

# Rethinking About Low Carbon Emission in Apartment Design: Lesson Learned From the Construction of an Experimental House

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## ABSTRACT

Housing demands in big cities have an impact on the growth of apartments, especially the lower middle class in Indonesia. Development will have an impact on the increasing carbon emissions due to the embodied energy design and construction phases, operational energy, as well as disposal. A consideration of sustainability in reducing carbon emissions is needed. Currently, the sustainability approach has not been widely applied in the apartment development. In the tropics, the biggest cause of carbon emissions is the energy burden for space cooling, so the efforts to reduce the impact of carbon emissions on tropical buildings tend to focus on the efforts to reduce the cooling load. This paper will discuss various efforts (passive design) in reducing carbon emissions by reducing the cooling load in apartment designs. These efforts have been applied in the construction of experimental apartments in Tegal City. These are shown through appropriate site development, door, and window design (interior and exterior), wind fin design, and the use of insulation. An analysis of various design strategies is conducted by using simulation methods and field testing. The results of observations show that each effort has a different impact in reducing the cooling load. Comprehensively, and in an integrated way, these various efforts are expected to reduce carbon emissions by at least 30% of the existing design that is currently applied.

**Keywords:** *apartment, carbon emission, design strategy, low energy, sustainability*

## 1. INTRODUCTION

The urbanizations significantly [1] affected the number of apartment constructions in urban areas. Likewise, with the one million housing program managed by the Indonesian government since mid-2015 to provide adequate housing in urban areas, these also affect an increasing number of apartment constructions [2]. With the target of reducing the housing backlog in 2017, the government was targeting to build 700,000 houses for low-income families and 300,000 homes for those who received higher incomes in the city per year [3]. The development of infrastructure like housing provision also affected the material constructions. According to the

National Statistics Agency data, the amount of construction material expenditure increased significantly since 2017 [4]. Due to the increasing demands toward new residential units in the city, the apartment constructions also have some impacts on the increase in the building energy sector from year to year. Construction can have severe impacts on the environment as buildings are the largest contributors of the material consumption and are responsible for the energy consumption up to 40% and 33% of carbon emissions in the world [5]. BAPPENAS RI (Indonesian Ministry of National Development Planning) stated that although

community development has moved towards the positive economic and social aspects, this development has affected the environment as indicated by the increasing carbon emissions in Indonesia [6]. As affirmed by BAPPENAS RI, this kind of development method is not environmentally friendly. Consequently, it will limit the growth and job creation; also, it will hinder Indonesia's potential to eradicate poverty as the goal of development itself.

Therefore, the Indonesian government has committed to focus on energy-oriented development. In 2019, Indonesia developed several policies and guidelines on energy-efficient development, including the Local Green Building Regulations and the recently drafted one, which is the Framework for the 2020-2045 Infrastructure Development Program on Low Carbon Development. This emphasizes that the principle of low carbon has begun to be considered in the development programs in Indonesia. The development of regulations is also in line with the "2016 Paris Agreement", which is one of the parties of the United Nations Framework Convention on Climate Change (UNFCCC), and the Sustainable Development Goal (SDG) as an effort to build a more sustainable world.

Although several policies have been established, the sustainability approach has not been widely applied in the apartment development. The consideration of sustainability in reducing carbon emissions is needed. In the tropics, the energy burden for cooling space is the greatest cause of carbon emissions. Therefore, the efforts to reduce the impact of carbon emissions in tropical buildings are things that must be taken seriously to reduce the cooling load. On the other hand, development also needs to consider using materials efficiently and low-embodied energy materials in order to reduce carbon emissions. This paper will discuss various approaches to reduce the burden of carbon emissions in the development of experimental apartment prototypes. The results of this study are expected to contribute to knowledge about the construction of energy-efficient apartments in the future.

## 2. BASIC CONSIDERATIONS FOR THE DEVELOPMENT OF TEGAL EXPERIMENTAL HOUSE DESIGN

### 2.1. Approach on apartment design trends in unit development

Since 2007, the construction of mid-level apartments has increased significantly, especially in big cities in Indonesia. Apartment development is becoming a new trend of residential areas in urban areas. According to Colliers, this increase was due to housing demands that occur every year, that in 2021, the increase in apartment construction can reach 60%, especially in lower-middle

apartment units [9]. In line with this, the results showed that the typology of apartment units in major cities in Indonesia shows that studio apartment units (22.5 m<sup>2</sup>) and unit 2 BR (34.04 m<sup>2</sup>) are the frequently constructed ones [7]. This shows that the trend of apartment construction is no longer aimed at attracting the upper-middle class, but also the lower middle class.

