DESIGN GUIDELINE OF TREES PLANTING ALONG THE ROADSIDE CONSIDERING IMPACTING OF THE CO2 EMISSION DISPERSION BY VEHICLES

Dissertation

学位論文

DESIGN GUIDELINE OF TREES PLANTING ALONG THE ROADSIDE CONSIDERING IMPACTING OF THE CO2 EMISSION DISPERSION BY VEHICLES

自動車排出ガスの遮蔽効果を考慮した街路樹のデザインガイドラインに関する研究

Graduate School of Natural Science and Technology

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Abstract

This Ph.D. research objective to evaluate the design of trees planting on the roadside in impacting the dispersion of CO_2 emitted from transportation. This research provides design guidelines of trees planting in urban roadside that can improve air quality. The result can support urban planners, government, or other stakeholders to solve the decreasing air quality due to CO_2 emission dispersion. It is important because the high CO_2 concentration influences human health, whereas the roadside is public space that provided for pedestrians who want to travel. Therefore, Computational Fluid Dynamics (CFD) was used to simulate the spread of CO_2 and analyze air quality in some design trees planting. The results of the simulation were validated using statistical analysis, which is correlation analysis. So, the result could be justified.

The first research is investigating the CO_2 dispersion emitted from transportation in the study area with trees planting and without tree planting on the roadside. The result confirms the impact of trees planting on CO_2 dispersion. This result also shows the CO_2 concentration in the area around the road.

The second research evaluates the row position of trees planting to the road-air quality from CO_2 emission. The trees planting have some row position that can be implemented on the roadside. Commonly trees area planted in one-row and double row but in a different position. Trees can plant as a one-row position in the middle of the road. Trees also can plant as double-row positions on both sides of the road as a barrier between road, roadside, and building. This research provides four positions of trees planting. So the result can confirm the best position of trees planting along the roadside in improving air quality that exposed vehicle emission.

On the other side, the trees planting on the roadside not only consider the position of trees planting in improving the air quality, but there is some element design that also influences the CO_2 dispersion. So, the next research predicts CO_2 dispersion in different design trees planting patterns. This stage carried out five design of tree planting patterns based on the row position, avenue-tree layout, and space. The result showed the design alternative of tree's planting pattern that can control air quality from CO_2 dispersion emitted from motor vehicle.

Keywords: *CO_2 emission, Computational fluid dynamics, trees planting pattern, design trees planting, air quality.*

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Chapter 1. Introduction

1.1 Research Background

A common problem that is often faced in urban areas is the growing vehicle number. This condition causes degradation in air quality because it produces CO_2 emissions from using gasoline and diesel as fuel. The fuel usage in motor vehicle disperse 34% of the total CO_2 in the air every day (Sullivan *et al.*, 2004; Jie, 2011; EPA, 2016). CO_2 from transportation spread quickly to the roadside, which is a facility for pedestrians who want to travel in public space that separates from roadway vehicles. But currently, Co2 dispersion that effects road-air quality can harm pedestrians. High CO_2 concentration can have a devastating effect on human health, such as headaches, sleepiness, stuffy air, stale, poor concentration, loss of attention, increased heart rate, etc. Based on the standard from The Wisconsin Department of health service (2019), good air quality in the outdoor is the air that has a CO_2 concentration of 0.025%-0.04% (250-400 ppm). Poor air quality is the ambient air that has a CO_2 level between 0.1%-0.2% (1,000-2,000 ppm). Meanwhile, CO_2 concentration affects human health at the level 0.2%-0.5% (2,000-5,000 ppm).

Indonesia, as a developing country, has a very rapid increase in the number of motor vehicles. Data from BPS (2016) shows that motor vehicles were increased by 300% since the 2008-2018. This condition makes the air quality worse decrease. Based on that, roadside design can be a solution to these problems. The roadside has some facilities for the pedestrian that can be implemented on that, such as tree planting. Roadside with trees is proven to influence the distribution of vehicle emissions. It because trees have a function as a barrier or windbreaker so that it will affect the CO_2 dispersion. (Gromke and Ruck, 2010; Šíp and Beneš, 2016; Jeanjean *et al.*, 2015; Brantley and Hagler, 2014) proved that there are differences in CO_2 distribution in roadside without trees and with trees.

(Gromke and Ruck, 2010; Šíp and Beneš, 2016 indicate that the presence of trees on the pedestrian way can increase the concentration of emission, while Jeanjean *et al.*, 2015 display the presence of trees can reduce the level of emission—the difference of trees planting design that analyzed effect to that result. It indicates that the design to create good road-air quality (Janhäll, 2015). But in reality, the design of trees planting on the roadside ignore this function and just considers to aesthetic value. This condition caused some different trees planting patterns on the roadside in the urban area.

This condition also happens in urban roadside in Indonesia. Trees planting design on the roadside in Indonesia have various patterns. Moreover, tree planting guidelines (Indonesian Ministry Of Public Works, 2012) do not explain the design of tree planting from an environmentally friendly-view at dispersing CO_2 emissions. So, some roads with high congestion in Indonesia have poor air quality because they do not have a good design in holding the spread of CO_2 emissions. Surabaya is a metropolitan city that has traffic jam on some roads. Therefore, Panglima Sudirman street in Surabaya City is made to be a study area in this Ph.D. research for planning the design of trees planting on the roadside that have an impact on the CO_2 dispersion emitted from transportation.

1.2 Research Purpose and Contribution

The design of trees planting on the roadside must consider the effect of CO_2 dispersion from transportation, especially in urban areas with chronic congestion to improving the air quality. Therefore, this Ph.D. dissertation aims to evaluate the trees planting design on the roadside considering the CO2 dispersion impacting on air quality. This research can contribute to providing the guideline of trees planting design on the roadside from the environmental-friendly view that impacting on the road-air quality. According to the research aims, these following several objectives to be achieved:

1. Investigating the CO_2 dispersion emitted from transportation in the study area with trees planting and without tree planting on the roadside.
2. Evaluating the row position of trees planting to the road-air quality from CO_2 emission
3. Evaluating the trees planting pattern on the roadside based on CO_2 dispersion

In line with research purpose, this study is expected to give a contribution by:

1. Confirm the effect of tree planting on the roadside to the distribution of CO_2 emitted from transportation. This result can be comparative data of air quality in a study area with trees and a study area without trees. So, it can show the function of tree planting to the road-air quality.

2. Provide the trees row position that can improve the air quality exposed to the CO_2 dispersion emitted from transportation.
3. Provide alternative design of trees planting patterns on the roadside that influence CO_2 dispersion. This design can be applied in roadside that has chronic congestion to improve air quality.

1.3 Literature Review

Trees are planted on the urban roadside with various patterns. Tree planting design is usually adjusted to the beautiful urban roadside, whereas trees have other functions that are no less important. As a result, some design of trees planting is not appropriate with other tree's functions.

This research focuses on impacting the trees planting to the road-air quality from the dispersion of CO_2 emission. It will create the roadside with an environmental-friendly view. So that, trees planting on the roadside must consider some design parameters that have an impact on CO_2 dispersion. It will automatically influence the near-road air quality. Therefore, this research combines the three-parameters design of trees planting patterns that can affect CO_2 dispersion. There is the position of trees planting, avenue-tree layouts, and tree spacing. These parameters, according to the related research and theory about trees planting patterns.

The first design parameters of trees planting patterns is the position of the tree row. There are two types of tree row positions, which are double rows and one rows. Double rows position has trees row in the left and right of the roadside. While one road position only has trees row on one side, which is in the middle of the road, in the windward or leeward of the roadside. The following figure shows the position of trees rows according to the previous research (Morakinyo and Lam, 2016).

The position of trees become one of design parameters in this research because in the study location was found trees positions that are more diverse than explained in previous studies.

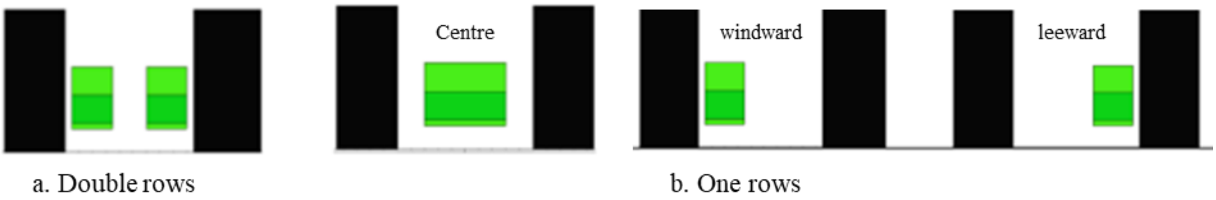


Figure 1.1 The position of trees row (Morakinyo and Lam, 2016).

The next design parameters in this research is avenue-tree layouts. This avenue tree layout influences the CO_2 concentration (Jian and Zhang, 2018). Gromke and Blocken (2015) display eight scenarios of avenue-tree design in the street. They divide the tree layout based on crown volume fraction (CVF). Trees are planted in the center of the road, which is the one-row position of trees planting. This research considers this parameters and will be combined with other parameters to create the guideline for trees planting design on the roadside to improving the air quality.

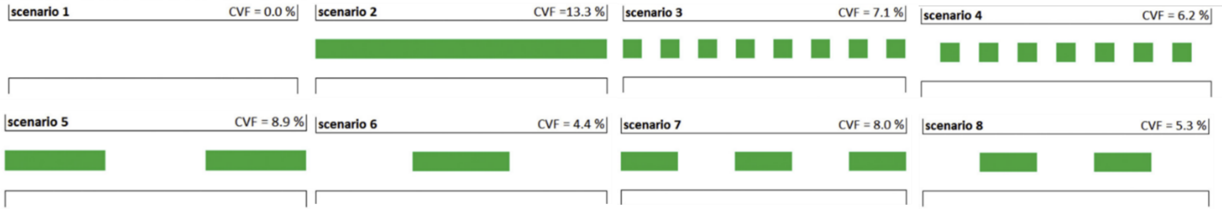


Figure 1.2 avenue-tree layouts (Gromke and Blocken, 2015)

The last design parameters of trees planting pattern is space. There is a theory about tree patterns, according to Nursery (1999). This theory divides planting patterns based on tree spacing (column) and row spacing. The type is square, hedgerow, double, and triangle. At the square profile, the distance between rows and between trees is approximately the same. For the Hedgerow pattern, the space between trees in a row is much closer. Meanwhile, in a square planting pattern, the double pattern is interplanting a tree in the center of four trees. The last pattern is a triangle, and all trees are the same distance from each other. Usually, these patterns are used to calculate the number of trees per acre. But this research will be implemented in the urban roadside.

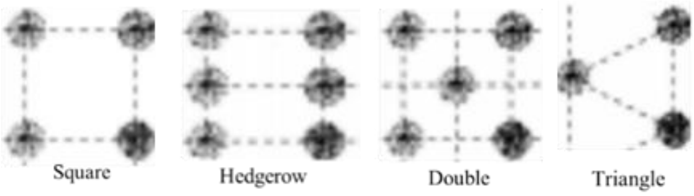


Figure 1. 3 Space of trees planting pattern

These three designs parameters will be combined and applied in the trees planting pattern on the roadside to get a better design for improving the air quality from the CO_2 emission dispersion.

1.4 Dissertation Organization

The main body in this research divided into 4 chapters (*Figure 1.5*). The first discussion displays investigating the CO_2 dispersion emitted from transportation in the study area with trees planting and without tree planting on the roadside. The next discussion is evaluating the row position of trees planting to the road-air quality from CO_2 emission. After that, the next section is predicting the CO_2 dispersion in different trees planting patterns based on some parameters design. The last discussion is analyzing the crown shape of trees planting on the roadside to improving the air quality.

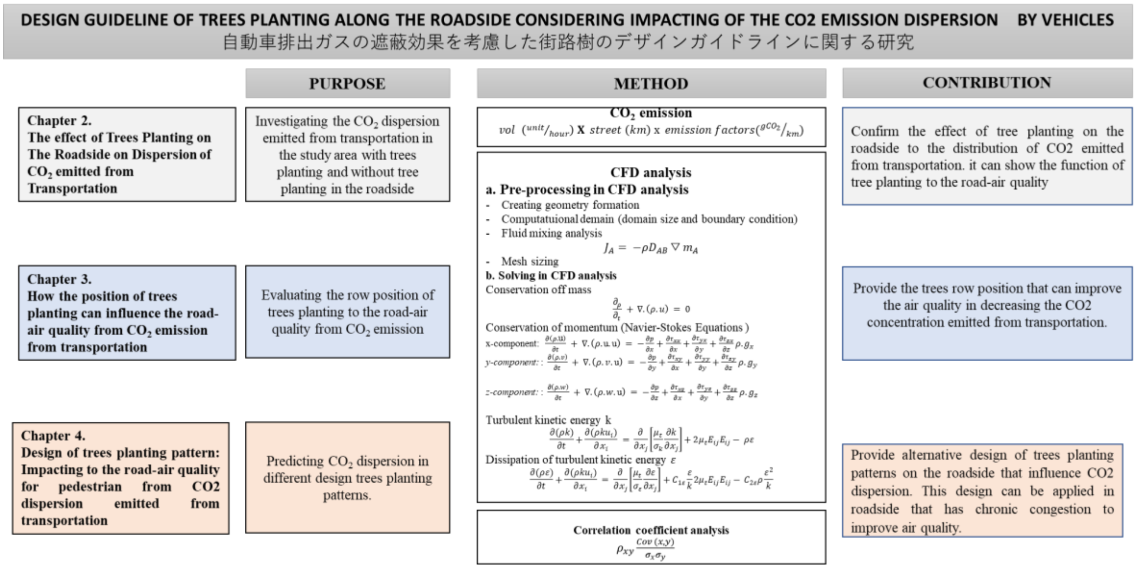


Figure 1. 4 Research framework

1.4.1 The effect of trees planting on the roadside on the dispersion of CO2 emitted from transportation.

This chapter simulates the CO_2 dispersion in the real 3D modeling according to the actual physical condition. It is mean that the characteristic of the trees and buildings in the study area were built according to reality. This research displays the comparison of CO_2 dispersion in the study area without trees and with trees. So, this work confirms the impact of trees planting on the near-road air quality from the distribution of CO_2 emitted from transportation. This result can be comparative data of air quality in a study area with trees and a study area without trees.

This chapter has been published on *International Review for Spatial Planning and Sustainable Development,* Volume 7 Issue 4 Pages 97-112, entitled The Effect of Tree Planting within Roadside Green Space on Dispersion of CO_2 from Transportation.

1.4.2 How positions of trees planting can influence the dispersion of CO2 emission from transportation.

This section discusses the influence of some design positions of trees planting on dispersing CO_2. Some row positions of trees planting can be applied to the urban roadside. This research found some type of single and double row positions in the study area. It will influence the tree's ability to dispersing CO_2. As a result, some row position is not effective in improving the air quality from the distribution of CO_2 emission. Therefore, this study evaluates this row position to get the best row position of trees planting in dispersing CO_2. So, it can influence optimally to improve near-road air quality. This chapter has been accepted in the International Journal of Sustainable Society.

1.4.3 Impact the design of trees planting patterns on the roadside to the near-road air quality from CO2 dispersion emitted from transportation

This section discusses some design of trees planting patterns to improve the near-road air quality. This chapter displayed five scenarios of trees planting patterns according to some parameters design, which is the position, the avenue-tree layout, and space. So, it can predict the CO_2 dispersion in different design trees planting patterns. So, it will provide some alternatives design of trees planting patterns on the roadside that influence CO_2 distribution. This design can be applied in roadside that has chronic congestion to improve air quality.

This chapter has been accepted in the International Journal of Sustainable Society, entitled Design of trees planting pattern: Impacting on the road-air quality for pedestrians from CO_2 dispersion emitted from transportation.

Chapter 2. The effect of trees planting on the roadside on the dispersion of CO_2 emitted from transportation.

2.1 Introduction

The growth of motor vehicles increases rapidly every year in urban areas, especially in developing countries such as in Indonesia. Most of the citizens prefer to use private vehicles than public transportation. The number of motor vehicle increase from 61,685,063 unit in 2008 become 146,858,759 unit in 2018. It causes a lot of congestion in Indonesia, especially in megapolitan and metropolitan cities that have a high population. This condition has a negative impact on near-road air quality because these vehicles disperse emissions emitted from fuel usage. There is some type of emission from transportation, which is CO_2, PM, and NOx. The use of gasoline in vehicles produces more CO_2 emissions than PM and NOx.

Conversely, traffic with diesel as a fuel can reduce CO_2 but produce more PM and NO_X emissions. But generally, most motorized vehicles in the world use gasoline, and others use diesel (Sullivan *et al.*, 2004; Jie, 2011). According to that, transportation became one of the biggest contributors to CO2 in the world (EPA, 2016).

CO_2 is a greenhouse gas that has many negative impacts. On a small scale, this gas can easily spread to the roadside located near the road. Roadside is a public facility for pedestrians who want to travel in space that separates from roadway vehicles. According to the location, this area is the space that will be directly affected by the spread of CO_2 emissions. So. it will be very vulnerable to have poor air quality. Therefore, proper roadside design should be considered to solve this problem.

As is generally known, CO_2 can spread to the larger area due to airflow, i.e., wind speed. On the other hand, the tree also has a function as a windbreak. Therefore, trees are important elements that must be considered on the side of the road. But there are still many urban roadside Indonesia that does not have trees. Even though, Indonesian Ministry Of Public Works (2012) in tree planting guidelines on-road network system suggests that the side of an urban road is better planted with trees. It proved from some previous research that shows the correlation between trees on the roadside and emission dispersion. Generally, it was simulated by CFD (Computational Fluid Dynamics), but there is a different result from this previous research. Research from Gromke and Ruck

(2010), Janhäll (2015), and Šíp and Beneš (2016) display that trees can increase the concentration of emission. These studies did not consider the various building height and building layout.

Meanwhile, other research from Jeanjean *et al.* (2015) proved that trees could reduce ambient levels of road traffic emissions. This research has built modeling based on real buildings with various height and layout on a city scale. However, their study ignored the roadside tree characteristics such as tree trunks and crowns in their simulation models. Therefore, this study focuses on investigating CO_2 distribution in a 3D model based on the actual physical condition of the environment. This research creates build and trees in 3D modeling based on the real situation. The result will confirm the effect of tree planting on the distribution of CO_2 emitted from transportation. It can be comparative data of air quality in a study area with trees and a study area without trees. So, it can show the function of tree planting to the near-road air quality. This research can contribute to providing comparable CO_2 distribution data on the side of the road planted with trees and without trees in a real physical environment.

2.2 Method

2.2.1 Study area

The study area of this research is Panglima Sudirman street in Surabaya city. Surabaya is geographically located in 07˚09’00 “- 07˚21’00” South Latitude and 112˚36`-112˚54` East Longitude. Surabaya is a metropolitan city with the most populous city in Indonesia, which is more than 3 million live there. There were many congestions on several main roads due to the high number of private vehicles. One of the roads that have chronic congestions in Surabaya City is Panglima Sudirman street. In peak hours, this road always has high congestions. The department of transportation in Surabaya city shows that vehicles number that through this road reached 130508 for 16 hours (Surabaya City Transportation Department, 2012). *Figure 2.1* displays the location of that road in Surabaya City. This road has a pedestrian on the right and left side. The buildings around the road have various layout and height. So, this road appropriate to be a case study to investigate the CO_2 dispersion.

