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CARBON FOOTPRINT ANALYSIS OF A T-45 HOUSE IN KUPANG

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ABSTRACT

Carbon dioxide (CO_2 and CO_2e) concentration in the atmosphere steadily increases and, in some places, has passed 360ppm, which is the limiting point agreed by world leaders to slow down and stop global warming. Housing sectors have been claimed to emit significant amounts of CO_2. This paper reports a research on the carbon footprint of a T-45 house in Kupang. The research calculated in detail the carbon emission of the house since its pre-construction stage (design process), construction stage, to the post-construction stage (house operation from year one to year 25). The T-45 house was selected as this type is the smallest standard house for a family of three in Indonesia. Literature, survey and analytical methods were adopted. The research found that the longer the house was used, the lower the carbon emission borne by each occupant per year. From year one to year 25, the total carbon emission borne by each occupant decreased from 3,590,793.44 to 145,568.38 $kgCO_2$ per year. The construction stage emits a considerable amount of CO_2 so that its carbon footprint still dominates the proportion of carbon emission per year per occupant, 98.61%. In the construction stage, use of cement in the wall and concrete structure works contributes the largest proportion of carbon emission, 96.7%. Therefore, using locally available construction materials, in particular, natural ones with less or zero carbon emission, is highly recommended.

Keywords: Carbon footprint; climate change; detailed calculation; remote location; T-45 housing.

INTRODUCTION

Indonesia is the fourth most populous country in the world with more than 255 million inhabitants (by 2015). Demand for housing, as a basic need, increases steadily, which occasions a rise in their prices. The Indonesian government should provide affordable housing for its diverse people to ensure their prosperity and humane standards of living (MPPWRI, 2002). The size of Indonesia's middle class is growing fast and will reach 60% of the population in 2016. New couples and families of three usually start in compact or small size housing from $45m^2$ to $70m^2$. Up to the year 2025, 30 million houses would be needed (1.2 million houses annually).

The vast demand for housing puts pressure on the environment. Fertile lands (such as forests and paddy fields) have to be cleared up for housing provision. One of the current major environmental issues is climate change, which experts believe is caused by global warming. Those experts also believe that three major greenhouse gasses (CO_2, CH_4 and N_2O) are responsible for global warming. Therefore, controlling the emission of those greenhouse gasses (GHG), especially those emitted by human activities, is important. The CO_2 emissions mostly come from the burnings of fossil-based fuels to get energy. CH_4 (methane) and N_2O (nitrous oxide) have, respectively, 23 and 297 times stronger global warming potential (GWP) than CO_2. CH_4 and N_2O come mainly from meat industries.

The carbon footprint of a house can be traced back from its design (pre-construction), construction through its occupancy (post-construction) stage. Building constructions and operations consume considerable amounts of energy, which emit carbon. Those energy consumptions depend on many factors such as climate, building functionality, building design, building materials, building demand, occupants' economy status, and occupants' behavior (UNEP, 2009). The Intergovernmental Panel on Climate Change (IPCC) calculates that global average temperature will rise between 1.8 and 4.0 degree Celsius from 1990 to 2100 based on the projection of current CO_2 concentration trend in the atmosphere, which can result in disastrous impacts (Schreuder, 2009).

This paper reports the analysis of the carbon footprint of T-45 house in Kupang, Timor. The provisions of housing in less densely populated islands such as Timor are encouraged to fulfill the need of local inhabitants for better housing. However, unlike the provision of housing in the densely populated islands such as Java, the provision of housing in less densely populated islands face more problems such as the availability of materials, which sometimes has to be transported from long distances. This means more energy for transportation and more carbon emission from burning the fuel. It is hoped that, by a detailed understanding of the carbon footprint of a T-45 house from its pre- to post-construction stage, a better idea on how to control the carbon emission can be drawn and applied to other types of houses.

RESEARCH QUESTIONS

The research questions are:

(1). What is the proportion of carbon emitted from pre-construction, construction and post-construction stage of a T-45 house?

