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Article

Energy and thermal load analysis of exposed brick houses on the coast

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Abstract: Energy conservation is an issue that is still being discussed in the architectural realm to create zero-net energy buildings. Buildings are considered to be significant contributors to energy waste, so they are a concern for experts in energy conservation issues. Buildings in hot areas require large amounts of energy in building operations. One of the hot areas is the coastal area. Residential houses on the coast of Indonesia use exposed brick materials. Energy use for buildings with exposed brick walls must be studied to create energy-efficient coastal buildings. The study aims to reveal the energy use and thermal load of residential houses with exposed brick walls on the coast. The study uses a simulation method using the Revit application. Data is obtained from a combination of field data and the Revit application. The analysis uses energy use analysis and cooling load analysis. Energy use analysis includes building performance factors, energy use intensity, life cycle energy use/cost, renewable energy potential, annual carbon emissions, and annual energy use/cost. The study results show that the energy use of residential houses in Demak is more significant than in Jepara. The characteristic of Demak, which has a higher air temperature than Jepara, is the main factor causing substantial energy use. Another condition is the architectural elements in each house that affect the thermal load on the building. The main findings obtained are that high air temperatures influence significant energy use. The shape of the building and ventilation elements of houses in Demak increase the air temperature in the room compared to houses in Jepara. Recommendations that need to be made are that when making a house, it needs to be designed to suit environmental conditions. The values of local wisdom in an area need to be maintained to increase the architectural value by providing thermal comfort for its occupants.

Keywords: architecture; energy; beach; local; material

1. Introduction

Energy use in buildings is one factor influencing global energy problems. Energy savings can be achieved by creating thermal comfort for building occupants [1]. Energy-efficient buildings are developed to create sustainability in the energy sector. Energy problems are issues that still need to be studied to find energy sustainability in all fields. Thermal comfort research can be done using many methods, resulting in energy efficiency in the building sector [2]. The comfort research method in architecture aims to develop an architectural design that creates energy efficiency, which can be done using simulation research. Simulation research can use building envelope variables as the central aspect of the subject of research [3].

In addition to the building envelope, the condition of the interior space of a building is also a subject of research in thermal comfort, which needs to be explored to create aspects of interior space elements that can produce thermal comfort [4]. The hot zone in a room is the basis for thermal analysis. The parameters that cause heat are analyzed using simulation methods to obtain optimal results [5]. Architectural parameters are variables used to evaluate building energy performance. Energy savings can be obtained by optimizing architectural parameters. Some architectural parameters that have an influence are walls, roofs, glazing, infiltration rate, window shading, and setpoint and setback temperatures [6]. All materials are essential factors to be studied in realizing energy efficiency. Building materials need to be selected so that heat inside the building can escape freely through the walls. The heat from outside the building must be reduced so it does not enter the building too much. Wall design with proper placement of natural ventilation can be one strategy for saving energy [7].

Optimization of building wall performance in creating thermal can be added with phase change material (PCM). Using PCM on walls will make the air conditions inside the room more relaxed than on walls without PCM. The determination of PCM needs to be adjusted to the thermal conditions in a region [8]. The application of PCM can inhibit heat transfer from the outside to the inside. In addition to heat from outside, heat from inside the room must also be anticipated. The heat from inside the room can be caused by the number of occupants and the presence of equipment that emits heat [9]. Cooling equipment will reduce the heat in the room, but on the other hand, there will be energy waste. Predictions regarding the use of cooling equipment in making energy waste are one way to determine the percentage of energy waste [10].

Alternative use of materials for walls is an issue that is still often discussed when finding optimal walls for energy saving. Several wall materials, such as aerated blocks, fly ash bricks, and concrete blocks, are compared for wall optimization. Combining reinforced concrete and clay brick walls is an optimal material for creating thermal comfort [11]. Ventilative cooling technology is one way to save energy. Technology can be applied to light and heavy buildings. Technology is believed to be able to adapt to climate change in the future [12]. Most coastal building wall materials use wood and unplastered bricks. Using unplastered brick walls is related to the community's ability to build. Buildings with exposed brick materials have more relaxed air temperature characteristics than wooden walls [13].