Figure 2. 1 Orientation of Panglima Sudirman Street as a study case

2.2.2 Research framework

This following figure displays the research framework of this chapter. This research focuses on investigating the dispersion of CO2 along the roadside without trees and with trees. The comparison of these two conditions provides the difference CO2 distribution on the side of the road planted with trees and without trees in a real physical environment. Achieving this goal requires several stages of analysis and requires some data to support each analysis. The stages of the analysis process in this study are displayed in the following research framework.

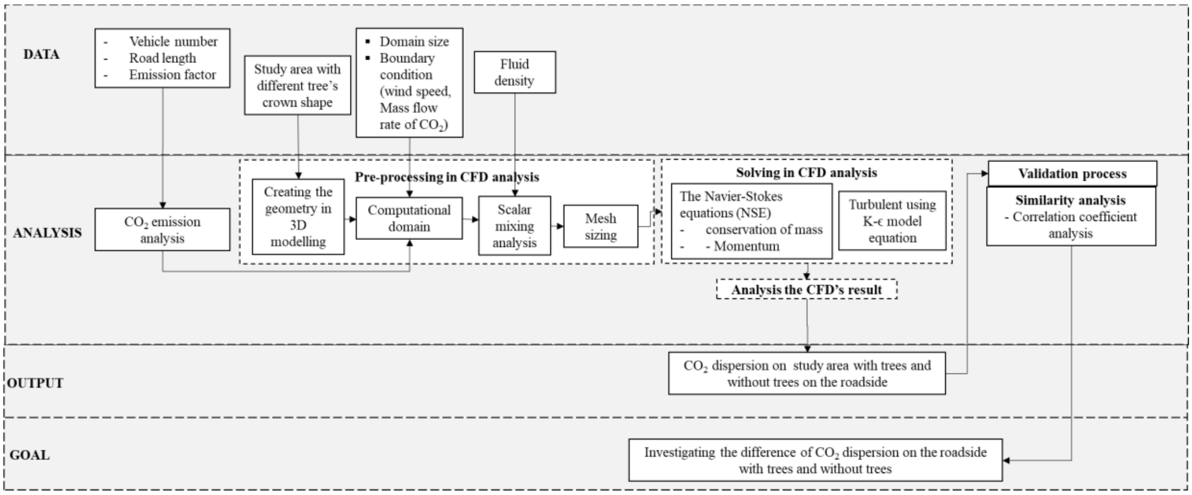


Figure 2. 2 Research framework of chapter 2

2.2.3 Create the geometry of the study case in 3D modeling.

The first stage in this research before simulating is to create the modeling in 3D. This research uses sim studio tools software to develop geometry. There is some element that must consider which are trees, pedestrian way, road, and the buildings. These elements were built according to reality. The length of the road that will be developed is 100 meters. The width of the road is 18 meters, and the width of the roadside is 6 meters.

The buildings and the trees built based on the actual conditions. Table 1 shows the characteristic of building in the study area, while *Table 2.1* displays the characteristic of the trees in the left and right of the roadside. Based on *Table 2.1* and *Table 2.2*, it can be seen the buildings and the trees have various characteristics. The geometry of this physical condition will create using a sim studio tool, but there is an assumption to create the trees. The canopy will build in the same shape. Then the canopy base height of 1/3 the canopy top height (Gromke and Ruck, 2010; Jeanjean *et al.*, 2015; Šíp and Beneš, 2016).

This research has two modeling to simulate which area study area with trees and study area without the trees. The geometry of this model display in *Figure 2.1*.

Table 2. 1 The characteristic of building in the study area

Number of Building	Width (m)	Length (m)	Height (m)
1	24	18	12
2	14	30	20
3	20	35	18
4	26	40	16
5	18	40	12
6	40	12	5
7	8	20	10
8	5	5	4

Table 2. 2 The Characteristics of trees in the Case Study.

Trees in The right side			Tress in The left side		
Diametre of Trunk	Height	Diameters Of Canopy	Diametre of Trunk	Height	Diameters Of Canopy
50	12	7	60	14	8
50	12	7	50	14	7
20	5	3	50	12	7
20	5	3	50	12	7
20	5	3	60	14	8
30	14	4	50	12	6
40	14	5	40	10	5
50	14	7	40	10	5
50	14	7	50	12	6

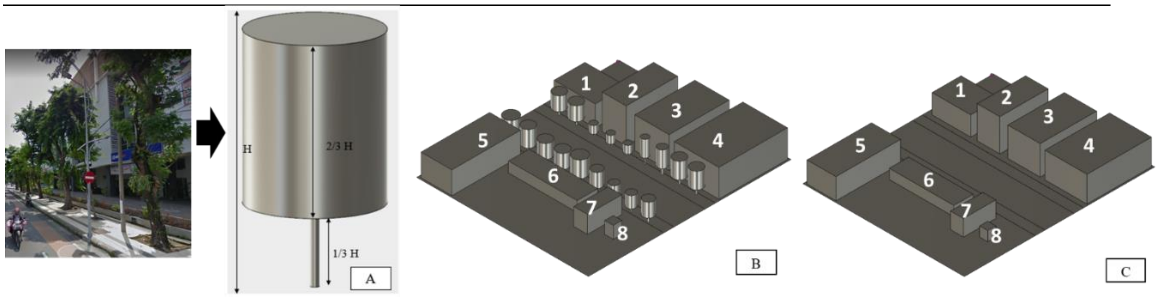


Figure 2.3 geometry of 3D modeling a) Trees modeling; b) study area with trees; c) study area without trees

2.2.4 Computational domain

The next step after creating the geometry in 3D modeling is to create the computational domain. The computational domain refers to a simplified form of the physical domain both in terms of geometrical representation in domain size and boundary condition for that domain. This computational domain has to maintain all the important physical features of the problem but can ignore small details (Li, 2008). So, there are two steps in the computational domain, which create the domain size and determine the boundary condition.

2.2.4.1 Domain size

This research creates the size according to the previous research from Franke et al. (2004, 2007). That domain size commonly used for urban research, especially in the street canyon or pedestrian way. Based on that, the inlet and the lateral in urban area simulation should be positioned $5H_{max}$ from the building. The outflow boundary should be a minimum of 15 H_{max} away from the building. The top boundary at least $5H_{max}$ away from the building. H_{max} is the size of the tallest building in the modeling. The domain size in this research shows in *Figure 2.4.*

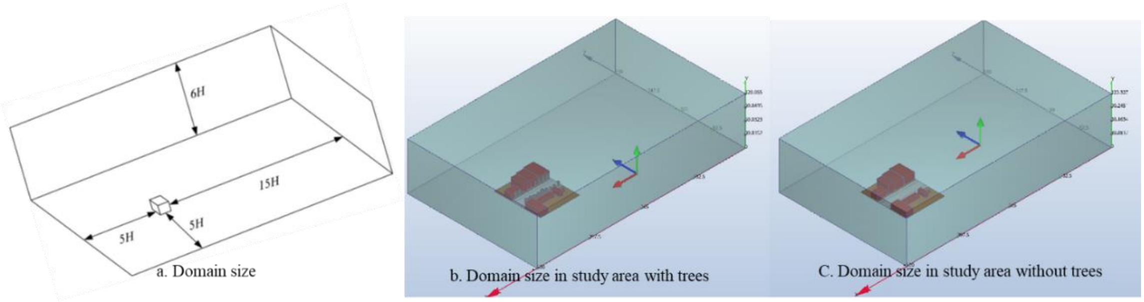


Figure 2. 4 Domain size in this simulation.

2.2.4.2 Boundary Condition

After creating the domain size, the next step is determining the boundary condition. There is some part of the boundary in 3D modeling that should be arranged. There are top, lateral, inlet, and outlet. The Inlet surface is the inflow of the fluid. This research has two inlets. The first inlet is the source of wind speed, and the second is the source of CO_2 emission from transportation. While the inlet surface is an outflow of the simulation, and 0 pressure is assigned in this part. Then, the top and lateral conditions assumed the fluid flow along a wall instead of stopping at the wall. So, the slip/symmetry condition assign on these surfaces. Figure 2.5 displays the boundary condition of this research.

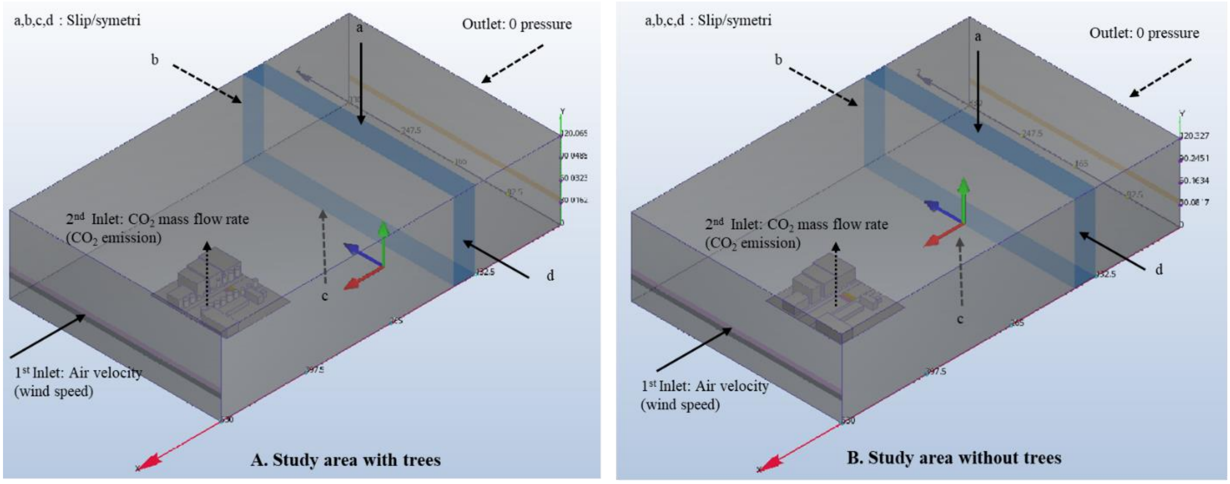


Figure 2. 5 Boundary condition at study area with trees and without trees

2.2.5 Fluids mixing analyze

2.2.5.1 Fluids condition (Air and CO_2)

There is two fluid that will simulate in this research, which is air and CO_2. Air and CO2 have different density. The density of air (ρ_A) is 1.2047 e-6 g/mm^3, and density of carbon dioxide (ρ_B) is 1.773e-6 g/mm^3. Air and CO_2 in the modeling need velocity to make fluids flow, so air velocity and mass flow rate of CO_2 is needed. Air can move in modeling if there is a velocity that is coming from wind speed. While the mass flow rate of CO_2 comes from CO_2 emission.

The data of wind speed is taken from Local Weather station (Indonesia Meteorology Climatology and Geophysics Council, 2019). Meanwhile, the value of the mass flow rate can be calculated using the CO_2 emission equation (AEA, 2012; Hidayat, 2013).

$$CO_2\ emission = vol\ \left({}^{unit}/_{hour}\right) \mathbf{X}\ street\ (km)\ \mathrm{x}\ emission\ factors\left({}^{gCO_2}/_{km}\right) \qquad \textit{Equation 2. 1}$$

Based on that equation, we should know the vehicle number per hour in the street, length of the street in modeling, and emission factor. This number vehicle obtained through a direct survey at the study location during peak hours. Peak Hours in the research area occur three times a day, which is in the morning, noon, and afternoon. The survey was conducted starting at 7-8 am in the morning, at 12 am – 1 pm at noon and at 6-7 pm in the afternoon for two days, which is on weekday and weekend. The next data that we need is the length of the street. This study uses 100 meters to simulate the study case. Whereas this equation also needs an emission factor of transportation for calculating this research, Then this research use standard of Vehicle classification according to (AEA, 2012). *Table 2.3* shows the standard of emission factor.

Table 2. 3 Vehicle emission factor

Transportation classification	Definition	Average emissions ($kgCO_2/km$)
Small car	Small petrol car, up to the 1.4-liter engine	0.16442
Medium car	Medium diesel car, from 1.7 to 2.0 liter	0.17573
Large Car	Large diesel car, over 2.0 litre	0.23381
Motorcycle	Small petrol motorbike (mopeds/scooters)	0.08499

2.2.5.2 Scalar mixing analysis

The important step in this research is mixing the air and CO_2. As explained before, these fluids have different density, so scalar mixing analysis is needed to know the fluid dispersion after mixing. The following equation is used to analyze the scalar mixing where A is air and display in scalar 0, while B is CO_2 and shows in scalar 1.

$$J_A = -\rho D_{AB} \nabla m_A$$

Equation 2. 2

J_A is the mass flux of air. This is how much air is transferred (per time and unit area normal to the transfer direction). It is proportional to the mixture mass density (ρ_{AB}). The density of air (ρ_A) is 1.2047 e-6 g/mm^3, and the density of carbon dioxide (ρ_B) is 1.773e-6 g/mm^3. D_{AB} is the diffusion of scalar quantities based on Fick's Law. The diffusion coefficient to mixing air and CO_2 is 0.16 cm^2/s. The units of the Diffusivity coefficient are length squared per time. This simulation uses 3D modeling, so to get J_A is proportional to the gradient (∇)of the species mass fraction (m_A).

2.2.6 Mesh sizing

This part is the last stage for pre-processing in CFD analysis. This part has divided the geometry of 3D modeling become a small shape, which is the element and node. Element is small pieces from geometry, and the node is a corner of each element. The nodes and elements make up the mesh. Mesh is needed in computational simulation to make the computer easy for the mathematical calculation in CFD analysis. There are many shapes of mesh that we can use. This research uses tetrahedral shape because this shape is appropriately used in 3D modeling.

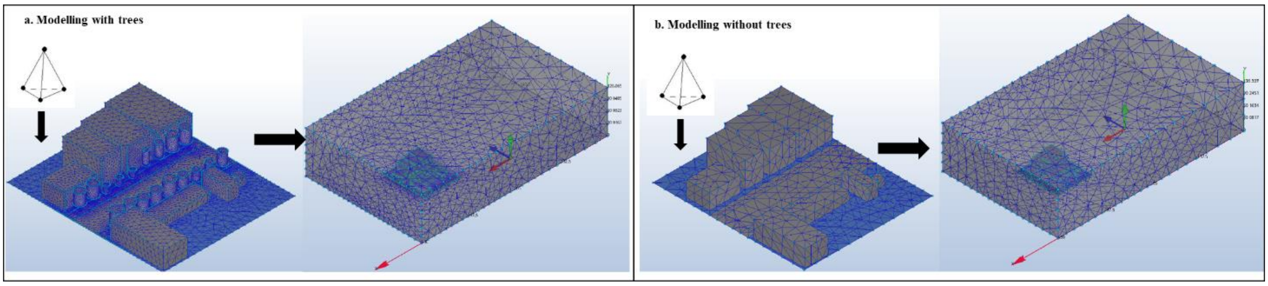


Figure 1. 5 Mesh Sizing in the geometry of modeling

2.2.7 Solving in CFD analysis

This part is a simulation part using CFD to get the result of CO2 dispersion in the study area. The airflow and co2 flow will be simulated, and this fluid will be mixing, so it can be known the air quality because of co2 dispersion in the study area. Therefore, some equation for CFD is needed to start the simulation. This research uses the Navier-Stokes equations (NSE) to describe the movements of fluids, which are air and CO2.

This research has some assumptions to simulate these fluid flow. Air moves in steady condition and not compressed (incompressible) or density (ρ) constant. The wind direction in the environment is considered unidirectional during the simulation. This airflow uses turbulent because this simulation wants to analyze the airflow and CO2 dispersion in two study cases with different physical environments. Then, this simulation just considers the airflow, so the parameters used are only related to airflow boundary does not heat transfer boundary.

Accordingly, some equation is needed to analyze a concentration gradient in the species. The following equation is used for the conservation of mass is (Equation 2.3).

$$\frac{\partial_\rho}{\partial_t} + \nabla.(\rho.u) = 0$$

Equation 2. 3

Where:

$\frac{\partial_\rho}{\partial_t}$ is the partial derivative of ρ with respect to t
ρ is density
t is time
The tensor gradient (∇) is the stress variable.
u is the flow velocity
∇u spatial derivatives of the flow velocity

Then the conservation of momentum based on Navier-Stokes Equations in 3D modeling using the following formula.

x-component: $\frac{\partial(\rho.u)}{\partial t} + \nabla.(\rho.u.u) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}\rho.g_x$ *Equation 2. 4*

y-component: : $\frac{\partial(\rho.v)}{\partial t} + \nabla.(\rho.v.u) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z}\rho.g_y$ *Equation 2. 5*

z-component: : $\frac{\partial(\rho.w)}{\partial t} + \nabla.(\rho.w.u) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\rho.g_z$ *Equation 2. 6*

Where:

ρ is the density

u is the flow velocity

∇ is divergence

p is the pressure

t is time

τ is the deviatoric stress tensor, and

g represents body accelerations acting on the continuum, for example gravity, inertial accelerations, electrostatic accelerations, and so on,

The Navier–Stokes equations have limitations for describing turbulent flows, which is the time-averaged RANS equation. The limitation is the introduction of the Reynolds stress term, which accounts for turbulent fluctuations. Hence, the K-ϵ model equation is used for turbulent kinetic energy used to support this CFD analysis. There is a two-equation. The first transported variable is the turbulent kinetic energy (k). The second transported variable is the rate of dissipation of turbulent kinetic energy (ε).

For turbulent kinetic energy k

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_i}\right] + 2\mu_t E_{ij} E_{ij} - \rho\varepsilon$$ *Equation 2. 7*

For dissipation of turbulent kinetic enegry ε

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t E_{ij} E_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$ *Equation 2. 8*

Where u is the fluid velocity ($m\, s^{-1}$), ρ is the fluid density ($kg\, m^{-3}$), i represent x.Then, j represents x,y, and z (coordinate geometry in boundary). E_{ij} is the component of the rate of deformation. u_i represents the velocity component in the corresponding direction. μ_t represents turbulent viscosity which is $\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$.

Accordingly, the equation has some standard constant that should be divided. There are σ_k, σ_ε, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and C_μ . The value of standard constants are the following:

$$\sigma_k = 1.00 \qquad \sigma_\varepsilon = 1.30 \qquad C_{1\varepsilon} = 1.44 \qquad C_{2\varepsilon} = 1.92 \qquad C_\mu = 0.09$$

2.3 Result

2.3.1 Identification the wind speed in the study area

This research chooses one of the roads in Surabaya city as a study case. Surabaya city as a tropical city has only two seasons, which are dry and rainy seasons. The dry season occurs from April-September when monthly rainfall is below 60 mm. The dry season occurs from April-September when monthly rain is more than 60 mm. But the climate change influence this time season. In 2017, the rainy season was longer than the dry season. This season occurs in November-June, whereas the dry season occurs in July-October. This condition influences the wind speed in this city.

The following figure shows the wind speed in 2017 in the study area. According to that figure, the average wind speed in 2017 is 1.6 knots, whereas the highest wind speed is 10 knots. This simulation uses 10 knots or 5.14 m/s of wind speed as a source of air velocity, which is 1st inlet (inflow) of fluids in this analysis.

