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STUDY ON THE USE OF SOLID AND ENGINEERED WOOD IN HOUSE BUILDINGS TO SUPPORT CLIMATE STABILISATION

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Abstract

The 2015 Paris Agreement/COP21 of the United Nations Framework Convention on Climate Change (UNFCCC) mandates the global community to commit to keeping the global average temperature rise below 2°C and working towards limiting temperature rise to 1.5°C in the world. This would significantly reduce the risks and impacts of climate change. For this reason, each country is fostered to implement low greenhouse gas emission development or – in other words – countries must reduce emissions in their development. Indonesia made a commitment to reduce emissions by 29 percent independently and 41 percent with international support. Indonesia's latest NDC document was submitted by the Ministry of Environment and Forestry on 21 July 2021. The document states that most of the emission reductions are expected to come from the forestry and land use sector by 2030, amounting to 24.5 percent. This produces about 692 metric tons (692,000 tons) of carbon dioxide equivalent. Indonesia's NDC will contribute to achieving the Convention's objectives by reducing greenhouse gas emissions and increasing climate resilience, which will lead to long-term economic development. Indonesia's NDC commitment needs to be supported by various sectors, both upstream and downstream, including the utilisation of timber forest products. However, until now there is no data and information on how big the contribution of the subsector of forest product utilisation to reducing GHG emissions, even though it is known that carbon is stored in wood.

The amount of carbon stored in wood used as a building material in Indonesia was assessed in this study. Purposive sampling was used for the study's selected locations, which were cities with rapid housing development around Jakarta's capital city. They are the Bekasi District, East Jakarta City, Depok City, and Bogor District..

The findings revealed that the wood species used as building materials for houses varied. The value of stored carbon in houses varies according to wood species. If a house is currently built with wood components only on door frames and doors, as well as window frames, shutters, and vents (roster), then calculations based on the standard EN 16449: 2014-06 yield a stored carbon of 450 – 680 kg, or an average of 554.50 kg in each housing unit. Meanwhile, according to EDX/S carbon analysis, between 130 and 430 kg, or an average of 400.42. If the backlog is 7.6 million housing units, and the demand rate is 800 thousand housing units, and the proportion of wood used is as in the three cities/districts sampled, then there is 4.2 million tons of carbon stored. This figure indicates that if the Indonesian backlog is built without the use of wood materials, there is a potential for carbon emissions of that magnitude (4.2 million tons). If the demand of house of 800,000 units per year were built and the door and window frame components were made of wood, then the housing construction sector stores 0.44 million tons of carbon per year.

Keywords: wood, house building, stored carbon.

1. INTRODUCTION

1.1. Background

Humans have been using wood as a building material for the construction of houses for over 10,000 years[1]. Wood is still an important building material for homes all over the world today. As the human population grows, so does the demand for shelter, which means that the demand for wood grows as well. However, the debate over the use of wood and other materials such as metal and concrete or cement continues, both in scientific and practical forums. This is consistent with the global rise of environmental movements attempting to maintain climate stability. Davis et al [2] concluded that global CO_2 emissions from cement and steel manufacturing were approximately 1320 and 1,740 Mt, respectively, in 2014. On the other hand, unless properly addressed, the modern global building sector's demand for construction materials will continue to be a major source of greenhouse gas emissions. Buildings are a missed opportunity for long-term carbon storage because they are designed to be occupied for decades. To address this issue, the most commonly used building materials, such as steel and concrete, store almost no carbon [3].

The extraction of natural resources such as wood, iron ore, limestone, and aggregates usually starts the cycle of use of structural building materials. Tracking energy use and emissions to air, water, and soil per unit of resource is where data collection begins. Fortunately, wood has a lower impact during this phase than concrete and steel, which are made of materials that must be mined and heated to extremely high temperatures [4].

According to wood scientists and technologists, wood products provide physical storage of carbon that was previously present in the atmosphere as a greenhouse gas. Significant climate benefits could be realized in the short to medium term by increasing the total carbon stock in wood products, using more wood products, or using longer-lived wood products. Long term, when product stocks stabilize at higher levels, wood products provide a stable carbon pool because new wood entering the pond is offset by old wood leaving the pond, allowing climate benefits from emissions substitution effects to be avoided [4]. Wood products used in construction, in fact, can act as a carbon sink. Churkina et al [3] revealed that wooden buildings for new urban dwellers can save 0.01–0.68 GtC per year depending on the scenario and the average floor area per capita.

Carbon captured from the atmosphere by trees and stored in wood is eventually released back into the atmosphere. As a result, shifting demand for wood products may play an important role in the global carbon cycle and climate change mitigation [5].

According to Ministry of Public Works and Public Housing (PUPR) data, the number of housing needs (backlog) in Indonesia is 7.6 million units [6, 7], with an annual demand rate of 800 thousand units [8]. If each standard house requires 4.85 m3 of wood for roof trusses (3.5 m3) and frames and doors (0.35 m2), 36.86 million m3 of processed wood will be used. If this volume of wood is converted to carbon at a 50 percent conversion factor, as suggested by Brown[9], Indonesia could store 18.43 million m3 of carbon in housing construction. Indonesia, as one of the world's major wood producers, can play a significant role in promoting the use of renewable and environmentally friendly building materials for carbon storage. However, there is insufficient research and data on this critical issue to accurately describe the potential and actual amount of carbon stored in buildings across the country.

This report describes the findings of a study on the use of wood in house construction to aid in climate stabilization. The ability of wood as a building material to store carbon indicates support for climate stabilisation. The amount of carbon stored in wood used as a component in building houses can be determined by calculating the volume and the weight of wood used as a component in building houses.

1.2. Objectives

The overall goal of this study is to calculate the carbon stored in solid wood and processed wood products in Indonesia. As a result, the role of wood products in maintaining climate stability will be recognized. Recognizing the contribution of harvested wood products to climate stability is important. In addition, the important goal of this research is to raise public awareness of the use of a sustainable, renewable, and environmentally friendly material - wood - for home construction.

The specific goals of this research are as follows:

(1) To identify wood species, volumes, and types of wood products currently used in house construction.

(2) To determine the amount of carbon stored in solid/processed wood used in the construction of a house.

(3) To promote the use of sustainable, renewable, and environmentally friendly materials in house construction..

1.3. Expected Output

This study is expected to produce data and information such as wood species, volume and type of processed wood products, both solid and processed wood used in current house construction, and the calculation of the carbon stored in these wood products. Furthermore, the results of this research can be disseminated in the form of scientific reports that will be published in international proceedings with global indexes and/or international journals. The detail of outputs are presented in Table 1.

Tabel 1. Expected output of the research

No.	Research Performance Indicators (Output)	Target	Keterangan (Terukur)
1	Wood species, volume and type of processed wood products, both solid and processed wood used in current house construction, and the calculation of the carbon stored in these wood products.	100%	Representative data were collected from 4 cities/districts.
2	Publications on International Seminars and Proceedings	100%	1 paper submitted on global indexed proceeding such as IOP, WOS, etc.
3	Publication on an internasional journal	100%	1 paper draft that will be submitted to international journal, globally indexed (Scopus, WOS, dll)

2. BENEFIT AND IMPORTANCE OF RESEARCH

2.1. Wood Products

All forest products (sawwood, veneer, chips, and their derivative products), including paper and paperboard, are included in the phrase processed wood forest products[10]. Wood harvesting is the first step in the wood processing process. 'Logs' are trees that have had their limbs removed and their trunks chopped lengthwise for transportation. Logs, solid sawn or shaped wood, and other pre-industrial building materials have a long history. Although wood is still used for structural purposes, particularly in the form of light frame construction for low-rise residential structures, the use of heavy solid wood for industrial and commercial high-rise buildings declined in the late nineteenth and twentieth centuries. Ramage et al. [11] address the widespread use of engineered wood structures and its possible global substitution for steel and concrete in medium-rise structural systems based on their findings.

Engineered wood products that are laminated from smaller boards or lamellas/slats into larger structural components such as glue-laminated beams (glulam) or cross-laminated wood panels (CLT) are now referred to as bulk wood. Mass production methods of wood which include the lamination of finger, longitudinal and transverse joints with liquid adhesives and mechanical fasteners allow reformulation of large structural wood [3]. Ramage et al. [11] explained that this new approach overcomes the natural inconsistency of wood and makes its mechanical performance in large structural members more predictable.

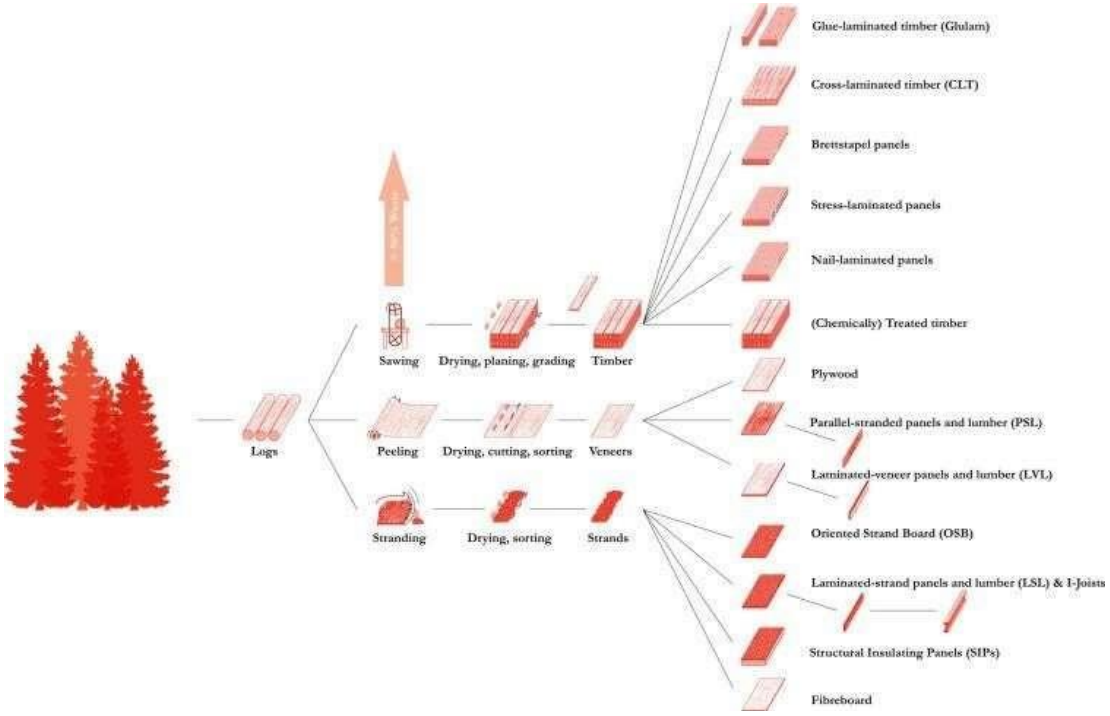


Figure 1. The processing chain of engineered wood products [11]

2.2. Wood Material in House Building

Architects, developers, and sustainability advocates are all working on new building materials that can significantly reduce greenhouse gas (GHG) emissions in the building sector, as well as waste, pollution, and construction-related costs, while also creating a more physically, psychologically, and aesthetically healthy built environment. Wood is undeniably the most environmentally friendly framing material. It is a renewable resource that, when used instead of other materials, helps to reduce greenhouse gas emissions. Wood has many advantages over other building materials because it is the only renewable building material. In terms of resource extraction, manufacturing, and transportation, it uses less energy to produce[12]. In the modern world, new ways of using wood have reintroduced the material, which is known as "mass wood" (short for "massive wood"). Bulk wood is a broad term that encompasses a wide range of products with varying sizes and functions, including glue laminated beams (glulam), laminated veneer wood (LVL), nail laminated wood (NLT), and dowel laminated wood (DLT). However, cross-laminated wood is the most common and well-known type of bulk wood, and it has enabled the most recent architectural possibilities (CLT)[11].

2.3. Global Carbon Capture and Storage

The effects of carbon sequestration can be understood when viewed at the global system level. On a global scale, CO_2 is stored in forests (and other vegetation), in the ocean, and in products (buildings, furniture, etc.)[13]. A good overview of the global carbon cycle and carbon sequestration in forests is provided by NASA Earth Science Enterprise as shown in Figure 2 [14]. This reveals that humans play three roles in CO_2 emissions:

- 5.5 Gt of CO_2 emissions per year from the combustion of fossil fuels;
- 1.6 Gt of CO_2 emissions per year from deforestation in the tropics and subtropics; and
- 0.5 Gt of CO_2 sequestration per year from regenerating forests in the Northern Hemisphere.

