

# Human Carbon Footprint as the Basis for Determining Healthy Indoor Volume Dimensions

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## Abstract

This paper was presented to determine the volume unit of indoor based on the human carbon footprint. The purpose of this approach was to formulate the ideal dimensions of an indoor, which was able to maintain human health. The basis for determining the dimensions was adapted to tropical conditions. For users in non-tropical areas, slight adjustments to temperature and ventilation may be required. Some examples of indoor dimension evaluation and planning were presented in this paper. In general, it was obtained that the indoor dimension could be found using the volume unit of a healthy room of  $3.0 \text{ m}^3/\text{person}/\text{hour}$ . The volume unit was linear with the number of users and time of existence in the room. This contributed significantly to people, who can easily and quickly find out the dimensions of space according to their needs.

**Keywords:** Carbon footprint; indoor; volume unit; public space; personal room

## Introduction

Living organisms are physically composed of organic matter, which easily breaks down into other forms. This organic material can basically be represented as glucose, and integrated into the material as biomass. The simple evidence is physical growth, which indicates an increase in biomass. Along with that growth is breathing, which gives off mainly carbon dioxide gas. The process of converting biomass into carbon dioxide is evidence that biomass is organic matter that is easily biodegradable.

Naturally, organic matter is a complex chemical compound containing carbon, symbolically represented as C. Except for the gases carbon dioxide ( $\text{CO}_2$ ) and

methane ( $\text{CH}_4$ ) and bicarbonate ions ( $\text{HCO}_3^-$ ) in solution, all of which are categorized as inorganic materials. On earth, carbon is the most important element and influences the earth's climate. The presence of carbon is in the atmosphere (the gases carbon dioxide and methane, which are known as greenhouse gases), the geosphere (hydrocarbon carbonate minerals), the biosphere (organic matter), and the hydrosphere (bicarbonate ions) (1-3). Especially for greenhouse gases in the atmosphere, which are the breathing medium for living organisms, there are safe levels for life, namely  $\text{CO}_2$  of 360 ppm and  $\text{CH}_4$  of 1.7 ppm<sup>(4)</sup>. The content and/or the proportion of the two gases in the atmosphere is dynamic, which can be influenced by the dynamics of living organisms, especially the activities of human life<sup>(5,6)</sup>.

In humans, the process of converting organic matter is known as respiration, which exhales a mixture of carbon dioxide, nitrogen, oxygen, water vapor and various volatile materials<sup>(7-9)</sup>. Most of the time, the activities of human life are indoors, at least 8 hours of sleep rest as a time considered capable of maintaining human health. The activity room can be a personal

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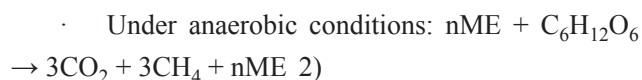
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space, for example a bedroom, family room, kitchen room, and others. The activity space is also in a format for the public, for example offices, shopping, tours, and the like. Every human being living in any place emits greenhouse gases and leaves a carbon footprint on the environment.

The carbon footprint can have a negative impact, both on the environment and on humans themselves<sup>(10-16)</sup>. This leads to the need for space, which is able to overcome the negative impact of these gases. So far there is no known way to determine the size of space, which is based on the results of human life activities, namely carbon from human life processes. Therefore, this paper has examined the human carbon footprint approach for determining the dimensions of spaces, both private and public places. The purpose of this approach is to provide an indoor spatial dimension capable of maintaining human health while in it.

## Methods

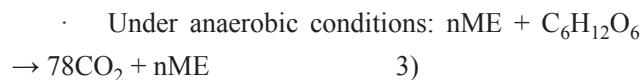
The method of calculating carbon footprint products is based on the reactions of human life and consumption of various living necessities. The general reaction of life is expressed as follows:



In these 2 equations, nME are the many types (n) of materials and energy (ME) that are used for human life. For example, various kinds of drinking water, various kinds of food, various kinds of building materials, various kinds of energy sources, various kinds of vehicles, and various kinds of products.

Various kinds of gas products resulting from life activities ( $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{SO}_x$ ,  $\text{NO}_x$ , HFC, etc.) can be equivalent to  $\text{CO}_2$  gas and expressed in units of emission/person/time (for example: kg/person/day). The equivalence of greenhouse gases to carbon dioxide is measured by the global warming potential (GWP). In

practice, the GWP of  $\text{CH}_4$  is variable over the source of the generation<sup>(17-19)</sup>, however, to illustrate the magnitude of the effect of heating, 1mol of  $\text{CH}_4$  is 25mol of  $\text{CO}_2$  equivalent. Thus, equation 2) can be stated as follows:



Equation 3) is appeared to give a warning that a room with insufficient oxygen leads to an increase in room temperature as a result of the carbon dioxide equivalent increasing sharply. This is important to consider in determining room ventilation.