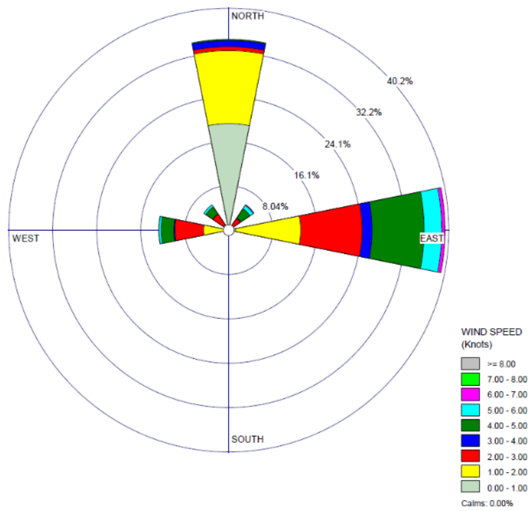


Figure 2. 6 *Wind speed and wind direction recorded by the local weather station in 2017*

2.3.2 Identification CO_2 emission in the study area

This part explains the calculation of CO_2 emission, and it will be used as a 2^{nd} inlet (mass flow rate of CO_2) in the simulation. *Table 2.4* shows the average number of vehicles per hour obtained by a survey in the study location. Then table 2,5 shows the calculation of CO_2 emission.

Table 2. 4 Average daily traffic

Classification	type of motor vehicle	Total (unit/hour)
Small car	Private car	2050
Small car	Public Transportation	111
Medium car	Mini Bus	233
Medium car	Pick Up / Box	1
Medium car	Mini Trucks	166
Large car	Big bus	3
Large car	Truck 2 axis	1
Large car	Truk 3 axis	1
Motorcycle	Motorcycle	6814
TOTAL		9380

Table 2. 5 CO_2 emissions in the research area

Transportation type	Average daily traffic(unit/hour)	Length of the street (km)	Emission factor	CO2 emission (kg/hour)
Small car	2161	0.1	0.16442	35.5
Medium car	400	0.1	0.17573	7.0
Large car	5	0.1	0.23381	0.1
Motorcycle	6814	0.1	0.08499	57.9
TOTAL				100.6

Based on that result, the number of motorcycles is the highest than other transportation classification, so CO_2 emitted from the motorcycle reaches 57.9 kg/hour. Meanwhile, the total CO_2 emission in one hour is 100.6 kg/hour. This emission is determined as the mass flow rate of CO_2 emission in this simulation.

2.3.3 CO_2 dispersion on the study area in various altitude

This section appearance the distribution of CO_2 in the study area. *Figure 2.7* and Figure 2.8 show the Dispersion of CO_2 at different elevations which is at 1.8 meters until 12 meters. In every altitude, there are differences in CO_2 dispersion between modeling with trees and modeling without trees. Scalar variable shows the percentage of CO_2 dispersion in the study area. Based on the color of the scalar in the following figure, the scalar of CO_2 in the study area without trees is higher than the study area without trees. Moreover, CO_2 in the study area without trees is more spread out than the study area with trees.

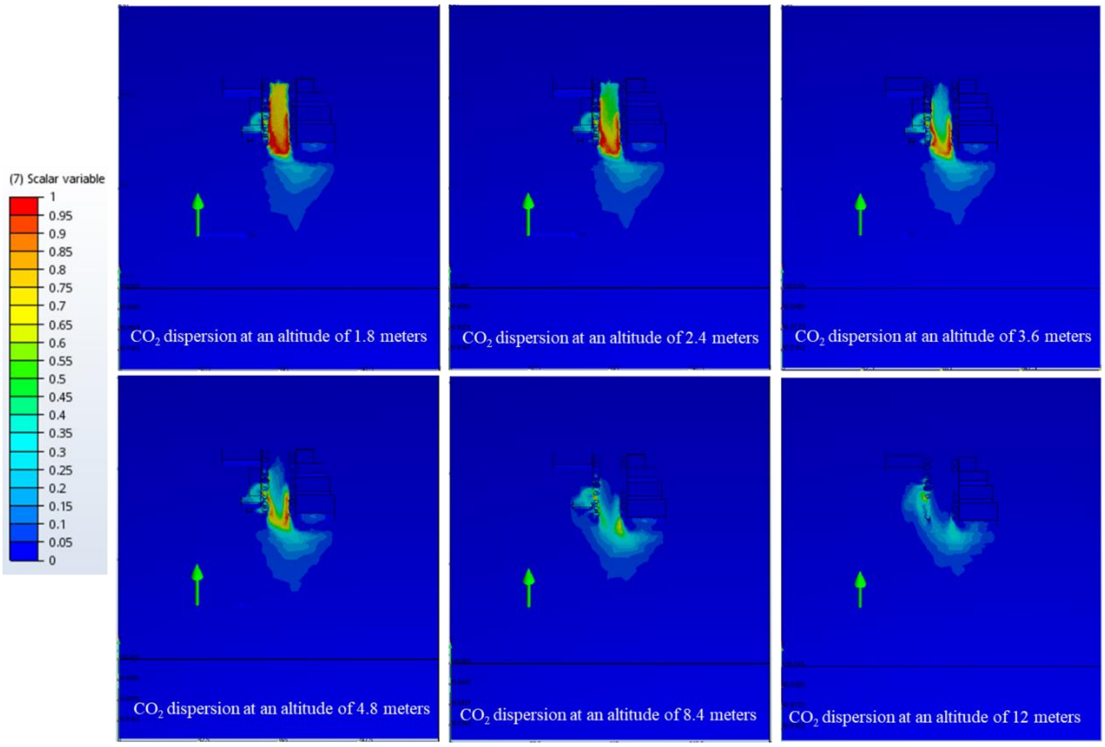


Figure 2. 7 CO_2 dispersion in the study area with trees planting at different altitude

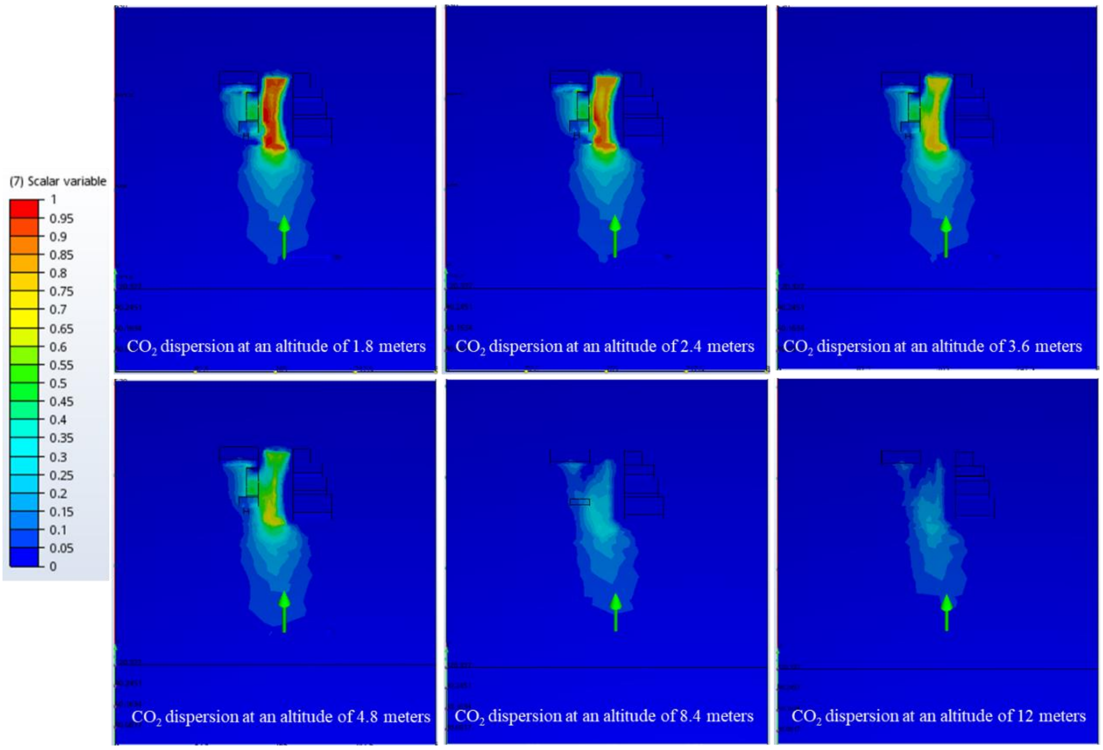


Figure 2. 8 CO_2 dispersion in the study area without trees plating at different altitude

The value of CO_2 distribution can be seen more clearly in *Figure 2.9.* This figure shows the comparison of CO_2 dispersion by percentage at several heights in both models. Based on that, the model with trees has a higher distribution value. At the height of 1.8 meters, the CO_2distribution in the study area without trees is 19.2%%. While CO_2 spread by10.2% in the modeling with trees, this result shows that trees in the roadside can decrease CO_2 dispersion by 9% at an altitude of 1.8 meters. It is also displayed in another different height.

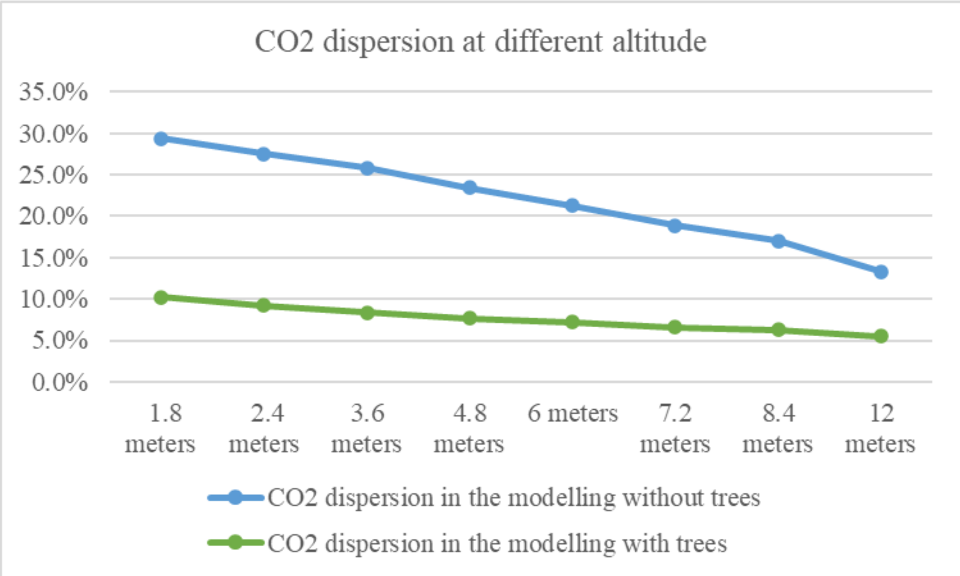


Figure 2. 9 The comparison of CO_2 dispersion on the study area without trees and with trees.

2.3.4 CO_2 concentration on the road and roadside of the study area

This part will compare the CO_2 dispersion between the roadside with trees and roadside without trees. The CO_2 dispersion on the roadside shows a different result because it has various characteristics of building around the roadside. On the right side, it has higher buildings than on the left side so that it will influence the result of CO_2 dispersion on both sides. Figure 2.10 displays the CO_2 concentration in the middle of the road. The graphic shows the CO_2 concentration on the road in the study area without trees and with trees—the result based on the CO_2 concentration at an altitude of 1.8 meters. Accordingly, the range of CO_2 concentration in the road of the study area with trees starts from 0-0.68% (0-6800 ppm). While 0.2-0.72% (2000-7200 ppm) disperse on the road of study area without trees, it is mean that that study area with trees can decrease the concentration of CO_2 in the road.

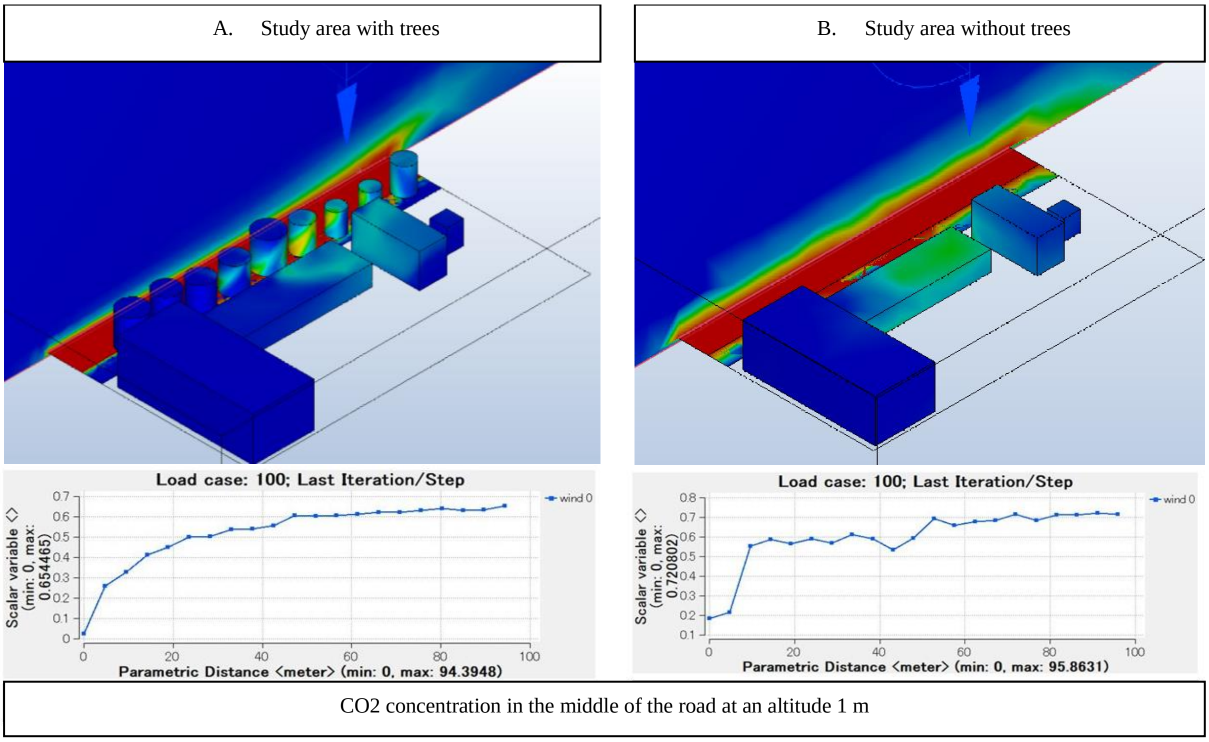
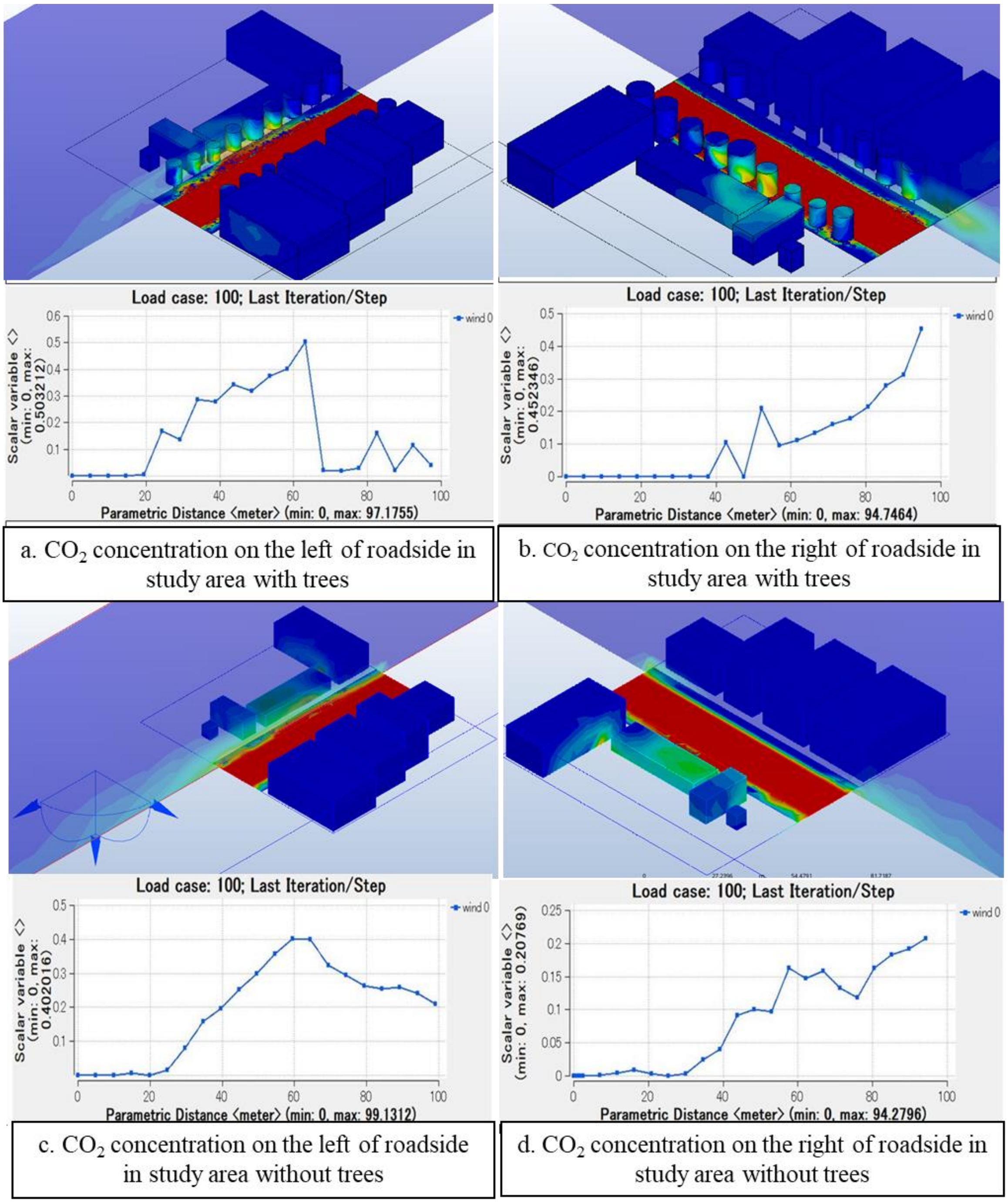


Figure 2. 10 CO_2 concentration in the middle of the road between the area with trees and area without trees

Another result also shows in *Figure 2.11*. This figure shows the CO_2 concentration in the left and right of the roadside. In the study area with trees, a range of CO2 concentrations in the left of the roadside start form 0-0.51 (0-5100 ppm), and CO2 concentration in the right of roadside start from 0-0.48 (0-4800 ppm). In the study area without trees, Co2 concentration has range 0-0.4 (0-4000 ppm) on the left side and 0-0.21 (0-2100 ppm) on the right side. This result indicates that the study area with trees has a higher Co2 concentration than the area without trees.