Thermal variables consist of four aspects: air temperature, radiation temperature, humidity and wind speed. The composition of the building design and its surroundings can make the wind speed faster or slower. Building design to facilitate wind flow will make thermal comfort in hot areas easier [14]. Heat changes occur in many places, making buildings into hot zones. The microclimate in an environment makes a difference in the thermal conditions of a building. The environment in tropical regions has two areas with different thermal characteristics: hot and cold. The treatment of buildings needs to be differentiated to create optimal thermal performance [15]. The condition of the outdoor space dramatically affects the thermal conditions inside the building. The density of the outdoor space will affect the average solar radiation temperature and create the building's thermal comfort. High outdoor space density will make it difficult for wind to flow between one building block and another [16]. The configuration of outdoor space with trees and without trees will make a difference in microclimate characteristics. Different types of trees cause temperature differences in the microclimate of an area [17].

Climate change must be included in considering energy design because it will increase the thermal load by 32% and the cooling load by 94%. Considering climate change will make the early design important to create sustainable buildings [18]. Thermal energy storage will make the thermal load lighter. The energy storage system can be done using an algorithm to be more effective. The control code estimates energy charging so that the thermal load becomes less [19]. Thermal load prediction continues to be developed using equipment and natural materials. Equipment is designed using the latest energy-efficient technology. Natural materials must be used to establish thermal load savings and create environmentally friendly materials [20]. Several researchers have conducted field research on thermal characteristics in coastal buildings. Research on exposed brick-walled buildings has not touched on energy-saving analysis using simulation. Simulation research has been believed to create energy-saving models, both mathematical and building models. Simulation results can be a reference for architects who want to design energy-efficient buildings. Many applications are used for research with simulation. One application is Revit. Several studies have used Revit to analyze the energy characteristics of a building [21]. Simulation research on exposed brick buildings on the coast needs to be done so that energy can be analyzed on exposed brick buildings and to create energy-efficient buildings in coastal areas. This study aims to explore energy and thermal loads on exposed brick buildings on the coast using the Revit application. The limitation of simulation lies in using parameters that are sometimes different from field conditions. Limitations can be validated by field observations or using data from other articles. This study has limitations in the suitability of parameters in the software with field conditions so that the study results can be continued with further research on field conditions.

2. Materials and methods

The study used a simulation method with the Revit application from several aspects related to energy use and thermal loads from residential houses. The study began with observations on three residential houses in Demak Regency and Jepara Regency. The criteria for residential houses are residential houses around the coast that use exposed brick wall materials. The research location was taken from two coastal areas in Central Java Province, namely the Demak Coast and Jepara Coast. Exposed brick houses in the Demak Coast area have a modern building model using a protruding terrace. Exposed brick houses in the Jepara Coast area do not have a protruding terrace and tend to be renovations of wooden houses with traditional roofs (**Figure 1**). The difference in residential houses in the two areas will create differences in the thermal characteristics of the building, making the analysis of energy and thermal loads interesting.

Figure 1. House in Demak (top) and house in Jepara (bottom).

The research steps begin with creating a building model using the Revit application. The data and parameters needed in the simulation are obtained directly from the building model and take several assumptions from software. Several parameters use the default from Revit such as energy use and thermal load. The energy setting parameter is a setting that determines building parameters before running an energy analysis. These settings include common setting, detail model setting, energy model setting and energy model—building services settings. The analysis discussed is energy use analysis and thermal load analysis. Energy use analysis includes building performance factors, energy use intensity, life cycle energy use/cost, renewable energy potential, annual carbon emissions, and annual energy use/cost. The conclusion from several analyses will be obtained from the house that uses the lowest or least energy. The discussion will be carried out on the aspects of orientation, opening volume, and wall material.