In addition, the construction of apartments also changes the methods in construction, such as the types of material used and the process of material construction. This apartment is a high-rise building, a type of building that currently tends to use modular materials to increase time and cost productivity. Nonetheless, this approach can actually contribute to the efforts to reduce carbon emissions as the modular method can reduce construction waste that affects carbon emissions consumption. The development of the Tegal Experimental House design was carried out to build the lower-middle apartment unit as the most widely constructed apartment unit in Indonesia i.e., unit 2 BR [7]. The data can be seen in Figures 1, 2, and 3 below [7,8].

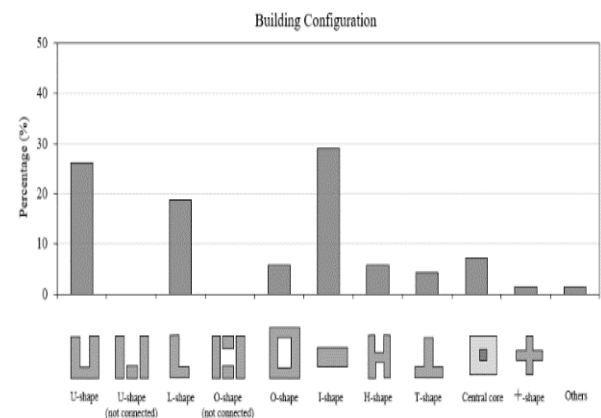


Figure 1. The mass configuration trend of the apartment development in Indonesia [8]

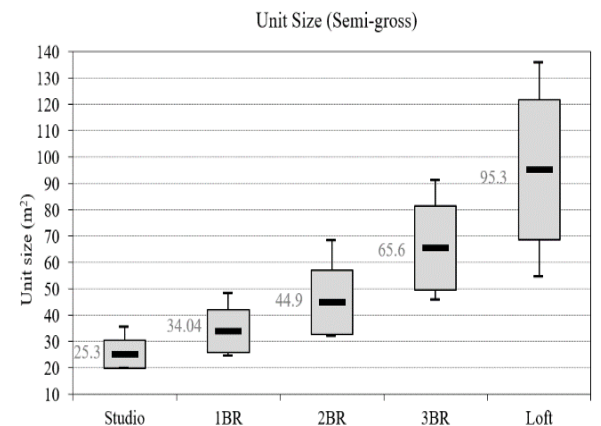
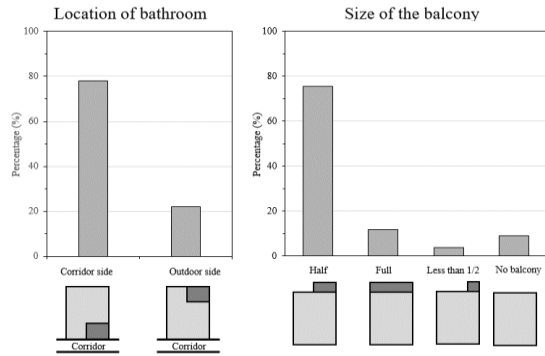


Figure 2. Unit size trends in apartment construction [8]



**Figure 3.** Bathroom location and balcony size trends in apartment development [8]

Based on the analysis of apartment building trends, a prototype design is developed and simulated (using CFD/Computational Fluid Dynamics simulations and the wind-rose and sun path diagram analysis) to get the best wind flow in the building, and get the best building orientation.

Furthermore, as an effort to design energy-efficient apartment units, the design development consideration of the building mass refers to the principles of low carbon, which uses the bioclimatic design approach and the modular material approach to reduce carbon emission in cooling load and embodied energy of material usage and waste.