Accordingly, CO2 concentration in some parts of the study area shows the difference result. So the next part of this research will validate this result to justify the result of this simulation.



a. CO_2 concentration on the left of roadside in study area with trees

b. CO_2 concentration on the right of roadside in study area with trees

c. CO_2 concentration on the left of roadside in study area without trees

d. CO_2 concentration on the right of roadside in study area without trees

Figure 2.11 CO_2 concentration in the right and left of the roadside

2.3.5 Similarity analysis

Based on the result of CO_2 dispersion at different altitudes and CO_2 concentrations in the study area, the validation stage is needed to justify that result. This part uses correlation coefficient analyses to describe the similarity of the result in the study area without trees and with trees. The value of the correlation coefficient has a range between -1 until +1. The values close to 1 and -1 have very strong correlations, while values close to 0 have weak correlation (*Figure 2.12)*. This values is obtained using *equation 2.9.* This research uses SPSS software to calculate correlation analyses.

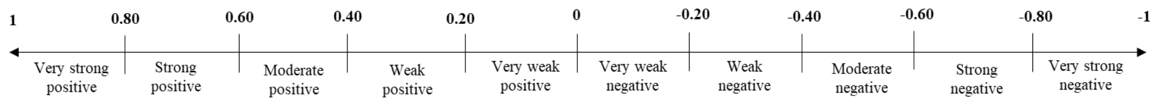


Figure 2. 12 Index of correlation coefficient

$$\rho_{xy} \frac{\text{Cov }(x,y)}{\sigma_x \sigma_y}$$ *Equation 2. 9*

Where ρ_{xy} is the correlation coefficient based on Pearson product moment. $Cov\ (x, y)$ is the covariance of variable x and y, and σ is the standard deviation. The first stage is to analyses the similarity of CO_2 dispersion in study area without trees and without tree. This stage uses 8 data (N) of CO_2 dispersion in different altitude (Table 2.6), which is 1.8 meters until 12 meters. The result shows in *Table 2.7,* where the correlation coefficient is 0.965.

The value of coefficient correlation indicates that the CO_2 dispersion between study area with trees and without trees study have strong correlation. It indicates that differences of physical environment condition at various heights do not affect the distribution of CO_2 in both study area. So, it can be justified that trees can decrease CO_2 dispersion.

Table 2. 6 CO2 dispersion at various altitude

Altitude (N)	CO_2 dispersion (%)	
	Study area with trees	Study area without trees
1.8 meters	10.2	19.2
2.4 meters	9.2	18.3
3.6 meters	8.4	17.4
4.8 meters	7.7	15.7
6 meters	7.2	14.1
7.2 meters	6.6	12.3
8.4 meters	6.3	10.7
12 meters	5.5	7.8

Table 2. 7 Correlation of CO_2 dispersion in study area with trees and without trees

		CO2 dispersion in the study area with trees at different altitude	CO2 dispersion in the study area without trees at different altitude
CO2 dispersion in the study area with trees at different altitude	Pearson Correlation	1	**,965****
	N	8	8
CO2 dispersion in the study area without trees at different altitude	Pearson Correlation	**,965****	1
	N	8	8

Meanwhile, table 2.8 shows the CO_2 concentration in the study area of this research. This step will analyze the similarity of that CO_2 concentration on the road and roadside in both study area, which is study area with trees and without trees. N refers to number of sample of CO_2 concentration. This research use five sample of CO_2 concentration in different distance of study area.

Table 2. 8 CO_2 concentration at an altitude of 1 meter in various distance of study area

Distance (N)	CO2 concentration (%) in the study area with trees			CO2 concentration in the study area without trees		
	road	left of roadside	right of roadside	road	left of roadside	right of roadside
20 m	0.49	0	0	0.2	0.02	0.01
40 m	0.56	0.3	0.03	0.59	0.2	0.05
60 m	0.6	0.42	0.1	0.68	0.2	0.15
80 m	0.65	0.1	0.2	0.7	0.28	0.18
100 m	0.68	0	0.5	0.71	0.2	0.23

Table 2. 9 Coefficient correlation of CO_2 concentration in study area with trees

		CO2 concentration on the road	CO2 concentration on the left side	CO2 concentration on the right side
CO2 concentration on the road	Pearson Correlation	1	**-.066**	**.860**
	Sig. (2-tailed)		.916	.062
	N	5	5	5
CO2 concentration on the left side	Pearson Correlation	-.066	1	**-.428**
	Sig. (2-tailed)	.916		.472
	N	5	5	5
CO2 concentration on the righ tside	Pearson Correlation	.860	-.428	1
	Sig. (2-tailed)	.062	.472	
	N	5	5	5

Table 2. 10 Coefficient correlation of CO2 concentration in study area without trees

		CO2 concentration on the road	CO2 concentration on the left side	CO2 concentration on the righ tside
CO2 concentration on the road	Pearson Correlation	1	.939*	.832
	Sig. (2-tailed)		.018	.080
	N	5	5	5
CO2 concentration on the left side	Pearson Correlation	.939*	1	.712

	Sig. (2-tailed)	.018		.177
	N	5	5	5
CO2 concentration on the right side	Pearson Correlation	.832	.712	1
	Sig. (2-tailed)	.080	.177	
	N	5	5	5

*. Correlation is significant at the 0.05 level (2-tailed).

Based on this result, the coefficient correlation of CO_2 concentration in the study area with trees shows the various result. CO_2 concentration has a strong correlation between the right side and the road. But it has a weak and very weak correlation between the left side and road, the left side and right side. On the other side, the coefficient correlation in the study area without trees show a strong correlation among CO_2 concentration in the road, left side, and right side.

Based on that similarity analysis, CO_2 concentration in the study area can change according to the physical condition, such as trees planting conditions. Hence, it is important to observe in detail the tree planting design to reduce the increase in CO_2 concentration around the road.

2.4 Conclusion of chapter 2

This research evaluates the CO2 dispersion in the study area with trees and without trees. There are some conclusions from this research. The first conclusion that study area with trees can decrease CO2 dispersion at many different altitudes. The value of CO2 dispersion in the study area with trees is lower than the area without trees. In the altitude 1.8 meters, trees can disperse 9% (9000 ppm) of CO2, while area without trees can distribute CO2 emission by 19.2% (19200 ppm). This result is supported by the validation analysis using correlation analysis. The coefficient correlation is 0.965, which is a strong correlation. So, it can be justified that trees can decrease CO2 dispersion. So, it is important to plant the trees on the roadside to decreasing CO2 dispersion in the air.

Meanwhile, there are differences in the conclusion of CO2 concentration on the road and roadside. The study area with trees indicates the lower CO2 concentration on the road than the study area without the tree. But, the study area with trees indicates higher CO2 concentration on the roadside than study area without trees. The validation process in the study area without trees shows a strong correlation. It is mean that CO2 concentration on the road, left side, and the right side has similarities of concentration in the various distance.

Meanwhile, CO2 concentration in the study area with trees shows a weak correlation. CO2 concentration on the left of the roadside has a weak correlation with CO2 concentration on the road and right side. It's mean that the value of CO2 concentration in the road, left side and right side have low similarity in various distance. It indicates that CO2 concentration can change according to the physical condition, such as trees planting conditions. So, this validation proves that planting trees does not always increase concentration on the side of the road and decrease concentration on the road. Hence, it is important to observe in detail the tree planting design to reduce the increase in CO2 concentration around the road.

Chapter 3. How the position of trees planting can influence the road-air quality from CO_2 emission from transportation

3.1 Introduction

This research focuses on analyzing the impact of the position of trees planting on the CO_2 dispersion to be consideration trees planting guidelines from an environmental-friendly view. The tree is an essential element in the design of the urban roadside. Trees planted on the roadside are not only for an urban aesthetic but also can give some advantage to the pedestrian because it can control the quality of the environment.

It is common knowledge that urban air quality is getting worse because of the increasing number of motorized vehicles. Gasoline and diesel as fuel usage for the motor vehicle are the primary CO_2 source in the air. The high CO_2 concentrations can give disadvantage to environmental quality. It can indicate poor air quality in the area, and it is not suitable for human health. The Wisconsin Department of health service (2019) showed that 0.1%-0.2% (1,000-2,000 ppm) of CO_2 concentration indicates poor air quality. Meanwhile, it can influence human health in the CO_2 level by 0.2%-0.5% (2,000-5,000 ppm).

Therefore, the existence of the tree on the roadside be a solver for that problem. Trees can influence the emission concentration emitted from transportation (Gromke and Ruck, 2010; Šíp and Beneš, 2016; Jeanjean *et al.*, 2015). Roadside with trees proved can decrease the CO_2 concentration (Jeanjean *et al.*, 2015; Aini and Shen, 2019). There is some position of trees planting on the roadside. (Morakinyo and Lam, 2016) divide the location of trees planting based on the number of the trees row, which is a double row and one row. Double row position shows that trees are planted on the left and right of roadside, while one row commonly plans the trees in the middle of the road.

In reality, there is some position of the trees row that can be found on the road. Surabaya city, as a study case in this research, has some position of the trees planting. It because there is no detailed guideline for the position of the trees planting that considers air quality for environmental-friendly view. Whereas, the position of the tree is very important so that the road that is passed by the pedestrian can have good air quality.

3.2 Method

3.2.1 Research Area

The research area for this study is Surabaya City in Indonesia. Surabaya, as a metropolitan city, has some roads which chronic congestion. This study chooses the road, namely Panglima Sudirman (*Figure 3.1*), as a road with high traffic jams. In this road, the researcher conducted the observation to calculate the number of the motor vehicle. This value will be used as basic data to calculate the amount of CO_2 emissions that will be simulated in this study. This research also creates the physical environment according to the real condition of this research area. There is the road, roadside, and the building. This study chooses 400 km of road as a study area with various building height and building layout. The wide of the road is 18 m, and the wide of the roadside is 6 m.

Meanwhile, for the position of the trees, this study considers some trees planting position in some road of Surabaya City. *Figure 3.2* shows the location of the trees planting that will simulate in this research. There is four research area based on different trees planting pattern. So, it will be known which position of the trees that have the biggest impact in the dispersing of CO_2 emitted from transportation.

Figure 3. 1 Location of Research Area

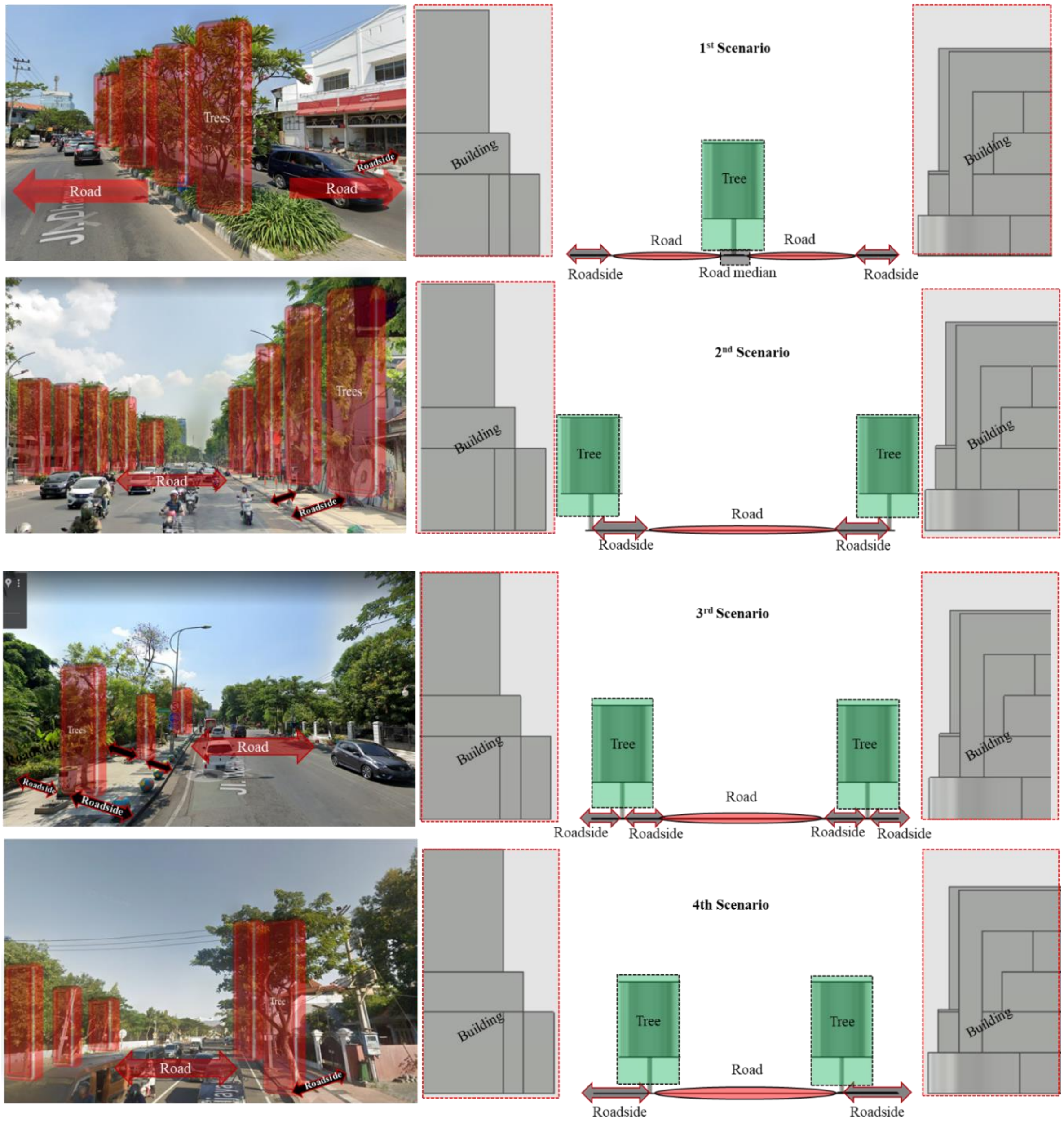


Figure 3. 2 The position of trees planting in Surabaya city.

3.2.2 CO_2 emission calculation

This study can be counted using a CO_2 emission analysis. The following equation will be used to get the total CO_2 emission from transportation while one hour (AEA, 2012; Hidayat, 2013).

$$CO_2\ emission = vol\ \left({}^{unit}/_{hour}\right) \times\ street\ (km) \times\ emission\ factors\left({}^{gCO_2}/_{km}\right) \qquad \text{Equation 3. 1}$$

The CO_2 emission from that equation will be used in the simulation as CO_2 sources in the mass flow rate. There are some data that we must prepare before calculation. The first data is the volume of the vehicle. This data gets from a survey that already done in the study area. The observation was done three times a day in the weekday and weekend. Three times show the peak hour in the study area, which is in the morning, noon, and afternoon. The second data is the length of the road that wants to analyze. Then the last data is the emission factor. This emission factor has a different value according to the classification of transportation. This following table shows the emission factor used in this research (AEA, 2012)

Table 3. 1 Vehicle emission factor

Transportation classification	Definition	Average emissions ($kgCO_2/km$)
Small car	Small petrol car, up to the 1.4-liter engine	0.16442
Medium car	Medium diesel car, from 1.7 to 2.0 liter	0.17573
Large Car	Large diesel car, over 2.0 liter	0.23381
Motorcycle	Small petrol motorbike (mopeds/scooters)	0.08499

3.2.3 Pre-processing in CFD Simulation

The next step for the simulation is pre-processing. There are some stages in this part and will be explained in the following section.

3.2.3.1 The geometry of 3D modeling

According to the position of trees row, this study creates four geometry of 3D modeling. These models were built using sim studio tools from Autodesk. 1^{st} scenario has a one-row position, and trees are planted in the middle of the road. 2^{nd} scenario is the double-row position. The trees are planted in both of roadside as a barrier between roadside and building. 3^{rd} scenario also has a double-row position. Trees are planted in the middle of the roadside. Then the last scenario has a double row position that trees are planted as a barrier between road and roadside.

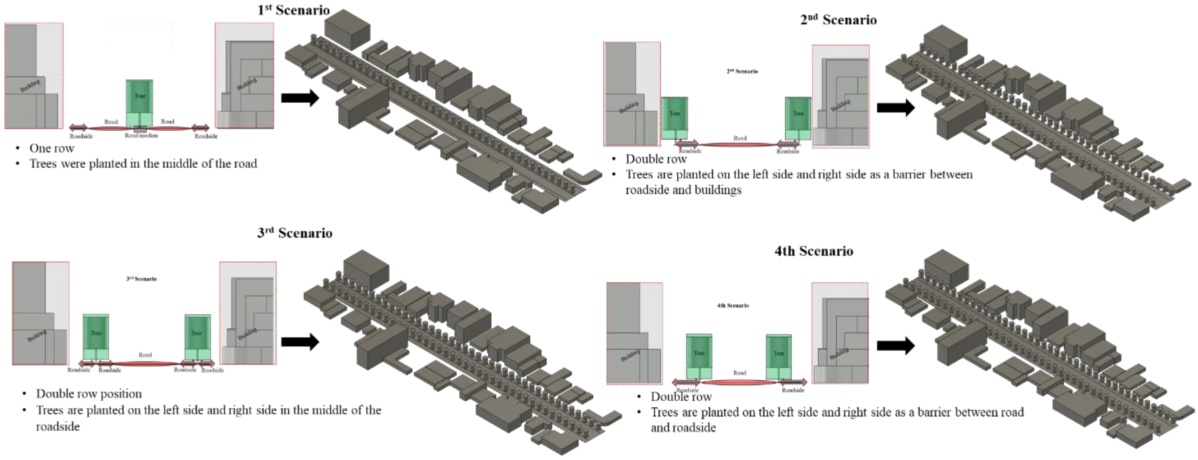


Figure 3. 3 The geometry of 3D modeling.

3.2.3.2 Computational domain

The computational domain is made simple the physical domain both in the form of geometrical representation in domain size and boundary condition for that domain. Hence, this part will maintain all of the important physical features of the problem but can ignore small details (Li, 2008).

