

## Evaluation of Residential Carbon Neutrality Through Carbon Emissions, Vegetation Carbon Sequestration, and Occupant Energy Behavior

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<b>Keywords:</b>	<b>ABSTRACT</b>
carbon-neutral housing; household carbon emissions; vegetation carbon sequestration; occupants' energy-use behavior	This study evaluates residential carbon neutrality by examining carbon emissions, vegetation carbon sequestration, and occupant energy behavior within urban housing. Global warming, driven by carbon dioxide emissions, underscores the need for integrated solutions addressing household carbon footprints. The objective of this research is to develop a comprehensive model that incorporates building carbon emissions, vegetation carbon sequestration, and occupant behavior to assess residential carbon neutrality. This study focuses on 49 households in Vila Dago Housing, Pamulang, South Tangerang, utilizing surveys and field data to estimate energy consumption, carbon emissions, and vegetation absorption. The findings reveal that operational carbon emissions are primarily driven by electricity usage, with average emissions ranging from 10,000 to 27,000 kg CO <sub>2</sub> e annually per household. Embodied carbon emissions from construction materials also contribute significantly, with variations depending on house type. Vegetation in the study area provides limited carbon sequestration, unable to offset the carbon emissions generated by household activities. Additionally, occupant behavior, including lighting, air conditioning, LPG use, and waste management, directly influences overall emissions. In conclusion, achieving carbon-neutral housing requires improved energy behavior and enhanced green spaces, with an integrated approach to passive building design and carbon sequestration strategies being essential for mitigation efforts.

### INTRODUCTION

Global warming caused by carbon dioxide emissions has become a major global issue. Between 2011 and 2020, the global mean temperature increased by 1.1°C compared to the pre-industrial period of 1850–1900, and is projected to exceed 1.5°C by the middle of this century (IPCC, 2023). In response, numerous studies have been conducted to examine carbon emissions, including those originating from households, as part of mitigation efforts toward achieving carbon neutrality. Carbon neutrality refers to a condition in which the amount of carbon emitted is balanced by the amount absorbed, thereby preventing excessive accumulation of carbon dioxide in the atmosphere (Martens et al., 2017; Yao Wang et al., 2021; Yang et al., 2023).

Households, as the smallest units within urban areas, contribute to carbon emissions through daily activities. It is estimated that household carbon emissions account for approximately 12.5% of global consumption-based emissions and about 8% of Indonesia's national emissions, totaling 1,053,476 thousand tons of CO<sub>2</sub>e (BPS, 2025; Ge, Friedrich, & Vigna, 2024). These figures highlight the importance of studying household carbon emissions as a crucial component of global warming mitigation strategies.

Previous studies have extensively investigated building carbon emissions throughout the life cycle, from construction to demolition. Surahman et al. (2015) assessed household building carbon emissions in planned residential areas in Jakarta and Bandung, Indonesia, using the Life Cycle Assessment (LCA) method. Li et al. (2021) employed a hybrid LCA approach to evaluate embodied carbon emissions of four different housing structural forms using straw-based and conventional materials in China. In Turkey, Gulcimen et al. (2021) compared life-cycle carbon emissions between single-family houses and multi-story apartments. Rinne et al. (2022) examined the environmental impacts of hybrid wood–concrete apartment buildings compared with conventional reinforced concrete and timber buildings using One Click LCA software in Finland. Luo et al. (2022) assessed carbon emissions associated with renovation stages of old residential settlements. Liu et al. (2023) evaluated carbon emissions of residential buildings constructed with engineered bamboo in rural China, covering production, transportation, construction, operation, and disposal stages. However, these studies have not integrated vegetation into building carbon emission evaluation models.

Research on the role of vegetation in mitigating carbon emissions has primarily focused on macro-scale emissions rather than household-level emissions. Fan et al. (2023) developed design models and plant lists with high carbon sequestration capacity and identified factors influencing sequestration performance. Zhang et al. (2024) analyzed optimal spatial pattern strategies of urban green open spaces (GOS) for carbon storage as a mitigation approach for future emissions. In Guangdong, Hong Kong, and Macau, Liu et al. (2024) examined the patterns and capacities of GOS in helping cities achieve carbon neutrality. Ariluoma et al. (2021) assessed the carbon storage and sequestration potential of residential yard vegetation in urban areas.