## Results and Discussion

### Basics of calculation

#### Healthy concentration of carbon dioxide

The outdoor  $\text{CO}_2$  concentration is in equilibrium with ambient air, which is about 360-380 parts per million (ppm)<sup>(4,20)</sup>. Likewise, in the room that is balanced with the outside. This concentration is a level that supports the health of human life. However, indoor  $\text{CO}_2$  concentrations can fluctuate and exceed these healthy concentrations, but humans still do not experience health problems. There are a number of concentrations that can be tolerated, but as a sustainable healthy concentration and for maximum protection for human life, the indoor  $\text{CO}_2$  level is as follows:

$$\text{Healthy indoor } \text{CO}_2 \text{ concentration} = 360 \text{ ppm} \quad 4)$$

#### Individual carbon dioxide emissions

The average annual carbon emission from energy demand for household use is 6.744 kg  $\text{CO}_2\text{e}$ <sup>(21)</sup>. In general, people do indoor activities for more than 19 hours a day<sup>(22)</sup>. In these activities, humans need energy 34 MJ/person/day for the basic needs of life, such as eating and drinking; and various activities, such as transportation and works. Thermodynamic energy stated that 1mol of glucose equals 2.8MJ. Stoichiometric glucose requirement is 34/2.8 or 12mol glucose/person/day. Emission of  $\text{CO}_2$  is 12\*6mol  $\text{CO}_2$  = 72mol  $\text{CO}_2$  = 72 \* 44g = 3.2kg  $\text{CO}_2$ /person/day<sup>(23)</sup>. About 25-40% of

them are sourced from human life, namely 0.8-1.2kg CO<sub>2</sub>/person/day. The calculations used are considered appropriate that confirmed to Prairie & Duarte<sup>(24)</sup> for the average human body weight of 70kg, which releases 1.4kg CO<sub>2</sub>/person/day. It is also confirmed respirometrically 0.9kg CO<sub>2</sub>/person/day<sup>(25)</sup>. For general calculations, the average individual CO<sub>2</sub> emission units is as follows:

$$\text{CO}_2 \text{ emission units} = 1.0 \text{ kgCO}_2/\text{person/day} \quad 5)$$

### **Carbon dioxide density**

The density of indoor air is in the same equilibrium as the outside air. The density of air is variable with temperature. The higher the temperature, the lower the air density. For tropical climatic conditions, the air temperature is in the range 20-35°C, which indicates air density in the range 1.12-1.20 kg/m<sup>3</sup><sup>(26,27)</sup>. While the density of carbon dioxide is about 50% higher than dry air<sup>(28)</sup>. For general calculations, the average CO<sub>2</sub> density is taken as follows:

$$\text{CO}_2 \text{ density} = 1.75 \text{ kg/m}^3 \quad 6)$$

### **Room ventilation**

According to eq. 3) means that the ventilation system must be sufficient to maintain the aerobic conditions of the room. The ventilation becomes the gate for air transportation between indoor and outdoor spaces. In that case, there is a release of CO<sub>2</sub> from the room to the outside air. For a general calculation, the approximate CO<sub>2</sub> release from the room is as follows:

$$\text{CO}_2 \text{ release} = 95\% \quad 7)$$

### **Space volume calculation**

#### **Public space**

Two examples of defining indoor dimensions are given for workspaces and lecture halls. Its implementation can be applied to a large number of public meeting rooms.

Example 1: Workspace carbon footprint for indoor dimensional planning

- For 1 person, the CO<sub>2</sub> emission unit is eq.5):(1.0 kg CO<sub>2</sub>/day)/(24 hours)= 0.04 kg CO<sub>2</sub>/hour.

- The CO<sub>2</sub> volume is the CO<sub>2</sub> emission unit divided by CO<sub>2</sub> density eq.6): (0.04 kg CO<sub>2</sub>/hour)/(1.75 kg/m<sup>3</sup>) = 0.023 m<sup>3</sup>/hour.

- Gas CO<sub>2</sub> in a healthy room eq.4) divided by normal working hours:(360 ppm) / (8 hours) = 45 ppm/hour.

- Total CO<sub>2</sub> in the room (95% release, eq.7) is [(100) / (100-95)] \* 45 ppm/hour = 900 ppm/hour. This is to be converted into volume by volume = (900/1,000,000)/hour = 0.0009/hour.

- Volume of space = (0.023 m<sup>3</sup>/hour) / (0.0009/hour) = 25.56 m<sup>3</sup>/person.

Thus, the volume of space of healthy room works 8 hours for 1 person is rounded to 25 m<sup>3</sup>, which is free of placement of length, width and height, and this follows the comfort of the architectural design of a workspace.

Example 2: Classroom carbon footprint to predict the length of the meeting in a certain dimensional indoor

- Assumed a classroom for 50 people, the CO<sub>2</sub> emission unit is eq.5): (50)\*(1.0 kg CO<sub>2</sub>/day)/(24 hours) = 2.08 kg CO<sub>2</sub>/hour.

- The CO<sub>2</sub> volume is the CO<sub>2</sub> emission unit divided by CO<sub>2</sub> density eq.6): (2.08 kg CO<sub>2</sub>/hour)/(1.75 kg/m<sup>3</sup>) = 1.19 m<sup>3</sup>/hour.

