Tes Jurnal

by Nurul Nurul

Design of tree planting pattern: impacting on the road-air quality for pedestrians from CO_2 dispersion emitted from transportation

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Abstract: This research focuses on the design of trees planting patterns based on CO_2 dispersion emitted from transportation in a real 3D environment. This study provides five scenarios based on some element design of trees planting pattern, which is the position of trees planting, avenue-tree layouts, and the spacing of the trees. This research simulates fluid flow, so computational fluid dynamics (CFDs) was used to simulate the spread of CO_2. The study area and emission data are according to the actual condition of the road in Surabaya City, Indonesia. The result displayed the CO_2 dispersion at an altitude of 1.8 metres as an average of human height and proved that the design influences CO_2 dispersion. Pattern B has a design that can disperse CO_2 emission better than other patterns. Meanwhile, pattern A is not good enough in dispersing CO_2 from transportation, so this design has large areas in poor road-air quality.

Keywords: computational fluid dynamics; CFD; CO_2 dispersion; design guideline; road air quality; trees planting pattern.

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Biographical notes: Nurul Aini is a PhD candidate at the School of Environmental Design, Kanazawa University, Japan. Her current research interest is urban greening that focuses on the design of tree planting on the roadside related to the distribution of vehicle emissions. She worked on several government projects on urban planning in various regions in Indonesia. She also has an overseas visiting and exchange experience to the Tohoku University, GIST, KAIST, Tsinghua University, and Tongji University. Her Bachelor and Master studies are obtained at Brawijaya University and ITS Surabaya. Currently, she also works as a Lecturer at the University of Merdeka Malang, Indonesia.

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1 Introduction

This research focuses on predicting the CO_2 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. The number of motorised vehicles on the road became the primary source of the CO_2 dispersion. Transport disperse 34% of the total CO_2 in the air every day from using gasoline and diesel as fuel (Sullivan et al., 2004; Jie, 2011; EPA, 2016). This condition will affect the air quality on the roadside because it is located close to the main source of CO_2, which is the roadway that is passed by motorised vehicles. Declining air quality because CO_2 concentration has an adverse impact on human health, whereas roadside provides space for pedestrians who want to travel in public space that separates from roadway vehicles. Then the roadside should have good air quality for pedestrians. Based on the Wisconsin Department of Health Service (2019), good air quality on the outdoor must have a CO_2 concentration between 0.025%–0.04% (250–400 ppm). Whereas, poor air quality is the ambient air that has CO_2 concentration between 0.1%–0.2% (1,000–2,000 ppm).

In this condition, trees become essential elements that must be considered in urban roadside planning because trees can control air quality. Trees have a significant impact on the dispersion of CO_2 emitted from transportation. Trees can disperse CO_2 effectively so that the level of air quality on the roadside is including in the good air quality. Based on previous research, there are different results of tree's impact on emission concentration.

The existence of the tree on the roadside can increase emission concentration because trees can reduce the wind speed. It's verified through simulations carried out by comparing the study area in the area without trees and with trees (Gromke and Ruck, 2010; Janhäll, 2015; Šíp and Beneš, 2016; Aini and Shen, 2019). Meanwhile, Jeanjean et al. (2015) proved that trees could reduce the emission concentration of road traffic emissions at pedestrian height on average. This research uses real environmental to simulate the dispersion. Several factors can cause this difference in results, and these factors can originate from the design of tree planting patterns.

Janhäll (2015) reviewed some previous papers to analyse the effect of the trees on urban air quality based on the pollutant dispersion. It is showed that the impact of trees on urban air quality depends on the vegetation design. Differences in tree planting patterns will affect the airflow so that it will also affect the distribution of pollutants or other gases in the vicinity. According to this result, there is some element of tree design that must be considered to decide the trees planting pattern on the roadside, e.g., the position of trees row, avenue-tree layout, and spacing of trees planting. This study combines these elements of tree planting designs to analyse the different effects on the distribution of CO_2.