The carbon cycle is closely linked to vegetation-based carbon sequestration. Carbon emissions generated by household activities such as electricity use, non-electric energy consumption, and building materials can be absorbed by vegetation through photosynthesis, thereby reducing atmospheric carbon levels and supporting the achievement of carbon-neutral buildings (Guangdong Wang et al., 2023). Thus, vegetation plays a critical role in building carbon emission calculations.

In addition to vegetation, occupant behavior indirectly contributes to carbon emission production through energy use. However, previous studies on occupant energy behavior and its relationship with building energy use and carbon emissions have been limited to behavioral–energy or behavioral–emission relationships and have not incorporated vegetation variables. Su et al. (2023) investigated household carbon emissions using a dynamic model of household energy consumption and carbon emissions from the occupant perspective, including behavioral variations during the operational phase. W. Zhang & Calautit (2022) analyzed occupant behavior patterns in high-rise residential buildings and their impacts on energy consumption.

Based on the above, a research gap remains: there is currently no integrated evaluation model that combines carbon emissions, vegetation carbon sequestration, and occupant energy behavior. Therefore, this study aims to quantify building carbon emissions by formulating carbon production and vegetation-based carbon absorption, while also characterizing occupant energy behavior patterns as part of a carbon-neutral housing evaluation model.

The study was conducted on 49 households in three residential blocks of Vila Dago Housing, Tampak Siring Cluster, Pamulang, South Tangerang. Pamulang is one of the most densely populated sub-districts in South Tangerang City due to its direct adjacency to South Jakarta, making it a strategic residential location. This is evidenced by continuous population growth in Pamulang over recent years (Disdukcapil Kota Tangerang Selatan, 2025). Uncontrolled population growth and migration have significantly impacted the availability of green open spaces in Pamulang. Increasing housing demand has led to the conversion of green open spaces into paved areas. This issue is further exacerbated by residents' tendencies to replace green yards with additional indoor spaces.

## **RESEARCH METHOD**

This study employed a quantitative research method using a survey and questionnaire approach. Surveys and questionnaire distribution were conducted among 49 households and green open spaces in Blocks F5, F6, and F7 of Vila Dago Housing, Tampak Siring Cluster, Pamulang, South Tangerang. Data collection through questionnaires aimed to obtain information on electricity consumption, non-electric energy use (LPG, solid waste, and private vehicles), and occupant energy behavior. Meanwhile, field surveys were conducted to inventory vegetation type and area, building area, and building materials.

Due to limited access to indoor spaces and the unavailability of electricity bills and LPG purchase records, data on electricity and non-electric energy use were self-reported based on residents' estimations. Electricity consumption was calculated based on the average monthly purchase of prepaid electricity tokens and installed power capacity in each household, by dividing the monthly electricity token expenditure by the applicable tariff per kWh. Solid waste generation was estimated using the average municipal waste volume data of South Tangerang City and converted into per capita values, amounting to 0.81 kg per person per day.

Vegetation data were collected by inventorying the green area of each household, the area of public green spaces, as well as the type and number of public vegetation in the three residential blocks. Carbon emission calculations comprised operational emissions (electricity, LPG, solid waste, and private vehicles) and embodied emissions (emissions from concrete beams and columns, brick walls, concrete roofs, ceramic floor finishes, and exposed concrete carports). Embodied emission calculations were based on the original house type prior to any building extensions, such that the calculated carbon emissions represent the minimum embodied emissions of the residential buildings. Data were analyzed using descriptive analysis to identify household carbon emission patterns across different levels of occupants' green behaviour.

## **RESULT AND DISCUSSION**

The study was conducted on 49 households located in Blocks F5, F6, and F7 of Vila Dago Housing, Tampak Siring Cluster, Pamulang, South Tangerang. These three blocks

consist of three original housing types prior to any extensions, namely Type 41, Type 53, and Type 64. Each block follows a grid layout with dominant north–south building orientations.



**Figure 1. Site Plan of Blocks F5, F6, and F7, Perumahan Vila Dago Cluster Tampak Siring, Pamulang**

Most houses have undergone modifications or extensions. Residential buildings generally utilize conventional construction materials, including red bricks or lightweight bricks, concrete, and steel structural elements. The current number of storeys ranges from one to three floors, with building areas ranging approximately from 72 m<sup>2</sup> to 576 m<sup>2</sup>.