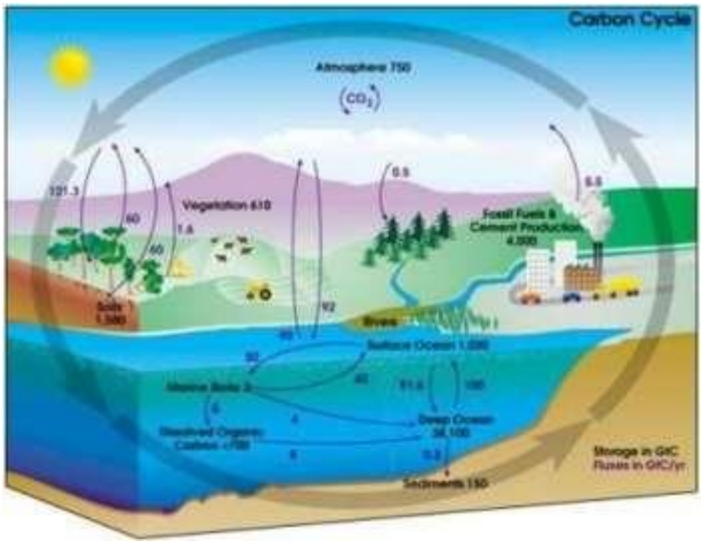


Figure 2. Diagram of carbon cycle

Regarding CO_2 emissions from biomass, Kazulis et al [15] explained that this emissions are generated by natural processes as well as from anthropogenic activities. If biomass is left to putrefy in open air conditions then gradually during the natural decomposition CO_2 and other gases are emitted into the atmosphere. Combustion of biomass is also releasing CO_2 into the atmosphere but the energy generated in the combustion process is used. Producing goods from biomass can be considered as carbon storage in bioproducts. The most important questions here are how much CO_2 emissions are generated during the production process of a bioproduct, how long will be the durability of a bioproduct and if a bioproduct is substituting a product which is made from fossil resources. The same way as carbon in biomass has three possible paths – open air putrefaction, combustion (energy source) and being turned into a bioproduct also bioproduct at the end of its life cycle faces these three potential paths: landfill (open air putrefaction), combustion and recycling (being turned into a new product). Carbon storage in bioproducts and recycling can create circular bioeconomy loop as the bioproducts at the end of their life would be recycled and turned into new products. For the environmental perspectives of production – the circular bioeconomy loop is the most desirable solution to manage CO_2 emissions. Even during this loop the CO_2 emissions might come from energy powering the production technologies and transportation. If fossil resources are used as energy resources then that means increase of carbon in the atmosphere and increase of CO_2 in the atmosphere; if biomass resources are used as energy sources the amounts of CO_2 in the atmosphere will increase, however the total amount of carbon in atmosphere will remain the same.

2.4. Wood as Carbon Storage

Trees absorb (sequester) atmospheric carbon dioxide during growth, with a portion of the carbon stored within the cambium and in the cells of the tree, both in the wood and in the bark, by splitting off oxygen during photosynthesis. The absorbed carbon dioxide is effectively bound as biogenic carbon in the wood. The biogenic carbon is transferred into the product system when wood is used. During the life of these products, wood products form a pool (reservoir) for biogenic carbon. The carbon exits the product system at the end of its useful life. When biogenic carbon is used to generate energy, it oxidizes to carbon dioxide and is released back into the atmosphere. An European Standard specifies a method for quantitatively determining the amount of atmospheric carbon dioxide based on the content of biogenic carbon. This information can also be used to estimate the potential benefits related to the storage of carbon in wood and wood products (harvested wood products – HWP); for example by architects in the early planning phase of buildings [11].

Depending on the tree species, wood consists in varying proportions of cellulose (40% to 55%), hemicellulose (12% to 15%), lignin (15% to 30%) and extracts (2% to 15%). As a result, wood is effectively 50% carbon. For the purposes of this European Standard, the value of the carbon content of the wood biomass is determined to be 0.5. The other main elements are oxygen (44%) and hydrogen (6%). Some species also contain small amounts of mineral components, which are irrelevant in the present case. Trees and wood also contain moisture in different forms and in different amounts. Wood is generally dried down to the moisture content appropriate for the end use. The moisture content of some wood products is proportionate to the manufacturing process. The amount of moisture contained in the wood affects both the dimensions and the bulk density; With the removal of moisture, the wood shrinks and the bulk density decreases. The moisture content at this point in time is also required to determine the amount of carbon dioxide absorbed on the basis of the specified values for volume and gross density of the wood to be used and the wood products [11].

In the context of the climate change issue, the carbon in HWP is important for at least three reasons. First, the carbon in HWP is sequestered from the atmosphere while the products are being used. Second, after use, a certain fraction of HWP is disposed of in landfills where it continues to sequester carbon. Third, methane released to the atmosphere from HWP in landfills adds to the greenhouse gas levels in the atmosphere. While HWP are being used, the carbon they contain is sequestered from the atmosphere, but the time in use varies considerably from one type of product to the next. In some cases, the products remain in use for very long periods of time. Many building materials are in this category [10].

There are three alternative approaches for carbon stored dealing with wood products as follows [15]:

(1) The flow approach adopts the same philosophy used for emissions from fossil fuels in tracking carbon emissions, reporting would be of actual carbon fluxes to or from the atmosphere at the time and place that they physically occur.

(2) The stock-change approach adopts a pure accounting for changes in carbon stocks, reporting stock changes where and when they occur regardless of whether the inputs and outputs occur as solid materials or as CO_2 exchanges with the atmosphere.

(3) The production approach adopts a philosophy of continuity, reporting all stock changes as continuous deriva- tions from the original forest harvest, i.e. the party that harvested the wood would continuously report the changes in the stock of the harvested wood products derived from its forests as this actually (or statistically) occurred, regardless of who physically held the carbon-containing products.

However, there are also some simplifications accounting carbon stored in wood products as proposed by Kazulis et al [16]. They reported that to find out the possible amounts of CO_2 that can be avoided by storing carbon in bioproducts it is important to do an analysis evaluating the amounts of the avoided CO2 emissions stored in the product. The possible amount of CO_2 avoided in a tonne of the raw material can be calculated assuming that a tonne of carbon needs 2.67 tonnes of oxygen to be completely transformed into CO_2, therefore it can be assumed that a tonne of carbon can produce 3.67 tonnes of CO_2.

Another simplification approach for calculating carbon content in wood products presented in DIN EN 16449:2014 Wood and wood-based products – Calculation of the biogenic carbon content of wood and conversion to carbon dioxide. This standard is used as a reference in this research.

2.5. Research Gap

Research on carbon stored in processed wood products and in the construction of houses has been widely carried out in developed countries. There are standards that determine how to calculate carbon content in processed wood products and how to calculate conversion to carbon dioxide, including DIN EN 16449: 2014 as mentioned above. Even the discussion of wood as a carbon store has enlivened the popular mass media, but this has not happened in Indonesia. We are still having trouble finding scientific articles that discuss the carbon stored in wood products in general, especially in wood for house construction.

This report presents a research result that was conducted for the first time this year, so there are no preliminary research results. Thus, it is hoped that the results of this study can fill the gaps in scientific data and information about wood stored in residential buildings.

2.6. Benefit and Importance of Research

The forestry sector, through both direct and indirect contributions, can help the global community achieve the 17 SDGs goals that must be met by 2030. According to Seymour and Busch [17], most people are aware of the importance of forest products to the well-being of local communities and the role of forest services in achieving global goals. Wild fruits, nuts, mushrooms, and meat are examples of complementary foods (SDG 2). Herbal plants are frequently used as the first line of defense in the treatment of disease (SDG 3). Forest products account for more than 20% of local people's household income (SDG 1), and tropical forests contain the majority of the world's terrestrial biodiversity (SDG 15). Furthermore, as natural reservoirs that sequester and store carbon, forests are increasingly being recognized as an essential component of any climate-stabilization strategy (SDG 13) [18].

When used for housing building materials, wood as a forest product emits far fewer emissions than other materials, as described above. In addition, when used in the construction of houses, wood acts as a carbon store. As a result, research into the calculation of stored carbon in processed wood products, including those used in house construction, is critical. This is useful for assessing the achievements of the Nationally Determined Contribution (NDC), specifically how much the national contribution is in reducing greenhouse gas emissions (CO_2).

3. METHODOLOGY

3.1. Location

This study was carried out in the field, with measurements and test samples taken from each of the target housing complexes in the Jakarta area, Bogor Regency, Bekasi Regency, Depok City, and Serang City. The housing sample unit is determined by the material used, specifically whether wood is still used as a building material. There is also easy access to data and information, as well as the ability to take measurements and samples. Table 2 lists the housing complex that serves as the research site..

Table 2. Housing complex as the location of research sampling

No	Name of Housing Complex	Loction	Coordinate Position
1	The Riscon Hill Bambu Apus	Kota Jakarta Timur	-6.326169534862831S, 106.89856809773443E
2	Pesona Kembang Setu	Kab. Bekasi	-6.317569470103991S, 107.0381699693129E
3	Green Garden Bojonggede	Kab. Bogor	-6.497594177106979S, 106.78965554006263E
4	Green Depok Residence	Kota Depok	-6.447205035445256S, 106.82625081221232E

3.2. Materials and Equipment

The material here means the harvested wood products (HWP) used in house buildings that are being or will be built on the samples of the site of house development area. The equipment required for taking wood samples are saw, moisture meter digital, plastic bags, measuring tape, tally sheet, recorder, camera and GPS.

3.3. Work Procedures

(1) From each cities, select one site of house development representing low-midle and one from high class of housing. Spot each location by GPS.

(2) Do measuring the size (length, width and thickness) of each wood part of the house that used for common type or size of the house, to obtain partial and total of wood component of the house. This depends on availability the house that are being or will be built. Common parts or house building components made from wood: column and beam, doors, door and window frame, and roof structure. For the measurement, SNI 7537.2-2010 Sawnwood - Part 2 - Measurements and dimensions will be referred; and SNI 01-5008.4-1999 Wood moulding.

(3) Wood identification through anatomical properties observation. The anatomical observation will done on macroscopic and microscopic features as follows: General characteristics will be observed from disc surfaces: colour, texture, lustre, feel, odour, grain direction, and figure (Mandang and Pandit, 2002). Microscopic structure will be evaluated from prepared slides according to Sass (1961) and macerations (Forest Product Laboratory in Tesoro (1989). Procedure for sectioning followed Sass (1961) that has been modified by the use of Entellan as permanent mounting media. The wood anatomical characteristics will be described using the IAWA Committee List for Hardwood Identification Wheeler et al. (1989). Determining wood species of the observed samples will be done by comparing to the wood references in Anatomy Laboratory of Forest Products Research and Development Centre, Bogor.

(4) Calculation of carbon dioxide based on the content of biogenic carbon, refers to DIN EN 16449:2014-06 EN 16449:2014 (D) [19]. The calculation is based on the atomic weights of carbon (12) and carbon dioxide (44). In addition, an Energy Dispersive X-ray Spectroscopy (EDS/EDX) analysis will be carried out to analyze the composition of wood samples taken from wood used in house construction.

Based on the biogenic carbon content of the product and the volume of wood, the bulk density and the moisture content, the following equation should be used:

$$P_{CO_2} = \frac{44}{12} \times cf \times \frac{\rho_\omega \times V_\omega}{1 + \frac{\omega}{100}} \quad \text{.................................(1)}$$

where:
PCO2 is the biogenic carbon oxidized as carbon dioxide emission from the product system into the atmosphere (e.g. energy source at the end of life) (kg); *cf* is the carbon content of the wood biomass (kiln-dry mass), 0.5 as the standard value; ω the moisture content of the product (e.g. 12%); ρ the gross density of the wood biomass of the product at this moisture content (kg/m^3); $V\omega$ is the volume of the solid wood product at this moisture content (m^3). In the case of wood products, the wood volume content $V\omega = VP$ x wood percentage; VP is the gross volume of the wood product.