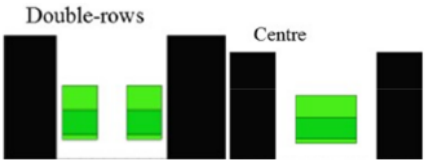
The first element that considers in this research is the position of trees row. This element is related to the row number of trees on the roadside. Morakinyo and Lam (2016) displays some trees planting patterns based on the position of trees rows like single row and double row. The second element is the avenue-tree layout. Other researchers display that the avenue-tree layout also influences the distribution of traffic pollutants. It is related to the crown position and volume (Gromke and Ruck, 2007; Gromke and Blocken, 2015; Pretzsch et al., 2015). The third is some trees planting patterns based on trees spacing and row spacing, according to Nursery (1999). This pattern usually used in a large area, but this research applies this pattern in the roadside with length 400 m and wide 6 m. Accordingly, this research combines this three-element to get some scenarios of trees planting patterns because the design of trees planting patterns becomes essential to monitor CO_2 dispersion on the roadside. Different trees planting design can give a disparate impact on the distribution of CO_2. Accordingly, it can be analysed the effectiveness of design trees planting patterns in disperse CO_2. From the next section, we discuss the method of simulating the CO_2 dispersion using computational fluid dynamics (CFDs) followed with the explanation in every stage of simulation.

2 Method

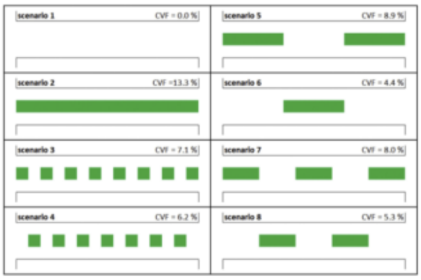
This research provides some scenarios of trees planting patterns with different designs. CFD are used for predicting the dispersion of CO_2. CFD is a branch of fluid mechanics that uses numerical analysis and data structures to analyse and solve problems that involve fluid flows. CFD Autodesk software used in the simulation. This research builds the 3D model based on real situations where the surrounding buildings are created based on the actual layout and height, whereas many previous studies did not use existing conditions. This study uses real environmental conditions because the roads in urban areas have various building conditions, both in terms of layout and height. So these results can contribute to design trees planting patterns that can be implemented on the roadside of urban that have several building developments based on the effectiveness of design trees planting patterns in disperse CO_2.

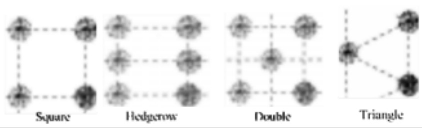
Table 1 Design parameter of trees planting pattern (see online version for colours)

<table>
<tr><th>No.</th><th>Parameter</th><th>Reference</th><th>Referred parameter</th></tr>
<tr><td>1</td><td>Position of the tree row</td><td>Morakinyo and Lam (2016) divide trees planting patterns based on the position of trees planting. The first type is double rows pattern that planting trees on both sides of the road (right and left of the road). The second is the centre pattern that planting trees in the middle of the road.



</td><td>The study area in this research does not have a median in the middle of the road but has a pedestrian way on both sides of the road. These sides are currently planted with trees. Hence, double rows are suitable for use in this study.</td></tr>
<tr><td>2</td><td>Avenue-tree layouts</td><td>Gromke and Blocken (2015) displays eight scenarios about avenue-tree layout in the street. They divide the tree layout based on crown volume fraction (CVF).


</td><td>According to that previous research. This research will create some scenarios of trees planting patterns based on CVF in some avenue-tree layout.</td></tr>
<tr><td>3</td><td>Space</td><td>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 pattern, 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 centre of four trees. The last pattern is a triangle and all trees are the same distance from each other.