**Figure 2. Existing Conditions of Several Residential Buildings**

The green areas within the three residential blocks vary in size, type, and vegetation composition. Block F5 does not contain any public green open space. In contrast, Block F7 includes a small green area dominated by mango and banana trees. Among the three blocks, Block F6 has the largest green area and the most diverse vegetation types.

**Table 1. Types and Amount of Vegetation in Public Green Spaces and Households by Block**

Block	Vegetation Type	Green Areas or Number of Trees
F7	Elephant grass	882 m <sup>2</sup>
	Mango tree	4
	Banana tree	3
F6	Elephant grass	1621 m <sup>2</sup>
	Palm tree	1
	Pine tree	2
	Frangipani tree	6
	Starfruit tree	1
	Spanish cherry tree	2
	Guava tree	3
	Pohon mangga	4
	Fiddle-leaf fig	2
	Avocado tree	2
Citrus tree	3	
F5	Elephant grass	312 m <sup>2</sup>

Data Source: Vegetation types and green areas were collected through field surveys at Vila Dago Housing, Tampak Siring Cluster, Pamulang, South Tangerang.

### Operational and Embodied Carbon Emissions

Operational household carbon emissions refer to the emission footprint generated from daily activities within a household, originating from both electrical and non-electrical energy use. The calculation of operational carbon emissions can be conducted using macro-level top-down and micro-level bottom-up approaches. However, most current studies and practices apply the emission factor method. The calculation of operational carbon emissions is based on the fundamental formula developed by the Intergovernmental Panel on Climate Change (IPCC), as follows:

- (i)  $E_{\text{electricity}} = \text{Electricity Consumption (kWh per month)} \times \text{Emission Factor}$
- (ii)  $E_{\text{LPG}} = \text{Mass of LPG (Kg per month)} \times \text{Emission Factor}$
- (iii)  $E_{\text{waste}} = \text{Volume of Waste (Kg per month)} \times \text{Emission Factor}$
- (iv)  $E_{\text{vehicle}} = \text{Vehicle Travel Distance (Km per month)} \times \text{Emission Factor}$
- (v)  $E_{\text{operasional}} = E_{\text{listrik}} + E_{\text{LPG}} + E_{\text{waste}} + E_{\text{vehicle}}$

The emission factors for each energy source are presented in Table 2.

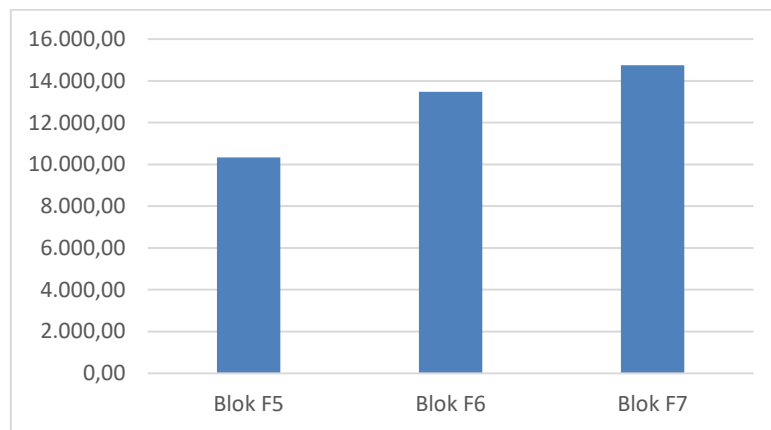
**Table 2. Emission Factors for Each Energy Source**

Energy Source	Emission Factor
Electricity	0,85
LPG	3
Waste	0,6
Four-Wheeled Vehicles	0,25
Two-Wheeled Vehicles	0,1

Data Source: Emission factors for each energy source were based on the standards provided by the Intergovernmental Panel on Climate Change (IPCC) and relevant environmental assessment practices.

Based on the calculation results, households in Block F7 produce operational carbon emissions ranging from 3,615.96 to 65,824.50 kg CO<sub>2</sub>e per year, with an average of 14,755.13 kg CO<sub>2</sub>e per year. Households in Block F6 generate operational carbon emissions ranging from 4,903.80 to 26,275.44 kg CO<sub>2</sub>e per year, with an average of 13,482.25 kg CO<sub>2</sub>e per year. Meanwhile, operational carbon emissions in Block F5 range from 5,173.74 to 18,465.84 kg CO<sub>2</sub>e per year, with an average of 10,258.94 kg CO<sub>2</sub>e per year.