If the exact moisture content of the wood and wood products is doubtful, a higher moisture content for a given volume of wood provides a more conservative estimate for carbon dioxide. For each project, the quantitative determination of the volume of wood of each type of wood used in each wood and wood product in the respective application and by applying the above calculation, the estimate of the total amount of carbon dioxide is determined in each case (i.e. $P_1CO_2 + P_2CO_2$ and so on).

4. RESULT AND DISCUSSION

4.1. Development of Residential Building Materials

According to the findings of discussions with the developer, very little wood is currently used as a building material for housing. Non-timber materials predominate over wood, except for the door leaf, which is made of solid and composite wood, such as particle board, thick block, or other types of wood panels. The main (front) door is made of solid wood, while the interior or inter-room doors are made of particle board. There is still some housing that uses wood as a frame material. The use of structural and non-structural wood materials as housing building materials can be divided into three time periods, as shown in Table 3.

Table 3. The development of material used for housing

Period	Materials used for structural	Community's perspective about wood
Until the 1990s	Dominated by wood	• Those who born until the 1970s still consider wood as an important building material for houses, • Wood is still available in abundance.
2000 – 2010	Wood + aluminum/mild steel	• Wood is impractical, needs more maintenance, not durable. • Timber is starting to decrease.
Setelah 2010	Dominated by mild steel/aluminum and GRC, wood only for doors	• Wood is impractical, needs more maintenance, not durable. • Wood availability is dwindling, and the price is rising.

From the standpoint of the developer, there is still a desire to use wood as the primary material for both structural (roof frames, frames) and non-structural components (doors, windows, ceilings). Even the developer has set up a special woodworking workshop for frames, structures, and doors. However, the supply of materials, specifically wood, does not exist or is extremely difficult, and even if it does exist, the price is exorbitant.

In Indonesia, the lower middle class still has a significant housing shortage. The declaration to build a thousand towers of flats/apartments has yet to be fulfilled. In stark contrast to residential buildings/housing in other countries, which use wood as a building material nearly 80 percent of the time, the materials used are mostly concrete and steel. Meanwhile, multi-story wooden apartment buildings with up to ten floors already exist in Europe, including England and Sweden[12]. Even in Norway today there are 18-story buildings made of wood construction [18].

In light of the global problem of carbon emissions, using wood as a building/construction material may be an option. The use of wood products in the construction sector has the potential to reduce the concentration of carbon dioxide (CO2) in the atmosphere in the future. The lower fossil fuel energy required to produce wood, the avoidance of emissions from industrial processes associated with the manufacture of non-timber products, the option to use wood waste for bioenergy, and the actual physical storage of carbon in wood products all contribute to the climate benefits of using wood in construction[20-23]. Consideration of wood products (HWP) as a carbon storage mechanism is relatively new [24].

4.2. The Species of wood used

4.2.1. Prediction of wood species used

Table 4 shows the wood used in this study's housing construction. The developer provided the name for the type of wood. This information from the developer is typically received by the community, and its veracity cannot be determined. Frequently, the wood type information is incorrect. Anatomical testing or wood type identification can be used to determine the definitive wood type. Table 5 does, however, provide an initial description of the wood's characteristics.

Table 4. Timber used in the housing construction of the research sampling location

No	Name of housing complex	Wood species
1	The Riscon Hill Bambu Apus, East Jakarta City	Keruing
2	Pesona Kembang Setu, Bekasi District	Meranti-1 (yellow)
3	Green Garden Bojonggede, Bogor District	Kamper
4	Green Depok Residence, Depok City	Meranti-2

Table 5. Characteristics of wood used in housing construction

Characteristics	Wood species			
	Keruing	Meranti-1 (kuning)	Kamper/Kapur	Meranti-2
Botanic name[a]	*Dipterocarpus spp.*	*Shorea spp.*	*Dryobalanops spp.*	*Shorea spp.*
Moisture content (%)[b]	17,50	15,50	17,50	14,80
Density (kg/m^3)[b]	888,17	578.29	875.86	769,97
Colour[a]	Greyish-brown	Light yellow - brown	Reddish brown	Red-dark red until brown
Cellulose content (%)[a]	51,4	51,9	60,0	52,9
Uses[a]	Construction, house building	Plywood, house building	Beam, pole, poke, house building	house building as frames and beams
Macroscopic figure[a]				

Remarks: [a]Martawijaya et al.[25] ; [b]Data resulted from Researcher Team

Based on the density value, the wood used is most likely keruing batu (Dipterocarpus lowii = 860 kg/m^3), yellow meranti (Shorea faguetiana = 570 kg/m^3), camphor/lime (Dryobalanops fusca = 840 kg/m^3), and red meranti (Shorea ovata = 750 kg/m^3 or S. pachyphylla = 770 However, the certainty of these types of wood is still awaiting the results of laboratory identification. The value of water content and density is related to the value of stored carbon content using a formula (1). While the cellulose content is related to the estimated carbon content, the results of which are determined by the EDX/EDS analysis. As a rough estimate of the carbon content, the value of the cellulose content is listed.

4.2.2. The wood species from identification results

The results of anatomical identification of wood samples collected from each housing are described in detail below.

(i) Kode yang tertera di spesimen (*Code on the specimen*) : B1 (Keruing)

Karakteristik kayu (*Wood Characteristics*)*

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
2	Growth ring boundaries indistinct or absent (Batas lingkar tumbuh tidak jelas)

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
5	Wood diffuse-porous (Porositas – baur)
7	Vessels in diagonal and / or radial pattern (Sebaran pembuluh – pola diagonal atau radial)
9	Vessels exclusively solitary (90% or more) (Pengelompokan pembuluh – hampir seluruhnya soliter)
13	Simple perforation plates (Bidang perforasi – sederhana)
22	Intervessel pits alternate (Ceruk antar pembuluh – selang-seling)
30	Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell (Percerukan pembuluh jari-jari dengan halaman yang jelas; serupa dalam ukuran dan bentuk dengan ceruk antar pembuluh)
37	Helical thickenings throughout body of vessel element (Penebalan ulir – pada seluruh badan pembuluh)
64	Helical thickenings in ground tissue fibres (Penebalan ulir pada jaringan serat dasar)
82	Axial parenchyma winged-aliform (Parenkima aksial paratrakea – aliform bersayap)
83	Axial parenchyma confluent (Parenkima aksial paratrakea – konfluen)
97	Ray width 1 to 3 cells (Jari-jari 1 - 3 seri)
104	All ray cells procumbent (Komposisi sel jari-jari – seluruhnya sel baring)
106	Body ray cells procumbent with one row of upright and / or square marginal cells (Komposisi sel jari-jari – sel baring – dengan satu jalur sel tegak dan/atau sel bujur sangkar marjinal)
142	Prismatic crystals in chambered axial parenchyma cells (Kristal prismatik dalam parenkim aksial berbilik)

* *International Association of Wood Anatomist*s (IAWA) (Wheeler, Baas, & Gasson, 1989)

Hasil identifikasi (*Identification result*):

Jenis kayu (*Species*) – Famili (*Family*)
Koompassia malaccensis - Leguminosae

Catatan (*Notes*) : Terlihat adanya penebalan ulir pada jaringan serat dasar

Hasil identifikasi kayu hanya berlaku untuk sampel uji yang telah diamati di laboratorium (*The wood identification results only apply to the samples that have been observed in laboratory*).

b. Cross section c. Tangensial section a. Radial section

Figure 3. Micro structure of Kempas wood

(ii) Kode yang tertera di spesimen (*Code on the specimen*) : B2

(Meranti)

Karakteristik kayu (*Wood Characteristics*)*

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
2	Growth ring boundaries indistinct or absent (Batas lingkar tumbuh tidak jelas)
5	Wood diffuse-porous (Porositas – baur)
7	Vessels in diagonal and / or radial pattern (Sebaran pembuluh – pola diagonal atau radial)
9	Vessels exclusively solitary (90% or more) (Pengelompokan pembuluh – hampir seluruhnya soliter)
11	Vessel clusters common (Pengelompokan pembuluh – bergerombol biasa dijumpai)
13	Simple perforation plates (Bidang perforasi – sederhana)
22	Intervessel pits alternate (Ceruk antar pembuluh – selang-seling)
30	Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell (Percerukan pembuluh jari-jari dengan halaman yang jelas; serupa dalam ukuran dan bentuk dengan ceruk antar pembuluh)
56	Tyloses common (Tilosis dan endapan dalam pembuluh – tilosis umum)
60	Vascular / vasicentric tracheids present (Elemen trakea tak berlubang, trakeida vaskisentrik dan vaskular)
61	Fibres with simple to minutely bordered pits (Jaringan serat dasar dengan ceruk sederhana sampai berhalaman sangat kecil)
64	Helical thickenings in ground tissue fibres (Penebalan ulir pada jaringan serat dasar)
65	Septate fibres present (Serat bersekat dijumpai)
66	Non-septate fibres present (Serat tanpa sekat dijumpai)
69	Fibres thin- to thick-walled (Tebal dinding serat – tipis sampai tebal)
80	Axial parenchyma aliform (Parenkima aksial paratrakea – aliform)
82	Axial parenchyma winged-aliform (Parenkima aksial paratrakea – aliform bersayap)
84	Axial parenchyma unilateral paratracheal (Parenkima aksial paratrakea – paratrakea sepihak)
97	Ray width 1 to 3 cells (Jari-jari 1 - 3 seri)
104	All ray cells procumbent (Komposisi sel jari-jari – seluruhnya sel baring)
106	Body ray cells procumbent with one row of upright and / or square marginal cells (Komposisi sel jari-jari – sel baring – dengan satu jalur sel tegak dan/atau sel bujur sangkar marjinal)
128	Axial canals in short tangential lines (Saluran interseluler – saluran aksial dalam baris tangensial pendek)
159	Silica bodies present (Butir-butir silika dijumpai)
160	Silica bodies in ray cells (Silika dalam sel jari-jari)

* *International Association of Wood Anatomist*s (IAWA) (Wheeler, Baas, & Gasson, 1989)

Hasil identifikasi (*Identification result*):

Jenis kayu (*Species*) – Famili (*Family*)
Shorea sp. - Dipterocarpaceae

Catatan (*Notes*) : White Meranti

Hasil identifikasi kayu hanya berlaku untuk sampel uji yang telah diamati di laboratorium (*The wood identification results only apply to the samples that have been observed in laboratory*).

c. Cross section a. Tangensial section b. Radial section

Figure 4. Micro structure of White Meranti

(iii) Kode yang tertera di spesimen (*Code on the specimen*) : B3 (Kamper)

Karakteristik kayu (*Wood Characteristics*)*

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
2	Growth ring boundaries indistinct or absent (Batas lingkar tumbuh tidak jelas)
5	Wood diffuse-porous (Porositas – baur)
7	Vessels in diagonal and / or radial pattern (Sebaran pembuluh – pola diagonal atau radial)
9	Vessels exclusively solitary (90% or more) (Pengelompokan pembuluh – hampir seluruhnya soliter)
13	Simple perforation plates (Bidang perforasi – sederhana)
22	Intervessel pits alternate (Ceruk antar pembuluh – selang-seling)
30	Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell (Percerukan pembuluh jari-jari dengan halaman yang jelas; serupa dalam ukuran dan bentuk dengan ceruk antar pembuluh)
56	Tyloses common (Tilosis dan endapan dalam pembuluh – tilosis umum)
60	Vascular / vasicentric tracheids present (Elemen trakea tak berlubang, trakeida vaskisentrik dan vaskular)
62	Fibres with distinctly bordered pits (Jaringan serat dasar dengan ceruk berhalaman yang jelas)
64	Helical thickenings in ground tissue fibres (Penebalan ulir pada jaringan serat dasar)
65	Septate fibres present (Serat bersekat dijumpai)
69	Fibres thin- to thick-walled (Tebal dinding serat – tipis sampai tebal)
80	Axial parenchyma aliform (Parenkima aksial paratrakea – aliform)
82	Axial parenchyma winged-aliform (Parenkima aksial paratrakea – aliform bersayap)