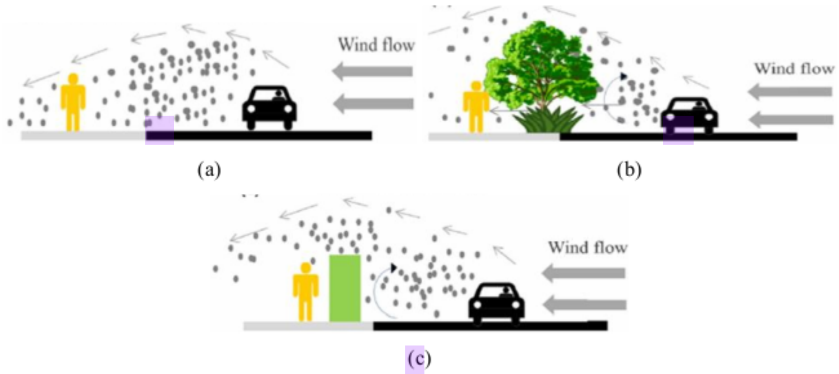


</td><td>Usually, these patterns are used to calculate the number of trees per acre. Meanwhile, this research area is roadside with a length of 400 m. So this research use hedgerow to design the trees planting on the roadside.</td></tr>
</table>

2.1 The scenario of trees planting pattern

The existence of the trees on the roadside influence on the CO_2 dispersion and design of trees planting gives an impact to the effectiveness in dispersing CO_2 (Figure 1). So 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. Table 2 display these parameters according to the related research and theory about trees planting pattern.

Figure 1 Dispersion patterns of road pollutants under open road configurations, (a) without vegetation barrier (b) with vegetation (c) with a green wall (see online version for colours)



Source: Abhijith et al. (2017)

2.2 CFD analysis

CFD in this research used to simulate the air velocity and the dispersion of CO_2 in some trees planting patterns. The result will show which pattern can increase CO_2 and decrease CO_2 concentration. Nowadays, there are many CFD software that can be used for analysis. But this research uses CFD Autodesk to simulation the dispersion of CO_2 because it can consider some conditions in the study area environment, whether physical or non-physical conditions. There are three stages to simulation the distribution of CO_2 using CFD software. The first stage is pre-processing, the second is solving, and the last is post-processing.

3 CFD process

3.1 Pre-processing in CFD analysis

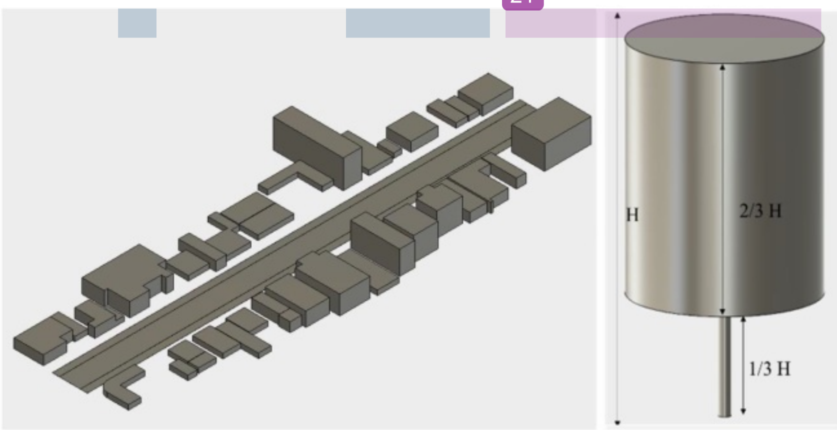
3.1.1 Build geometry formation

This study creates geometry formation use Sim Studio Tools software. This software is one of the CAD software that belongs to Autodesk. Geometry formation for this study is built-in 3D modelling. But there is some element that must be considered in creating geometry formation. The first is geometry formation for 3D modelling of the study area, and the second is geometry formation for the domain size of the study area.

3D modelling in this research build based on the real condition in the study area. Jalan Panglima Sudirman (Figure 1), with a length of 400 m, is chosen as the study area because it is one of the streets in Surabaya city that has a high traffic jam. The value of the motor vehicle that passing this road gained 8,157 units/hour. Based on that, some elements must build in geometry formation such as buildings, trees, roads, and roadside. The result of geometry formation display in Figure 2. It can be shown the buildings have a different layout, size, and height of building similar to reality. Then trees also modelled using the same canopy shape (rounded) like in the study area but with some assumption (Figure 2). The height of the tree displayed use the average height of the tree in the study area. The height average (H) in the study area is 11 m. This study assumes the canopy base height of 1/3 the canopy top height (Jeanjean et al., 2015; Xue and Li, 2017).