The median values of operational carbon emissions across the three blocks show a similar pattern, namely 11,108.57 kg CO<sub>2</sub>e per year in Block F7, 10,212.39 kg CO<sub>2</sub>e per year in Block F6, and 10,055.04 kg CO<sub>2</sub>e per year in Block F5. These figures indicate that household operational carbon emissions in all three blocks are relatively high.



**Figure 2. Average Household Operational Carbon Emissions in Blocks F5, F6, and F7 (Kg CO<sub>2</sub>e per Year)**

The high operational carbon emissions of households in Block F7 are primarily attributed to electricity consumption, with an average value of 9,460.18 kg CO<sub>2</sub>e per year. Other emission contributions originate from LPG use, averaging 579.13 kg CO<sub>2</sub>e per year, waste disposal with an average of 661.81 kg CO<sub>2</sub>e per year, four-wheeled vehicle use averaging 3,122.60 kg CO<sub>2</sub>e per year, and two-wheeled vehicle use averaging 931.41 kg CO<sub>2</sub>e per year.

A similar pattern is also observed in Blocks F6 and F5, where operational carbon emissions from electricity consumption represent the largest contribution, averaging 9,306.20 kg CO<sub>2</sub>e per year in Block F6 and 7,700.52 kg CO<sub>2</sub>e per year in Block F5. These figures indicate that electricity consumption is the dominant source of household operational carbon emissions in Blocks F7, F6, and F5.

Electricity occupies a more dominant position compared to LPG, waste, and transportation because it is multifunctional and constitutes the primary component of building energy consumption. Electricity is used for lighting, cooling, water pumping, electronic appliances, and mechanical equipment operation. Most household operational energy demands rely heavily on electricity. In contrast, LPG is mainly used for specific domestic needs such as cooking and heating. Meanwhile, waste-derived energy contributes relatively little due to technological limitations and the small proportion of energy generated and utilized in buildings; therefore, waste does not serve as a major contributor to household operational emissions.

**Table 3. Sources of Household Operational Emissions in Blok F5, F6, and F7 (Kg CO<sub>2e</sub> per year)**

Emission Source	Residential Block		
	F5	F6	F7
Electricity	7.700,52	9.306,20	9.460,18
LPG	520,363	367,2	579,13
Waste	540,785	664,848	661,805
Four-Wheeled Vehicles	973,636	1572	3.122,60
Two-Wheeled Vehicles	523,636	1572	931,40

Data Source: Household operational emissions data were collected through surveys conducted on 49 households in Blocks F5, F6, and F7 of Vila Dago Housing, Pamulang, South Tangerang. Emission sources include electricity, LPG, waste, and vehicle usage.

Embodied carbon emissions are the emissions embedded in a building prior to its occupancy. The calculation of embodied carbon emissions developed by the Intergovernmental Panel on Climate Change (IPCC) is expressed as follows:

$$(i) E_{\text{embodied}} = \text{Quantity of Materials} \times \text{Emission Factor}$$

The emission factors for each material are presented in Table 4.

**Table 4. Sources of Household Operational Emissions in Blok F5, F6, and F7 (Kg CO<sub>2e</sub> per year)**

Material Type	Emission Factor
Concrete	300
Brick	0,22
Concrete Roof	0,2
Ceramic Flooring	1
Exposed Concrete Carport	1,8

Data Source: Emission factors for household construction materials (concrete, brick, roof, ceramic flooring, and exposed concrete carport) are based on standards from the Intergovernmental Panel on Climate Change (IPCC) for Life Cycle Assessment (LCA) of building materials.

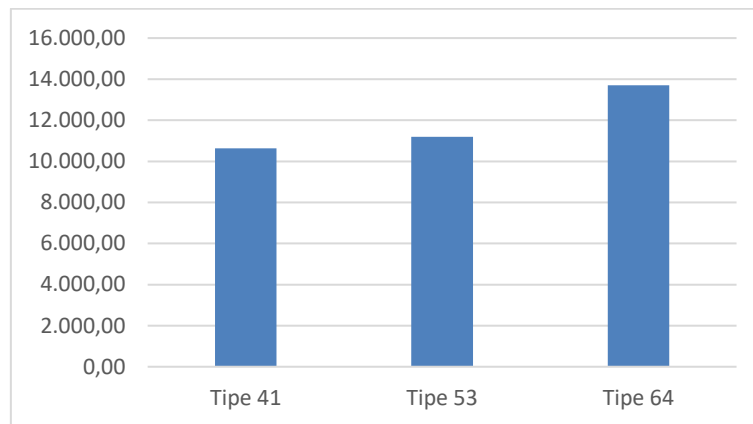
The calculation results indicate that embodied carbon emissions in the original house types 41, 53, and 64 have average values of 10,634.80 kg CO<sub>2e</sub>, 11,193.80 kg CO<sub>2e</sub>, and 13,695.80 kg CO<sub>2e</sub>, respectively.