The formulas used by Revit include energy use intensity (EUI) and thermal load (heating load and cooling load).

$$EUI = \frac{Total\ Energy\ Consumption\ (\frac{kWh}{year})}{Building\ Floor\ Area\ (m2)}$$

$$Qheating = U\ x\ A\ x\ \Delta T + Qinternal\ gains - Qsolar\ gains$$

$$Qcooling = U\ x\ A\ x\ \Delta T + Qinternal\ gains +\ Qsolar\ gains$$

where:

$Q_{heating}$ = Heating load (in watts)

$Q_{cooling}$ = Cooling load (in watts)

U = Overall heat transfer coefficient ($W/m^2 \cdot K$) of the building envelope (windows, walls, roof)

A = Area of the building envelope component (in m^2)

ΔT = Temperature difference between inside and outside (in °C)

$Q_{internal\ gains}$ = Internal heat gains from occupants, lighting, and equipment

$Q_{solar\ gains}$ = Heat gained from solar radiation through windows and walls

3. Results and discussion

3.1. Energy usage

3.1.1. Building performance factors

This report presents factors that affect energy consumption in the analysis model. Data is obtained based on weather stations at the research location. Some parameters use the default Revit settings. From the analysis results above, we can see a significant difference, namely the average outdoor temperature (outdoor temperature), where the outdoor temperature in the Jepara area is a maximum of 37 °C and a minimum temperature of 18 °C. In contrast, in the Demak area, the maximum temperature is 37 °C, and the minimum temperature is 17 °C (**Figure 2**). The building envelope material is one of the parameters in seeing the comparison between outside and inside air temperatures.

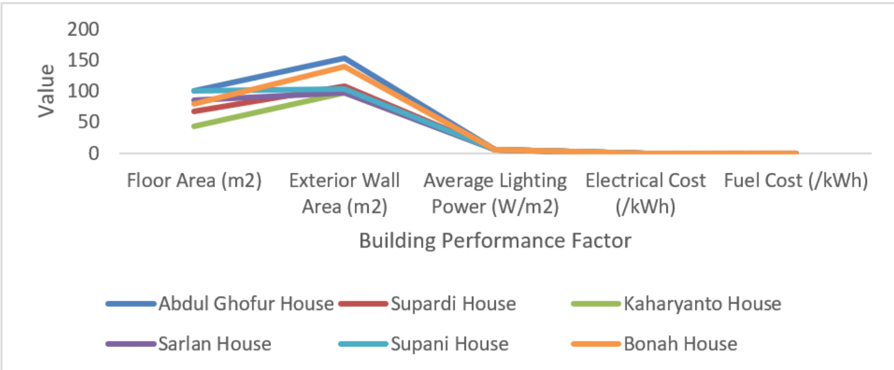


Figure 2. Building performance factor of six houses.

3.1.2. Energy use intensity

This report provides information about energy usage per unit floor area. The parameter data used is the default setting of Revit. From the analysis results above, we can see that the largest energy usage is the house owned by Mr. Kaharyanto in Demak at 1116 MJ/sm/yr, and the smallest energy usage is the house owned by Mr. Sarlan in Jepara at 747 MJ/sm/yr (**Figure 3**). The energy use intensity standard for residential homes is around 360 MJ/m^2 per year, so the energy use intensity of residential dwellings is considered to exceed the standard.

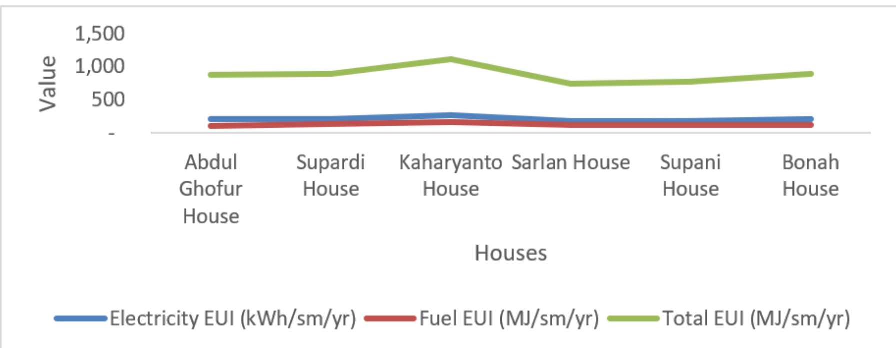


Figure 3. Energy use intensity of six houses.