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
84	Axial parenchyma unilateral paratracheal (Parenkima aksial paratrakea – paratrakea sepihak)
97	Ray width 1 to 3 cells (Jari-jari 1 - 3 seri)
104	All ray cells procumbent (Komposisi sel jari-jari – seluruhnya sel baring)
107	Body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells (Komposisi sel jari-jari – sel baring – dengan 2 – 4 jalur sel tegak atau sel bujur sangkar marjinal)
127	Axial canals in long tangential lines (Saluran interseluler – saluran aksial dalam baris tangensial panjang)

* *International Association of Wood Anatomists* (IAWA) (Wheeler, Baas, & Gasson, 1989)

Hasil identifikasi (*Identification result*):

Jenis kayu (*Species*) – Famili (*Family*)
Dryobalanops sp. - Dipterocarpaceae

Catatan (*Notes*) :

Hasil identifikasi kayu hanya berlaku untuk sampel uji yang telah diamati di laboratorium (*The wood identification results only apply to the samples that have been observed in laboratory*).

c. Cross section b. Tangensial section a. Radial section

Figure 5. Micro structure of Kapur wood

(iv) Kode yang tertera di spesimen (*Code on the specimen*) : D1 (Meranti)

Karakteristik kayu (*Wood Characteristics*)*

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
2	Growth ring boundaries indistinct or absent (Batas lingkar tumbuh tidak jelas)
5	Wood diffuse-porous (Porositas – baur)
7	Vessels in diagonal and / or radial pattern (Sebaran pembuluh – pola diagonal atau radial)

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
9	Vessels exclusively solitary (90% or more) (Pengelompokan pembuluh – hampir seluruhnya soliter)
13	Simple perforation plates (Bidang perforasi – sederhana)
22	Intervessel pits alternate (Ceruk antar pembuluh – selang-seling)
31	Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular (Percerukan pembuluh jari-jari dengan halaman yang sempit sampai sederhana; ceruk bundar atau bersudut)
56	Tyloses common (Tilosis dan endapan dalam pembuluh – tilosis umum)
60	Vascular / vasicentric tracheids present (Elemen trakea tak berlubang, trakeida vaskisentrik dan vaskular)
61	Fibres with simple to minutely bordered pits (Jaringan serat dasar dengan ceruk sederhana sampai berhalaman sangat kecil)
64	Helical thickenings in ground tissue fibres (Penebalan ulir pada jaringan serat dasar)
65	Septate fibres present (Serat bersekat dijumpai)
66	Non-septate fibres present (Serat tanpa sekat dijumpai)
69	Fibres thin- to thick-walled (Tebal dinding serat – tipis sampai tebal)
80	Axial parenchyma aliform (Parenkima aksial paratrakea – aliform)
81	Axial parenchyma lozenge-aliform (Parenkima aksial paratrakea – aliform lozenge)
85	Axial parenchyma bands more than three cells wide (Parenkim pita >3 lapis sel)
96	Rays exclusively uniseriate (Jari-jari seluruhnya 1 seri)
97	Ray width 1 to 3 cells (Jari-jari 1 - 3 seri)
98	Larger rays commonly 4 - to 10 seriate (Jari-jari besar umumnya 4 - 10 seri)
103	Rays of two distinct sizes (Jari-jari dua ukuran yang jelas)
104	All ray cells procumbent (Komposisi sel jari-jari – seluruhnya sel baring)
106	Body ray cells procumbent with one row of upright and / or square marginal cells (Komposisi sel jari-jari – sel baring – dengan satu jalur sel tegak dan/atau sel bujur sangkar marjinal)
127	Axial canals in long tangential lines (Saluran interseluler – saluran aksial dalam baris tangensial panjang)
130	Radial canals (Saluran interseluler – saluran radial)
137	Prismatic crystals in upright and / or square ray cells (Kristal prismatik dalam sel tegak)
138	Prismatic crystals in procumbent ray cells (Kristal prismatik dalam sel baring)
142	Prismatic crystals in chambered axial parenchyma cells (Kristal prismatik dalam parenkim aksial berbilik)
143	Prismatic crystals in fibres (Kristal prismatik dalam serat)

* *International Association of Wood Anatomist*s (IAWA) (Wheeler, Baas, & Gasson, 1989)

Hasil identifikasi (*Identification result*):

Jenis kayu (*Species*) – Famili (*Family*)
Shorea sp. - Dipterocarpaceae

Catatan (*Notes*) : Yellow Meranti

Hasil identifikasi kayu hanya berlaku untuk sampel uji yang telah diamati di laboratorium (*The wood identification results only apply to the samples that have been observed in laboratory*).

c. Cross section b. Tangensial section a. Radial section

Figure 6. Micro structure of Yellow Meranti

(v) Kode yang tertera di spesimen (*Code on the specimen*) : D2 (Singkil)

Karakteristik kayu (*Wood Characteristics*)*

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
2	Growth ring boundaries indistinct or absent (Batas lingkar tumbuh tidak jelas)
5	Wood diffuse-porous (Porositas – baur)
7	Vessels in diagonal and / or radial pattern (Sebaran pembuluh – pola diagonal atau radial)
9	Vessels exclusively solitary (90% or more) (Pengelompokan pembuluh – hampir seluruhnya soliter)
13	Simple perforation plates (Bidang perforasi – sederhana)
22	Intervessel pits alternate (Ceruk antar pembuluh – selang-seling)
25	Small - 4 - 7 µm (Ukuran ceruk antar pembuluh (yang selang-seling dan berhadapan) – kecil 4 – 7 µm)
30	Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell (Percerukan pembuluh jari-jari dengan halaman yang jelas; serupa dalam ukuran dan bentuk dengan ceruk antar pembuluh)
31	Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular (Percerukan pembuluh jari-jari dengan halaman yang sempit sampai sederhana; ceruk bundar atau bersudut)
56	Tyloses common (Tilosis dan endapan dalam pembuluh – tilosis umum)
60	Vascular / vasicentric tracheids present (Elemen trakea tak berlubang, trakeida vaskisentrik dan vaskular)
62	Fibres with distinctly bordered pits (Jaringan serat dasar dengan ceruk berhalaman yang jelas)
64	Helical thickenings in ground tissue fibres (Penebalan ulir pada jaringan serat dasar)
69	Fibres thin- to thick-walled (Tebal dinding serat – tipis sampai tebal)
80	Axial parenchyma aliform (Parenkima aksial paratrakea – aliform)
82	Axial parenchyma winged-aliform (Parenkima aksial paratrakea – aliform bersayap)
97	Ray width 1 to 3 cells (Jari-jari 1 - 3 seri)
98	Larger rays commonly 4 - to 10 seriate (Jari-jari besar umumnya 4 - 10 seri)
104	All ray cells procumbent (Komposisi sel jari-jari – seluruhnya sel baring)

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
107	Body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells (Komposisi sel jari-jari – sel baring – dengan 2 – 4 jalur sel tegak atau sel bujur sangkar marjinal)
128	Axial canals in short tangential lines (Saluran interseluler – saluran aksial dalam baris tangensial pendek)
129	Axial canals diffuse (Saluran interseluler – saluran aksial tersebar)
159	Silica bodies present (Butir-butir silika dijumpai)
160	Silica bodies in ray cells (Silika dalam sel jari-jari)

* *International Association of Wood Anatomists* (IAWA) (Wheeler, Baas, & Gasson, 1989)

Hasil identifikasi (*Identification result*):

Jenis kayu (*Species*) – Famili (*Family*)
Dipterocarpus sp. - Dipterocarpaceae

Catatan (*Notes*) :

Hasil identifikasi kayu hanya berlaku untuk sampel uji yang telah diamati di laboratorium (*The wood identification results only apply to the samples that have been observed in laboratory*).

a. Cross section b. Tangensial section c. Radial section

Figure 7. The micro structure of Keruing-1 wood

(vi) Kode yang tertera di spesimen (*Code on the specimen*) : D3 (Meranti)

Karakteristik kayu (*Wood Characteristics*)*

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
2	Growth ring boundaries indistinct or absent (Batas lingkar tumbuh tidak jelas)
5	Wood diffuse-porous (Porositas – baur)

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
7	Vessels in diagonal and / or radial pattern (Sebaran pembuluh – pola diagonal atau radial)
10	Vessels in radial multiples of 4 or more common (Pengelompokan pembuluh – berganda radial 4 atau lebih biasa dijumpai)
13	Simple perforation plates (Bidang perforasi – sederhana)
14	Scalariform perforation plates (Bidang perforasi – bentuk tangga)
22	Intervessel pits alternate (Ceruk antar pembuluh – selang-seling)
23	Shape of alternate pits polygonal (Ceruk antar pembuluh – selang-seling bersegi banyak)
30	Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell (Percerukan pembuluh jari-jari dengan halaman yang jelas; serupa dalam ukuran dan bentuk dengan ceruk antar pembuluh)
32	Vessel-ray pits with much reduced borders to apparently simple: pits horizontal (scalariform, gash-like) to vertical (palisade) (Percerukan pembuluh jari-jari dengan halaman yang sempit sampai sederhana; ceruk horisontal atau vertikal)
33	Vessel-ray pits of two distinct sizes or types in the same ray cell (Percerukan pembuluh jari-jari dua ukuran atau tipe yang jelas dalam sel yang sama)
60	Vascular / vasicentric tracheids present (Elemen trakea tak berlubang, trakeida vaskisentrik dan vaskular)
64	Helical thickenings in ground tissue fibres (Penebalan ulir pada jaringan serat dasar)
65	Septate fibres present (Serat bersekat dijumpai)
70	Fibres very thick-walled (Tebal dinding serat – sangat tebal)
75	Axial parenchyma absent or extremely rare (Parenkima aksial – tidak ada atau sangat jarang)
76	Axial parenchyma diffuse (Parenkima aksial apotrakea – tersebar)
93	Eight (5-8) cells per parenchyma strand (Sel parenkim aksial 5 – 8 sel per untai)
94	Over eight cells per parenchyma strand (Sel parenkim aksial > 8 sel per untai)
98	Larger rays commonly 4 - to 10 seriate (Jari-jari besar umumnya 4 - 10 seri)
104	All ray cells procumbent (Komposisi sel jari-jari – seluruhnya sel baring)
107	Body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells (Komposisi sel jari-jari – sel baring – dengan 2 – 4 jalur sel tegak atau sel bujur sangkar marjinal)
136	Prismatic crystals present (Kristal prismatik dijumpai)
142	Prismatic crystals in chambered axial parenchyma cells (Kristal prismatik dalam parenkim aksial berbilik)
143	Prismatic crystals in fibres (Kristal prismatik dalam serat)

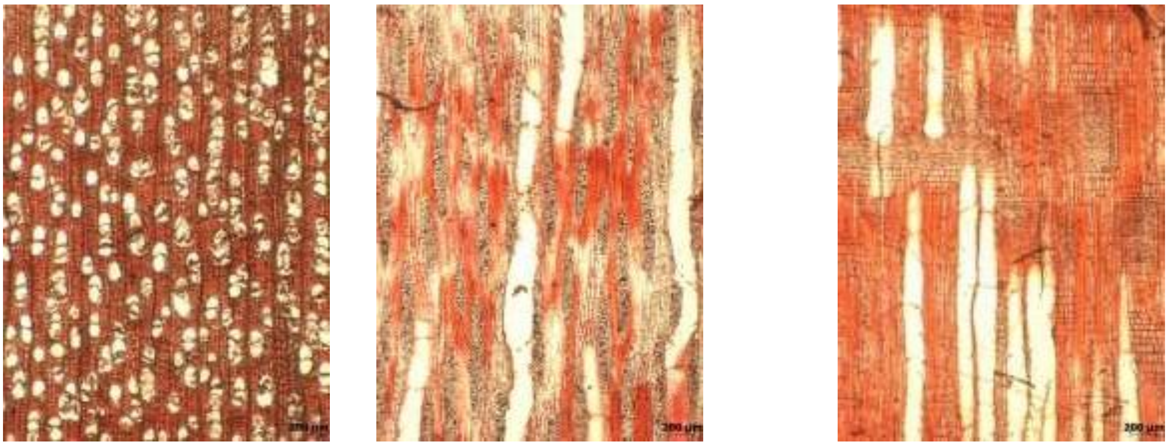
* *International Association of Wood Anatomist*s (IAWA) (Wheeler, Baas, & Gasson, 1989)

Hasil identifikasi (*Identification result*):

Jenis kayu (*Species*) – Famili (*Family*)
Kurrimia paniculata - Escalloniaceae

Catatan (*Notes*) :