For the original Type 41 house, embodied carbon emissions from the concrete roof amount to 701.80 kg CO<sub>2e</sub>, emissions from concrete columns and beams reach 750 kg CO<sub>2e</sub>, ceramic tile flooring contributes 943 kg CO<sub>2e</sub>, brick contributes 1,760 kg CO<sub>2e</sub>, and exposed concrete carport accounts for 6,480 kg CO<sub>2e</sub>. These findings indicate that the largest embodied

carbon contribution comes from the exposed concrete carport, while the smallest contribution comes from the concrete roof.

A similar pattern is also observed in the original Type 53 house, where the exposed concrete carport contributes the most to embodied carbon emissions at 8,208 kg CO<sub>2e</sub>, while the smallest contribution is from the concrete roof at 734.80 kg CO<sub>2e</sub>.

A different pattern is found in the original Type 64 house, where the smallest embodied carbon contribution originates from the concrete columns and beams.



**Figure 3. Average Embodied Carbon Emissions per House Type (kg CO<sub>2e</sub>)**

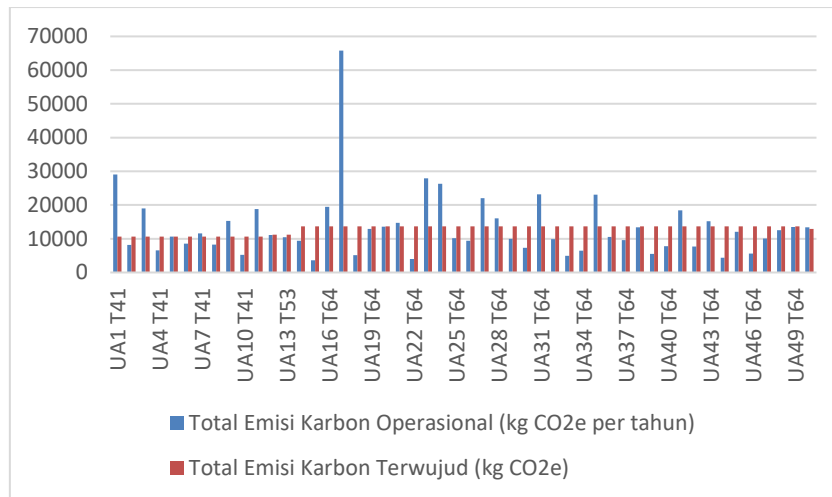
Although the three original house types use the same types of materials, their embodied carbon emission values differ due to variations in design, material quantity, and material weight. Larger house sizes result in higher embodied carbon emissions. These findings emphasize that during the architectural design stage, it is essential to evaluate embodied carbon emissions not only based on the type of materials used, but also on the quantity of materials applied.

**Table 5. Embodied Carbon Emissions by House Type (kg CO<sub>2e</sub>) (Kg CO<sub>2e</sub> per Year)**

House Type	Concrete Column–Beam Emissions	Brick Emissions	Concrete Roof Emissions	Ceramic Flooring Emissions	Exposed Concrete Carport Emissions
41	750	1760	701,8	943	6480
53	780	1980	734,8	1219	8208
64	810	2200	1005,8	1472	8208

Data Source: Emissions calculated based on IPCC standards for Life Cycle Assessment (LCA) of building materials.

Based on the calculation results of operational and embodied carbon emissions, it was found that the average operational carbon emissions of the 49 houses are higher than their embodied carbon emissions, with a difference of 468.31 kg CO<sub>2e</sub>. This finding is consistent with the statement by Liang et al. (2022), which indicates that a greater amount of carbon emissions is generated during the operational phase.