(2). How much carbon is borne by each occupant of a T-45 house per year, from year one to year 25?

GLOBAL WARMING AND CARBON FOOTPRINT OF HOUSING

Global Warming and Greenhouse Gases

Nowadays, cities in tropical countries experience air temperature rise caused by global warming and urban heat islands. Global warming in the last three decades has been triggered by the growing concentration of greenhouse gasses in the atmosphere and it happens globally. Meanwhile, urban heat island is caused by heat emitting urban activities and heat absorbing surfaces of the cities; thus it happens locally. Both phenomena create a thermally uncomfortable environment, which encourages people to install air conditioners (ACs) as the easiest way to obtain thermal comfort. High energy consuming ACs emit more carbon from burning fossil-based fuels, thus they worsen the global warming (CECCIAQPH, 2011). This is problematic as passive ventilation (zero energy ventilation) can only be applied if the outdoor air temperature is in the comfort range, which, for Indonesia, is 24°C – 27°C. Unfortunately, records show that nowadays outdoor air temperatures exceeding 32°C are becoming more common, which is far beyond the thermal comfort zone. Indonesia is the third biggest AC consumer in the world after India and China (Davis, 2015).

Conference of the Parties 21 (COP21) held in Paris in December 2015, which was attended by 195 countries, produced five agreements aimed at reducing climate change caused by global warming. Those agreements are to limit the environment's temperature increase by 1.5°C through the reduction of greenhouse gas emission from fossil-based fuels (C2ES, 2015). Experts agree that CO_2 concentration of 360ppm in the atmosphere can keep the air temperature around 1°C above the air temperature of pre-industrial revolution of 280ppm (Hansen, 2013). However, measurement in Mauna Loa (Hawaii) in February 2015 and February 2016 found the average CO_2 concentration in the atmosphere were, respectively, 400.26 ppm and 404.02 ppm. Thus, the CO_2 concentration is increasing (http://www.esrl.noaa.gov/, 2016). Indonesia's carbon emission per capita is the fourth largest in ASEAN (Fig. 1.) Industries of cement, steel, pulp and paper, petrochemical, ceramic, food and beverages are big carbon emitters as shown in Table 1.

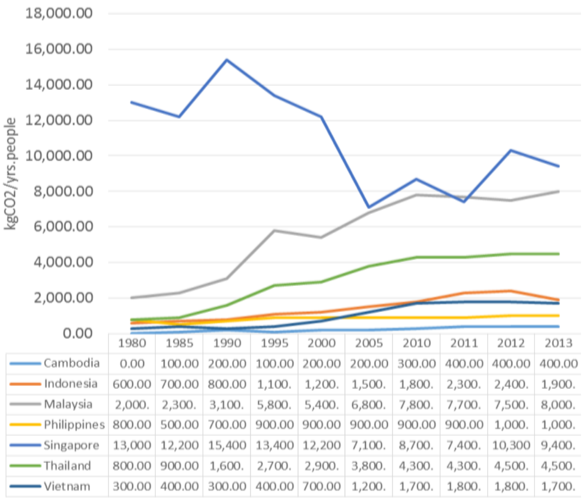

Fig. 1. Carbon emission for some ASEAN countries per capita based on fuel and cement consumption (processed from: worldbank.org, 2016)

Table 1. GHG from some types of industries (BPKIMI, 2012)

Industry sub-sector	GHG emission (Mton CO_2e) 2010	Percentage (%)	Target of GHG emission reduction in 2020, scenario 26% (MtonCO$_2$e)	Target of GHG emission reduction in 2020, scenario 41% (Mton CO_2e)
Cement	32.00	27.97	0.280	1.398
Steel	8.34	7.29	0.073	1.364
Pulp and paper	31.02	27.11	0.271	1.356
Textile	11.09	9.69	0.097	0.485
Petrochemical	11.46	10.02	0.100	0.501
Ceramics	1.36	1.19	0.012	0.059
Fertilizer	11.23	9.82	0.098	0.491
Food and beverages	7.91	6.91	0.069	0.346
Total	114.41	100	1	5