Hasil identifikasi kayu hanya berlaku untuk sampel uji yang telah diamati di laboratorium (*The wood identification results only apply to the samples that have been observed in laboratory*).



a. Cross section   b. Tangensial section   c. Radial section

Figure 8. Micro structure of Ki tulang wood

(vii) Kode yang tertera di spesimen (*Code on the specimen*) : BJ1 (Meranti)

Karakteristik kayu (*Wood Characteristics*)*

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
2	Growth ring boundaries indistinct or absent (Batas lingkar tumbuh tidak jelas)
5	Wood diffuse-porous (Porositas – baur)
7	Vessels in diagonal and / or radial pattern (Sebaran pembuluh – pola diagonal atau radial)
9	Vessels exclusively solitary (90% or more) (Pengelompokan pembuluh – hampir seluruhnya soliter)
13	Simple perforation plates (Bidang perforasi – sederhana)
22	Intervessel pits alternate (Ceruk antar pembuluh – selang-seling)
31	Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular (Percerukan pembuluh jari-jari dengan halaman yang sempit sampai sederhana; ceruk bundar atau bersudut)
60	Vascular / vasicentric tracheids present (Elemen trakea tak berlubang, trakeida vaskisentrik dan vaskular)
61	Fibres with simple to minutely bordered pits (Jaringan serat dasar dengan ceruk sederhana sampai berhalaman sangat kecil)
64	Helical thickenings in ground tissue fibres (Penebalan ulir pada jaringan serat dasar)
65	Septate fibres present (Serat bersekat dijumpai)
70	Fibres very thick-walled (Tebal dinding serat – sangat tebal)
80	Axial parenchyma aliform (Parenkima aksial paratrakea – aliform)
81	Axial parenchyma lozenge-aliform (Parenkima aksial paratrakea – aliform lozenge)
98	Larger rays commonly 4 - to 10 seriate (Jari-jari besar umumnya 4 - 10 seri)
104	All ray cells procumbent (Komposisi sel jari-jari – seluruhnya sel baring)
128	Axial canals in short tangential lines (Saluran interseluler – saluran aksial dalam baris tangensial pendek)
136	Prismatic crystals present (Kristal prismatik dijumpai)
138	Prismatic crystals in procumbent ray cells (Kristal prismatik dalam sel baring)
142	Prismatic crystals in chambered axial parenchyma cells (Kristal prismatik dalam parenkim aksial berbilik)
143	Prismatic crystals in fibres (Kristal prismatik dalam serat)

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
156	Crystals in enlarged cells (Ciri diagnostik lainnya – kristal dalam sel yang membesar)

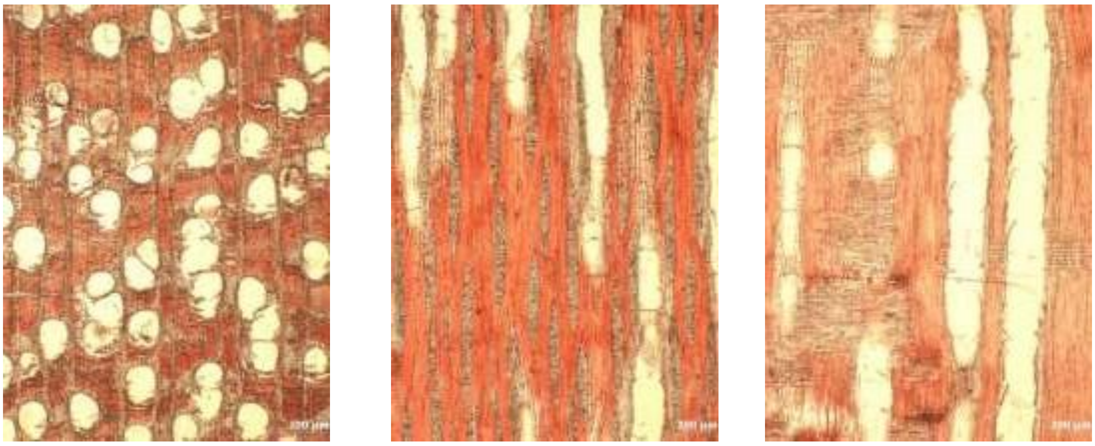
* *International Association of Wood Anatomists* (IAWA) (Wheeler, Baas, & Gasson, 1989)

Hasil identifikasi (*Identification result*):

Jenis kayu (*Species*) – Famili (*Family*)
Shorea sp.- Dipterocarpaceae

Catatan (*Notes*) : Red Meranti

Hasil identifikasi kayu hanya berlaku untuk sampel uji yang telah diamati di laboratorium (*The wood identification results only apply to the samples that have been observed in laboratory*).



a. Cross section b. Tangensial section c. Radial section

Figure 9. Micro structure of Red Meranti

viii. Kode yang tertera di spesimen (*Code on the specimen*) **: BJ2 (Singkil)**

Karakteristik kayu (*Wood Characteristics*)*

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
2	Growth ring boundaries indistinct or absent (Batas lingkar tumbuh tidak jelas)
5	Wood diffuse-porous (Porositas – baur)
7	Vessels in diagonal and / or radial pattern (Sebaran pembuluh – pola diagonal atau radial)
9	Vessels exclusively solitary (90% or more) (Pengelompokan pembuluh – hampir seluruhnya soliter)
13	Simple perforation plates (Bidang perforasi – sederhana)
22	Intervessel pits alternate (Ceruk antar pembuluh – selang-seling)

IAWA Code	IAWA Item Description (Deskripsi struktur anatomi)
30	Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell (Percerukan pembuluh jari-jari dengan halaman yang jelas; serupa dalam ukuran dan bentuk dengan ceruk antar pembuluh)
62	Fibres with distinctly bordered pits (Jaringan serat dasar dengan ceruk berhalaman yang jelas)
65	Septate fibres present (Serat bersekat dijumpai)
70	Fibres very thick-walled (Tebal dinding serat – sangat tebal)
84	Axial parenchyma unilateral paratracheal (Parenkima aksial paratrakea – paratrakea sepihak)
97	Ray width 1 to 3 cells (Jari-jari 1 - 3 seri)
104	All ray cells procumbent (Komposisi sel jari-jari – seluruhnya sel baring)
107	Body ray cells procumbent with mostly 2-4 rows of upright and / or square marginal cells (Komposisi sel jari-jari – sel baring – dengan 2 – 4 jalur sel tegak atau sel bujur sangkar marjinal)
128	Axial canals in short tangential lines (Saluran interseluler – saluran aksial dalam baris tangensial pendek)
129	Axial canals diffuse (Saluran interseluler – saluran aksial tersebar)

* *International Association of Wood Anatomists* (IAWA) (Wheeler, Baas, & Gasson, 1989)

Hasil identifikasi (*Identification result*):

Jenis kayu (*Species*) – Famili (*Family*)
Dipterocarpus sp. - Dipterocarpaceae

Catatan (*Notes*) :

Hasil identifikasi kayu hanya berlaku untuk sampel uji yang telah diamati di laboratorium (*The wood identification results only apply to the samples that have been observed in laboratory*).

a. Cross section b. Tangensial section c. Radial section

Figure 10. Micro structure of Keruing-2

(ix) Kode yang tertera di spesimen (*Code on the specimen*) : BJ3 (Mahoni)

Karakteristik kayu (*Wood Characteristics*)*

1	Growth ring boundaries distinct (Batas lingkar tumbuh jelas)
4	Wood semi-ring-porous (Porositas – semi tata lingkar)
7	Vessels in diagonal and / or radial pattern (Sebaran pembuluh – pola diagonal atau radial)
10	Vessels in radial multiples of 4 or more common (Pengelompokan pembuluh – berganda radial 4 atau lebih biasa dijumpai)
11	Vessel clusters common (Pengelompokan pembuluh – bergerombol biasa dijumpai)
13	Simple perforation plates (Bidang perforasi – sederhana)
23	Shape of alternate pits polygonal (Ceruk antar pembuluh – selang-seling bersegi banyak)
25	Small - 4 - 7 µm (Ukuran ceruk antar pembuluh (yang selang-seling dan berhadapan) – kecil 4 – 7 µm)
31	Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular (Percerukan pembuluh jari-jari dengan halaman yang sempit sampai sederhana; ceruk bundar atau bersudut)
65	Septate fibres present (Serat bersekat dijumpai)
66	Non-septate fibres present (Serat tanpa sekat dijumpai)
68	Fibres very thin-walled (Tebal dinding serat – sangat tipis)
69	Fibres thin- to thick-walled (Tebal dinding serat – tipis sampai tebal)
89	Axial parenchyma in marginal or in seemingly marginal bands (Parenkim pita marjinal atau tampaknya marjinal)
92	Four (3-4) cells per parenchyma strand (Sel parenkim aksial 3 – 4 sel per untai)
93	Eight (5-8) cells per parenchyma strand (Sel parenkim aksial 5 – 8 sel per untai)
97	Ray width 1 to 3 cells (Jari-jari 1 - 3 seri)
98	Larger rays commonly 4 - to 10 seriate (Jari-jari besar umumnya 4 - 10 seri)
103	Rays of two distinct sizes (Jari-jari dua ukuran yang jelas)
104	All ray cells procumbent (Komposisi sel jari-jari – seluruhnya sel baring)
106	Body ray cells procumbent with one row of upright and / or square marginal cells (Komposisi sel jari-jari – sel baring – dengan satu jalur sel tegak dan/atau sel bujur sangkar marjinal)
118	All rays storied (Susunan bertingkat – semua jari-jari)
122	Rays and / or axial elements irregularly storied (Susunan bertingkat – jari-jari atau unsur aksial bertingkat tak teratur)
136	Prismatic crystals present (Kristal prismatik dijumpai)
138	Prismatic crystals in procumbent ray cells (Kristal prismatik dalam sel baring)
142	Prismatic crystals in chambered axial parenchyma cells (Kristal prismatik dalam parenkim aksial berbilik)

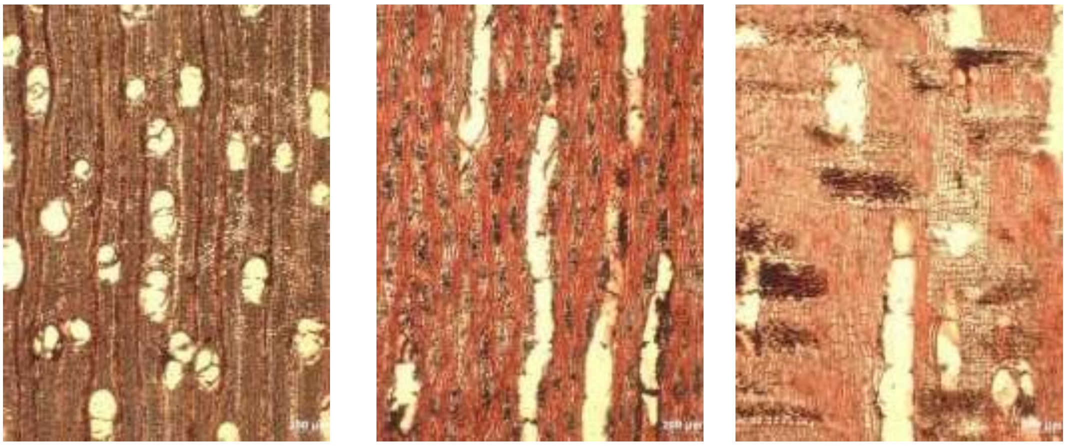
* *International Association of Wood Anatomist*s (IAWA) (Wheeler, Baas, & Gasson, 1989)

Hasil identifikasi (*Identification result*):

Jenis kayu (*Species*) – Famili (*Family*)
Swietenia sp. - Meliaceae

Catatan (*Notes*) :

Hasil identifikasi kayu hanya berlaku untuk sampel uji yang telah diamati di laboratorium (*The wood identification results only apply to the samples that have been observed in laboratory*).



a. Cross section b. Tangensial section c. Radial section

Figure 11. Micro structure of Mahogany

Table 6 shows the definitive types of wood used in each housing after matching with the sample code from each housing. The identification results show that the wood species obtained based on information or estimates in the field differs from the species after Anatomical testing and species identification were carried out on wood samples taken from the field and tested in the laboratory. These definitive wood species are then used to calculate the amount of carbon stored in residential buildings.