**Figure 4. Comparison between Annual Operational and Embodied Carbon Emissions**

### Carbon Sequestration by Vegetation

In this study, the calculation of carbon sequestration by vegetation is conducted using the following formula:

$$(i) \quad \text{SCO}_2 = (\text{Agreen} \times \sigma_{\text{m}^2} + \text{Ntree} \times \sigma_{\text{tree}})$$

Where:

Agreen = Vegetated area (m<sup>2</sup>)

$\sigma_{\text{m}^2}$  = Average CO<sub>2</sub> sequestration rate of vegetation per m<sup>2</sup> per year (kg CO<sub>2</sub>/m<sup>2</sup>·year)

Ntree = Number of trees

$\sigma_{\text{tree}}$  = Average CO<sub>2</sub> sequestration rate per tree per year (kg CO<sub>2</sub>/tree·year)

The estimated carbon sequestration by vegetation is presented in Table 6.

**Table 6. Estimated Carbon Sequestration Based on Vegetation Type (kg C/year)**

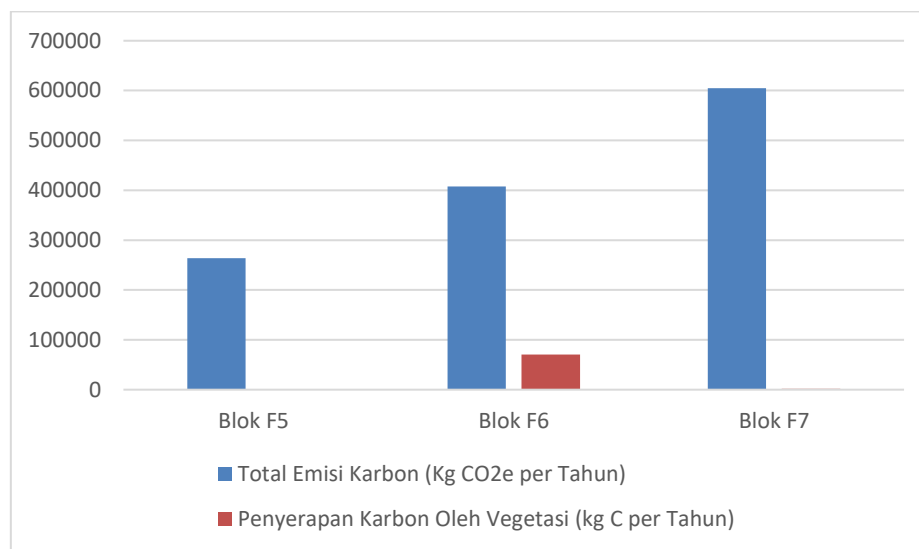
Nama Tumbuhan	Serapan Karbon
Rumput Jepang	0,8
Pohon Palembang	40
Pohon Cemara	300
Pohon Kamboja	20
Pohon Belimbing	90
Pohon Tanjung	52,2
Pohon Jambu biji	90
Pohon Mangga	150
Ficus Lyrata	30
Pohon Pisang	75
Pohon Alpukat	200
Pohon Jeruk	75

Data Source: Carbon sequestration rates are based on vegetation studies and research on carbon absorption capacity of different plant types.

The green area in Block F7 accounts for 14% of the total land area of the block. In Block F6, the green area covers 25% of the total land area, while in Block F5, green space constitutes only 5% of the total land area.

Vegetation in Blocks F7 and F6 is unable to offset most of the carbon emissions generated. Carbon sequestration by grass and vegetation in Block F7 amounts to 1,530.60 kg C per year, which is 60,323.81 kg C per year lower than the total household carbon emissions produced in the block. Household carbon emissions in Block F6 reach 407,670.80 kg CO<sub>2e</sub>, exceeding vegetation carbon sequestration by 336,964.60 kg C per year. In contrast, vegetation in Block F5 is capable of sequestering 26,325.64 kg C per year, which is still 264,168.48 kg C per year lower than household carbon emissions in the block.

Therefore, carbon emissions in all three residential blocks remain at a significant level and have not yet achieved carbon neutrality.



**Figure 5. Comparison between Carbon Emissions and Carbon Sequestration by Residential Block**

### Household Energy Behavior

The residents' green behavior variables are classified into five categories, namely lighting, air conditioning, LPG use, waste management, and private vehicles. The lighting, air conditioning, and other appliance variables consist of several sub-variables. Lighting is divided into daytime lighting, nighttime lighting, and type of lighting. Air conditioning is divided into daytime and nighttime use. The details of the variables and questionnaire items are presented in Table 7.