Figure 2 Study area (see online version for colours)

Figure 3 Building and tree modelling in the study area (see online version for colours)



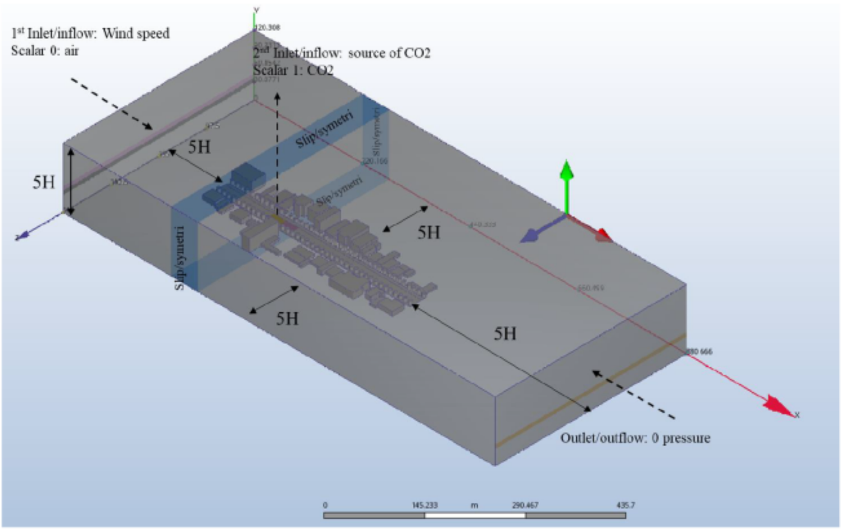
Source: Author (2019)

3.1.2 Determine computational domain (domain size and boundary condition)

After creating the geometry of the study area in 3D modelling, then the domain size can be created. Domain size used in this research display in Figure 3 that refers to domain size by Franke et al. (2004, 2007). Many researchers also used this domain to simulate their model or develop other domain based on this size (Revuz et al., 2010, 2012).

Franke et al. (2004, 2007) displayed that inlet, the lateral in urban area simulation should be positioned 5 H_{max} from the building. The top boundary at least 5 H_{max} away from the building. Then outflow boundary should be a minimum of 15 H_{max} away from the building. H_{max} is the size of the tallest building in the modelling (Figure 1). So, this research uses this domain size because it also related to the study area that analysis the condition in the pedestrian way of the urban area (Figure 1).

Figure 4 Domain size and boundary condition (see online version for colours)



The next step after determining the domain size is assigning the boundary condition. This step is needed to design interacts with its surroundings. This research focuses on the fluid flow, not on heat transfer. Hence only flow boundary condition is assigned on the surface of geometry.

Figure 3 shows the flow boundary condition for this research. There is some surface that must consider, which is the inlet, outlet, lateral, and top boundary. For the top and lateral condition, the slip/symmetry boundary is assigned on this surface. The slip condition causes 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 for the inlet, it comes from two directions, which are air velocity (wind speed) as 1st inlet and mass flow rate of CO_2 as 2nd inlet. The wind speed as of 1st inlet used in this research according to the data from local weather station. This research uses the highest average wind speed, which is 10 knots or 5.14 m/s (Badan Meteorologi Klimatologi dan Geofisika, 2019). Meanwhile, the mass flow rate of CO_2 emission as 2nd inlet is 402.4 kg/hour is obtained based on this following formula (AEA, 2012; Hidayat, 2013)

$$CO_2 \ emission = vol\left({}^{unit}\!/_{hour} \right) \times street\ (km) \times emission\ \ factors \left({}^{gCO_2}\!/_{km} \right) \quad (1)$$

The number of vehicles obtained through observation at the study location during peak hours in the weekday and weekend. In the morning, observation is started at 7–8 am. At noon it is started from 12 am until 1 pm, and in the afternoon it started at 6–7 pm. Based on that. The value of CO_2 emission can be calculated in this research area based on the type of transportation. Table 2 displays the calculation of the CO_2 emission in this research.