3.1.3. Life cycle energy use/cost

This report presents a summary of estimated energy usage and costs over the life of the building, assuming a 30-year lifespan. The energy usage cost parameters used are Revit's default settings. From the simulation results above, it can be seen that the largest energy usage cost is the house owned by Mr. Supani Jepara at $15,831, which is around Rp. 210,505,650 in 30 years, and the smallest is the house owned by Mr. Kaharyanto Demak at $10,088 or around Rp. 134,347,883. The life cycle energy use/cost standard for residential houses is around Rp. 6,000,000 annually. In 30 years, it will become Rp. 180,000,000 (**Figure 4**). Jepara residential houses exceed the standard. In contrast, residential houses in Demak have a life cycle energy use/cost value below the standard.

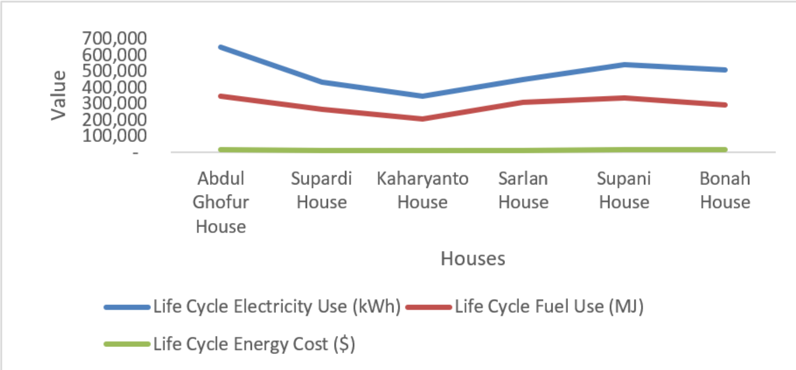


Figure 4. Life cycle energy use/cost of six houses.

3.1.4. Renewable energy potential

This report displays the estimated potential of electrical energy that can be generated by the analysis model using solar panels and wind turbines. This analysis is based on weather station data from the project location. Parameters use the default Revit settings. From the analysis above, the Jepara area has more potential to utilize wind energy as a source of electrical energy. Moreover, the house with the most potential in Demak to implement the PV system is the house owned by Mr. Abdul Ghofur, which, if used with a high-quality PV system (high efficiency), will produce 32,676 kWh/yr of energy (**Figure 5**). The standard renewable energy potential of a residential house is around 5000 kWh/yr. The house in Demak has a renewable energy potential exceeding the existing standard.

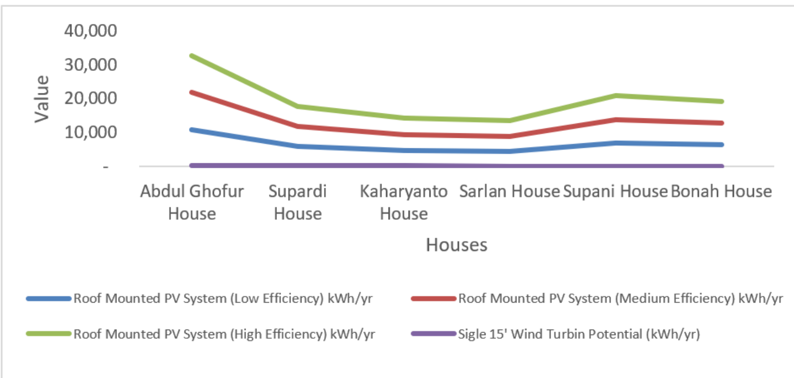


Figure 5. Renewable energy potential of six houses.

3.1.5. Annual carbon emissions

This result displays a graph summarizing the estimated carbon emissions associated with energy consumption for the model analyzed. The emissions data for a project are based on the fuel use at the site and the fuel source for electricity in the region. For example, a project located in a region with coal-fired power plants has higher carbon emissions per kilowatt-hour of electricity consumption than the same project located in a region where the power plants are powered by hydroelectric power. Total carbon emissions are obtained from energy use (total energy use)—energy generation potential (total renewable energy potential). From the annual carbon emission simulation data, we can see that the house with the largest estimated net carbon is Mr. Sarlan's house, and the smallest is Mr. Kaharyanto's house. The carbon standard in residential houses is around 5 tons per year (**Figure 6**). The carbon content in the sample houses is less than 1 ton per year.