## 2.2. Bioclimatic approach in the development of building mass

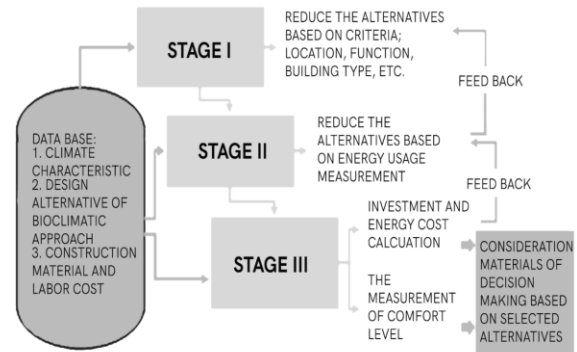
The bioclimatic design approach, an approach to achieve thermal comfort, is applied to this building. This approach is used by utilizing the potential of wind (natural ventilation) in the city of Tegal. Modular materials, precast materials, and other materials, which were obtained from demolished buildings and were reused, are also applied to reduce waste materials and carbon during building construction.

The bioclimatic design aims to get the maximum level of comfort for the users in building operations. On the other hand, it also aims to reduce energy consumption, building operation, and construction costs. Bioclimatic design in buildings is used as a passive system of sustainable design criteria. In the passive design, energy savings can be implemented through passive use of natural lighting and wind, without the use of electrical energy. The passive design relies more on the ability of architects to design buildings that can anticipate climate problems. The bioclimatic design framework is shown in Figure 4 below.

The bioclimatic design approach consists of three stages, namely the stage of alternative selection based on needs, the stage of adjustment to energy use, and the stage of adjustment to user comfort and construction costs.

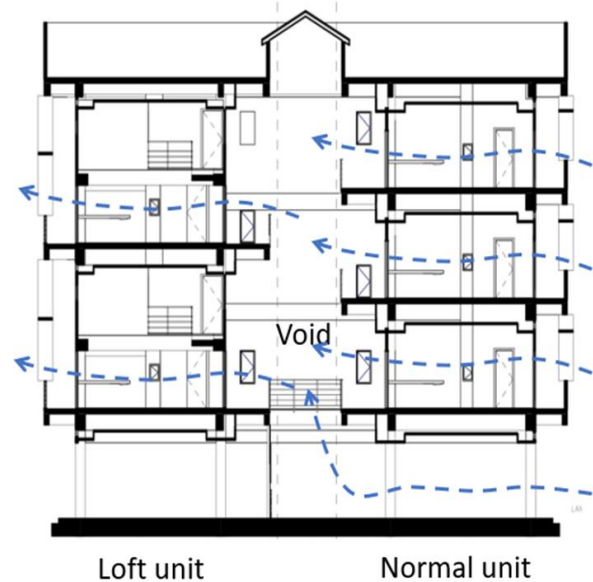
To achieve an optimal bioclimatic design, a research is carried out on climatic conditions in Tegal. Climate data are used to compile the simulation models that are conducted by using Open Studio and CFD applications. The simulation is conducted to examine the possibility of passive cooling techniques suitable for the experimental house, which was conducted in the previous research [7].

### FRAMEWORK OF MODEL DESIGN



**Figure 4.** The bioclimatic design framework [9]

The results of the previous study found that the optimal orientation for upper and middle apartments on this site is 22.5 degrees from the North (i.e., one of the facade units facing the NNE). This is due to the wind direction. It is the most optimal wind direction for the building that can let seasonal wind from the front and back of the building in the right corner flow in during the dry season. Therefore, the shape of the building in this apartment is I shaped with a single-loaded corridor with internal void since, based on the simulation result, this shape can utilize the natural ventilation and daylighting more optimally (Figure 5).



**Figure 5.** Simulation model of passive cooling techniques [8]

### 2.3. Passive strategy approach in developing building elements

To create energy-efficient buildings, buildings must be able to reduce the possible energy use by using passive design strategies [9]. Passive design strategies are very dependent on the climate and conditions around the site [10,11]. Passive design strategies can be classified into two categories, aspects of planning and building envelope, as shown in Table 1 [12].