Table 2 Vehicle emission factor

Transportation		*Average daily traffic (unit/hour)*	*Length of the street (km)*	*Emission factor (kgCO$_2$/km)*	*CO$_2$ emission (kg/hour)*
Classification	*Type*				
Small car	Private cars	2,050	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	6,814	0.4	0.08499	231.6
Total					402.4

3.1.3 Assigning the material of 3D modelling

This study area has some material parameter that should be input in modelling. CFD Autodesk provides some material to support the simulation. So, the result of the simulation can be more accurate. But this research has some assumptions for dividing the material because the simulation is not too focused on material details. This is adjusted to the time and availability of the material in the CFD software.

The first step is determining the physical material, which is the building, road, roadside, and tress, which are brick for building material, concrete for road, and roadside. Then for the trees, CFD Autodesk provides hardwood material for use as a tree material. The second step is determining the fluids. There is two material of fluid that must be mixed in this research, which is CO_2 and air.

Scalar mixing analysis displays the result of simulation in the scalar boundary. The scalar boundary has a function to track the relative concentration of two-fluid. Accordingly, this is needed to distinguish the distribution of two liquids. The scalar boundary condition of 0 is used to represent air as a 1st fluid, and a Scalar boundary condition of 1 to describe CO_2 as 2nd fluid. Equation (2) used in the simulation to mix two fluids, where A is scalar 0 (air) and B is scalar 1 (CO_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}

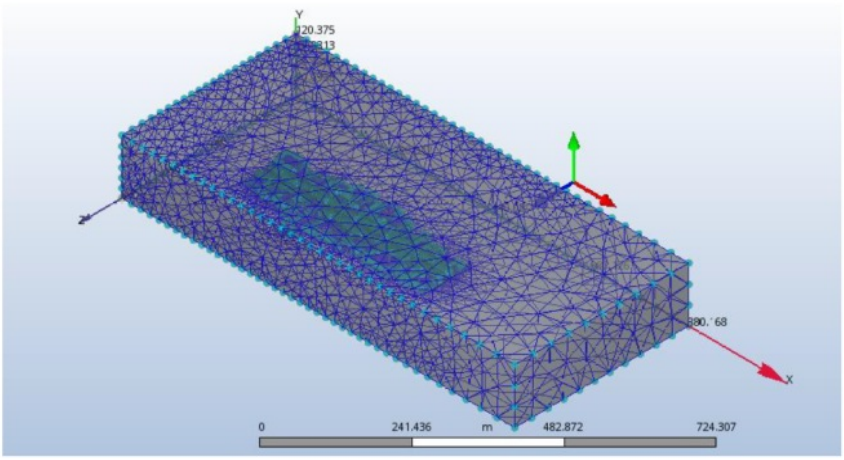
g/mm^3, and the density of carbon dioxide (ρ_B) is 1.773e^{-6} g/mm^3. DAB is the diffusion of scalar quantities based on Fick's Law. The diffusion coefficient to mixing air and CO_2 is 0.16 cm^2/s. The units of the diffusivity coefficient are length squared per time. This simulation uses 3D modelling, so to get J_A is proportional to the gradient (∇) of the species mass fraction (m_A).

$$J_A = -\rho D_{AB} \nabla m_A \tag{2}$$

3.1.4 Mesh sizing

Another essential step in CFD simulation is mesh sizing. The geometry that already builds will be broken up into becoming an element and node. Element is small pieces from geometry, and the node is a corner of each element. These elements and nodes make up the mesh. This research uses three-dimensional models, so this simulation uses tetrahedral: a four side, triangular-faced element. Figure 5 shows the result of mesh sizing in 3D modelling of this research.