Table 6. The definitive species of wood used in the housing location

No	Name of housing complex and location	Wood species	
		Prediction	Definitive
1	The Riscon Hill Bambu Apus, Kota Jakarta Timur	Keruing	Kempas
2	Pesona Kembang Setu, Bekasi District	Meranti-1 (yellow)	White Meranti
3	Green Garden Bojonggede, Bogor District	Kamper	Red Meranti
4	Green Depok Residence, Depok City	Meranti-2	Yellow Meranti

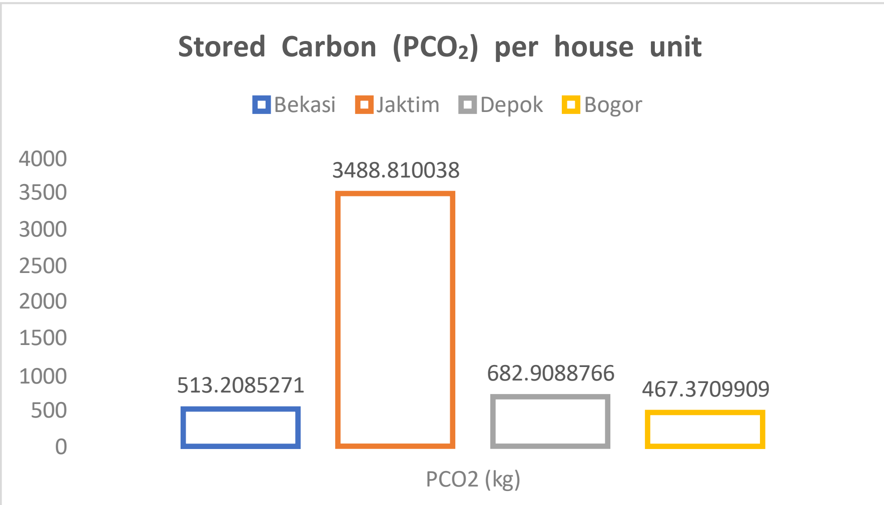
4.3. Carbon Stored in Residential Buildings

4.3.1. Carbon stored by mass of wood

The calculation result of stored carbon (PCO_2) which was calculated based on formula (1) of DIN EN 16449: 2014-06/EN 16449: 2014(D) from housing measured in four cities/districts is presented in Tabel 7 and Figure 12.

Table 7. Carbon stored in the housing based on standard calculations

Location	House component	Wood species	Moisture content (%)	Density (ρ), kg/m^3	Stored carbon (PCO_2), kg
Bekasi District (60)	Door frame	White Meranti	15.5	578,29	8146,82
	Leaf door	White Meranti	15.5	578,29	2798,91
	Windows frames	White Meranti	15.5	578,29	15960,71
	Shutters	White Meranti	15.5	578,29	3886,09
Total					30792,51
Average per house unit					513.21
East Jakarta City (50)	Door frame	Kempas	15.3	888,17	126612,66
	Leaf door	Kempas	15.3	888,17	15659,32
	Windows frames	Kempas	15.3	888,17	18280,58
	Shutters	Kempas	15.3	888,17	33939,90
	Stairs/ladder	Kempas	15.3	888,17	13887,95
Total					174440,50
Average per house unit					3488,81
Depok City (204)	Door frame	Yellow Meranti	14,8	769,97	36452.65
	Leaf door	Yellow Meranti	14,8	769,97	118956.77
	Windows frames	Yellow Meranti	14,8	769,97	7881.84
	Shutters	Yellow Meranti	14,8	769,97	2092.025
	Roster	Yellow Meranti	14,8	769,97	9657.43
Total					139313.41
Average per house unit					682.91
Bogor District (254)	Door frame	Red Meranti	14,8	800,71	31462.22
	Leaf door	Red Meranti	14,8	800,71	65979.03
	Windows frames	Red Meranti	14,8	800,71	11313.42
	Shutters	Red Meranti	14,8	800,71	3186.49
	Roster	Red Meranti	14,8	800,71	6771.08
Total					118712.23
Average per house unit					467.37



Gambar 12. Total of stored carbon (PCO_2, kg) in one single house unit

Table 7 shows the total carbon stored in each housing measured, while Figure 12 shows the average carbon stored in each housing unit in each housing. There is a striking difference in the carbon stored in housing units in East Jakarta City due to the different types of houses from the other three cities/districts, where the type of house in East Jakarta is a two-story house type with many doors and windows and there are stairs with rails/railings. wooden handle (Appendix 1 – 4). This is to show that in addition to the large volume (V) of wood components used, the type of wood that has a higher density (ρ) will also increase the number of stored carbon.

The contribution of stored carbon to the NDC (National Determined Contribution) in reducing the emission rate must be calculated in aggregate. According to the 2015 Paris Agreement/COP21 of the United Nations Framework Convention on Climate Change (UNFCCC), the global community must commit to keeping global average temperature rise below 2°C and make efforts to keep temperature rise below 1.5°C above pre-industrial levels, recognizing that doing so will significantly reduce the risks and impacts of climate change[26]. For this reason, each country is fostered to implement low greenhouse gas emission development or – in other words – countries must reduce emissions in their development. One year later, Indonesia made a commitment to reduce emissions by 29 percent independently and 41 percent with international support. As nationally determined contributions (NDCs), these pledges were presented to the UNFCCC secretariat in 2016.

Indonesia's latest NDC document was submitted by the Ministry of Environment and Forestry on July 21 this year (2021). The document states that most of the emission reductions are expected to come from the forestry and land use sectors by 2030, amounting to 24.5 percent [27]. This produces about 692 metric tons (692,000 tons) of carbon dioxide equivalent[28]. Indonesia's NDC will contribute to achieving the Convention's objectives as stated in Article 2 by reducing greenhouse gas emissions and increasing climate resilience, which will lead to long-term economic development. Climate change policies will be aligned with long-term economic development by reducing GHG emissions and increasing climate resilience. This policy then places forestry and other land uses as the leading sector along with industrial processes and product use in the large-scale industrial sector (IPPU) by increasing the efficiency of raw material utilization and CO_2 recovery upstream. Furthermore, Indonesia has taken significant steps in the land use sector to reduce emissions, including a moratorium on clearing primary forests, reducing deforestation and forest degradation, restoring ecosystem functions, and implementing sustainable forest management[27].

If the number of stored carbon potentials from the three cities/districts surveyed, namely Kab. Bekasi, Kab. Bogor, and Depok City, are averaged, and assuming that this is the average size of Indonesian houses, the potential carbon stored in each house, if currently built with wood components only on door frames and doors, as well as window frames and frames, is 554,50 kg/house carbon stored. If a backlog of 7.6 million housing units [6,7] or a demand rate of 800 thousand housing units [8] is built with the proportion of wood found in the three cities/districts studied, 4.2 million tons of carbon will be stored. This figure indicates that if the Indonesian backlog is built without the use of wood materials, there is a potential for carbon emissions of that magnitude (4.2 million tons). If the housing needs of 800 thousand units/year are built with door and window frame components made of wood, then there is a stored carbon of 0.44 million tons/year from the housing construction sector.

According to Kazulis et al [16], carbon storage in bioproducts and recycling can create a bioeconomy loop because bioproducts at the end of their life will be recycled and converted into new products. From a production environment perspective – the bioeconomic circle is the most desirable solution for managing CO_2 emissions, including using wood for end products and its application to building materials.

4.3.2. Stored carbon based on EDX analysis

Energy Dispersive X-Ray Spectroscopy - often abbreviated as EDX or EDS, is a standard method for identifying and measuring the elemental composition in very small samples of material (even a few cubic micrometers). In general, EDX/EDS is a completeness of Scanning Electron Microscopy (SEM). In a well-equipped SEM, the atoms on the surface are excited by the electron beam, emitting certain wavelengths of X-rays that are characteristic of the atomic structure of the element. Energy dispersion detectors (solid-state devices that distinguish between X-ray energies) can analyze these X-ray emissions. The corresponding element is given, resulting in the atomic composition on the specimen surface [29, 30].

The results of the EDX analysis are shown in the table as a percentage of the weight of non-normalized carbon, a percentage of the weight of normalized carbon, a percentage of carbon atoms, and an error rate. According to the findings of this study, the percentage of weight of carbon that has not been normalized (unn. C) and the percentage of weight of carbon that has been normalized (unn. C) (norm. C). Table 8 shows the results of the EDX/EDS analysis on the carbon content of wood samples taken from several housing estates in this study. The full set of results can be found in the Appendix 5.

Tabel 8. Proportion of carbon in wood used in housing

No	Location	Code of wood sample	Wood species	Content of carbon (C), % w/w	
				Unnormlised	Dinormalisasi
1	The Riscon Hill Bambu Apus, East Jakarta City	B1	Kempas (*Koompassia malaccensis*)	42,42	42,42
		B2	Meranti putih (*Shorea sp.*)	42,39	42,39
		B3	Kapur (*Dryobalanops sp.*)	46,96	46,96
	Mean			**43.92**	**43.92**
2	Pesona Kembang Setu, Bekasi District	B1	Kempas (*Koompassia malaccensis*)	42,42	42,42
		B2	Meranti putih (*Shorea sp.*)	42,39	42,39
		B3	Kapur (*Dryobalanops sp.*)	46,96	46,96
	Mean			**43.92**	**43.92**
3	Green Garden Bojonggede, Bogor District	BJ1	Meranti merah (*Shorea sp.*)	45,37	45,37
		BJ2	Keruing (*Dipterocarpus sp.*)	43,98	43,98
		BJ3	Mahoni (*Swietenia sp.*)	44,26	44,26
	Mean			**44.54**	**44.54**
4	Green Depok Residence, Depok City	D1	Meranti kuning (*Shorea sp.*)	44,70	44,70
		D2	Keruing (*Dipterocarpus sp.*)	45,60	45,60
		D3	Ki Tulang (*Kurrimia paniculata*)	45,95	45,95
	Mean			**45.42**	**45.42**

From Table 8 we can see the carbon content of each type of wood used as a raw material for house construction varies. In general, the carbon value that is used as the basis for further calculations is the unnormalized carbon value because it is closer to the absolute value [31]. According to the results of this study's analysis, which are shown in Table 8, the proportion of carbon content that was not normalized was the same as the value of normalized carbon. However, these figures are lower on average than the theory, which states that the proportion of carbon in wood is around 50%[9, 32]. The results of this study, which obtained a portion of carbon (C) less than 50% were similar, among others, to the findings of Silva et al. [33].

Tabel 9. Carbon storage of the housing based on EDX analysis

Location	Komponen rumah	Wood species	Moisture content (%)	Density (ρ), kg/m^3	Volume (m^3)	Weight (kg)	Stored Carbon (kg)
Bekasi District(60)	Door frame	White Meranti	15.5	578,29	8.8754	5132.555	2175.69
	Leaf door	White Meranti	15.5	578,29	17.3880	10055.31	4262.444
	Windows frame	White Meranti	15.5	578,29	3.0492	1763.322	747.4721
	Shutters	White Meranti	15.5	578,29	4.2336	2448.249	1037.813
	Total					30792,51	8223.4192
	Average per house unit					513.21	137.0570
East Jakarta City(50)	Door frame	Kempas	15.3	888,17	32.2317	28627.2290	12143,6705
	Leaf door	Kempas	15.3	888,17	57.4223	51000.7649	21634,5242
	Windows frame	Kempas	15.3	888,17	11.0883	9848.2954	4177,6469
	Shutters	Kempas	15.3	888,17	12.9444	11496.8278	4876,9543
	Stairs/ladder	Kempas	15.3	888,17	19.6680	17468.5276	7410,1494
	Total					118441.6439	50242,9453
	Average per house unit					2368.8329	1004,8589
Depok City (204)	Door frame	Yellow Meranti	14,8	769,97	29.6455	23737,4483	10769,6803
	Leaf door	Yellow Meranti	14,8	769,97	67.6872	54197,8179	24589,5499
	Windows frame	Yellow Meranti	14,8	769,97	4.5957	36798,2295	16695,3567
	Shutters	Yellow Meranti	14,8	769,97	1.7014	13623,2799	6180,8821
	Roster	Yellow Meranti	14,8	769,97	7.8540	62887,7634	28532,1783
	Total					191244,5390	86767,6474
	Average per house unit					937,4732	425,3316
Bogor District (254)	Door frame	Red Meranti	14,8	800,71	23.0226	22826,1456	10203,2871
	Leaf door	Red Meranti	14,8	800,71	48.2803	52117,1134	23296,3497
	Windows frame	Red Meranti	14,8	800,71	8.2786	35385,5113	15817,3236
	Shutters	Red Meranti	14,8	800,71	2.3317	13100,2696	5855,8205
	Roster	Red Meranti	14,8	800,71	4.9548	60473,4438	27031,6294
	Total					183902,4837	82204,4102
	Average per house unit					901,4828	323,6394

The stored carbon value as presented in Table 9 was calculated based on the carbon content of the EDX analysis for each wood species used in the sample housing, namely 42.42% (Kempas), 42.39% (White Meranti), 45.37% (Red Meranti) and 44.70% (Yellow Meranti) (Table 8). The values of moisture content and density were obtained from measurements made on the test samples from the wood taken. Based on the volume and density of the water content, it is known the weight of the wood used in each sample house building. From the weight and percentage of each type of wood used in the building of the house, it can be calculated the weight of carbon stored from the wood used in the building of the house (Table 9, rightmost column).