**Table 1.** Passive design strategy categorization

No	Category	Passive design indicators
1.	Planning	Building mass
		Building orientation
		Landscape and vegetation
2.	Building envelope	Thermal insulation for wall and flooring
		Roof – considering the material and colour
		External wall – considering the material, colour, and OTTV
		Window – considering the window characteristic, WWR and window orientation
		Natural ventilation
		Glazing
		Shading device
Daylighting		

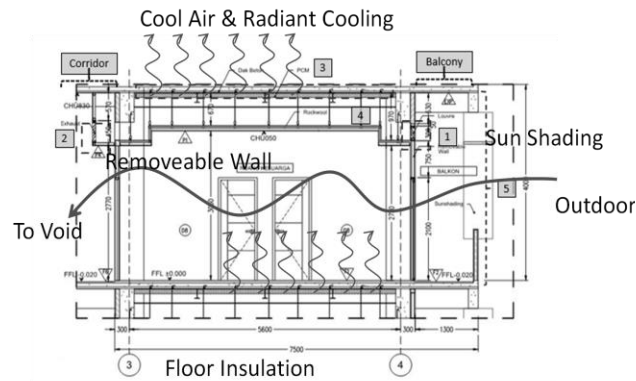
The bioclimatic strategy factors are obtained from the results of the literature review used by the previous studies. These factors are elaborated through the categories of passive design strategy factors in Table 2.

**Table 2.** Passive design strategy

Design strategy	Impact
<b>Building Orientation</b> [13,14,15,16,17,18]	<ul style="list-style-type: none"> <li>• Optimizing the building orientation with a longer building facade facing north and south</li> <li>• Facades and openings facing east or west</li> <li>• Saving cooling loads with the right orientation that can reach 8% -11%</li> </ul>

<b>WWR</b> [19,20,21,22,23]	<ul style="list-style-type: none"> <li>• Optimizing WWR size at 24% with additional horizontal overhangs.</li> <li>• Radiation on the east side is hotter than on the west; however, with WWR 25%, the radiation is almost the same</li> <li>• WWR rate cannot be more than 40%</li> </ul>
<b>Opening or Natural ventilation</b> [23,24]	<ul style="list-style-type: none"> <li>• The application of cross ventilation and building layout can make cooling in buildings faster and better.</li> <li>• The application of natural ventilation (crossing) is good, depending on the window and the appropriate shading device</li> <li>• Saving cooling load up to 19%</li> </ul>
<b>Glass / glazing</b> [25,26,27]	<ul style="list-style-type: none"> <li>• Double low-e glass types are more effective than other types of glass that are able to block heat and receive light very well</li> <li>• Saving total energy up to 35,2%</li> </ul>
<b>Overhang</b> [28,29]	<ul style="list-style-type: none"> <li>• Overhangs of 0.3 m, 0.6 m, and 0.9 m reduce the cooling load by 3%, 7% and 10% in the East facade, and 3%, 6% and 9% in the West facade</li> </ul>
<b>External wall</b> [30,31,32,33,28]	<ul style="list-style-type: none"> <li>• Bright colours and reflective paint can help reducing heat build-up</li> <li>• The insulation for external walls is able to create a stable temperature of application</li> </ul>
<b>Roof</b> [34]	<ul style="list-style-type: none"> <li>• The dividing wall along the roof must not be high and the slope must be at least 300 to protect the walls and openings from radiation and rainfall</li> <li>• Light-coloured coatings and reflective paint can reflect solar radiation</li> </ul>

The results of the categorization of these factors become the references for the Tegal apartment design. As a design element is based on the results of the bioclimatic discussion, this includes the optimization of Appropriate Site Development (ASD) in the form of building that has been previously approved. The implementation of the passive strategy in experimental building design is as follows: (Figure 6)