Building Carbon Footprint and Emission Factor

The carbon footprint analysis (CFA) of a building can be done by a detailed calculation of the carbon emission of all items that directly and indirectly relate to the creation and utilization of the building since its design to operation stages. CFA is a subset of life cycle assessment (LCA) of a building that covers building demolition or recycling. The carbon emission in the building sectors is significant so that many institutions around the world introduce ways to control it. Green Building Council Indonesia (GBCI) with its assessment standard of greenship, for example, encourages people to be more aware of the environmental impact of their buildings, especially their carbon emission. GBCI provides a checklist, which helps people to easily check how green their buildings are based on the obtained points. Building construction and operation are two major stages where high carbon emission is expected.

Carbon footprint is the total amount of carbon dioxide which is, directly or indirectly, emitted by human activities and consumption (Wiedmann dan Minx, 2007). The carbon footprint of a building can be measured by summing up all carbon emitted by items that relate to that building such as the production of building materials and the construction of the building. Each item has an emission factor which is “a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant”. The primary emission factor is a factor to be multiplied by the amount of fuel being used to get its carbon emission. The secondary emission factor is carbon emission from the consumed electricity energy. Every item releases some amount of carbon dioxide or its equivalent. Databases of emission factors are published by institutions such as the National Atmospheric Emissions Inventory (NAEI) of the United Kingdom. Software is also available on the internet for free such as Building for Environmental and Economic Sustainability (BEES), which integrates emission factors to the building construction activities so that the software users can instantly know the impact of their design decision on the environment.

The T-45 House in Kupang

The T-45 house being studied is situated in Lopo Indah Permai Housing, Gang III, Block G, No. 32, RT. 35/RW 12, Kelurahan Kolhua, Kecamatan (sub-district) Maulafa, Kupang city (Fig. 2). The T-45 house has 45m^2 floor area and 108m^2 site area. This house was built in 2013 and has been occupied since 2014. A T-45 house consists of a living room, two bedrooms, a kitchen-dining room, and a toilet. It is basically a core house that can be enlarged when it is necessary (Fig. 3).

The selected T-45 house represents the common conditions of T-45 houses which usually host a family of two to four people and were designed and built according to the building regulations of simple housing. The occupants’ or families’ activities in these houses are also typical of residential activities, which involve the use of common electrical households. A car and a motorcycle are commonly owned by a family. As an addition, in Kupang kerosene is still used for cooking (Fig. 4).

Kupang has 378.425 population and is bordered by 100^{o}36’14” - 100^{o}39’58” South Latitude (S.L.) and 123^{o}32’23” - 123^{o}37’01” East Elongation (E.E.). Its area is 180.27 km^2 with its higher part at the southern side 100 – 350m above sea level (Maulafa sub-district and Kota Raja). The proportion of built-up and unbuilt-up area is 20.84% (34.45km^2) and 79.16% (130.88 km^2). The built-up area is 10.27% (16.98km^2) for residences while the unbuilt-up area is 40.11% for moors (BAPPEDA, 2009). Lopo Indah Permai Housing is situated in Kecamatan (sub-district) Maulafa, Kelurahan Kolhua. Its geographical position is at 10°12'0"S.L., 123°37'40"E.E. (BPS, 2015; BAPPEDA, 2009).

The Developer

The developer of the T-45 house has two divisions, i.e. design and construction division. The design division is responsible for the whole design process from surveying to producing a detailed engineering drawing. The construction division is doing all the construction process from the land clearing, the construction to the environment finishing. The design division has three staff including one architect. The construction division has a team of eight people (1 foreman, 1 leader and 6 builders), which builds six T-45 houses per block. Averagely, each T-45 house can be built in three months.

METHOD

The research used literature, survey and the analytical method. The survey collected information on everything that was likely to emit CO_2 during the pre-construction (design process), construction and post-construction (building operation) stages. Those data were then manually calculated and analyzed using available equations and post-processed with Microsoft Excel 2010.

