An evaluation of the tropical architectural concept on the building design for achieving thermal comfort (Case study: engineering faculty of Syiah Kuala university)

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Abstract. Thermal comfort is one of the main goals in architectural design. For the tropics, thermal comfort can be achieved with passive cooling and active cooling. Buildings in the tropics should be designed to maximize the application of passive cooling to achieve thermal comfort by adapting to the climate using the concept of tropical architecture. The study was performed at the building of the Faculty of Engineering of Syiah Kuala University seen to be applying tropical architecture. The research aims to find out how the application of tropical architectural concepts in building designs to achieve thermal comfort. The methodology used was a qualitative method by observing the mass and orientation of the building, roofs, ceilings, walls, openings and vents, shading, and landscaping. The results indicated that the rectangular building with the shortest side faces east-west aiming to reduce the hottest exposure to solar radiation in the east and west. There are many openings on the north-south side to maximize air flow. The gable shape with a slope of 30° is a form of adaptation to the tropical climate to shade the building from the sun and rain. The use of vertical, horizontal, and hallway shading devices as shade can protect direct light from the sun. The building maximizes cross air flow with many openings. It is recommended to conduct further research in this study which is accompanied by field measurements and thermal comfort simulation tests.

1. Introduction
Every building ideally is designed to be functional, safe, healthy, beautiful, having aesthetic value, environmentally friendly, and comfortable [1]. Comfort, especially thermal comfort, is one of the main goals in architectural design. Thermal comfort can be achieved with passive cooling and active cooling strategies [2]. Szokolay mentioned that thermal comfort depends on climate variables (sun/radiation, air temperature, humidity, and wind speed) and several individual factors such as clothes, age and gender, obesity level, type of food and drink consumed, level of health, and skin color [3]. However, active cooling which is by mechanical airing uses electricity which mostly uses fossil energy that can have a negative impact on the environment and sustainability. The design of the building should apply a passive cooling design by adjusting the building to the climate and environment which achieves thermal comfort in order to not have a negative impact on the environment. Building construction and operation accounts
for around 50% of all energy resources consumed across the planet. It makes the construction industry the 'most unsustainable industry on earth' [4].

Climate has a significant impact on building performance and energy consumption. In building design it is important to identify, understand and regulate climate because it has the advantage of reducing the burden of energy costs, utilizes natural energy, as well as provides a healthy and comfortable environment [5]. Indonesia is a tropical country with humid characteristics. The humid tropical climate has temperatures close to the comfortable temperature range for humans in tropical climate regions. Hence, it provides opportunities to design buildings with a local tropical climate approach. In tropical climates the building should be designed to adapt to the environment and climate by using the concept of tropical architecture to achieve thermal comfort. Tropical architecture is a specific design of architectural work that leads to problem solving caused by tropical climate [1].

Each region has a characteristic building design that presents the characteristics of buildings that have been adapted to the local climate. The case study taken is the Engineering Faculty of Syiah Kuala University (FT Unsyiah), because it is considered to apply a tropical architectural approach based on visible characteristics to find out how the concept of Tropical Architecture is applied to the building. In general, the building characterizes the vernacular architecture of Aceh culture with a broad saddle roof and elongated mass forms. The building has three floors and operates from morning to afternoon. The Faculty of Engineering of Unsyiah is on St. Teuku Syiah Abdul Rauf, Kopelma Darussalam, Banda Aceh. The research aims to find out how the application of tropical architectural concepts in building designs to achieve thermal comfort. To find out how the concept of Tropical Architecture is implemented to the building design to achieve thermal comfort, it takes a review and research that can be used as knowledge and can also input for tropical buildings.

2. Tropical architectural concepts and thermal comfort
The tropical area is defined as areas that lie between the isotherm line of 20° to the north and south of the earth [2]. The humid tropical climate has the characteristics of having rainforest areas in the lowland, having soil which is usually red or brown with a green soil surface from vegetation, having a variety of types of vegetation throughout the year, having a slight seasonal difference from the hottest months which is from moist heat to wet and the coldest months which is medium heat as well as humid, wet, cloudy as well as foggy throughout the year, having annual rainfall that is 500-1250 mm, having the dry season which has little rain, having relative humidity which ranges from 20-85% depending on the season, having a strong and constant wind where in the jungle it gets slower and it gets faster when it rains. Usually there are one or two main wind directions [2].