Figure 5 Mesh sizing the 3D modelling of the study area (see online version for colours)



3.2 Solving in CFD analysis

In this stage, some equations should be assigned to analyse the dispersion of CO_2. This research uses the Navier-Stokes equations (NSEs) in the simulation to describe the movements of fluids (air and CO_2). The NSE and continuity equations provide the foundations for modelling fluid motion. The law of motion that applies to solids is valid for all matter, including liquids and gases. The difference between fluids and solids is that fluids distort without limit. For example, if shear stress is applied to a fluid, then layers of fluid particles will move relative to each other, and the *particles* will not return to their original position if the application of the shear force is stopped. So that, analysis of fluid needs to take account of such distortions (Sayma, 2009). Based on that explanation, this research has some assumptions, which are 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 and comes from one direction. This research uses turbulent for the airflow, not laminar, because this research wants to analyse the airflow and CO_2 dispersion in different characteristic trees planting patterns. Then, this simulation just considers the airflow, so the parameters used are only related to airflow boundary does not heat transfer boundary.

Accordingly, the species continuity equations involving mass transport of chemical species are needed to analyse concentration gradient in the species. Moreover, the energy equation would have an additional term to account for energy transport due to the diffusion of species. Based on the above restrictions in mind, the governing equations for air moves in steady-state, turbulent, three-dimensional modelling, incompressible (conservation), so the equation for the conservation of mass is [equation (3)]:

$$\frac{\partial_\rho}{\partial_t} + \nabla \cdot (\rho.u) = 0 \tag{3}$$

$\frac{\partial_\rho}{\partial_t}$ is the partial derivative of ρ with respect to t. Where $\rho\nabla$ is density, and t is time. Tensor gradient (∇) is the stress variable. The stress variable is based on Galilean invariant which does not depend directly on the flow velocity (u), but only on spatial derivatives of the flow velocity (∇u). Meanwhile, this following equation is used to calculate the conservation of momentum based on NSEs in 3D modelling

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

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

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

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.

On the other side, this research will analyse the CO_2 dispersion in different trees planting design. So, turbulent flows used in this simulation. But, the NSEs 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. There is 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

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

- For dissipation ε

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

The explanation of that 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 (ms^{-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:

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

4 Result and discussion

4.1 *Design of trees planting pattern*

This research creates five trees planting patterns based on the three-parameter design, which is the position of trees row, avenue-tree layout, and the space of the tree. Figure 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.

Figure 6 Trees planting pattern based on the position of trees row (see online version for colours)

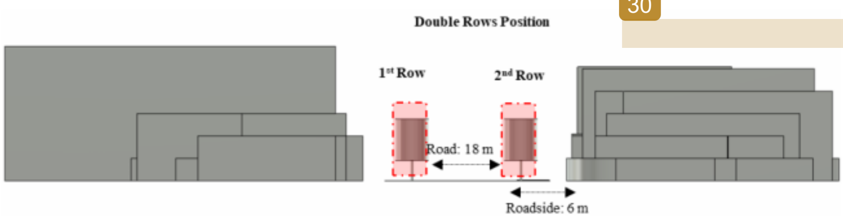


Figure 6 displays the tree-avenue layout in every tree planting pattern. The deference of avenue-tree layout is indicated by crown volume fraction (CVF). CVF is the volume occupied by tree crowns within a street canyon (Gromke and Blocken, 2015). The volume of this street canyon in this study is 11 × 30 × 400. The following figure shows five CVF used in this research and applied in five scenarios. It can be seen in Figure 6, there is a CVF with the same value applied in two models but with a different tree-planting pattern design. It is because this research also considers in the spacing parameter, which is column space and row space. This research use hedgerow space to create the trees planting pattern. The spacing parameters used in this study are shown in Figure 8.

Figure 7 Trees planting pattern based on the avenue-trees layout in CVF (see online version for colours)

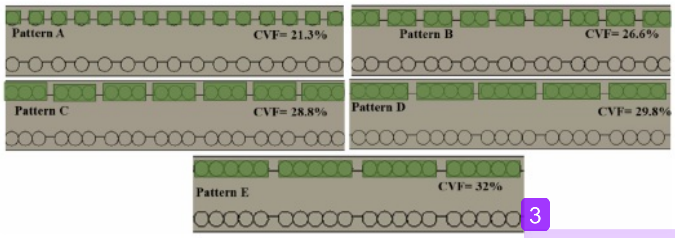
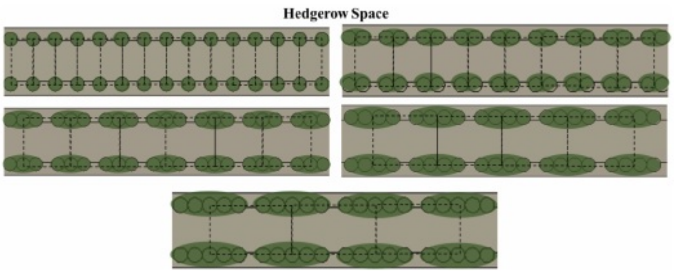