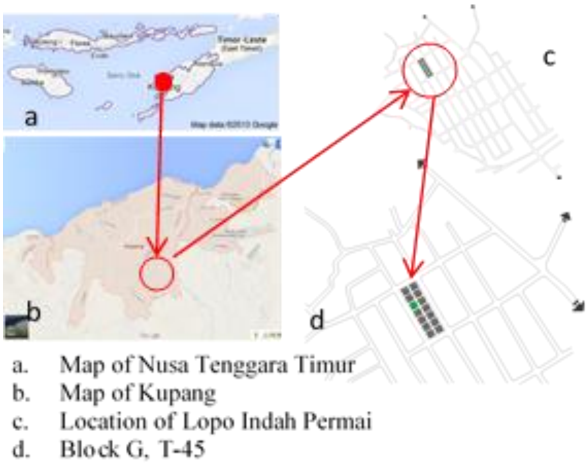

Fig. 2. Location of the selected T-45 house (source: PT Lopo Indah Permai)

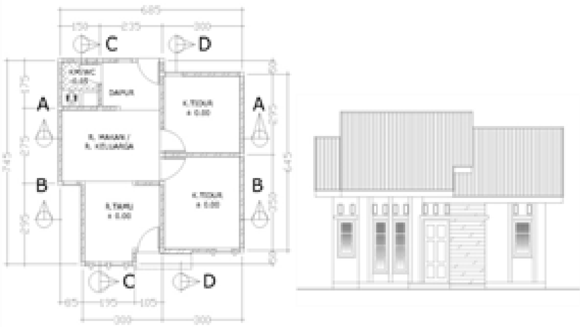

Fig. 3. Plan and front façade of a T-45 house (source: PT Lopo Indah Permai)

Fig. 4. Exterior and interior photos of the T-45 house (source: author)

Four steps were conducted (1) reviewing references on the building carbon footprint and emission factors, (2) surveying the selected T-45 house, (3) reviewing the detailed engineering drawing, (4) calculating the total carbon emission, i.e. from pre-construction, construction and post-construction stages (one year operation), (5) finding carbon emission per capita (per occupant of the house) in 5, 10, 15, 20 and 25 years. The 25 years period is assumed to be the normal operational standard of the house. The 5 years interval is taken as the house maintenance interval (such as repainting and other minor maintenance). The results of the calculations were then mapped to find the proportion of carbon emission based on the pre-construction, construction and post-construction stages.

This research had some limitations, those were:

(1) The T-45 being studied was in its original stage. The research did not take into account carbon emission from any modification, which is normal in real life.
(2) The T-45 house was occupied by a family of three, i.e. a couple with one child.
(3) For emission factors from items that could not be found in any references, emission factors of relatively similar items were used.
(4) The lifestyle of the occupants was assumed to be relatively the same in 25 years.
(5) New technology, which might dramatically change the carbon emission, was not taken into account. Solar powered air conditioners (ACs), for example, will not emit carbon dioxide in their operation. Since ACs consume up to 65% of the building electricity, which might be generated by burning fossil fuels, the conversion to solar powered ACs will reduce the carbon footprint of the T-45 house dramatically.

CALCULATION

The calculation of T-45 carbon footprint used simple equations, i.e. multiplying items' volume with their emission factor and adding them up. Five equations were used to calculate the carbon emission of electric devices, transports, construction materials, and cooking.