The tropical architecture is a specific design of architectural work that leads to problem solving caused by tropical climate [1]. The tropical architecture is a concept of architecture that provides answers/adaptation of building forms to the influence of tropical climate, where tropical climate has certain characteristics caused by solar heat, humidity, rainfall, wind movement, and others. Moist tropical architecture is an architectural concept that provides answers to the adaptation of buildings to the influence of the humid tropical climate with the conditions that influence it. Tropical architectural design for the aim of adapting to climate and environment is done by maximizing the application of passive cooling in the building. Several conditions affect buildings in humid tropical climates. They are thermal comfort, air flow through buildings, natural glow and lighting, air temperature, rainfall, and air humidity [6]. There are several characteristics of humid tropical architectural design. They are the orientation of the main function room placed in the south and north, the longest side of the building facing north-south, the sloping roof design which has a broad roof space, having a wide roof terraces, maximizing openings on the south-north side and minimizing on the east-west side, utilizing the flow of the wind with the concept of cross ventilation, the shade of buildings, optimizing lighting and natural ventilation with lean buildings, choosing the type of material affecting the heat distribution of the room, and structuring outdoor space [1].

Comfort in a building can be defined as a condition that can provide a comfortable and pleasant feeling for its inhabitants [1]. Thermal comfort is a condition related to nature that can affect humans
and can be controlled by architecture [7]. According to Idham the main principle of design consideration with passive cooling to tropical climates to achieve thermal comfort is to eliminate or reduce external heat sources during the day by building envelope designs. There are several main elements in the design of passive cooling. They are the orientation of buildings to the wind and sun, zoning plans by maximizing day and night activities, proper window and glass openings, the use of effective shading, the use of appropriate insulation, the use of high thermal mass construction in areas with significant diurnal temperature ranges, and the use of low thermal mass construction in areas with low diurnal temperature ranges [5].

3. Research method
This study used a descriptive qualitative method carried out by observing the building of the Engineering Faculty of Syiah Kuala University, by recording data and physical conditions in the field. Observations focused on observing the mass and orientation buildings, roofs, ceilings, walls, openings and ventilation, shading, and landscaping (Table 1). This parameter is used in Lisa's research [8]. In addition, the writer also observed the conditions that could interfere with comfort. Observations were made by analysing, documenting, and measuring elements of research objects. The Faculty of Engineering consists of the FT-1 and FT-2 buildings. The object of the research is carried out only at the FT-1 Building, because the FT-1 and FT-2 buildings have almost the same shape.

| Element | Indicator             | Element | Indicator                      |
|---------|-----------------------|---------|--------------------------------|
| 1 Building mass and orientation | Sun path | Openings and Ventilation | Orientation and location |
|         | Form                  | 5 Opening’s type | Material |
|         | Dimension             | 6 Dimensions and quantities | Air movement |
|         | Position              | 7 Roof shape | Sun path |
| 2 Roof  | Roof slope            | 8 Roof slope | Type |
|         | Material              | 9 Shading | Material |
|         | The volume of roof space | 10 Shading | Material |
| 3 Ceiling | Ceiling elevation | 11 Landscape | Potition |
|         | Ceiling material      | 12 Landscape | Ground cover material |
| 4 Wall  | Material type and dimensions | 13 Wall | Material properties |

The method for data collection used was descriptive analysis method. Data collection begins with direct observation of the field by data recording, measurement, and analyzing the observed object elements. Then the data obtained were juxtaposed and compared with theories and literature to find out the relation and description of the tropical architecture concept’s application in buildings. After knowing the relation, then describe each corresponding element.

4. Results and discussion
Generally, the building of the Engineering Faculty of Syiah Kuala University applies the concept of tropical architecture which aims to adapt the building design to the local climate and environment, namely a tropical climate with a humid character. The shape and mass of the building in this building characterizes the application of the concept of vernacular architecture with the characteristic of Aceh's culture (Figure 1). The vernacular architecture itself is an architecture that is formed from a process that
is long and repetitive following the behavior, habits, and culture in its place of origin which also aims to anticipate and respond to local climate problems [9]. The observations can be seen in Table 2.