In general, as shown in Table 3, the use of wood as a building material in modern house construction began to decline in the early 2000s. Aluminum or mild steel dominated structural parts such as roof trusses in houses built between 2000 and 2010. Wood is used in door frames, door leaves, window frames, shutters, vents (roster), and stairs (Table 9). As a result, the house serves as a carbon storage in these areas..

The amount of carbon stored in each house built in the four cities/districts sampled varied. This is determined by the amount or volume of wood used in each unit of the house, as well as the type of wood used. The amount of carbon stored in each of the housing units sampled is as follows: Bekasi Regency (137.06 kg), East Jakarta City (1004.86 kg), Depok City (425.33 kg), and 323.64 kg (District of Bogor). If the average house size is represented by three regencies/cities, namely Kab. Bekasi, Depok City, and Kab. Bogor, one unit of a house built with some of its components made of wood can store between 130 – 430 kg of carbon, or an average of 400.42 kg. The house in East Jakarta City is a model of a large house. This variation in the amount of carbon stored can be explained by the fact that the volume of wood used in the field varies greatly. Furthermore, the wood species used differs. Because different wood species have different densities or specific gravity, the weight varies. This has implications for calculating various weights of carbon stored.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

(i) Timber components in modern house buildings are currently decreasing due to their scarcity, despite the developer's desire to use wood as the primary material for both structural (roof frames, frames) and non-structural (doors, windows, ceilings).

(ii) There is a discrepancy in the mention of the type of wood between the developer, the seller of the wood, and the laboratory identification results. Accuracy in determining the type of wood is required to calculate the carbon stored in wood. As a result, the laboratory results of wood species identification are used as the foundation for calculations.

(iii) ((iii) Carbon stored (PCO_2, kg) in each housing unit ranges from 450 to 680 kg (average 554.50 kg) based on the standard formula and from 130 to 430 kg (average 400.42 kg) based on EDX/S carbon analysis.

(iv) The variation in the amount of carbon stored is understandable given the wide range in the volume of wood used per housing unit. Furthermore, the type of wood used differs. Because different types of wood have different densities or specific gravity, the weight varies. This has implications for calculating various weights of carbon stored.

(v) ((v) Carbon emissions can be reduced by using wood as a building material, particularly in residential buildings. As a result, the downstream sector, particularly construction, can contribute to stabilise the climate.

5.2. Recommendation

Regarding the limited data and information on carbon stored in wood products in general and in wood used as housing construction materials, especially in Indonesia, this research needs to be continued. Comprehensive research on wood products as carbon storage can be carried out starting from wood cut in forest areas to processing and utilization industries. This is done in order to gain an overview of changes in carbon stored in each process until the final utilisation.

6. PRINCIPAL INVESTIGATOR AND OTHER RESEARCHERS

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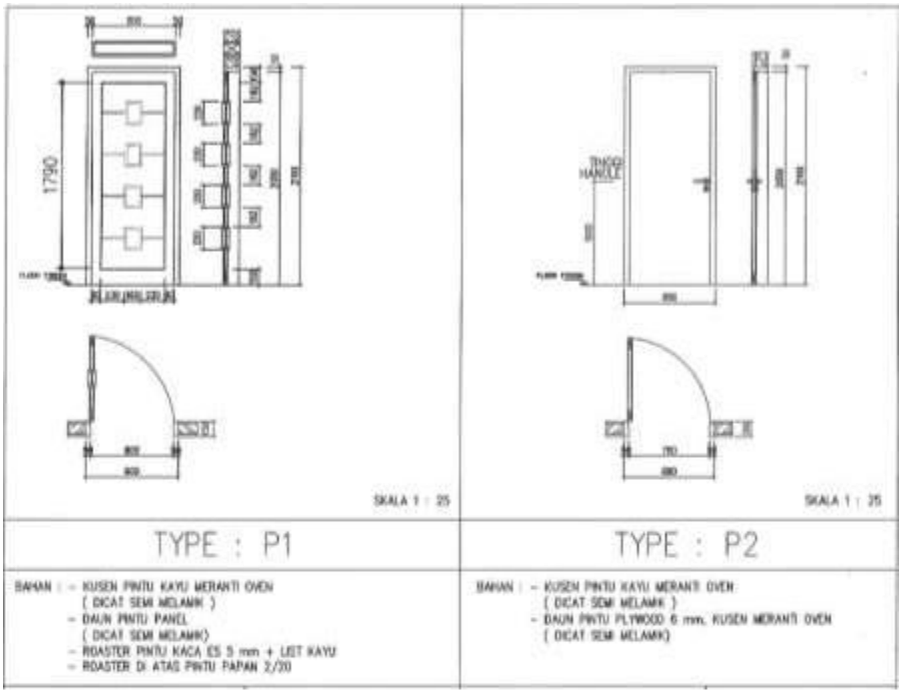
APPENDIX

1. Measurement of wood components in houses of Pesona Kembang Setu housing in Bekasi District

a. Measurement activity



b. Type and size of doors

2. 1. Measurement of wood components in houses of The Riscon Hills Bambu Apus, Cipayung, East Jakarta City

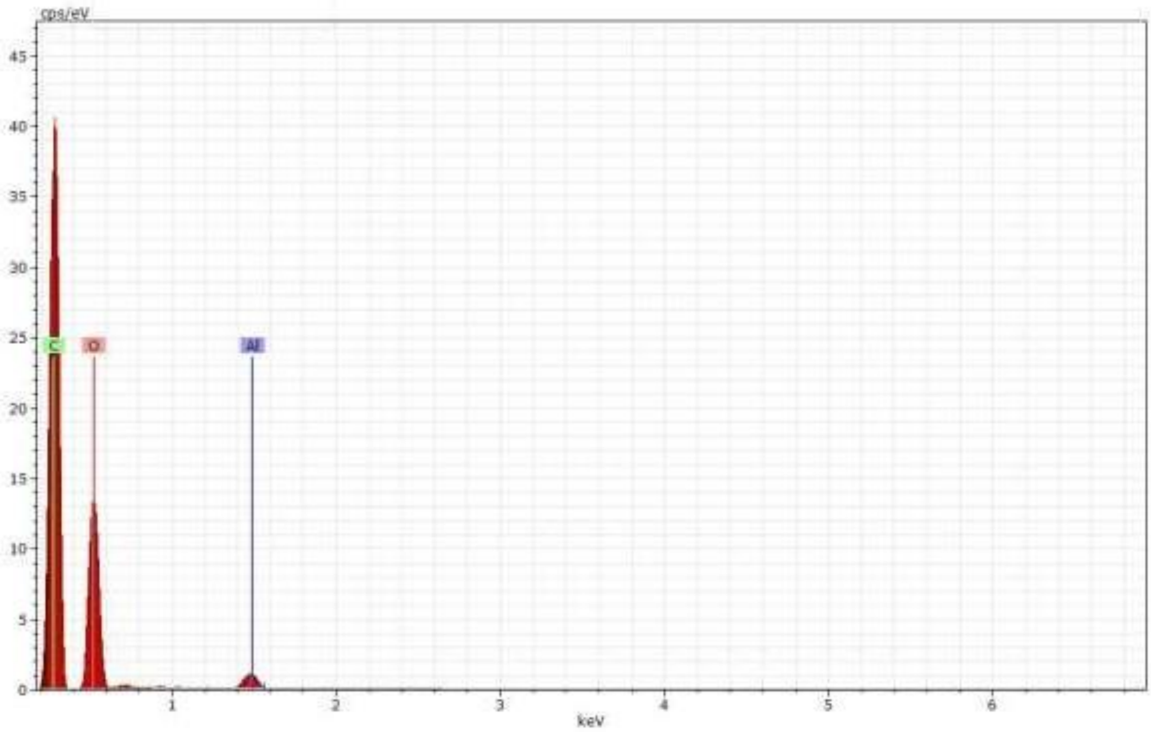



3. Measurement of wood components in houses of Green Depok Residence, Depok City


4. Measurement of wood components in houses of Green Garden Bojong Gede, Bogor District

5. The equipment and the results analysis of carbon content using EDX/EDS

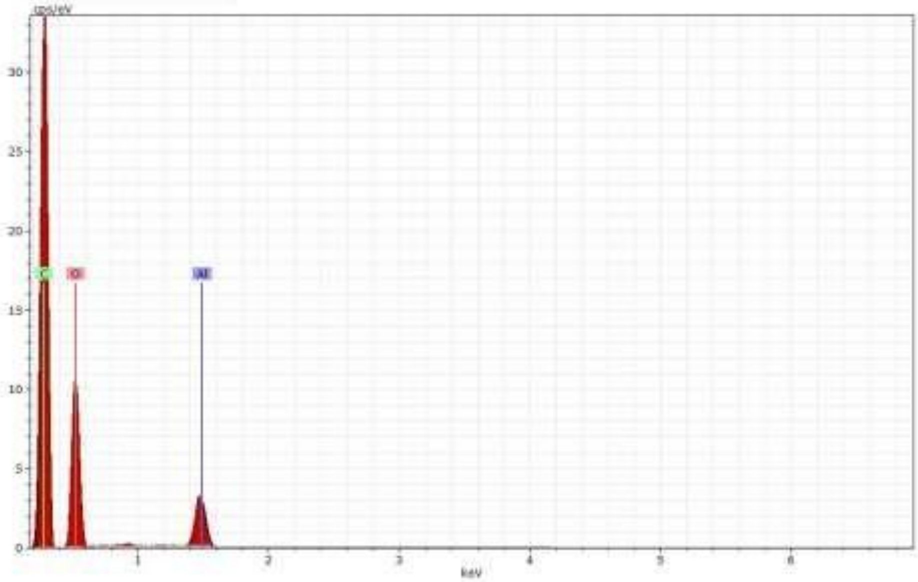
B1



Spectrum: Acquisition 62

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Oxygen	K-series	52.16	52.16	46.62	31.8
Carbon	K-series	42.42	42.42	50.50	26.0
Aluminium	K-series	5.42	5.42	2.87	0.6
	Total:	100.00	100.00	100.00	