The first step in the computational domain is determining the domain size. This research use domain size according to the previous study by Franke et al. (2004, 2007). This domain is appropriate to use in urban studies, especially in the street canyon. Based on that domain size, the inlet and the lateral in urban area simulation have to positioned 5Hmax from the building. The outflow boundary should be a minimum of 15 Hmax away from the building. The top boundary at least 5Hmax away from the building. Hmax is the size of the tallest building in the modeling. Domain size in this research shows in Figure 3.4

The second step in the computational domain is assigning the boundary condition. There are the inlet, outlet, lateral, and top boundary. For the top and lateral conditions, it will be assigned as the slip/symmetry boundary. It will cause the fluid to flow along a wall instead of stopping at the wall. It typically occurs along a wall. Then outflow/outlet condition is a static pressure with a value of 0. Then the last surface is the inlet. The inlet of this research comes from 2 sources, which are the source of wind and CO_2 (*Figure 3.4*)

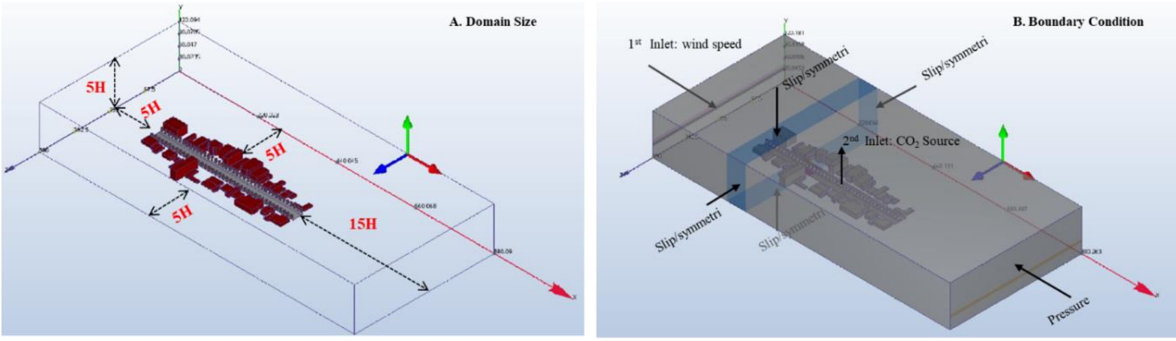


Figure 3. 4 Computational Domain

3.2.3.3 Fluid characteristic

This part is the same as the previous chapter that there is a different density between air and CO_2. The density of air (ρ_A) is 1.2047 e-6 g/mm^3, and the density of carbon dioxide (ρ_B) is 1.773e-6 g/mm^3. So that, it needs the scalar mixing analysis to mix this fluid. The formula of scalar mixing analysis displays in equation 3.3

$$J_A = -\rho D_{AB} \nabla m_A$$ *Equation 3. 2*

Where:

J_A is the mass flux of air.

ρ_{AB} is mass density

D_{AB} is the diffusion of scalar quantities based on Fick's Law

∇m_A is the gradient (∇)of the species mass fraction.

3.2.3.4 Mesh Sizing

The last stage in the pre-processing part in CFD simulation is mesh sizing. The shape of mesh sizing in this research is tetrahedral that have a four side with a triangular-faced element. The following figure shows the mesh sizing in four scenarios of trees planting position.

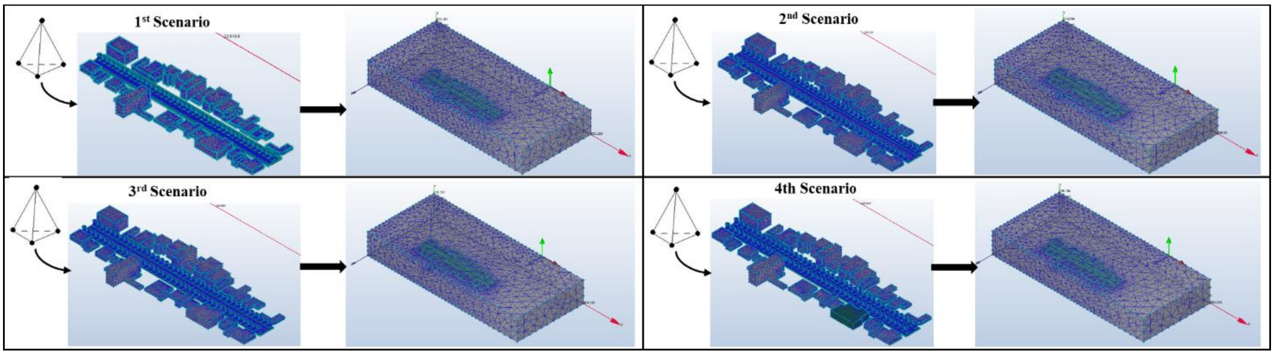


Figure 3.5 Mesh Sizing

3.2.4 Solving in CFD Simulation

The Navier-Stokes equations (NSE) describe the movements of fluids (air and CO2). Air movement in this research is assumed steady condition, not compressed (incompressible), and density (ρ) constant. This research will simulate the CO2 dispersion in different position of trees row, so the airflow is assumed turbulent.
Accordingly, equation 3.4 is formula to calculate the conservation of mass

$$\frac{\partial_\rho}{\partial_t} + \nabla.(\rho.u) = 0$$

Equation 3. 3

Where $\frac{\partial_\rho}{\partial_t}$ present the partial derivative of ρ with respect to t. ρ itself is density, and t is time. Then, ∇ (Tensor gradient) display the stress variable based on Galilean invariant. While, u is the flow velocity.
The Navier-Stokes Equations also provide calculation for conservation of momentum that displayed in this following equation.

x-component: $$\frac{\partial(\rho.u)}{\partial t} + \nabla.(\rho.u.u) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}\rho.g_x$$

Equation 3. 4

y-component: : $$\frac{\partial(\rho.v)}{\partial t} + \nabla.(\rho.v.u) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z}\rho.g_y$$

Equation 3. 5

z-component: : $$\frac{\partial(\rho.w)}{\partial t} + \nabla.(\rho.w.u) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\rho.g_z$$

Equation 3. 6

where ρ is the density, u is the flow velocity, ∇ divergence, p is the pressure, t is time, τ is the deviatoric stress tensor and g represents body accelerations acting on the continuum, for example gravity, inertial accelerations, electrostatic accelerations, and so on, In the other side, the Navier–Stokes equations have limitations for describing turbulent flows. The limitations with the time-averaged RANS equation is the introduction of the Reynolds stress term, which accounts for turbulent fluctuations. Hence, the CFD model for turbulent kinetic energy using K-ϵ model equation. This K-ϵ model equation has two-equation to calculate the turbulent kinetic energy. *Equation 3.8* is calculation for turbulent kinetic energy (k)., while *Equation 3.9* is formula for calculate the dissipation of turbulent kinetic enegry ε

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij} E_{ij} - \rho\varepsilon$$

Equation 3. 7

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k} 2\mu_t E_{ij} E_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$

Equation 3. 8

Generally, the explanation of these equation is:

Rate of change of k or ε in time + Transport of k or ε by advection = Transport of k or ε by diffusion + Rate of production of k or ε – rate of destruction of k or ε

Where ρ is the fluid density ($kg\, m^{-3}$), u is the fluid velocity ($m\, s^{-1}$). i represent x and j represent x,y, and z (coordinate geometry in boundary). u_i represents the velocity component in the corresponding direction. E_{ij} represents the component of the rate of deformation. μ_t represents turbulent viscosity which is $\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$. Based on that, the equation has some standard constant that should be divided. There are σ_k, σ_ε, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and C_μ. The value of standard constants are followed:

$\sigma_k = 1.00$ $\sigma_\varepsilon = 1.30$ $C_{1\varepsilon} = 1.44$ $C_{2\varepsilon} = 1.92$ $C_\mu = 0.09$

3.3 Result

3.3.1 Identification of CO_2 emission in the research area

This research calculates the CO_2 emission based on the type of transportation classification. This classification, according to the fuel usage that can emit CO_2 emission. The following table shows the average number of vehicles in the study area. Based on that table, people in Indonesia prefer to use motor vehicles on the road. Motorcycle has the highest number than other transportation classification. The total number can reach

6814 units in one hour. The total unit of the motor vehicle in the study area is 9380. This number will be calculated and displayed in *Table 3.2.*

Table 3. 2 The daily average of motor-vehicle number

Number	Type of motor vehicle	Total (Unit/Hour)	Classification	Total (unit/hour)
1	Private car	2050	Small car	2161
2	Public Transportation	111		
3	Mini Bus	233	Medium car	400
4	Pick Up / Box	1		
5	Mini Trucks	166		
6	Big bus	3	Large Car	5
7	Truck 2 axis	1		
8	Truk 3 axis	1		
9	Motorcycle	6814	Motorcycle	6814
TOTAL	9380		9380	

Table 3. 3 CO2 emission

Number	Type of motor vehicle	Total (Unit/Hour)	Road (km)	Emission factor	CO2 emission
1	Private car	2050	0.4	0.16442	134.8
2	Public Transportation	111	0.4	0.16442	7.3
3	Mini Bus	1	0.4	0.17573	0.1
4	Pick Up / Box	233	0.4	0.17573	16.4
5	Mini Trucks	166	0.4	0.17573	11.7
6	Big bus	3	0.4	0.23381	0.3
7	Truck	2	0.4	0.23381	0.2
8	Motorcycle	6814	0.4	0.08499	231.6
Total of CO2 emission			402.4		

According to *Table 3.2*, the CO_2 emission from transportation that can spread is 402.4 kg/hour. This value will be input in the simulation to analyze the spread of CO_2 in some position trees planting. This result of this step explained in the next section, so it can be known which position of trees planting patterns that have the biggest impact in decreasing CO_2 concentration.

3.3.2 CO_2 dispersion at various altitude in some position of trees planting pattern

This section shows the result of CO_2 dispersion in four scenario of trees planting positions at various altitude. There are four scenarios of tree planting position analyzed in this study. 1st scenario has one-row trees planting, while others scenario has the double-row position of trees planting. In the 1st scenario, trees are planted in the middle of the road. In the 2nd scenario, trees are planted on the roadside as a barrier between roadside and building. It is the same with the 3rd scenario and 4th scenario that trees are planted on the roadside. But trees are planted in the middle on the roadside in 3rd scenario. Whereas trees are planted as a barrier between road and roadside in the 4th scenario.

Figure 3.6 displays CO_2 dispersion at an altitude 1.8 meter in four scenarios. This figure shows a comparison of CO_2 distribution at different altitudes. The color of the scalar indicates CO_2 concentration. The red color shows the area that has 100% CO_2 dispersion emitted from transportation, and the blue one indicates that the area is not affected by CO_2 emission (0% of CO_2). Based on that figure, 1st scenario and 2nd scenario have the highest CO_2 dispersion. 46.2% CO_2 disperse in the 1st scenario, and 47% CO_2 can disperse in 2nd scenario. Meanwhile, 3rd scenario and 4th scenario have lower CO_2 concentration than others scenario. 3rd scenario can disperse 41.7% of CO_2 concentration. This value shows a decrease of 6.2% from the 2nd scenario. Then, the most effective in decreasing CO_2 dispersion is the 4th scenario. This scenario has the lowest CO_2 dispersion, which is 33.1%. It indicates that this position can reduce 13.9% of CO_2 dispersion compare with the 2nd scenario. Consideration of the validation data, so the result of CO_2 distribution also shows at different altitudes in the next figure.

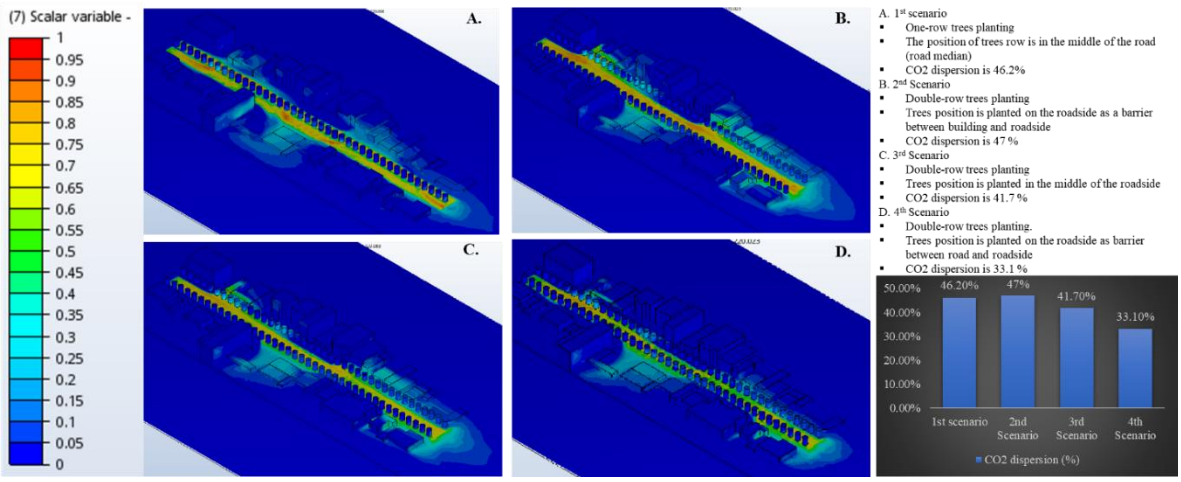


Figure 3. 6 CO_2 dispersion at an altitude of 1.8 meter

Figure 3.7 displays the CO_2 dispersion in another altitude, which is at an altitude of 6 meters. While in the previous elevation, the height is identical with the height of trees trunk. There are little different outcome with earlier results at an altitude of 1.8 meters. Firstly, it will show the similarity of the result. The tree's position that can disperse better among other locations in the 4th scenario and the bad position in dispersing CO_2 emission is the 2nd scenario. In the 4th scenario, CO_2 disperse by 7.5%, then 17% of CO_2 emission disperse in the 2nd scenario. This result indicates that the 4th scenario can decrease of CO_2 emission by 10.5%. This result is the same as the CO_2 dispersion at an altitude of 1.8 meters, which is the 4th scenario as the best tree's position in CO_2 distribution, then the 2nd scenario as the worst position in the CO_2 dispersion.

Meanwhile, there is a difference in the 2nd and 3rd positions of trees planting. At an altitude of 6 m, 3rd scenario has CO2 concentration higher than the 2nd scenario. 2nd scenario has 13.1% of CO_2 dispersion, and the 1st scenario has 12.5% of CO_2 dispersion.

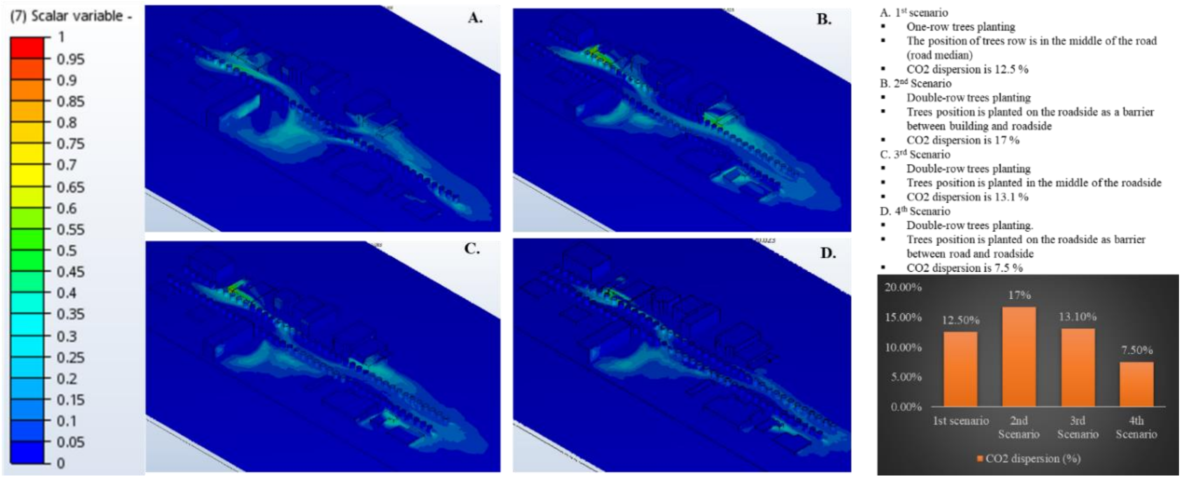


Figure 3. 7 *CO_2 dispersion at an altitude of 6 meter*

Figure 3.8 displays the CO_2 dispersion at a higher altitude than the previous figure, which is 9.6 meters. In this elevation, the CO_2 distribution becomes lower than the previous altitude. Because the distance from the source of CO_2 emission is farther than the last altitude, according to this result, it can indicate that the 4th scenario still has the lowest CO_2 dispersion than other scenarios. Then 2nd scenario is the position of trees planting that has the highest CO_2 concentration. This result is the same with CO2 dispersion in previous altitude.

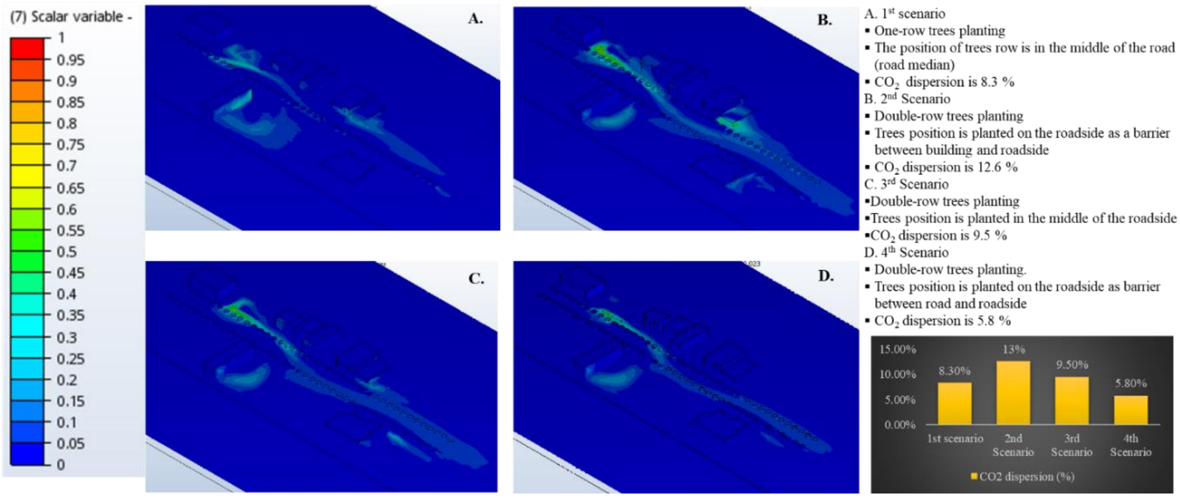


Figure 3. 8 *CO_2 dispersion at an altitude of 9.6 meter*

The CO2 dispersion in another various altitudes is described in the following table and figure. Accordingly, scenario 2 has the highest CO_2 concentration. 47% of CO_2 distribute in the modeling at an altitude of 1.8 meters. It also happens at another altitude. At an altitude 12 meters, CO_2 distribute by 10.2%, while other scenarios have CO_2 dispersion below that value. On the other side, the following scenario that has high CO_2 dispersion is scenario one. This scenario has high CO_2 dispersion at an altitude of 1.8- 4 meters. After that, at an altitude of 4-12 meters, scenario 3 has a high CO_2 concentration more than scenario 2.

Among the four scenarios, scenario four, which is trees, are planted on the roadside as a barrier between road and roadside, has the lowest CO_2 dispersion than others scenario. Scenario four can disperse 33.1% of CO_2 emission at an altitude 1.8 meters. It's mean that this position of trees planting can decrease CO_2 dispersion of 13.1%.