4.1. Mass and orientation of the building
The building of the Faculty of Engineering of Syiah Kuala University consists of several rectangular building masses with different floors story. In the three west building masses, it has three building stories, and the rest of the building has two stories. The total mass of the building is connected by corridors and stair circulation paths (Figure 2). The three-story mass of the building provides shadowing of the lower building mass and courtyard when exposed to sunlight from the west. The masses with a rectangular shape are positioned with the longest side of the building facing north-south, and the shortest side facing west-east. The shape and orientation are appropriate and optimal in the humid tropical area [10]. The west-east side of the tropics gets more heat than the north-south side, so on the west side it is optimized to reduce the width of the building surfaces.
The building of the Engineering Faculty of Syiah Kuala University has 13 meters width for 3 masses in the west and 3 masses in the east, and 9.8 meters width in 4 masses in the middle. This allows air and light to pass through the room more optimally. The sunlight and wind can reach the farthest distance of about 6 meters from the window to a room height of about 3 meters accompanied by open the openings. Therefore, the optimal width of the shortest side of the building is no more than 12 meters [1]. The masses of the buildings which are intermittently connected through the hall provide space for an open courtyard in the middle of the building. The intermittent building mass also allows air to flow heavily and can be captured by each building mass [11].

4.2. Roof
According to Lippsmeier, the roof is the most important element in tropical design [3]. The roof determines the temperature of the air space under the roof, because the solar thermal radiation exposed to the roof is partially reflected, partly absorbed by the roof material and channeled into the space under the roof [1]. The building of the Engineering Faculty of Syiah Kuala University uses a saddle roof with ceramic tile material with a slope of approximately 30 degrees. The slope of the roof serves to protect the building from direct sunlight and rain that often occurs in tropical areas. Compared to flat roofs and shielding roofs commonly used in tropical buildings, the use of gable roofs results in a greater volume of space under the roof (between the roof and ceiling layers) supported by the slope. However, on the gable, the roof cannot protect the entire wall of the building. Roofs with ceramic tile material allow heat reflection and slow heat absorption. Under the ceramic tile roof there is a layer of aluminum foil that can prevent heat from entering the roof space, to reduce heat.

4.3. The ceiling
The storey height of the building of the Engineering Faculty of Syiah Kuala University varies between floors. The storey height of the 1st floor to the 2nd floor is 4.8 meters, the 2nd floor to 3rd floor is 5 meters, and the second-floor height to the 3rd floor is 4.55 meters. This condition is used to use a high ceiling from the floor of each floor. The average ceiling height is almost 3.7 meters. The high ceiling allows air to flow more freely so that it can reduce humidity and heat (Figure 3a). Indoor ceilings in tropical climates are very important so that heat radiation from the roof layer above it can be retained in the roof space and not directly enter the room below it [1].

4.4. Wall
The main construction building’s materials using concrete and brick. The wall material is brick that has a thickness of 15 cm. Concrete and brick material has the ability to keep heat and has a heat release delay that is longer. With the delay in the release of heat in the material, it removes the peak heat flow conditions at night so the room during the day stays cool when equipped with good air movement and shade. It is very suitable to be applied in the study room which is only used from morning to evening in the tropical climate. Cooling and heating by utilizing the appropriate time shift can reduce the cost of electrical usage [2]. Lippsmeier explained that concrete with a thickness of 15 cm has a time lag of 3.8 hours, a thickness of 20 cm has a time lag of 5.1 hours, while bricks with a thickness of 10 cm have a time lag of 2.3 hours, and thickness 20 cm has a time lag of 5.5 hours [2]. The walls of the building are painted in white and the columns beige. White is the color with the best reflective properties [12]. White walls allow a large reflection of sunlight and reduce absorption [12].

4.5. Openings and ventilation
In the laying of openings, it is necessary to pay attention to the direction of orientation so that direct sunlight does not enter the room, which is utilized indirect light from the sun (Figure 3). In the tropics, the west and east sides are the most receptive to solar radiation, while the north-south is the least. In the
tropics, the light utilized is indirect light from the sun. In the building of the Faculty of Engineering of Syiah Kuala University, the north-south side of the building maximizes many openings (Figure 5a). Conversely on the west-east side minimize openings (Figure 5b). The east-west side with few openings aims to block direct sunlight from entering the room. Side opening of the north-south side allows the flow of air in and out crossing the room without direct sunlight from the west and east.