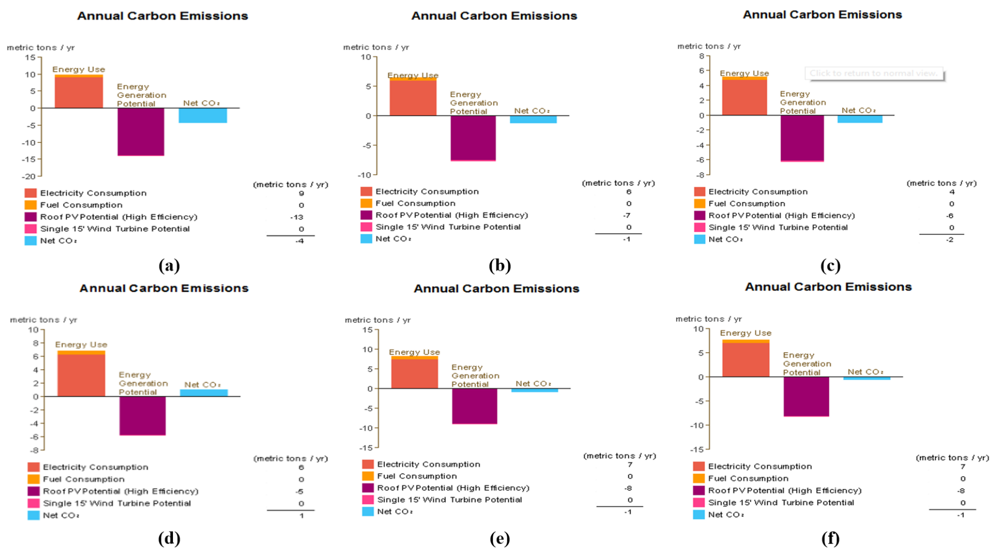


Figure 6. Annual Carbon Emissions. **(a)** Abdul Ghafur; **(b)** Supardi; **(c)** Kaharyanto; **(d)** Sarlan; **(e)** Supani; **(f)** Bonah.

3.1.6. Annual energy use/cost

The annual energy use/cost result compares the estimated energy usage for primary fuels compared to electricity. Annual energy costs and consumption information can inform the comparison of energy costs that can be used as considerations for making initial design decisions before building a building (**Figure 7**). The cost parameters used are based on Revit's default settings. Based on the simulation data above, we can compare the energy potential that we can utilize and apply in the design. This result also displays the estimated total annual cost of energy consumption. The largest annual energy cost is the house owned by Mr. Abdul Ghafur, which is $1397 or around Rp. 18,648,553, and the smallest is the house owned by Mr. Sarlan, which is $533 or around Rp. 7,115,017.