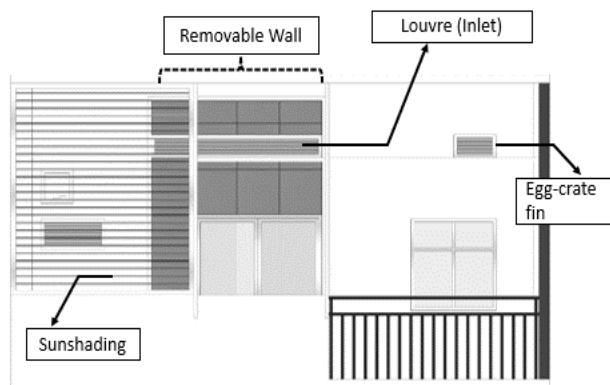


**Figure 6** Tegal apartment unit section

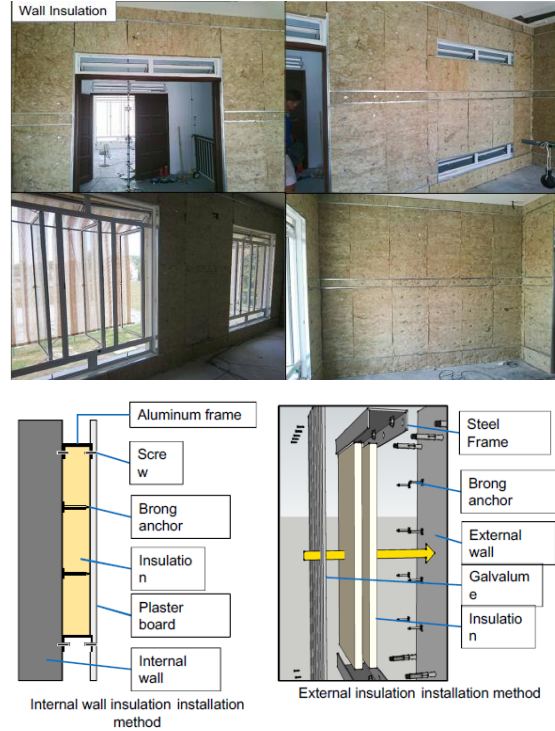
Figure 6 shows an elevation image of an apartment residential unit that implemented passive design strategies.

In detail, this strategy was supported by the use of design elements that can provide energy saving and carbon consumption efforts. The elements, among others, are:

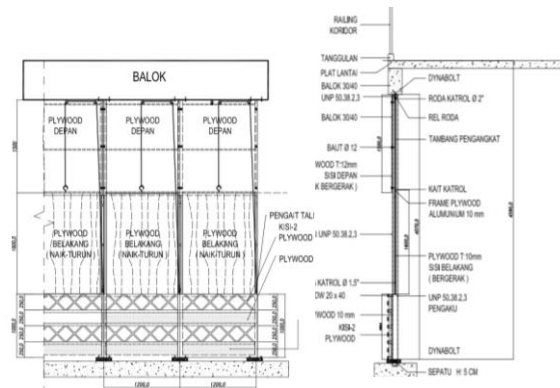
- Sun shading is installed on the balcony, as well as reflective paint, to prevent heat from solar radiation (Figure 7).
- Radiation cooling uses wall insulation (rockwool), ceiling insulation, and floor insulation (PCM) (Figure 8).
- Narrow vertical voids are equipped with vertical wind fins (fin) to move the existing wind upward during the day (Figure 9).
- Night ventilation uses a louvre and exhaust fan.



**Figure 7** Design elements in the facade of experimental apartment



**Figure 8** Insulation system on the interior and exterior walls



**Figure 9** Wind fin installation system on the ground floor (*pilotis*) directs the wind towards voids and building units

## 2.4. Modular approach for the efficient use of materials

The efficient usage of materials to reduce Embodied Energy (EE) to achieve low carbon emissions is also considered in the unit design. The design is adapted through the material module to reduce the waste material of the building construction. It is important to be considered since apartments were frequently built without considering the material module aspect, which resulted in large amounts of construction waste [35,36].



**Figure 11** Modular design on the Tegal apartment unit heights



**Figure 12** Modular design on the Tegal apartment unit area

In the design process, the wall and flooring material module are the main references of the unit size. The homogenous tiles with a module size of 60x60 are used as floor coverings. Meanwhile, the material used for the walls is a removable panel with 120x120 cm. Hence, the unit area and height of the unit are adjusted based on the modules. There are two types of unit designed in this apartment, namely the default 2BR unit and the 2BR loft unit. After completing the design using the floor module approach, it is found that the area of the 2BR unit is 43.2 (7.2 x 7.2) m<sup>2</sup> and the 2BR loft unit is 57.6 (6x6 + 6x3.6)

m<sup>2</sup>. The height measured from the floor to the ceiling is 3 m (Figures 11, 12).