CO_2 emission of an electric device =

$$EF.EC.T\ kgCO_2 \qquad (1)$$

where:

EF : emission factor ($kgCO_2$/kWh)
EC : electricity consumption (kW)
T : time (h, hour)

CO_2 emission of a transport =

$$EF.FC.D\ kgCO_2 \qquad (2)$$

where:

EF : emission factor ($kgCO_2$/liter)
FC : fuel consumption (liter/km)
D : distance (km)

CO_2 emission of a material =
EF.MV $kgCO_2$ (3)
where:
EF : emission factor ($kgCO_2$/liter)
MV : material volume (liter)

CO_2 emission of a cooker =
EF.MV.T $kgCO_2$ (4)
where:
EF : emission factor ($kgCO_2$/liter)
MV : fuel volume (liter/hour)
T : time of cooking (hour)

CO_2 emission of a combustible construction equipment = EF.ME.T $kgCO_2$ (5)
where:
EF : emission factor ($kgCO_2$/liter)
FC : fuel consumption (liter/hour)
T : time of operation (hour)

Carbon emission from the pre-construction stage was calculated based on the design team's activities, which involved energy consuming items. The developer has two motorcycles (a Kawasaki KLX 150 cc and a Honda Mega Pro 150 cc), two computers (HP Pavilion Core i3), a printer (Pixma iX6560), two LED monitors (19"Asus VS197D), and an AC (LG 9000Btuh, equivalent to 750 watt). The distance between the housing location and PT Lopo Indah Permai Kupang office is 1.2 km. Equations 1 and 2 were used to calculate carbon emission from the electric equipment and transports, respectively. Emission from an electric equipment was calculated by multiplying its power input with its emission factor and duration of use. Emission from a motorcycle was calculated by multiplying its fuel efficiency with its daily traveling distance. Since it was not easy to find the exact distance, an assumption was made, i.e. return trip from the developer's office to the housing location. Likewise, assumption was made for the duration of daily use of the electric equipment.

Carbon emission from the construction stage was the total emission of the whole construction process, from the land preparation until the housing environment tidying up. It covered all emission from, among others, material transportation (by trucks and ships), material production and construction equipment (their transportation and operation). Material data were taken from the bill of quantity and drawing documents. Equation 3 was used. They consisted of natural and artificial materials. Emission factor of those materials was taken from references such as Frick's book (2007) and IPCC (2006). The carbon emission of a construction equipment with combustible engine was also simple. For example, the developer used a *concrete mixer* DTR 85-Honda 160 GX, which consumed 1.9-liter diesel fuel per hour. Its carbon emission was calculated using equation 5.

Carbon emission from the post-construction stage was based on the activities of the occupants. The selected T-45 house hosted a family of three. For daily transportation, this family relied on a car (Suzuki Escudo XL7) and a motorcycle (Suzuki Escudo XL7). Owning a car and a motorcycle are also a common practice for a small Indonesian family. For cooking, a kerosene stove with two burners is used even though the government has encouraged its people to change to a gas stove. Equation 4 was used.

Carbon emission per occupant per year was simulated from year one to year 25 of the house occupancy. The carbon emission from the pre-construction and construction stages was unchanged once the house construction was finished. The carbon emission from the post-construction (from occupants' activities) was multiplied by the number of the occupancy year, i.e. from 1 to 25 with 5 years interval. The total carbon emission per step was then divided by the number of corresponding years and the number of occupants to find the carbon emission per year per person.

RESULTS AND DISCUSSIONS

Tables 2, 3 and 4 show, respectively, carbon emission from the pre-construction, construction, and post-construction (one-year operation) stages. At the pre-construction stage, which was dominated by studio works, 99.493% of carbon emission came from electricity equipment, especially the AC. At the construction stage, carbon emission from the materials reached 98.96%. During one year operation, electricity equipment emits 68.015% carbon dioxide. Figures 4, 5 and 6 show pie charts of each stage. Construction stage emitted 10,766.289 tCO_2 or 10,766,289.000 $kgCO_2$, which made emission from other stages seemed insignificant. Table 4 and Figure 7 show that the total carbon emission of a one-year house operation was dominated by emission from electric equipment, 68%.

Figures 8, 9 and 10 show the carbon emission load per occupant for 25 years. It represents the simulation if the carbon emission from the house's lifetime (pre-construction, construction and post-construction) was borne by each occupant per year. The longer the operation of the T-45 house, the lower the carbon emission borne by each occupant per year. If the T-45 house can be used for 25 years, each occupant would bear 145,568.38 $kgCO_2$ per year or 3,234.85 $kgCO_2$ per year per m^2.