Table 3. 4 CO_2 Dispersion in different position trees planting based on the different altitude of the modeling

Position of trees planting	CO_2 dispersion at different altitude (%)										
	1.8 m	2.4 m	3 m	3.6 m	4.8 m	6 m	7.2 m	8.4 m	9.6 m	10.8 m	12 m
scenario 1	46.2	31.1	24.5	19.2	14.5	12.5	10.3	9.1	8.3	7.5	6.9
scenario 2	47.0	32.8	27.7	23.1	19.5	16.7	14.5	13.4	12.6	11.1	10.2
scenario 3	41.7	25.4	21.6	18.2	15.5	13.1	11.2	10.2	9.5	8.5	8.0
scenario 4	33.1	19.2	14.7	12.6	10.1	7.5	6.6	6.2	5.8	5.5	5.7

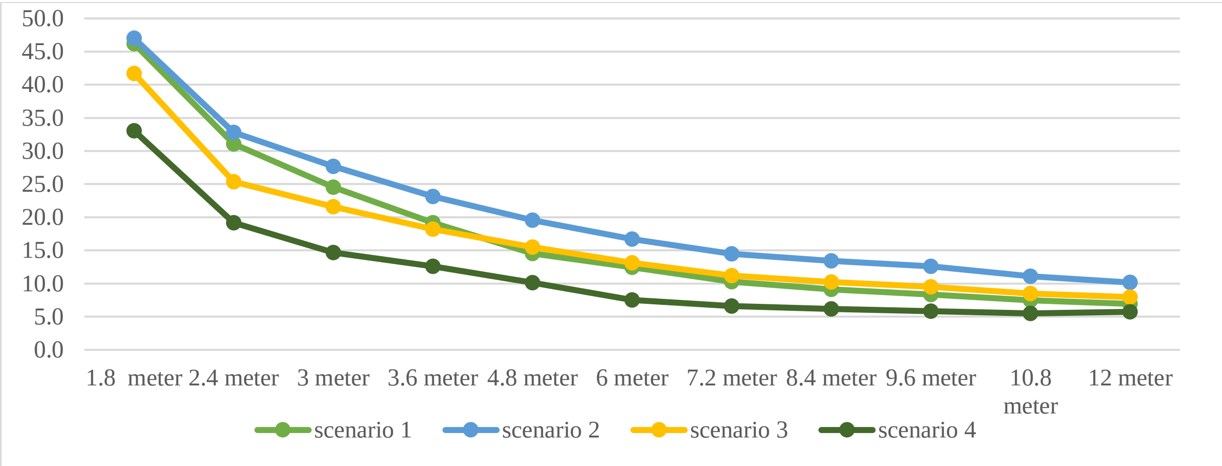


Figure 3. 9 Comparison of the dispersion of CO_2 in every position of trees planting

3.3.3 Tree's row position impact on CO_2 dispersion and CO_2 concentration.

This section shows the influence of tree's row position to the CO_2 dispersion and CO_2 concentrations. The visualization of CO2 distribution and CO_2 concentrations in four scenarios are displayed by wall that have distance 436 meters from the wind source (*Figure 3.10*). Therefore, the effect of the tree's planting position in CO_2 dispersion and CO_2 concentration can be known (*Figure 3.11*) This figure shows that trees planting in the 1st, 2^{nd,} and 3rd scenarios can spread CO_2 to the roadside and road easily. Whereas in the 4th scenario, the position of the trees planting can withstand the distribution of CO_2 to the roadside. This value can be seen in *Figure 3.12*. This figure indicates that the lowest CO_2 dispersion on the wall is in the 4th scenario. It has value 0.16% of CO2 dispersion. On the other side, the highest CO_2 dispersion is 2nd scenario, which is 0.44%. The 3rd scenario also has high CO_2 dispersion by 0.43%.

Moreover, the CO_2 concentration on the 4th scenario is the lowest than other scenarios. It starts from 0-0.04% (0-400 ppm). Meanwhile, CO_2 concentration in the 2nd and 3rd positions reach 0-0.09% (0-900 ppm) and 0-0.11% (0-1100 ppm). Therefore, the tree's position as a barrier between road and roadside is appropriately decreasing the distribution of CO_2 emission. Accordingly, the next section will explain the air quality among the four scenarios, so it can be known which scenario that can control the air quality.

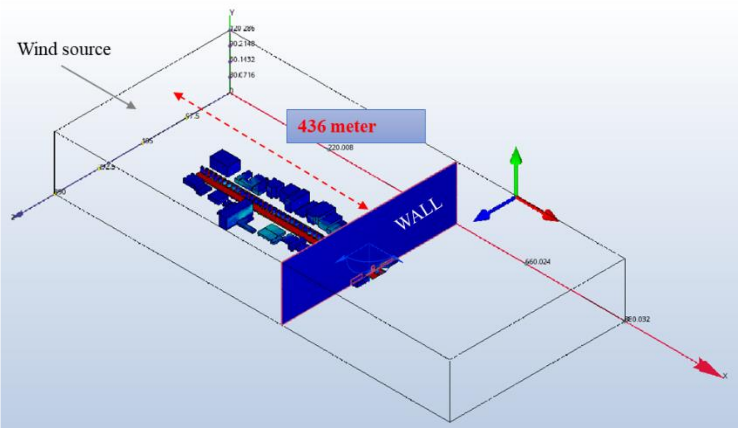


Figure 3. 10 The location of the Wall

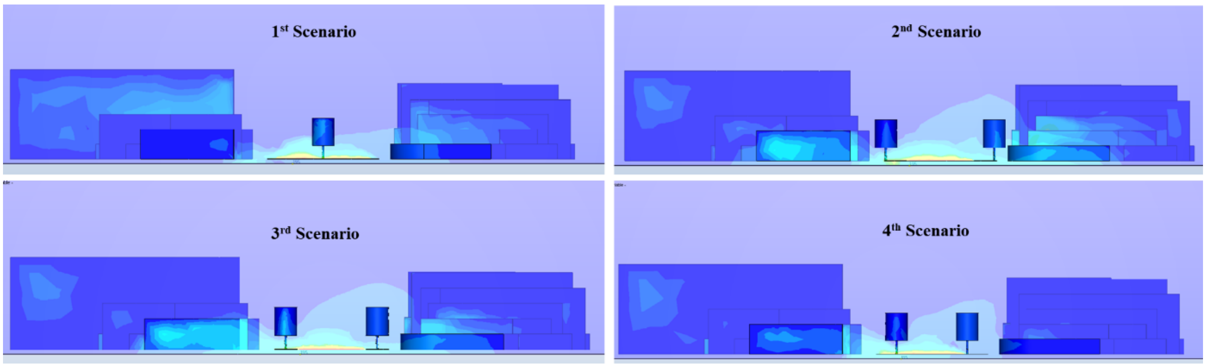


Figure 3. 11 The effect of the tree's position to CO2 dispersion

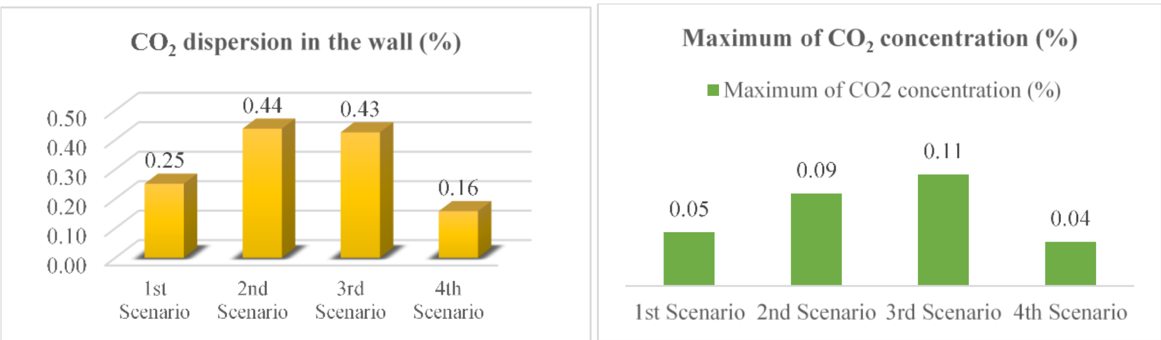


Figure 3. 12 CO_2 dispersion and CO_2 concentration on the wall

3.3.4 The impact of tree's row position on level air quality

This section shows the analyses of air quality in different tree's row position. Air quality is indicated by CO_2 concentration in the study area. This analysis use standard from Wisconsin Department of health service (2019). *Table 3.5.* shows the level of air quality. Scenario 4 has the highest good level air quality than other scenarios, which is 92.4% good air quality. While, scenario that has lower percentage of good air quality is 2nd scenario, which is 89.1%. Then 1st and 3rd scenario has similar value of good air quality in outdoor.

On the other side, the scenario that has lower percentage of poor air quality is 4th scenario. This scenario only has 6% area that has poor air quality. While, poor air quality in 2nd scenario is 9%, which is the highest area than other scenario.

Table 3. 5 Level of air quality

The standard of CO_2 concentration in the air		CO2 level (%)			
Level of air quality	CO2 concentration	1st scenario	2nd scenario	3rd scenario	4th scenario
Good air quality (Normal background concentration in outdoor ambient air)	>0.04% (400 ppm)	90.5	89.1	90.2	92.4
Good air quality (minimal CO2 concentrations in indoor spaces) exchange	0.04%-0.1% (400-1,000ppm)	1.4	1.5	1.1	1.3
Poor air quality (Complaints of drowsiness and poor air)	0.1%-0.2% (1,000-2,000 ppm)	3.2	2.5	2.7	1.6
Poor air quality (Headaches, sleepiness and stagnant, stale, stuffy air. Poor concentration, loss of attention, increased heart rate, and slight nausea may also be present.	0.2%-0.5% (2,000-5,000 ppm)	5.0	6.9	6.0	4.7

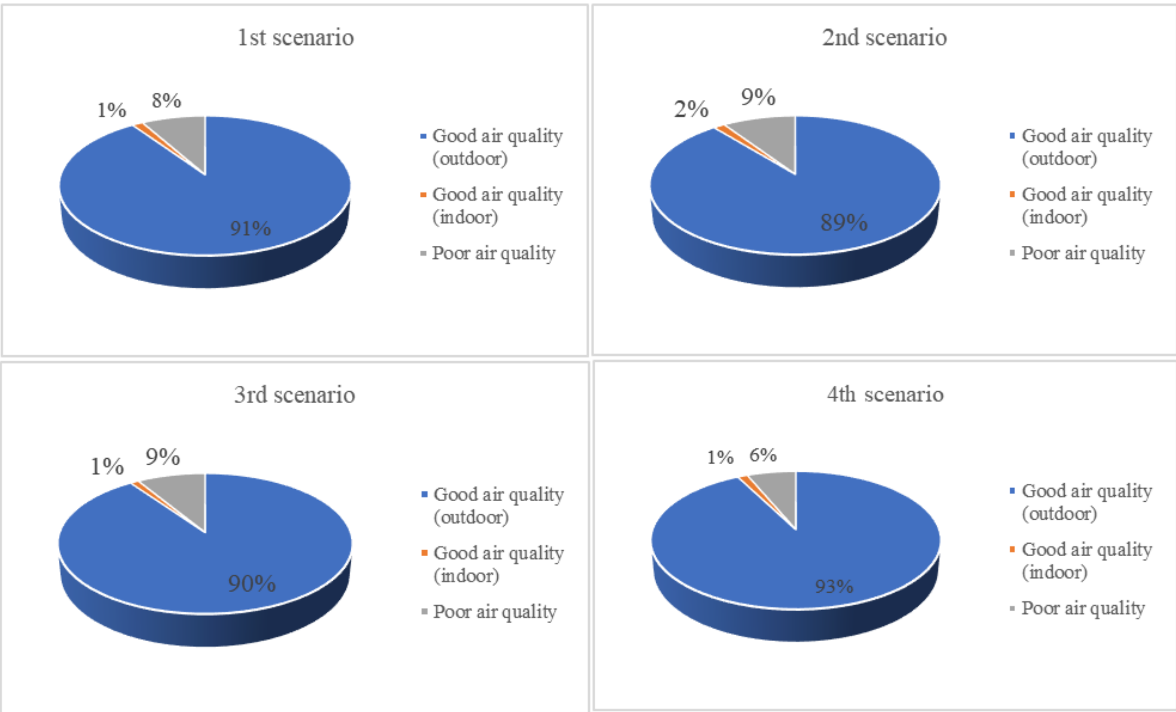


Figure 3. 13 Comparison of Level of air quality in every scenario

3.3.5 Validation using similarity analysis

This step is a validation process for the result. Similarity analysis using coefficient correlation analysis is used in this stage. The value of the correlation coefficient has a range between -1 until +1. The index of coefficient correlation is displayed in *Figure 2.12.* The equation used in this research is shown in *equation 3.9.* This research uses SPSS software to calculate correlation analyses.

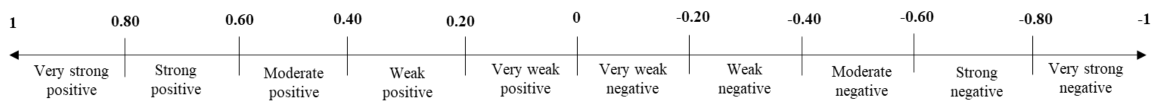


Figure 2. 13 Index of the correlation coefficient

$$\rho_{xy} \frac{\text{Cov } (x,y)}{\sigma_x \sigma_y}$$ *Equation 3. 9*

Where ρ_{xy} is the correlation coefficient based on Pearson product moment. $Cov\ (x, y)$ is the covariance of variable x and y, and σ is the standard deviation. There are two stages of the validation process in this chapter. The first is the similarity of CO2 dispersion among the four scenarios (*Table 3*.6). Then, similarity analysis of air quality among the four scenarios. The first stage uses 11 (N) samples of CO2 dispersion at different altitudes, whereas the second analysis using four samples of air quality, which are good air quality in outdoor, indoor, poor air quality, and poor air quality that have an impact to human health.

Based on *Table 3.6,* CO_2 dispersion in four scenarios shows a strong correlation. It is mean that CO_2 dispersion has similarities among the 1st Scenario, 2nd scenario, 3rd scenario, and 4th scenario. Moreover, the similarity analysis of air quality in four scenarios also shows a strong correlation (*Table 3.7).* Then this value proves that the simulation results in the previous stage has a valid result because the distribution of CO_2 in all scenarios have a strong correlation.

Table 3. 6 Coefficient correlation of CO_2 dispersion

		CO2 dispersion in Scenario 1	CO2 dispersion in Scenario 2	CO2 dispersion in Scenario 3	CO2 dispersion in Scenario 4
CO2 dispersion in Scenario 1	Pearson Correlation	1	.998**	.995**	.991**
	Sig. (2-tailed)		.000	.000	.000
	N	11	11	11	11
	Pearson Correlation	.998**	1	.995**	.988**

CO2 dispersion in Scenario 2	Sig. (2-tailed)	.000		.000	.000
	N	11	11	11	11
CO2 dispersion in Scenario 3	Pearson Correlation	.995**	.995**	1	.996**
	Sig. (2-tailed)	.000	.000		.000
	N	11	11	11	11
CO2 dispersion in Scenario 4	Pearson Correlation	.991**	.988**	.996**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	11	11	11	11

**. Correlation is significant at the 0.01 level (2-tailed).

Table 3. 7 Coefficient correlation of Air quality

Correlations

		Air quality in the 1st scenario	Air quality in the 2nd scenario	Air quality in the 3rd scenario	Air quality in the 4th scenario
Air quality in the 1st scenario	Pearson Correlation	1	1.000**	1.000**	1.000**
	Sig. (2-tailed)		.000	.000	.000
	N	4	4	4	4
Air quality in the 2nd scenario	Pearson Correlation	1.000**	1	1.000**	1.000**
	Sig. (2-tailed)	.000		.000	.000
	N	4	4	4	4
Air quality in the 3rd scenario	Pearson Correlation	1.000**	1.000**	1	1.000**
	Sig. (2-tailed)	.000	.000		.000
	N	4	4	4	4
Air quality in the 4th scenario	Pearson Correlation	1.000**	1.000**	1.000**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	4	4	4	4

**. Correlation is significant at the 0.01 level (2-tailed).

3.4 Conclusion

This research aims to evaluate the row position of trees planting to the road-air quality exposed to CO_2 emission from vehicle. The result proved that the position of trees influences the air quality from CO2 dispersion and high CO2 concentration. There are four positions of trees planting in the study area. The conclusion shows that the 4th scenario is better in improving air quality. This scenario plants the trees in the double-row position as a barrier between roadside and road. Scenario four with that position indicates the lowest CO2 emission dispersion than other positions of trees planting patterns. This position can decrease CO2 emission by 13.1% compared with the highest CO2 dispersion in other positions. Moreover, this modeling has the highest level of good air quality and the lowest level of poor air quality. Level of good air quality in 4th scenario is 93% and only 6% area that has poor air quality.

This result is validated by similarity analysis. Coefficient correlation analysis using SPSS used to analyses the similarity of the CO2 dispersion and air quality level in these four scenarios. The result shows that CO2 dispersion in four scenarios shows a strong correlation. Then, another result also show that the similarity analysis of air quality in four scenarios has a strong correlation. It indicated that the result of CO_2 dispersion and air quality in these four scenarios has similarity. So it can justify that trees should be plant on the roadside as a barrier between road and roadside to decreasing CO_2 dispersion and control the air quality emitted from transportation.

Chapter 4. Design of trees planting pattern: Impacting to the road-air quality for pedestrian from CO2 dispersion emitted from transportation

4.1 Introduction

This research focuses on predicting the CO2 dispersion emitted from transportation based on design scenarios of trees planting patterns in a real 3D environment for considering a design guideline of tree planting from an environmental-friendly view. The urban area is currently facing a problem of declining air quality due to the increase of CO_2 concentration. High traffic volume on the road is a common problem in urban areas due to decreasing air quality. Transportation is one of the sources of CO_2 emission in the air. Gasoline and diesel usage for motor vehicle distribute 34% of the total CO_2 in the air every day (Sullivan *et al.*, 2004; Jie, 2011; EPA, 2016). Then areas close to CO_2 sources, which are road and roadsides, will be affected by this emission. Air quality in the area will be decreased because it has a high CO_2 concentration. Whereas this condition has a bad influence on human health, moreover the roadside is space for pedestrians who want to travel on walking. Therefore, the air quality in that area should be good that must have 025%-0.04% (250-400 ppm) of CO_2 concentration. If there is 0.1%-0.2% (1,000-2,000 ppm) of CO_2 concentration in that area, so the air quality is poor.

Trees planting on the roadside can be a solver to that problem. Based on previous research, trees proved have an impact on the dispersion of vehicle emission. However, there are different results of tree's impact on emission concentration. (Gromke and Ruck, 2010; Janhäll, 2015; Šíp and Beneš, 2016; displayed that tree can increase the level of emission concentration. Their research obtained by comparing the emission concentration in the study area without trees and with trees. Meanwhile, Jeanjean et al. (2015) showed that trees could reduce the level of emission concentration from road traffic at pedestrian height on average. The difference result is caused by the difference modeling that they used. (Gromke and Ruck, 2010; Janhäll, 2015; Šíp and Beneš, 2016; use the single building for the simulation, while Jeanjean et al. (2015) build the building based on the real case. The trees are planting on the modeling also different. They did not consider the character of trees and the design of trees planting patterns. Even though the design of trees also influences the dispersion.

Janhäll (2015) compared some previous research to review the effect of trees on urban air quality according to the pollutant dispersion. The result displayed that urban air quality depends on vegetation design. Tree planting patterns influence the airflow, then it will influence the pollutant dispersion. Therefore, the design of trees planting pattern is important to improve the air quality on the roadside that has high traffic volume. This research combines some component design of trees planting to analyze the impact of CO_2 dispersion.