- Volume of room (assumed the dimensions of the existing space) = 20m \* 10m \* 3m = 600 m<sup>3</sup>.

- Room CO<sub>2</sub> concentration is the CO<sub>2</sub> volume divided by volume of existing room = (1.19 m<sup>3</sup>/hour) / (600 m<sup>3</sup>) = 0.0020\*1,000,000(this is the number to convert into parts per million, ppm) = 2,000 ppm/hour.

- Gas escaping out of the room is 95% (eq.7), then the indoor gas becomes(5%)\*(2,000 ppm/hour) = 100 ppm/hour. Therefore, the maximum time of meeting for healthy conditions is (360 ppm) / (100 ppm/hour) = 3.6 hours.

### Personal room

Often and many people ask about the size of a healthy personal space for bedrooms, living rooms, kitchens, and homes as a whole. Several examples below provide the answer.

Example 3: Bedroom carbon footprint, an evaluation of the size of the existing space:

- For 1 person, the CO<sub>2</sub> emission unit is eq.5): (1.0 kg CO<sub>2</sub>/day)/(24 hours) = 0.04 kg CO<sub>2</sub>/hour.

- The CO<sub>2</sub> volume is the CO<sub>2</sub> emission unit divided by CO<sub>2</sub> density eq.6): (0.04 kg CO<sub>2</sub>/hour)/(1.75 kg/m<sup>3</sup>) = 0.023 m<sup>3</sup>/hour.

- Room volume (assumed with existing dimensions) = 3m x 3m x 3m = 27m<sup>3</sup>.

- Room CO<sub>2</sub> concentration = (0.023 m<sup>3</sup>/hour) / (27 m<sup>3</sup>) = 0.000852 \* 10<sup>6</sup> (this is the number to convert into parts per million, ppm) = 852 ppm/hour.

- Gas escaping out of the room = 95% (eq. 7), then the indoor CO<sub>2</sub> becomes 43 ppm/hour.

These results can then be adjusted for the number of people and the length of time in the bedroom, such as:

→ 1 person may stay in the bedroom for 360/43 = 8.4 hours.

→ 2 people may stay in the bedroom for 360/86 = 4.2 hours.

Example 4: Bedroom carbon footprint, a new plan for a spouse for 8 hours stay at room:

- For a spouse (2 person), the CO<sub>2</sub> emission unit is eq.5): (1.0 kg CO<sub>2</sub>/day)/(24 hours) = 0.08 kg CO<sub>2</sub>/hour.

- The CO<sub>2</sub> volume is the CO<sub>2</sub> emission unit divided by CO<sub>2</sub> density eq.6): (0.08 kg CO<sub>2</sub>/hour)/(1.75 kg/m<sup>3</sup>) = 0.046 m<sup>3</sup>/hour.

- Gas CO<sub>2</sub> in a healthy room eq.4) divided by normal working hours: (360 ppm) / (8 hours) = 45 ppm/hour.

- Total CO<sub>2</sub> in the room (95% release, eq.7) is [(100) / (100-95)] \* 45 ppm/hour = 900 ppm/hour. This is to be converted into volume by volume = (900/1,000,000)/hour = 0.0009/hour.

- Volume of bedroom for a spouse= (0.046 m<sup>3</sup>/hour) / (0.0009/hour) = 51.11 m<sup>3</sup> (rounded to 50 m<sup>3</sup>).

Example 5: House carbon footprint, a new plan for 24 hours (longest time on a holiday):

- For 1 person, the CO<sub>2</sub> emission unit is eq.5): (1.0 kg CO<sub>2</sub>/day)/(24 hours) = 0.04 kg CO<sub>2</sub>/hour.

- The CO<sub>2</sub> volume is the CO<sub>2</sub> emission unit divided by CO<sub>2</sub> density eq.6): (0.04 kg CO<sub>2</sub>/hour)/(1.75 kg/m<sup>3</sup>) = 0.023 m<sup>3</sup>/hour.

- Gas CO<sub>2</sub> in a healthy room eq.4) divided by normal working hours: (360 ppm) / (24 hours) = 15 ppm/hour.

- Total CO<sub>2</sub> in the room (95% release, eq.7) is [(100) / (100-95)] \* 15 ppm/hour = 300 ppm/hour. This is to be converted into volume by volume = (300/1,000,000)/hour = 0.0003/hour.

- The indoor volume unit is (0.023 m<sup>3</sup>/hour) / (0.0003/hour) = 76.67 m<sup>3</sup> (rounded to 75 m<sup>3</sup>), which is for 1 person.

By knowing the indoor volume unit, it is easy to find out the volume of the house for a number of residents who live in the house during a healthy holiday. As an illustration for a family of 4 residents, they need a house with volume 300 m<sup>3</sup>. In dimensions, the house is 1 floor with a fixed height of 3 m, so a length and width of 10m are required.

### Conclusion

Based on the calculation examples above, the volume of space is linear with the number of users and the time of existence. It is known that the volume unit of a healthy room is rounded to 3.0 m<sup>3</sup>/person/hour. The space volume calculation based on carbon footprint is applicable to all indoor functions, both for personal and public activities.

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