Some information can be derived from the tables and figures:

(1) Though construction time of the T-45 house only takes a fraction of its 25 year lifetime, the carbon emission from the construction stage is still the biggest percentage of the total carbon emission per year per occupant Fig. 8).

(2) The T-45 house uses modest materials. However, it was found that these modest materials still contribute the largest proportion of carbon emission (Table 5). Thus, it is important to carefully select materials in the design stage. Local materials, particularly the natural ones, would emit less or even zero carbon. The use of these materials could be encouraged. However, it does not mean at all that high-quality materials will emit more carbon as better technology introduces greener materials, i.e. lower carbon emission.

Table 2. Carbon emission from the pre-construction stage

Equipment	Total Emission ($kgCO_2$)	Percentage (%)
Means of transportation	0.199	0.507
Electric and electronic equipment	39.128	99.493
TOTAL	39.328	100.000

Table 3. Carbon emission from construction stage

Items	Total emission (tCO_2)	Percentage (%)
Construction materials	10,654.698	98.964
Transportations of materials	111.162	0.033
Transportation of equipment and material leftover	0.013	0.000122
Electric equipment and combustible engines	0.416	0.0039
TOTAL	10,766.289	100.000

Table 4. Carbon emission from post-construction stage, one-year operation

Equipment	Annual total emission ($kgCO_2$)	Percentage (%)
Transports	1,019.135	16.839
Electric equipment	4,116.425	68.015
Lamps	3.746	0.062
Fuel for cooking	912.924	15.084
TOTAL	6,052.230	100.000

Table 5. Carbon emission from construction materials

Items	Total emission ($kgCO_2$)	Percentage (%)
Project preparation	0.261	0.000
Site preparation and filling	8.683	0.000
Structure and concrete	2,756,729.981	25.874
Walls	7,563,600.966	70.988
Floors	273,776.057	2.570
Roof and ceiling	38,883.411	0.365
Doors and windows	201.976	0.002
Hanger and keys	1,816.000	0.017
Paintings	19,529.869	0.183
Sanitary and plumbing	150.048	0.001
Wiring and electricity	0.000	0.000
TOTAL	10,654,697.250	100.000

Table 6. Carbon emission of one-year operation

Equipment	Total Emission ($kgCO_2$)	Percentage (%)
Pre-construction	39.33	0.364
Construction	10,766,289.00	99.580
Post-construction	6,052.23	0.056
TOTAL	10,772,380.56	100,000