**Table 7. Variables and Questionnaire Questions**

Variable	Questions
Daytime Lighting	Do you use lights during the daytime?
Nighttime Lighting	How many rooms use lights during the nighttime?
Type of Lighting	Do you use LED, CFL, or incandescent light bulbs?
Daytime Air Conditioning	Do you use AC during the daytime?
Nighttime Air Conditioning	How many rooms use air conditioning during the nighttime?
LPG	How many LPG cylinders do you purchase per month, and what is their weight?

Waste	Do you separate all, some, or none of your household waste?
Private Vehicle Use	Do you use a private vehicle on a daily basis?

Data Source: Data was obtained through a questionnaire survey conducted among 49 households in the Vila Dago housing complex, Pamulang, South Tangerang.

The questionnaire results indicate that 84% of respondents across the three residential blocks use artificial lighting during the daytime, representing approximately 41 households. Meanwhile, 16% of households do not use artificial lighting during the day. These findings suggest limited utilization of natural daylight in most houses, which is likely influenced by building design, particularly the number and size of openings.

The majority of houses, especially those that are closely flanked by neighboring houses on both sides, experience limitations in receiving natural daylight. Furthermore, most houses are currently dominated by built-up areas, resulting in suboptimal layout and opening design. Relatively optimal openings are generally located at the front or rear of houses that have open spaces. The addition or expansion of houses from their original designs negatively affects natural lighting, as new structures tend to block openings and open areas of the original house layouts.



**Figure 6. Condition of a House Directly Bordered by Buildings on Both Sides**

A total of 23% of respondents use lighting in four to six rooms at night, while 20% use lighting in seven rooms, 14% in five rooms, 10% in two rooms, 6% in three rooms, and 4% in one room. These figures indicate that most respondents tend to turn on lights in rooms that do not necessarily require intensive lighting at night, such as family rooms, living rooms, and laundry areas. These spaces are typically used during the period before bedtime. These findings may indicate that current architectural design has not yet effectively guided user behavior toward more energy-efficient lighting use.

Although lighting utilization is not yet efficient, the type of lighting chosen by the majority of respondents can be considered energy-efficient. A total of 88% of respondents use LED lights, which are more energy-efficient compared to CFL and incandescent bulbs. Meanwhile, 4% of respondents use incandescent bulbs. These findings indicate that although lighting usage behavior has not yet been optimal, most respondents have considered energy efficiency aspects through the selection of LED lighting.

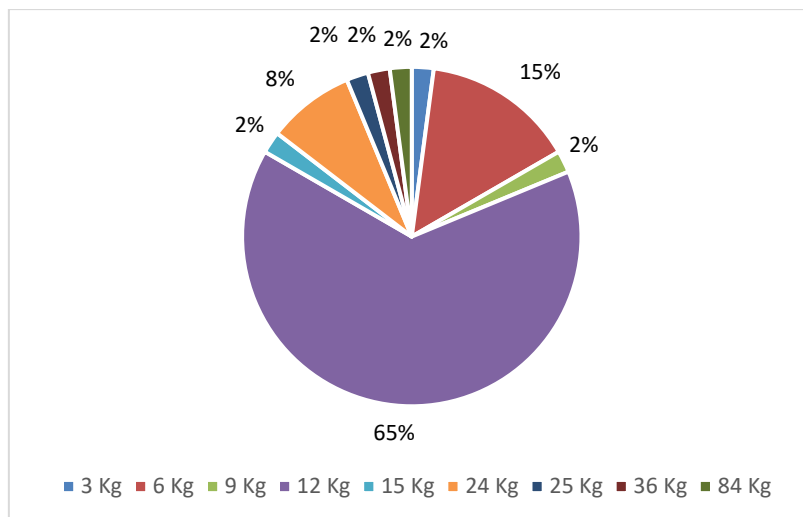
A total of 67% of respondents reported using air conditioning during the daytime, while 33% do not use air conditioning during the day. These findings suggest that some houses are still able to provide thermal comfort for their occupants without relying on air conditioning. However, the proportion of daytime AC use remains relatively high, indicating that most

households have not yet achieved satisfactory thermal comfort conditions. This situation is likely influenced by building materials, which are predominantly concrete-based and generally exhibit poor thermal performance. Therefore, during the house design stage, it is important to consider material selection and building envelope design.

The questionnaire results show that 80% of respondents use air conditioning in one room at night, which is generally the bedroom. 10% of respondents use air conditioning in two rooms, and 2% in three rooms, while 7% of respondents do not use air conditioning at night.

