعي للتحقيق في جرد الحلول المستجيبة للمناخ في المستوطنات العامية، وتحليل كمي نوعي لتقييم المبادئ المشتركة بين دراسات الحالات الإفرادية من خلال المحاكاة الحسابية. تتمثل النتائج المتوقعة للبحث في مجموعة من بارامترات التصميم المستجيبة للمناخ لتطوير المستوطنات مع الأخذ في الاعتبار استراتيجيات التصميم السلبية وإيجاد جرد لحلول التصميم المستجيبة للمناخ بناءً على الممارسة من المستوطنات العامية القابلة للتطبيق على تطوير المستوطنات الحديثة الحديثة.ة

الكلمات الرئيسية :مستجيبة للمناخ، عامية، مستوطنة، مناخ مناخي حيوي، استوائي

إقرار

هذه الرسالة مقدمة في جامعة عين شمس وجامعة شوتجارت للحصول على درجة العمران المتكامل والتصميم المستدام. إن العمل الذي تحويه هذه الرسالة قد تم إنجازه بمعرفة الباحث سنة ...

هذا ويقر الباحث أن العمل المقدم هو خلاصة بحثه الشخصي وأنه قد اتبع الإسلوب العلمي السليم في الإشارة إلى المواد المؤخوذه من المراجع العلمية كلٌ في مكانه في مختلف أجزاء الرسالة..

وهذا إقرار مني بذلك،،،

التوقيع:

الباحث: Melvina Pramadya Puspahati

التاريخ: 31/07/2022

النهج المستجيب للمناخ في المستوطنات العامية

(دراسة حالة: منطقة مناخ الغابات الاستوائية المطيرة في إندونيسيا)

لجنة أشراف

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Professor of Building Technology
and Climate Responsive Design
Academy of Art and Design (ABK)
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Prof. Dr. Leonie Fischer
Professor of Landscape
Planning and Ecology
University of Stuttgart
Germany

Prof. Dr. Mohamed Salheen
Professor of Regional Planning
Ain Shams University
Egypt

لجنة الحكم

التوقيع

أ.د. .... الممتحن الخارجي
أستاذ.............
جامعة ....

أ.د. ....
أستاذ.............
جامعة ....

أ.د. ....
أستاذ.............
جامعة ....

تاريخ المناقشة:..............

الدراسات العليا

ختم الإجازة

أجيزت الرسالة بتاريخ:.............

موافقة مجلس الكلية .../.../...

موافقة مجلس الجامعة .../.../...

جامعة عين شمس

جامعة شتوتجارت

31/07/2022

جامعة عين شـــــمس

جامعة شتوتجارت

النهج المستجيب للمناخ في المستوطنات العامية

دراسة حالة: منطقة مناخ الغابات الاستوائية المطيرة (في إندونيسيا)

رسالة مقدمة للحصول على درجة الماجستير في العمران المتكامل والتصميم المستدام

إعداد

(Melvina Pramadya Puspahati)

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(31 July 2022)