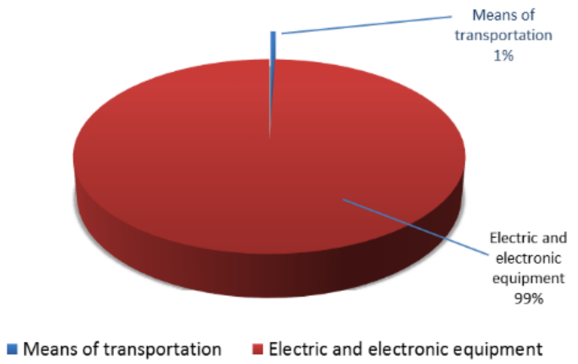

Fig. 5. Carbon emission from pre-construction stage

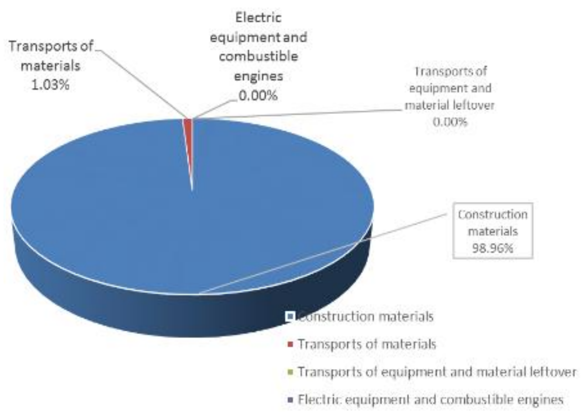

Fig. 6. Carbon emission from construction stage

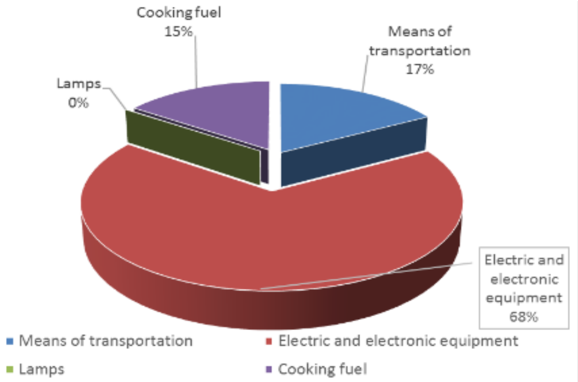

Fig. 7. Carbon emission from one-year operation

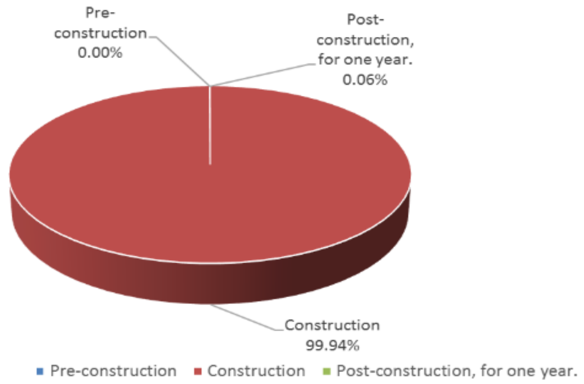

Fig. 8. Carbon emission from the design stage until one-year operation stage

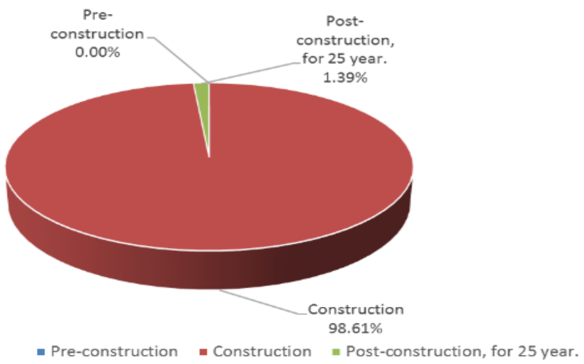

Fig. 9. Proportion of carbon emission after 25-year occupancy

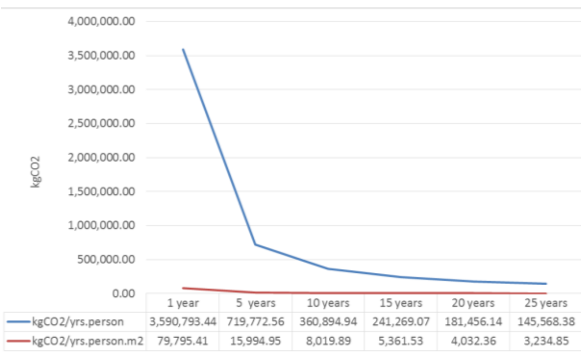

Fig. 10. Carbon emission from 1 to 25 years of the T-45 house occupancy

CONCLUSION

A comprehensive carbon emission calculation of a T-45 house in Kupang, i.e. from pre-construction, construction to post construction stages, found that the construction stage contributes the largest proportion. In its 25 years of operation, the carbon emission from the construction stage is still the largest percentage. It is 98.61%, which is equivalent to 45,568.38 kgCO2/yrs/person. In its construction stage, construction materials contribute the largest percentage, 98.61%. Therefore, it is important to use locally available construction materials, in particular, natural materials, which emit less or zero carbon.

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