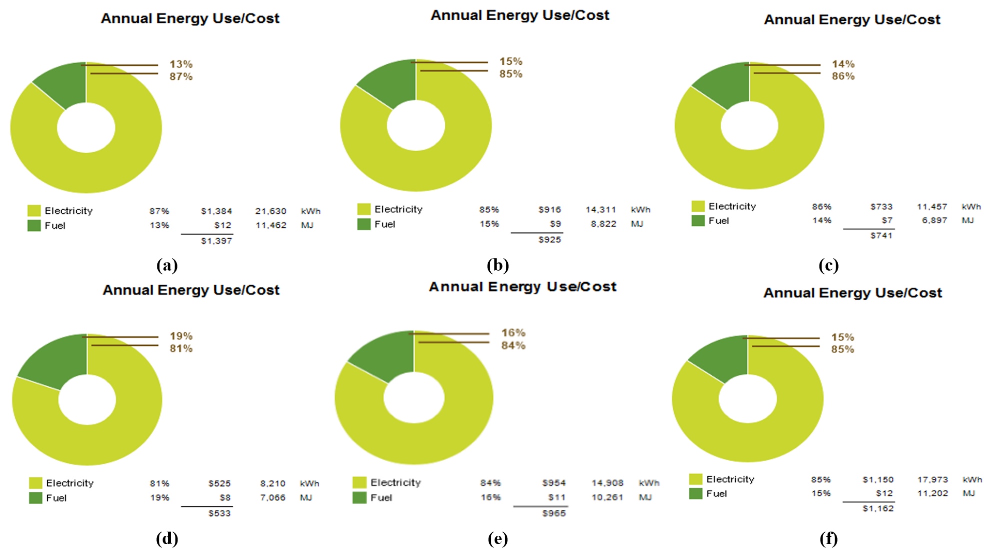


Figure 7. Annual Energy Use/Cost. **(a)** Abdul Ghafur; **(b)** Supardi; **(c)** Kaharyanto; **(d)** Sarlan; **(e)** Supani; **(f)** Bonah.

3.2. Thermal load analysis

Calculation of the cooling load of a room to be air-conditioned is a necessary step to obtain the desired level of comfort. The heat obtained by the room can come from external loads, internal loads, infiltration and ventilation. The heat must be removed from the room to create a suitable room. The amount of heat released is called the cooling load. The results of this thermal load analysis are presented in the form of a table with several components. Some components, such as household furniture and electronic devices, are not included due to a lack of available data. The air conditioning used is desetting using a natural ventilation split system for all homes.

The simulation results, using Revit software, display the total cooling load value of each house with air conditioning using the Split(s) system with natural ventilation (split system(s) with natural ventilation). So, after we know the estimated amount of heat released in each room in the house, we will have an idea of how effective treatment or design strategies are in obtaining a comfortable space.

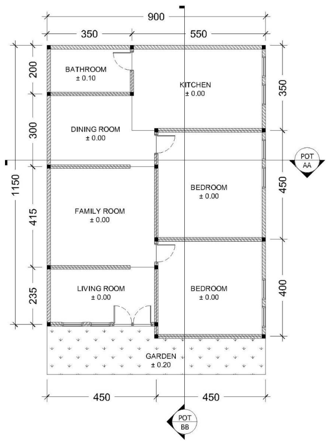
From the simulation results above, we can see that the largest cooling load value is the house owned by Mr. Bonah, which is 5501 W, which is a house with exposed brick walls in the Jepara area. The house with the smallest total cooling load is the house owned by Mr. Abdul Ghofur, which is 3637 W and is located in Demak (**Figure 8**). The large total cooling load value indicates the amount of heat that must be removed from each residential building. So, the greater the cooling load value, the more things need to be evaluated in the house's design.

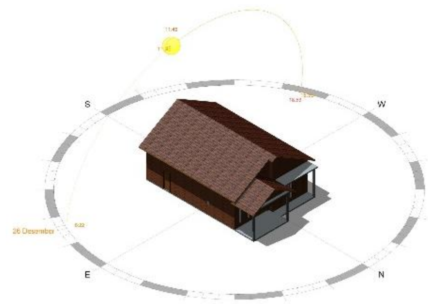
- Orientation

  Mr. Abdul Ghofur's house faces north. We can see the direction of the sun's rotation in the picture above. With the orientation towards the north, the temperature of the house will tend to be cooler because its position is facing away from the sun, especially the afternoon sun. Meanwhile, Mr. Supardi's house faces south. If we look at the analysis of the sun's rotation above, Mr. Supardi's house will be exposed to more sunlight, so the temperature of the house will tend to be hotter (**Figure 9**).

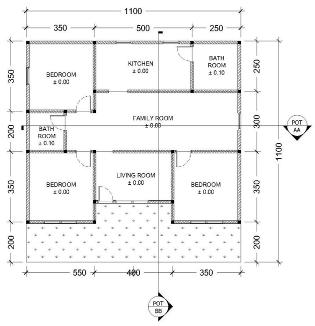
- Volume of ventilation
  The volume of openings, especially glass windows, in Mr. Supardi's house is greater than in Abdul Ghofur's house. The large amount of sunlight entering the house increases the temperature.
- Wall materials
  Mr. Abdul Ghofur's house's wall material is exposed red brick (without finishing). Brick walls absorb more heat, so the room temperature becomes cooler. Mr. Supardi's wall material is also exposed brick.