The first component is the position of trees row. This component is related to the row number of trees planting in the research area. Single row and double row are a common position of trees planting on the pedestrian way (Morakinyo & Lam (2016). Another element is related to the crown position and volume, which is the avenue-tree layout. (Gromke and Ruck, 2007; Gromke and Blocken, 2015; Pretzsch *et al.*, 2015) proved that avenue-tree layout also influences the distribution of traffic pollutants. The last component that should be considered is trees spacing and row spacing. Nursery (1999) shows some rule to plant the trees in different spacing and row spacing on the large area. Accordingly, this research combines these components to create in some scenarios of trees planting patterns on the roadside with length 400 m and wide 6 m. These scenarios display different design trees planting pattern because it becomes essential to improving air quality from CO_2 dispersion on the roadside. The trees planting and the condition on environmental is created according to the real case where buildings are built with various layouts and heights, then trees are built with crowns and tree trunks. This research uses Computational Fluid Dynamics (CFD) to simulate the scenarios of trees planting design on the roadside and it will be discussed in the next section.

4.2 Method

4.2.1 Pre-processing in CFD analysis

4.2.1.1 Build Geometry formation

The first stage in CFD analyze is creating the geometry of 3D modelling. Sim Studio Tools software that belongs to Autodesk is used to create this modelling in this research. This study creates geometry formation use Sim Studio Tools software. 3D modeling in this research created according the real situation in the study area. One of the road in Surabaya city, namely is Panglima Sudirman street (*Figure 4.1***)** become research area in this study area. 400 m of this road is chosen because it has a high traffic volume. The motor vehicle number in that road is 8157 units/hour.

There is some elements must be consider to build in geometry formation such as buildings, trees, roads, and roadside. *Figure 4.2* displays the result of geometry formation with different layout, size, and height of building similar to reality. Then trees also modeled using the same canopy shape with trunk in some assumption (*Figure 4.2*.). The height of the tree (H) is 11 m which is the average height of the tree in the location. This study assumes the canopy base height of 1/3 the canopy top height (Jeanjean *et al.*, 2015; Xue and Li, 2017)

Figure 4. 1 Study Area

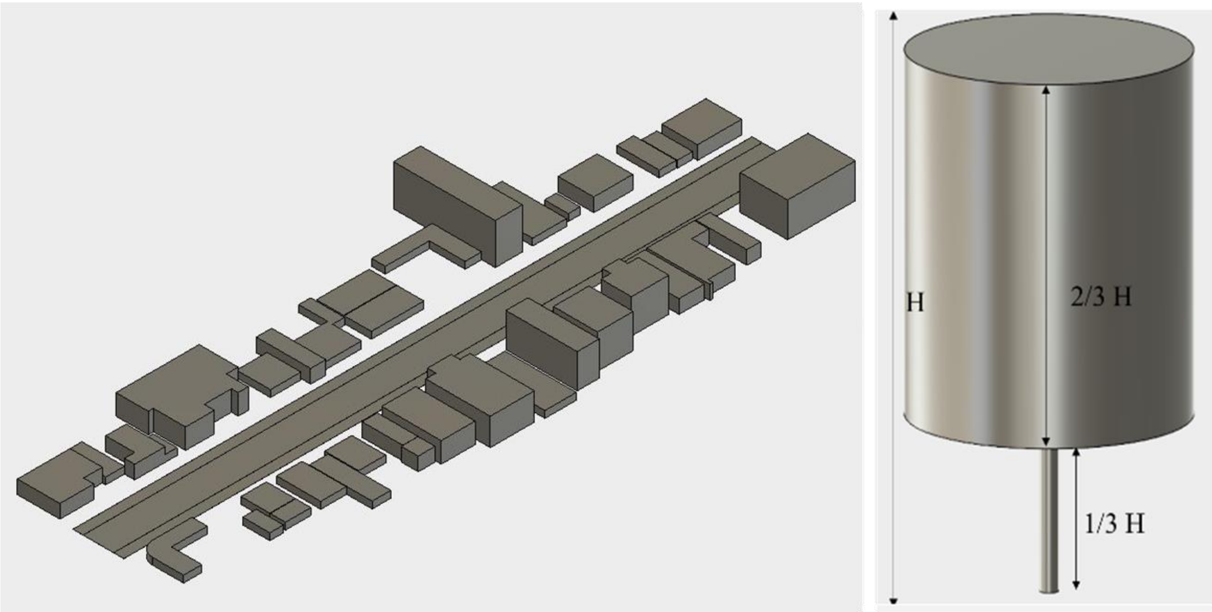


Figure 4. 2 Building and tree modeling in the study area
Source: Author, 2019

4.2.1.2 Determine Computational domain (domain size and boundary condition)

The next step is determining the computational domain. There is two part that must be created in this stage. There are domain size and the boundary condition. This research use domain size refers to size by (Franke *et al.*, 2004, 2007). (Revuz, Hargraves, & Owen, 2010; Revuz, Hargreaves, & Owen, 2012) also use this domain to simulate their research. This size is appropriate to simulate CFD in urban area or street canyon. So, that size is suitable for this research.

Based on that domain size, the inlet and lateral in urban area simulation should be positioned $5H_{max}$ from the building. Size minimum for top boundary is $5H_{max}$ away from the building. Then size for outflow must be a minimum of 15 H_{max} away from the building. H_{max} indicates the tallest building height in study area (figure 1).

Meanwhile for the boundary condition, there is some surface that must be determined, which are the inlet, outlet, lateral, and top boundary. Inlet is the source of fluid flow. 1st inlet is source for wind speed and 2nd inlet is the source of CO_2 emission. Lateral surface is assigned by the slip/symmetry condition. It causes the fluid to flow along a wall instead of stopping at the wall. It typically occurs along a wall. Another surface that must be determined is outflow. Outflow/outlet condition is a static, and there is no pressure in this part. The domain size and the boundary condition for this research displayed in this following figure.

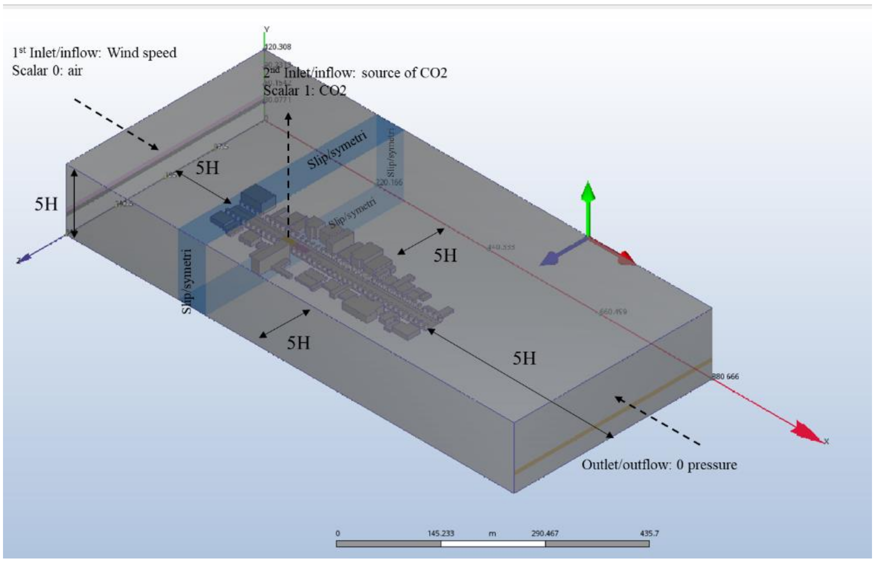


Figure 4. 3 Domain size and boundary condition

Based on *Figure 4.3*,. As explained before, there is two inlets in this simulation that become source of the fluid flow. This inlet comes from 2 directions, which is air velocity (wind speed) as 1st inlet, and mass flow rate of CO_2 as 2nd inlet.

Wind speed data which is 1st inlet in this research according to the data from Local Weather station. This research uses 10 knots or 5.14 m/s as the source of air velocity because this speed is the highest average wind speed in that area (Indonesia Meteorology Climatology and Geophysics Council, 2019). Meanwhile**,** the source of 2nd fluid flow is according to the value of CO_2 emission. This values is obtained based on this following formula (AEA, 2012; Hidayat, 2013)

$$CO_2\ emission = vol\ \left({}^{unit}/_{hour}\right) \mathbf{X}\ street\ (km)\ \mathrm{x}\ emission\ factors\left({}^{gCO_2}/_{km}\right)$$ *Equation* 4. 1

Based on this formula, there are several variables that must be known to get the vehicle emission value. The first variable is the number of motorized vehicles. this value is obtained by calculating the daily average of vehicles in the study area. Direct observation for three times a day is done to get this value. Peak hour is chosen as the time to do observation, including in the morning, noon, and afternoon. The next variable is length of the street. This research uses 400 meters as a study area. Then last variable is emission factor. This emission factor will be different according to the transportation classification. This following table shows the calculation to get CO_2 emission as a 2nd inlet in this research simulation.

Table 4. 1 Vehicle emission factor

Transportation classification	Type	Average daily traffic(unit/hour)	Length of the street (km)	Emission factor ($kgCO_2/km$)	CO_2 emission (kg/hour)
Small car	Private cars	2050	0.4	0.16442	134.8
	Public transport	111	0.4	0.16442	7.3
Medium car	Pick Up / Box	1	0.4	0.17573	0.1
	Medium/mini bus	233	0.4	0.17573	16.4
	Medium Truck	166	0.4	0.17573	11.7
Large Car	Large Buses	3	0.4	0.23381	0.3
	large trucks	2	0.4	0.23381	0.2
Motorbike	Motorcycle	6814	0.4	0.08499	231.6
TOTAL					402.4

4.2.1.3 Assigning the material of 3D modeling

After determining the computational domain, the next step is determining the material of 3D modelling. CFD Autodesk as a software used in this research provides some material to support this research simulation. There is some physical material that should be assigned, which are the building, road, roadside, and tress. This software provides brick material for building, concrete material for road/roadside, and hardwood material for the trees.

4.2.1.4 Scalar mixing analysis

This research simulation will mix two fluid with different characteristic, which is CO_2 and Air. So, this research needs scalar mixing analysis in processing and it will displays the result in the scalar boundary. The scalar boundary has a task to trace the relative concentration of two-fluid. Therefore, this is needed to distinguish the distribution of two liquids. 1st fluid (air) is presented as the scalar boundary condition of 0, and 2nd fluid (CO_2) is displayed as scalar boundary condition of 1. This following formula is scalar mixing equation used in this simulation.

$$J_A = -\rho D_{AB} \nabla m_A$$

Equation 4. 2

Based on that equation, A present scalar 0 (air) and B present scalar 1 (CO_2). J_A in that equation is the mass flux of air that have meaning how much air will be transferred (per time and unit area normal to the transfer direction). It is consistent to the mixture mass density (ρ_{AB}). Air (ρ_A) has density of 1.2047 e-6 g/mm^3, and carbon dioxide (ρ_B) has density of 1.773e-6 g/mm^3. D_{AB} is the diffusion of scalar quantities. This diffusion is according to Fick's Law, which is 0.16 cm^2/s to mixing air, and CO_2 with units are length squared per time. Moreover, this research simulation uses 3D modeling, so to get J_A is proportional to the gradient (∇)of the species mass fraction (m_A)

4.2.1.5 Mesh sizing

The last step in pre-processing for CFD simulation is mesh sizing. The geometry that already created will be broken up into becoming an element and node. Element in the geometry is small pieces that have shape, and the node is a corner of each element. There is some shape of element in geometry modelling. This research use 3D modelling, so it decides to use tetrahedral: a four side, triangular-faced element. The following figure shows the mesh sizing in 3D modeling of this research.

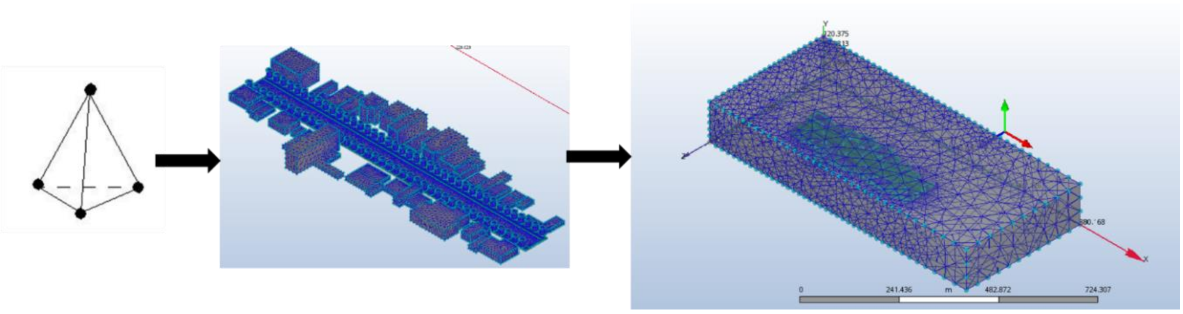


Figure 4. 4 Mesh sizing for the 3D modeling of the study area

3.2.3 Solving in CFD analysis

In this stage, the simulation will be running. Hence, some equations should be decided to analyze the distribution of CO_2. The Navier-Stokes equations (NSE) is used in the simulation to describe the movements of fluids which is the movement air and CO_2. The Navier-Stokes equations (NSE) and continuity equations serve the basis for modeling fluid motion. The law of motion that occurs to solids is authentic for all thing, consist of liquids and gases. Fluids and solids have difference of movement, which is fluid can distort without limit. For example, if shear stress is given to a fluid, then particle of fluid will transfer relative to each other. It will not return to their original location if the application of the shear force is stopped. So, the analysis of fluid needs to take account of distortions (Sayma, 2009).

Therefore, there is some assumption in this research simulation. Air moves in steady condition and not compressed (incompressible) or density (ρ) constant. The wind direction comes from one direction and it is considered unidirectional during the simulation. While for the airflow, this research use uses turbulent for the airflow, not laminar, because this research consider the different characteristic trees planting patterns.

Therefore, to analyzing a concentration gradient in the fluids, this research needs the species continuity equations involving mass transport of chemical.

Accordingly, this energy formula would have an additional term to account for energy transport due to the diffusion of species. Based on the above restrictions in mind, There is the governing equations for air moves which is steady-state, turbulent, three-dimensional modeling, incompressible (conservation). So, this following equation for the conservation of mass (Equation 3.):

$$\frac{\partial_\rho}{\partial_t} + \nabla.(\rho.u) = 0 \qquad \textit{Equation 4. 3}$$

Where:

$\frac{\partial_\rho}{\partial_t}$ is the partial derivative of ρ with respect to t

ρ is density

t is time.

Tensor gradient (∇) is the stress variable. The stress variable is based on Galilean invariant.

u is velocity

∇u is flow velocity

Meanwhile, this following equation is used to calculate the conservation of momentum based on Navier-Stokes Equations in 3D modeling

x-component: $\frac{\partial(\rho.\mathrm{u})}{\partial t} + \nabla.(\rho.\mathrm{u}.u) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}\rho.g_x$ *Equation 4. 4*

y-component: : $\frac{\partial(\rho.v)}{\partial t} + \nabla.(\rho.v.u) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z}\rho.g_y$ *Equation 4. 5*

z-component: : $\frac{\partial(\rho.w)}{\partial t} + \nabla.(\rho.w.u) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\rho.g_z$ *Equation 4. 6*

Where:

ρ is the density

u is the flow velocity

∇ is divergence

p is the pressure

t is time

τ is the deviatoric stress tensor, and

g represents body accelerations acting on the continuum, for example gravity, inertial accelerations, electrostatic accelerations, and so on,

Another consideration in this research simulation is different trees planting design in every simulation. So, turbulent air flows used in this simulation. But, the Navier–Stokes equations have limitations for analyze the turbulent flows. The time-averaged RANS equation will be solve to this limitation. It will be introduction of the Reynolds stress term, which accounts for turbulent fluctuations. Therefore, turbulent kinetic energy for CFD simulation uses K-ϵ model equation. There is two-equation in K-ϵ model which is turbulent kinetic energy (k), and the rate of dissipation of turbulent kinetic energy (ε).

Formula for turbulent kinetic energy k

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij} E_{ij} - \rho\varepsilon$$

Equation 4. 7

Equation of dissipation ε

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k} 2\mu_t E_{ij} E_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$

Equation 4. 8

Where:

ρ is the fluid density ($kg\ m^{-3}$),

u is the fluid velocity ($m\ s^{-1}$)

i represent x and *j* represent x,y, and z (coordinate geometry in boundary)

u_i represents the velocity component in the corresponding direction.

E_{ij} represents the component of the rate of deformation.

μ_t represents turbulent viscosity which is $\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$.

Based on that, the equation has some standard constant that should be divided. There are σ_k, σ_ε, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and C_μ . The value of standard constants are follows:

$\sigma_k = 1.00$ $\sigma_\varepsilon = 1.30$ $C_{1\varepsilon} = 1.44$ $C_{2\varepsilon} = 1.92$ $C_\mu = 0.09$

4.3 Result

4.3.1 CO_2 Emission

The following table shows the calculation of CO_2 emission in the study area. According to the count, the motorcycle is the highest contribution of CO_2 emission in the study area. It because the average motor-vehicle number reaches 6814 unit/hour. This number causes chronic congestion in the study area. Motor vehicle contributes 57,6% of CO_2 emission in the study area or disperses 231.6 kg/hour of CO_2 emission. Meanwhile, small cars that are divided into private and public transport are the second most significant contributors to the distribution of CO_2 emission. It contributes 35.3% of CO_2 emitted from transportation in the study area.

Accordingly, the total CO_2 emission based on the calculation is 402.4 kg/hour. This value will be used as a mass flow rate of CO_2 in this research to simulate the CO_2 dispersion.

Table 4. 2 CO2 emission in study area

Transportation classification	Type	Average daily traffic(unit/hour)	Length of the street (km)	Emission factor ($kgCO_2$/km)	CO_2 emission (kg/hour)
Small car	Private cars	2050	0.4	0.16442	134.8
	Public transport	111	0.4	0.16442	7.3
Medium car	Pick Up / Box	1	0.4	0.17573	0.1
	Medium/mini bus	233	0.4	0.17573	16.4
	Medium Truck	166	0.4	0.17573	11.7
Large Car	Large Buses	3	0.4	0.23381	0.3
	large trucks	2	0.4	0.23381	0.2
Motorbike	Motorcycle	6814	0.4	0.08499	231.6
TOTAL		9380 unit			402.4

4.3.2 Design of trees planting pattern

This research creates five trees planting patterns based on the three-parameters design, which is the position of trees row, avenue-tree layout, and the space of the tree. This study creates double rows position to build the modelling. It because in the previous stage, the result of research proved that double row is better in improving the air quality. *Figure 4.5.* shows the row positions applied in this research. The double rows position has one row in every roadside. This rule applied in the scenarios of trees planting patterns and be combined with other parameters which is the avenue-tree layout, and the space of the tree.

Figure 4.6. displays the tree-avenue layout in design trees planting. The avenue-tree layout of this research is showed by CVF (crown volume fraction). CVF is the volume occupied by tree crowns within a street canyon (Gromke and Blocken, 2015). The volume

of this street canyon in this study is 11 x 30 x 400. The following figure shows five CVF used in this research and applied in five scenarios. This CVF also according to the spacing parameters, which is column space and row space. So, the hedgerow spacing is used to design trees planting on the *roadside* shows in *Figure 4.7*.