![Figure 3. Layout, circulation of air flow movement.](image)

![Figure 4. Building section, cross air movement, courtyard help air distribution.](image)

The concept of cross ventilation is also supported by the open space in the middle of the building as one of the many spaces flowed by air (Figure 4). Some rooms only have one side opening for air in and out with no air exchange crossing. In addition, the ventilation has been closed for AC use (Figure 5c). The flow of air can no longer flow into the room. The position of the window in the corridor has a distance of 1.85 meters from the floor. This is less beneficial because the air flows above the human body when sitting indoors (Figure 5d). The body is only slightly passed by the wind. The type of opening used is the window with the type of awning hung-up, and the type of ventilation above the window and door used are the horizontal fin (Figure 5d). Window with awnings hung-up type has effectiveness 75%, whereas according to Bell and Paskins, horizontal fin ventilation has an effectiveness of 85-90% [13] [14]. The windows use dark tinted glass so that it reduces light entering the room and it is able to absorb some of the heat.

![Figure 5. (a) west view, (b) north view, (c) classroom, (d) corridor](image)

On the stairs and lobby there is a hole made of a concrete roster that allows air to get in and out and also can dispel the light and rain splash (Figure 6a). Holes of the concrete roster are also found in railings in corridors and walls above corridor railings (Figure 6b).

4.6. Shading
In tropical area, sunlight occurs from morning to evening throughout the year. Therefore, shading is needed to provide shade to buildings for reduce the heat. The main roof of the building has a roof overhang with a width of up to 2.20 meters which can provide a lot of shading to the building walls, especially the wall on the story where the roof is located (Figure 5a). Sun shading with type of overhang in the form of a ceramic tile-coated roof located above the window and above the corridor also provides shade and dispels direct sunlight (Figure 5a). Sun shading with over-hang type is effective on
the building with openings facing to the north and south, the effectiveness depends on changes in the movement of the angle of arrival of sunlight [15]. Prominent beams also give shading to the wall as vertical shading. Vertical sun shading is effectively placed on the west-east side to block sunlight from the south-north side [16]. Several types of shading are applied according to the tropical climate. Corridors or hallways provide shelter to the sun's rays so that the light entering the room is indirect light (Figures 6a, 6c). The previously mentioned roster grille allows light to enter with shade (Figure 6b). Poles that are advanced out of the building can also function as shading vertical blocking sunlight from east-west towards the north-south side (Figure 5a).

4.7. Landscape

The efficient use of the courtyard is applied as a bioclimatic thermal controller in the built environment with natural air comfort control [17]. The courtyard will let the air move throughout the house plans that surround the courtyard especially those directly facing the open courtyard. High indoor air temperatures will be solved through shade from plants planted in the courtyard and shade from subsequent rooms [18]. The Courtyard is able to suck air from outside and also circulate air [5]. Based on Kubota's research, the small yard that is usually built in Chinese shop houses is effective for cooling the high thermal structures of building masses through night ventilation and radiation coolers [19]. Trees in the central courtyard of the building can also provide fresh air and help lowering the temperatures (Figure 7). Plants on the west and east sides can provide shade to buildings (Figure 8). There are many trees between buildings that provide shade and can help lowering the temperatures.

4.8. Conditions that interfere with thermal comfort

Some rooms in the building of the Engineering Faculty of Syiah Kuala University use artificial air conditioning system named air conditioner (AC). The use of air conditioners in rooms that were previously designed to use natural ventilation is less beneficial. High ceilings in the room can aggravate the AC workload because it has a large volume of space and is not optimal for cooling the room. For air conditioning usage, most of the ventilation is closed so that air cannot flow into and out of the room (Figure 9). Some placements of AC machines are in the corridor and close to the circulation path of people, and some are at the top of the corridor. Placement of the AC compressor engine generates heat
and causes an increase in temperature around its location (Figure 10). This is not beneficial in thermal comfort.