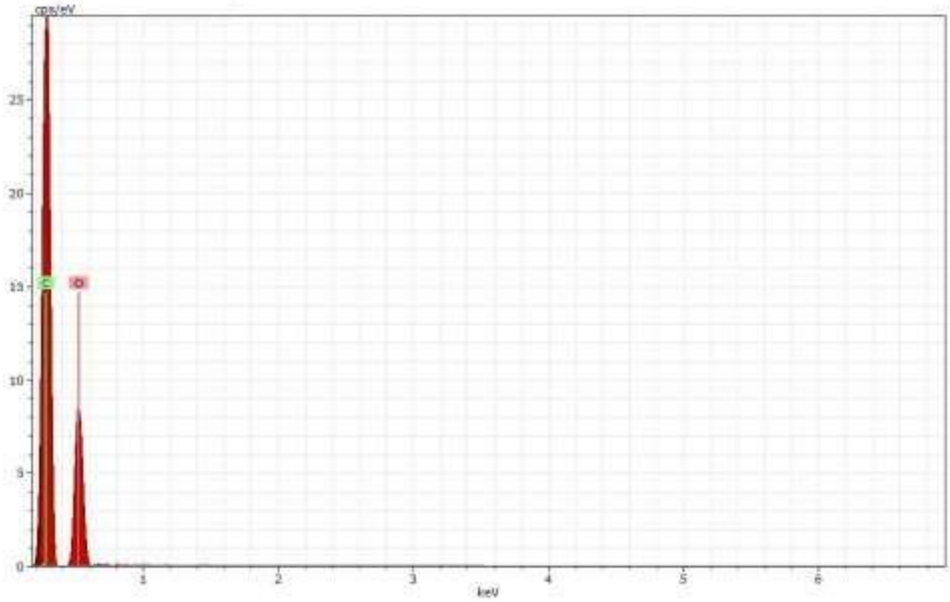
B2



Spectrum: Acquisition 63

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Oxygen	K-series	46.23	46.23	42.24	28.8
Carbon	K-series	42.39	42.39	51.60	26.5
Aluminium	K-series	11.38	11.38	6.16	1.1
	Total:	100.00	100.00	100.00	

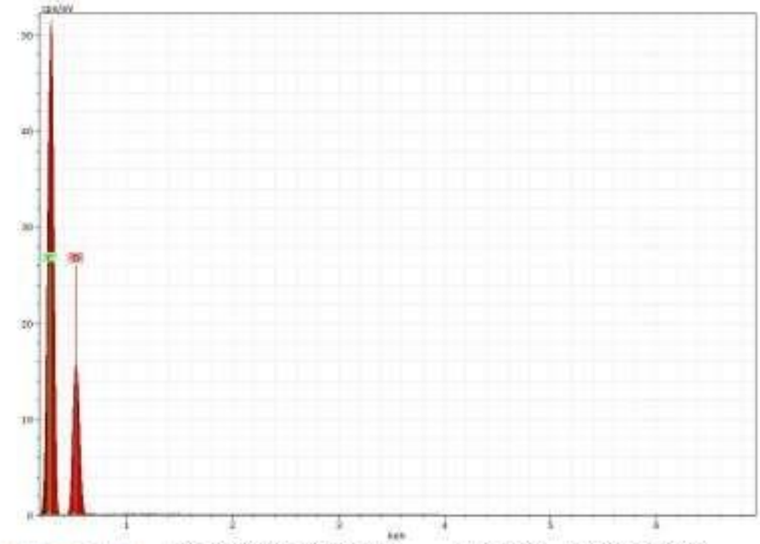
B3



Spectrum: Acquisition 64

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Oxygen	K-series	53.04	53.04	45.89	31.9
Carbon	K-series	46.96	46.96	54.11	28.2
	Total:	100.00	100.00	100.00	

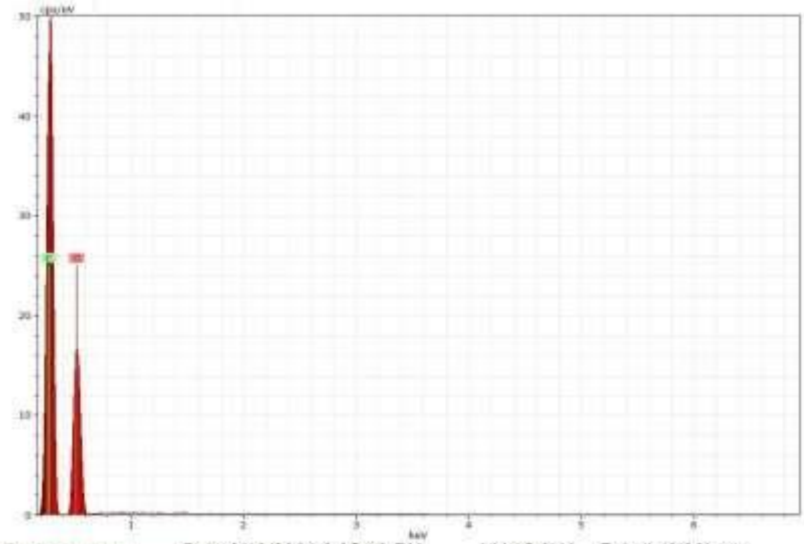
BJ1



Spectrum: Acquisition 68

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Oxygen	K-series	54.63	54.63	47.48	32.8
Carbon	K-series	45.37	45.37	52.52	27.3
	Total:	100.00	100.00	100.00	

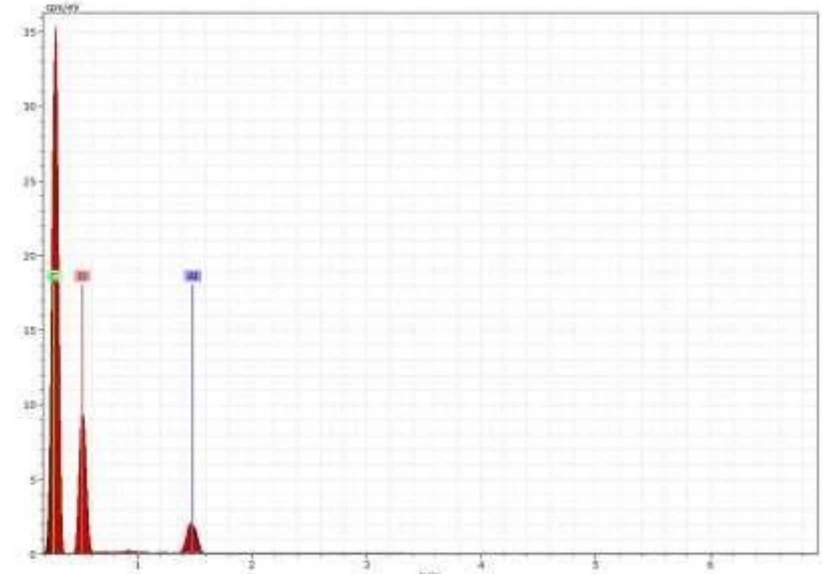
BJ2



Spectrum: Acquisition 69

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Oxygen	K-series	56.02	56.02	48.88	33.7
Carbon	K-series	43.98	43.98	51.12	26.4
	Total:	100.00	100.00	100.00	

BJ3

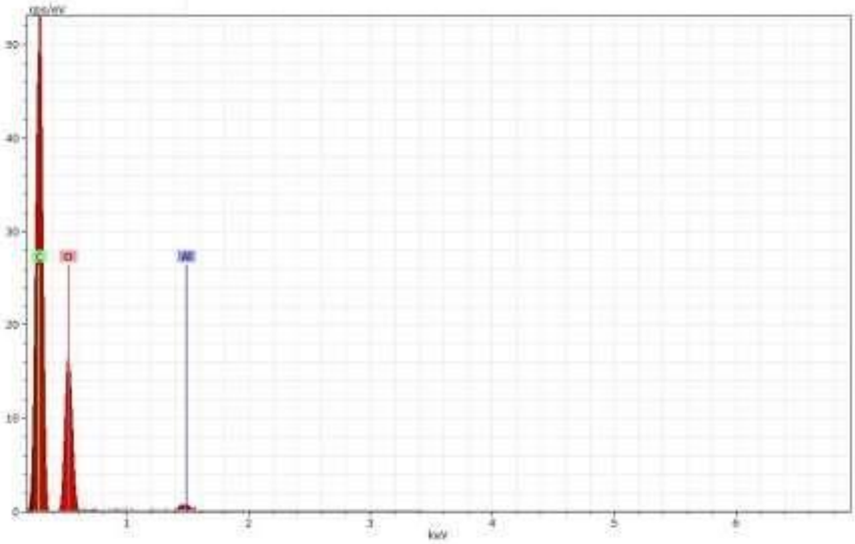


Bremsstrahlung Date:8/13/2021 3:38:21 PM HV:15.0kV Puls th.:0.19kcps
Acquisition 70 Date:8/13/2021 3:38:21 PM HV:15.0kV Puls th.:3.46kcps
Sum Date:8/13/2021 3:38:21 PM HV:15.0kV Puls th.:3.03kcps

Spectrum: Acquisition 70

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Oxygen	K-series	45.03	45.04	40.82	28.1
Carbon	K-series	44.26	44.26	53.43	27.6
Aluminium	K-series	10.71	10.71	5.75	1.0
	Total:	100.00	100.00	100.00	

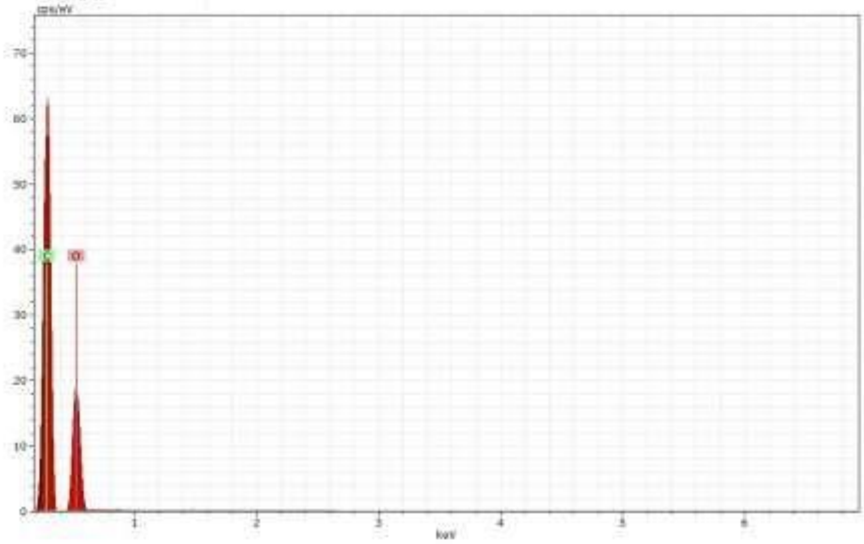
D1



Spectrum: Acquisition 65

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Oxygen	K-series	53.09	53.09	46.60	32.1
Carbon	K-series	44.70	44.70	52.26	27.1
Aluminium	K-series	2.20	2.20	1.15	0.3
	Total:	100.00	100.00	100.00	

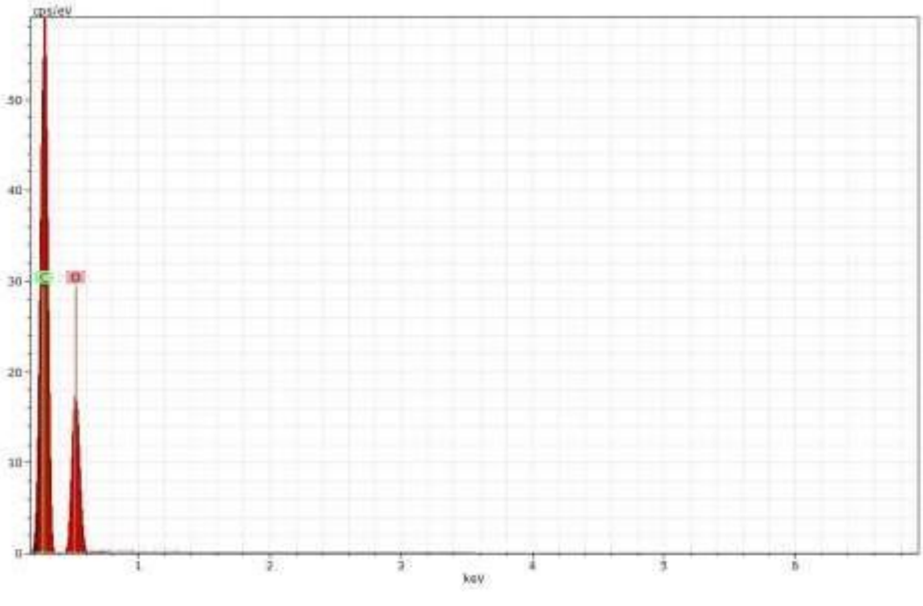
D2



Spectrum: Acquisition 66

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Oxygen	K-series	54.40	54.40	47.25	32.7
Carbon	K-series	45.60	45.60	52.75	27.4
	Total:	100.00	100.00	100.00	

D3



Spectrum: Acquisition 67

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Oxygen	K-series	54.05	54.05	46.89	32.5
Carbon	K-series	45.95	45.95	53.11	27.6
	Total:	100.00	100.00	100.00	