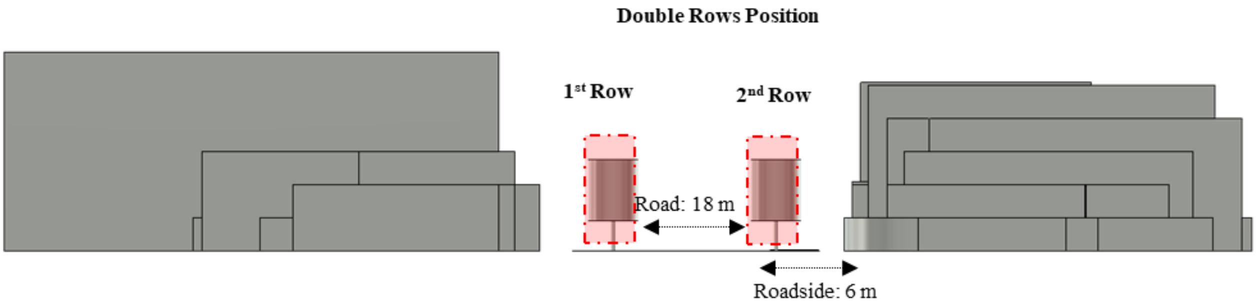


Figure 4. 5 Trees planting pattern based on the position of trees row

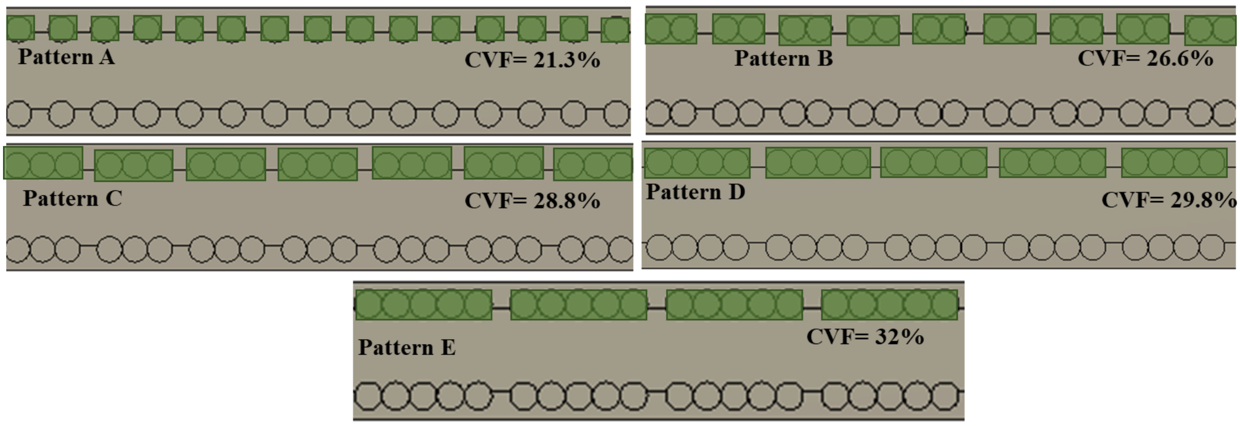


Figure 4. 6 Trees planting pattern based on the avenue-trees layout in CVF

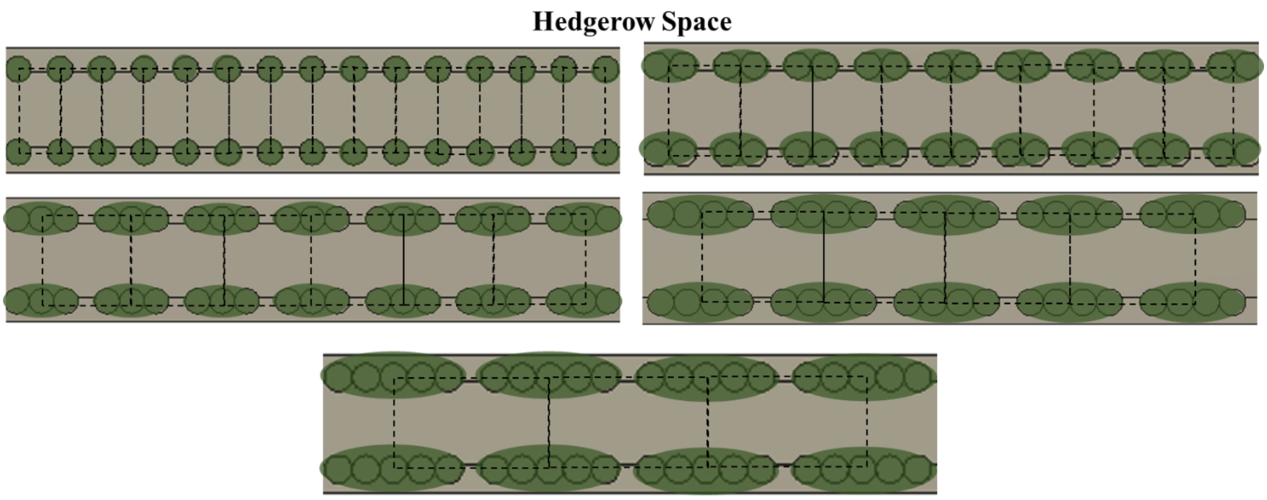


Figure 4. 7 Trees planting pattern based on the spacing of the trees

Therefore, this research creates five scenarios based on the three parameters design of trees planting patterns. This design trees planting has double row position, different avenue trees layout with same hedgerow space. The explanation of every design is displayed in *Figure 4.8*

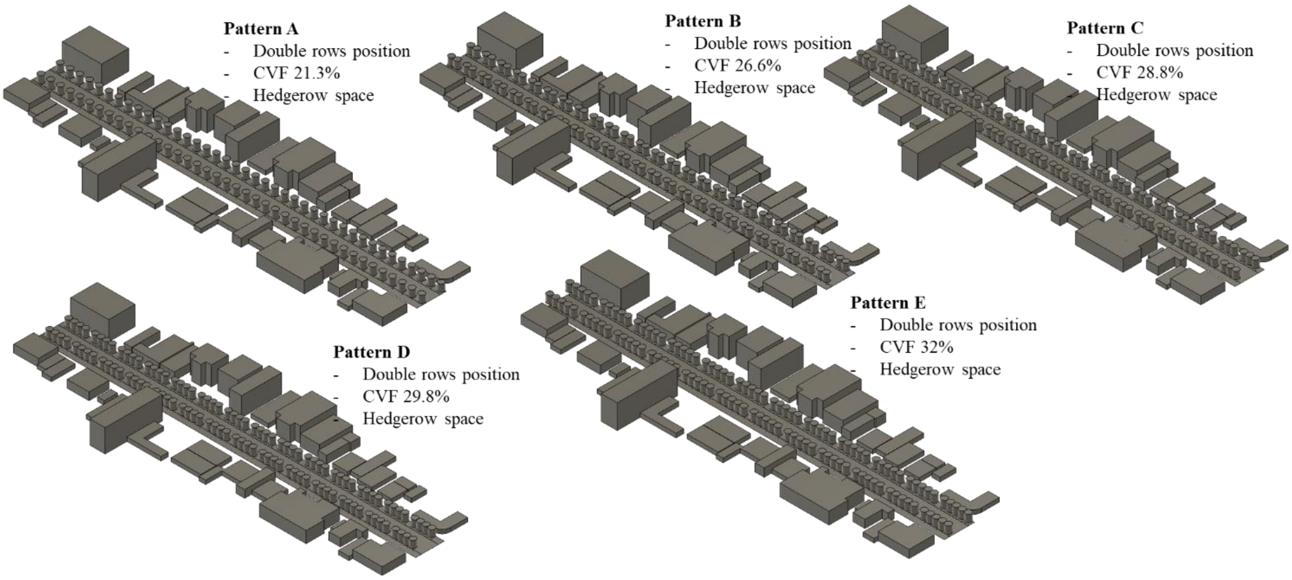


Figure 4. 8 .Five scenarios of trees planting pattern

4.3.3 The dispersion of CO_2

CFD simulation shows the dispersion of CO_2 in five trees planting patterns. The result of the simulation displays CO_2 dispersion in the scalar (a quantity). The scale of the scalar used to see the CO_2 concentration is 0-1 (0%-100%). Dispersion happens because of an unequal concentration. This simulation uses a scalar mixing analysis to mix two-fluid, which is air and CO_2. *Figure 4.9* shows the CO_2 dispersion on various trees planting pattern at an altitude of 1.8 meters which is the average pedestrian height. Based on that figure, CO_2 can disperse with difference concentration in every design of tree planting patterns. The result of analyzing this dispersion can be seen in *Table 4.3* This table explained the value of CO_2 dispersion in every design, so it can be known which design that can decrease and increase CO_2dispersion.

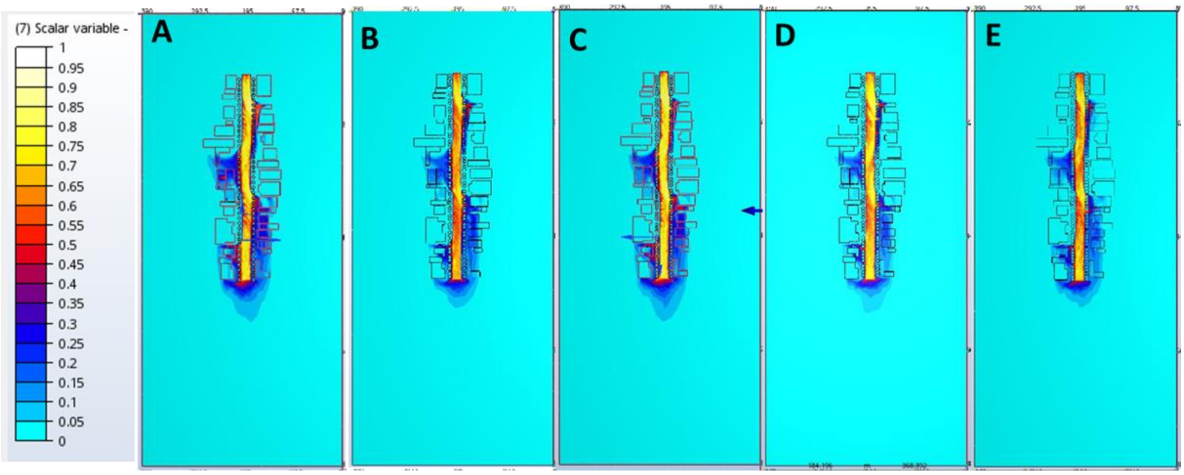
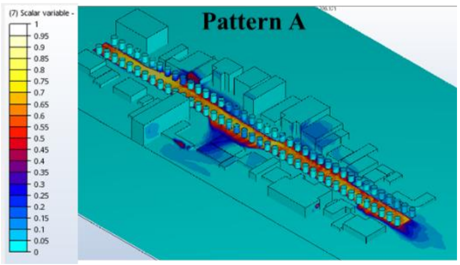
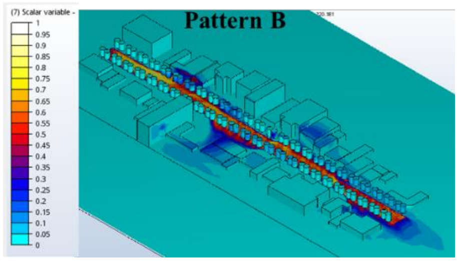
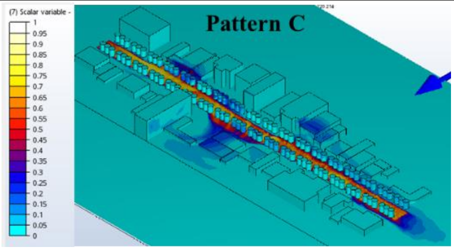
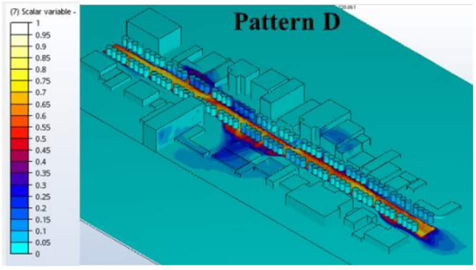
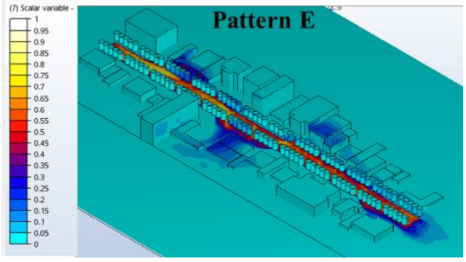


Figure 4. 9 CO2 dispersion at an altitude of 1.8 meters in 2D Modelling

Table 4. 3 Analysis of CO_2 dispersion in the different characteristic of trees planting pattern at an altitude of 1.8 meters

The scenario of trees planting pattern	**Parameters of trees planting pattern**	**CO_2 dispersion at an altitude of 1.8 m**
	Position of trees row: Double rows Space of trees: Hedgerow Avenue-tree layout: CVF: 21.3%	34.1% of CO2 can disperse in pattern A at an altitude of 1.8 meters. The range of CO2 concentration in this simulation starts from 0-0.82% (0-8200 ppm) at an altitude of 1.8 meters. The total area that has poor air quality in this pattern, which has CO2 concentration by >0.1% (>1000 ppm), is 4.35% of the total area at an altitude of 1.8 meters
	Position of trees row: Double rows Space of trees: Hedgerow Avenue-tree layout: CVF: 26.6%	Pattern B can distribute CO2 by 28.6% at an altitude of 1.8 meters. The range of CO2 concentration in this simulation starts from 0-0.78% (0-7800 ppm) at an altitude of 1.8 meters. 3.86% of the total study area has a poor air quality level, which has CO2 concentration by >0.1% (>1000 ppm).

The scenario of trees planting pattern	Parameters of trees planting pattern	CO_2 dispersion at an altitude of 1.8 m
	Position of trees row: Double rows Space of trees: Hedgerow Avenue-tree layout: CVF: 28.8%	30.1% of CO2 emission can disperse in pattern C at an altitude of 1.8 meters. The range of CO2 concentrations in the simulation start from 0-0.77% (0-7700 ppm) at an altitude of 1.8 meters. The study area has 0.86% of the total area that has CO2 concentration by >0.1% (>1000 ppm). It indicates that area has poor air quality
	Position of trees row: Double rows Space of trees: Hedgerow Avenue-tree layout: CVF: 29.8%	Pattern D can distribute CO2 by 32.3% at an altitude of 1.8 meters. The range of CO2 concentrations in the study area starts from 0-0.79% (0-7900 ppm) at an altitude of 1.8 meters. 3.82% of the total study area in the simulation has CO2 concentration by >0.1% (>1000 ppm). It is mean that 3.82% of the total area has poor air quality
	Position of trees row: Double rows Space of trees: Hedgerow Avenue-tree layout: CVF: 32%	Pattern E can spread CO2 by 30.06% at an altitude of 1.8 meters. This pattern has CO2 concentrations in the range from 0-0.79% (0-7900 ppm) at an altitude of 1.8 meters. 4.0% of the total area at an altitude of 1.8 meters has a poor air quality level, which has >0.1% (>1000 ppm) of CO2 concentration.

There is some result based on the analysis of simulation in table 11. This table displays CO_2 dispersion, CO_2 concentration, and the air quality at an altitude of 1.8 meters. Based on the total CO_2 dispersion, pattern B has the lowest CO2 dispersion compare with others design. Pattern B can disperse CO_2 by 28.6%. Meanwhile, different models can disperse CO_2 above 30%. Pattern A can disperse CO_2 by 34.1%, and this value is highest than another pattern. Pattern C, pattern D, and pattern E can disperse CO_2 by 30.1%, 32.3%, and 30.06%.

While, the concentration of CO_2 in the study area at an altitude of 1.8 meters relative have same result except pattern A. Pattern B, C, D, and pattern E have CO_2 concentrations below the value of 8%. While, there is CO2 concentration above 0.8% in pattern A. This CO2 concentration can indicate the air quality on the roadside, so it can be known the impact of tress planting design in improving air quality. Based on the result of simulation, the total area that has poor air quality in pattern A and pattern E is highest than others pattern. 4.35% of the total area in pattern A has poor air quality, while 4% of total area in pattern E has poor air quality.

4.4 Conclusion of chapter 4

The research of this chapter generates five scenarios of tree planting patterns. These scenarios were build based on the design parameters of trees planting, which are the position of trees row, avenue-tree layout, and tree spacing. The CO_2 dispersion in every design is displayed at an altitude 1.8 meters, which is the average of pedestrian height. The research proved that road-air quality is influenced by the design of trees planting patterns, which is the position of trees row, avenue-tree layout, and tree spacing. It can be seen from the difference of CO_2 distribution in each tree planting design.

According to the result of this study, it can be concluded that pattern A is trees planting designs that cannot improve the road-air quality, whereas pattern A is a common design that can be seen in the urban roadside. But based on this simulation result, pattern A can disperse 34.1% of CO_2 in the study area at an altitude 1.8 meters. Moreover, this design also has the highest concentration value, which is 0-0.78% (0-7800 ppm) at an altitude of 1.8 meters. So, 4.35% of the total area has poor air quality. This value is highest than other designs. Therefore, trees planting design with the double-row position, hedgerow position, and one by one tree planting (21.3% CVF) are not effective in improving the air quality.

Then the conclusion of trees planting design that can improve air quality is pattern B. Pattern B can decrease CO_2 dispersion by 28.6%. It indicates that pattern B with the double-row position, hedgerow space with one by one tree planting (26.6% CVF), can decrease 8% of CO_2 dispersion in the study area compared with others. Hence, the area that has poor air quality in this pattern only 3.86% with the Co2 concentration range of 0-0.78%

Chapter 5. Conclusion

CO_2 emitted from transportation is a common problem that is faced in the urban roadside—increasing the vehicle number influence on the CO_2 dispersion. This Ph.D. research aims to evaluate the design of trees planting patterns on the urban roadside in impacting CO_2 emitted from transportation. This research confirms that trees planted on the study area can decrease CO_2 dispersion. On the other side, the study area with trees has higher CO_2 concentration on the roadside (around the trees), while the study area without trees has higher CO_2 concentration on the road. The high CO_2 concentration on the roadside is caused the position of the trees. Accordingly, this condition is not good for human health.

Therefore, in the next result of this research shows that the position of trees planting influence CO_2 dispersion. Trees planted on the roadside as a barrier between road and roadside can disperse CO_2 better than others' position in decreasing CO_2 dispersion. Planting the trees in that position can control the air quality better than other tree's row position.

Then in the next research, some design parameters are applied in the study area, which are positions of trees row, space of the tree, and avenue-tree layout. The research provides some trees planting patterns that impact air quality that exposed to CO_2 emission. Double row position, hedge-row space, and 26.6% CVF (trees are planted two by two) is effective in decreasing CO_2 dispersion.

Publication

Aini, N. and Shen, Z. (2019) ‘The Effect of Tree Planting within Roadside Green Space on Dispersion of CO 2 from Transportation’, *International Review for Spatial Planning and Sustainable Development*, 7(4), pp. 97–112.

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