Ideally, nighttime outdoor air temperatures should provide sufficiently comfortable conditions for sleeping if passive house design strategies function optimally. Nighttime thermal discomfort indicates that building materials have a high heat storage capacity, causing stored heat to be released slowly at night. This condition leads to increased intensity of nighttime air conditioning use.

The majority of respondents use 12-kg LPG cylinders for cooking. Variations in LPG consumption are influenced by the number of occupants and the duration of cooking activities. In addition, the thermal condition of the kitchen potentially affects occupants' comfort during cooking. High kitchen temperatures may reduce thermal comfort, making cooking activities less efficient and potentially increasing LPG consumption. Therefore, the selection of materials that are capable of maintaining occupants' thermal comfort is crucial as an effort to control household energy consumption. Attention to material selection is essential to ensure adequate thermal comfort within the kitchen space.



**Figure 7. Percentage of Monthly LPG Consumption**

The questionnaire results indicate that 82% of respondents do not practice waste separation, 12% partially separate their waste, and only 6% fully separate their waste. These findings suggest that the low level of waste separation behavior may be associated with building design conditions that do not yet support waste separation practices. This is reflected in the design of waste disposal spaces, which typically consist of only a single bin, causing all types of waste to be collected in one place.

**Table 8. Distribution of Respondents Based on Waste Separation Behavior**

Waste Separation	Number of Respondents
No	40
Yes, partially	6
Yes, fully	3

Data Source: Data was collected through a survey of 49 households in the Vila Dago housing complex, Pamulang, South Tangerang, regarding their waste separation behavior

The original house types in the three residential blocks were designed with a relatively large proportion of open space. In addition, the developer planned single-family houses with the provision of private vehicle parking spaces within the house yard. In practice, these open areas have been utilized for parking space expansion, allowing homeowners to increase vehicle parking capacity within their properties. Figure 18 illustrates the condition of a Type 41 house before and after expansion and renovation.



**Figure 8. Floor Plan of the Original Type 41 House Before Expansion (Left) and a Type 41 House After Expansion (Right)**

The freedom of residents to expand private vehicle parking capacity within their homes potentially encourages private vehicle ownership and use. The larger the available parking space, the easier private vehicles are to access and use, leading residents to prefer private vehicles over other transportation modes in their daily activities. This condition contributes to increased fuel energy consumption.

Based on the questionnaire results, 46 respondents use private vehicles to support their daily activities, while only 3 respondents do not use private vehicles. These findings indicate that current housing design tends to support private vehicle use.

### CONCLUSION

Average household carbon emissions in Block F7 amount to 26,298.01 kg CO<sub>2e</sub> per year, while those in Block F6 reach 27,178.05 kg CO<sub>2e</sub> per year, and 23,954.74 kg CO<sub>2e</sub> per year in Block F5. These emission levels are significantly higher than the amount of carbon sequestered by vegetation in the three residential blocks. The differences between carbon emissions and carbon sequestration in Blocks F7, F6, and F5 are 603,323.81 kg C per year, 336,964.60 kg C per year, and 263,252.63 kg C per year, respectively. This indicates that existing green areas and vegetation are not yet sufficient to help the housing areas achieve

carbon-neutral conditions. Energy behavior patterns among most households show that respondents who use lighting during the daytime and in multiple rooms at night tend to require higher electricity consumption. In addition, daytime air-conditioning use and the number of air-conditioned rooms at night increase household electricity loads. This condition is reflected in the average household electricity consumption in the three residential blocks, which reaches 884.2 kWh per month, a relatively high value. Daily private vehicle uses by residents' results in considerable vehicle-related emissions, averaging 3,201.48 kg CO<sub>2e</sub> per year. Furthermore, the majority of respondents who do not practice waste separation contribute to increased carbon emissions. Waste separation can indirectly reduce carbon emissions through improved waste processing, increased recycling, and reduced waste accumulation at landfills. Thus, these findings indicate that household carbon emissions are closely related to residents' energy behavior patterns and building design. The presence of green areas as part of sustainable housing design strategies has the potential to support carbon-neutral housing, although current conditions remain insufficient to significantly reduce emissions. Therefore, efforts toward achieving carbon-neutral housing should be implemented in an integrated manner by controlling energy consumption through improved passive house design and by enhancing the quality and extent of green areas, both within residential plots and in public spaces, as carbon sequestration media.

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