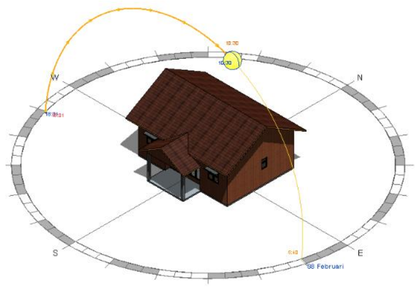
Figure 8. Thermal load of six houses.





(a) **(b)**





(c) **(d)**

Figure 9. **(a)** Abdul Ghafur house Floor Plan; **(b)** Abdul Ghafur house Sun Direction; **(c)** Supardi house Floor Plan; **(d)** Supardi house Sun Direction.

4. Discussion

Several aspects of building performance related to energy are analyzed using building performance factors that cover many aspects. The results of building performance factors for residential houses in Jepara are cooler than those in Demak. Many factors, including the air conditions outside the building, influence air temperature. The air outside the building tends to be polluted, which will make the air temperature hotter. The condition of the Demak Regency, which has more factories, makes the outdoor air conditions hotter than the Jepara Regency. The particulate matter content in an area will make the air temperature hotter [22]. Energy use intensity is influenced by various building elements related to heat per unit floor area. Residential houses in Demak have a higher energy use intensity value than residential houses in Jepara. The energy use intensity value is in line with the outdoor air conditions in the Demak area, which are hotter than those in Jepara. Energy use intensity in an area can be optimized by using materials that can withstand heat entering the building, such as the use of heat-absorbing glass for ventilation. Heat-absorbing glass can be met by using double glass [23].

Life cycle energy use/cost of residential houses in Demak, is greater than that of residential houses in Jepara. The costs for the sustainability of energy circulation are in accordance with the conditions of energy use in each residence. In general, hot areas have greater energy use than cooler areas. In addition, the shape of the building affects the life cycle energy cost. Buildings that have a long or thin shape are more efficient than wide or fat buildings [24]. Renewable energy potential is applied to predict the possibility of using environmentally friendly energy. Potential residences are located in the Jepara area because they have good access to wind conditions. In addition, consistent solar heat conditions improve the application of environmentally friendly energy. The use of technology will increase the potential for environmentally friendly energy. The use of equipment needs to be explored in buildings to create energy savings [25].

Annual carbon emissions have the highest and lowest values. The highest value is obtained from residential houses in the Jepara area and the lowest from residential houses in the Demak area. Annual carbon emissions are not only tied to the condition of the outside space of an area but also the condition of ventilation and air circulation in the building. The carbon obtained can also come from inside the house when residents use equipment that produces smoke, such as motorcycle exhaust fumes or the use of stoves. The proper use of natural ventilation will reduce carbon in the room, but it needs to be balanced with the use of equipment that can make the air clean [26]. Annual energy use/cost of residential houses in the Demak area is greater than that of the Jepara area. The hotter conditions of the Demak area require more energy, so the costs required are also greater. The settlement pattern in an area affects the condition of energy use. Rural settlements require less energy than urban settlements. Wind movement becomes easier when implementing a rural settlement pattern. Wind conditions will create thermal comfort in buildings so that energy use will be less [27].

5. Conclusion

The outdoor conditions in an area will create different thermal characteristics in a building. Energy use in buildings in hotter areas is greater than that in buildings in cooler areas. Many factors, including particles in the air, influence outdoor conditions. Energy analysis can produce the energy needs of a building so that it can create predictions of energy-efficient buildings. Energy-efficient building design is related to many building element factors such as building envelopes, ventilation shapes and sizes, use of equipment and building materials and several architectural elements. Outdoor configurations and settlement elements, such as vegetation arrangement and type, also affect energy use in buildings. Residential houses in Demak require more energy on average than residential houses in Jepara. The factors that affect energy needs in residential houses in Demak are greater than those in residential houses in Jepara. Future study recommendations are researched using field tests to validate research results according to actual conditions. Decision-making in architectural design must be based on detailed data so that the resulting architectural design can be optimal.

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