## 2.5. BIM Utilization in Design and Construction Process

Efficiency in project performance was also considered in the apartment design process because the better the efficiency of the project, the greater the chance for the project to reduce carbon emissions from the construction process [37,38]. BIM has been implemented in the design and construction process of this apartment building for approximately one year.

The data of concrete material usage from the contractor show that the accuracy of material volume calculation with BIM reaches 93.7%, which is bigger than the use of real material in the field. This difference is caused by the ordering system and the difference in material transportation capacity (Table 3).

**Table 3** Level of accuracy on material calculation by BIM

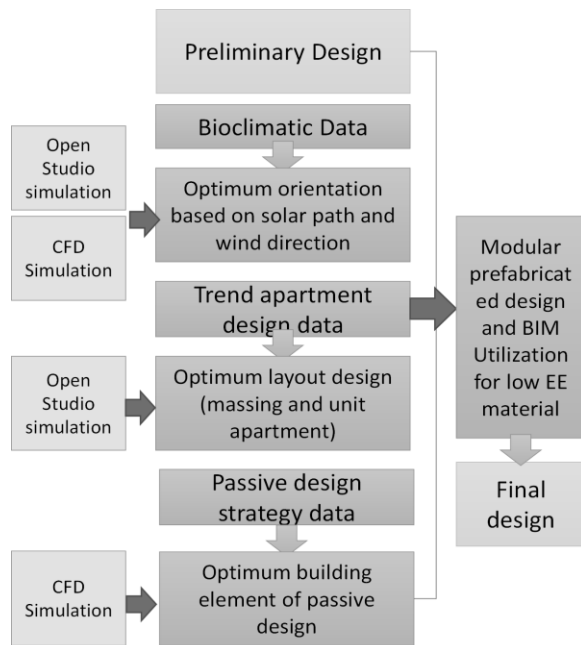
	Material	Volume (m <sup>3</sup> )
Material need by BIM Calculation	Concrete in cast	478,08
Material installed based on purchase order calculation	Concrete in cast	510,00
	Level of Accuracy	93,70%

The use of information technology increases the efficiency of material usage. This approach allows a reduction in the amount of material waste. Efficient material use is one of the efforts to achieve a lower embodied energy value and reduce carbon emissions.

## 3. LESSON LEARNED FOR FUTURE DEVELOPMENT

The result of temperature measurement shows that the interior temperature has a significant difference with the outside temperature of the building. At the highest temperature during the day, the average difference is as high as 3.9 degrees Celsius. This indicates the success of the passive design approach in reducing the cooling load. The results of the calculation of embodied energy also show a decrease in embodied energy (EE). EE value with discrepancy means 22% lower in energy consumption through the use of the modular prefab and BIM method, which reduce 31% of Carbon Emission.

The process of developing energy-efficient experimental apartment model requires a comprehensive framework for obtaining optimal energy savings. In the experimental apartments construction in Tegal, the workflow framework carried out is shown in Figure 13.



**Figure 13** The scheme of energy-efficient apartment design

However, the design development problems involve weak climate data and lack of passive catalogue design data that include construction methods and materials. Improving climate data through collaboration with BMKG is very much needed by architects in the future. Similarly, research on passive strategies needs to be conducted and distributed to practitioners in order to increase design choices.

#### 4. CONCLUSION

The development of designs with sustainable concepts that is oriented to energy savings in the tropics requires a comprehensive design approach to ensure optimal results. The design approach has been performed quantitatively and qualitatively with good data support, e.g. data for simulation and data for energy calculation. Qualitatively, it considers data trends in apartment design needs and identifies various alternative passive strategies. Quantitatively, it assesses design performance through simulations by using the help of relevant software, particularly in assessing comfort and energy performance that include information technology and modelling. This combination of quantitative and qualitative approaches results in design decisions that are supported by credible information; thus, these generate the confidence of various stakeholders in the application of green concepts in apartment development.

The main performance indicators in assessing the success of energy-efficient designs are the decrease in space cooling load and the optimization of natural light utilization.

The use of a modular system with the prefabricated method also shows a significant decrease in the value of embodied energy due to more efficient use of materials and reduced material waste.

Some weaknesses in expanding the idea of energy-efficient buildings are the lack of human resources in assessing performance quantitatively and the weak climate data in ensuring the success of bioclimatic design approaches.

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