**Table 2. Observation Results.**

| Element                     | Indicator            | Theory                                                                 | Function                                           | Observation Results                                                                 |
|-----------------------------|----------------------|------------------------------------------------------------------------|----------------------------------------------------|-------------------------------------------------------------------------------------|
| Building mass and orientation | Sun path             | The shortest side of the building faces west-east, the longest side of the building faces north-south | reducing the sun's hottest exposure on the east-west side | The shortest side of the building faces west-east, the longest side of the building faces north-south |
| Building orientation        | Form Dimension       | Rectangle (optimum in a ratio of 1: 1.7)                               | reducing the sun's hottest exposure on the east-west side | Rectangle                                                                         |
|                             | Position             | Not parallel to each other                                            | air flow moves a lot in each mass                 | Not parallel to each other                                                          |
| Roof                        | Roof shape           | Not a flat roof (over 20°), wide or narrow terraces, but consider the wind | Protect from rain, sunlight. Roof space reduces heat | Gable roof                                                                         |
|                             | Roof slope           | The roof slope is more than 30°                                       | Drains rain well, reducing wind suction            | The roof slope is more than 30°                                                   |
|                             | Dimension            | Wide or narrow terraces, but consider the wind                        | Give shading to the building                      | The width of the eaves is 2.20 m, the roof eaves are damaged and replaced with PVC, the roof gives a good shading effect on the walls |
|                             | Material             | A strong material, not lightweight, waterproof coating, reduce heat   | Consideration of strong winds, can reduce heat not flowing directly into the cellars, protecting against rain | Using a ceramic tile roof layer, with radiation and heat absorption 62-66%          |
|                             | Volume of roof space | spacious roof space (space between the roof and ceiling)              | Give room so that air can freely flow             | spacious rooftop space                                                               |
| Ceiling elevation           | Ceiling elevation    | High ceilings                                                          | Gives room so that air can freely cross (cross ventilation) reduce heat | The average ceiling height of 3.8 meters                                              |
|                             | Ceiling material     | material with the ability to reduce heat                               | Acoustic gypsum tile ceiling material              |                                                                                      |
| walls                       | Material type and dimensions | Bricks and concrete (massive wall), waterproof, moisture resistant, noisy | using material and color properties             | Bricks and concrete                                                                  |
|                             | Material properties  | Time Leg, slow to absorb heat                                         | Release the heat at the desired time              | release heat at night                                                                |
| Openings and Ventilation    | Orientation and location | Many openings in north-south, few openings in east-west              | Blocking east-west sunlight                       | Many openings in north-south, few openings in east-west                              |
|                             | Type                 | Maximizing air flow                                                   | Maximizing air flow                               | Using a hung-up window, horizontal fin ventilation, a partial ventilation was closed for the use of Air Conditioner. |
|                             | Material             | A strong material, waterproof, moisture resistant                     | Durable, avoid mold, water and termites          | Wood with dark glass                                                                 |
|                             | Dimensions and quantities | Maximize opening area                                              | Maximizing natural air flow                       | Has a wide and many openings                                                         |
|                             | Air movement         | Using the concept of cross ventilation                               | Maximizing natural air flow                       | Most use the concept of cross ventilation,                                            |
| Shading                     | Sun path             | shadowing the wall on the east-west side                               | Block out direct sunlight                         | A little shading on the east-west side, a lot of shading on the north-west side Horizontal shading (overhangs) of ceramic tile roofs on the south-north side Gable roof |
|                             | Type                 | Vertical shading on the east-west side, horizontal shading on the north-south waterproof | Block out direct sunlight                         |                                                                                    |
|                             | Material             | Not leak, not mold, not damp, and durable                             |                                                                                                    |                                                                                    |
| Landscape                   | Position             | Shade vegetation especially in the east-west, not too close to the building, giving an area for air movement towards ventilation | Shadowing and producing fresh air                 | Vegetation on the west side gives a shadow in the afternoon, there is vegetation around the building |
Most of the ceiling on the 3rd floor has been damaged causing a hole between the roof space and the space under the ceiling (Figure 11,12). This leads the loss of divider between the roof spaces and the space below the roof so that it can increase the heat of the room because of the heat of solar radiation from the roof is channeled directly to the room below.

5. Conclusions
Overall, the building of the Engineering Faculty of Syiah Kuala University has applied the building design rules to adapt to the humid tropical climate based on a tropical architectural approach to achieving thermal comfort. The results indicated that the rectangular building with the shortest side faces east-west aiming to reduce the hottest exposure to solar radiation in the east and west. There are many openings on the north-south side to maximize air flow. The shape of the gable with a slope of 30° is a form of adaptation to the tropical climate to shade the building from the sun and rain. The brick wall is suitable for lecture buildings in the tropics moving from morning to evening because it releases heat at night. The use of vertical, horizontal shading and hallway as shade can protect direct light from the sun. The building maximizes cross air flow with many openings, high ceilings, and the presence of a courtyard. Parks with trees around the building provides a shading device to the building and can reduce heat. However, the use of air conditioners, closed ventilation, and broken ceilings under the main roof can interfere the thermal comfort.

This study only analyzes the application of tropical architecture concept in buildings to achieving thermal comfort. Consequently, a further research is needed which is accompanied by field measurements and thermal comfort simulation tests to determine the effect of applying tropical architecture to the level of thermal comfort in buildings.

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