Figure 8 Trees planting pattern based on the spacing of the trees (see online version for colours)



According to the three parameters design of trees planting patterns, this research creates five scenarios with different the position of row, avenue-tree layout, and trees spacing. The characteristic of these patterns is displayed in Figure 9.

Figure 9 Five scenarios of trees planting pattern (see online version for colours)

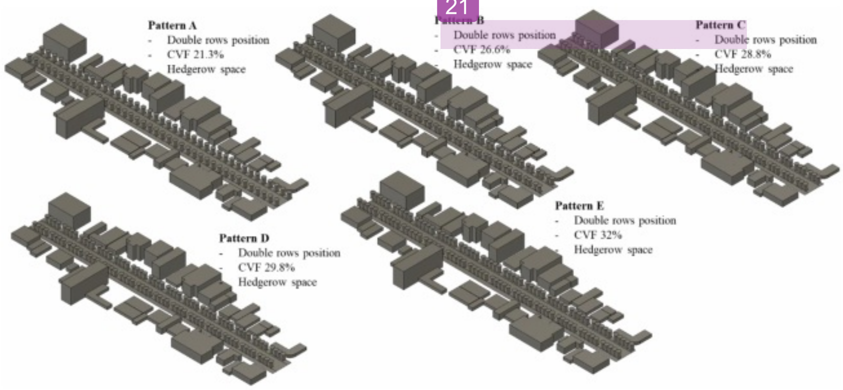


Table 3 Analysis of CO_2 dispersion in the different characteristic of trees planting pattern at an altitude of 1.8 metres (see online version for colours)

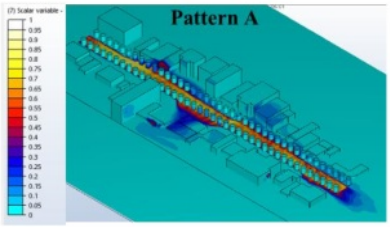
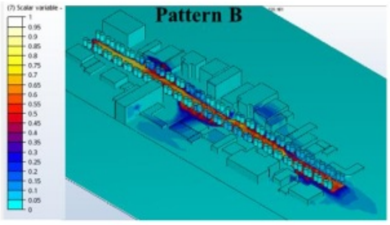
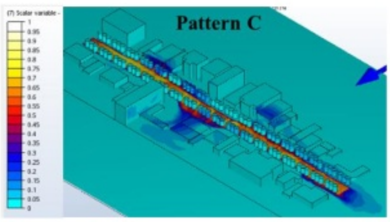
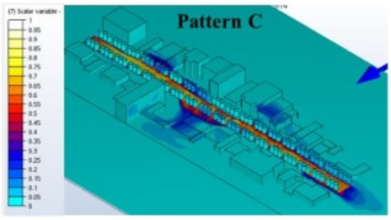
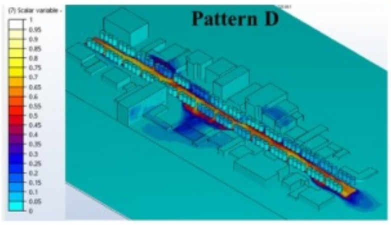
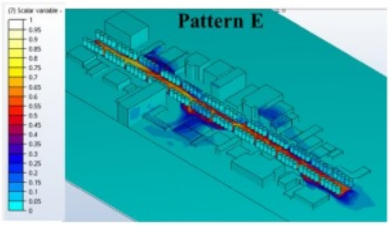
The scenario of trees planting pattern	*Parameters of trees planting pattern*	*CO_2 dispersion at an altitude of 1.8 m*
	• *Position of trees row:* Double rows • *Space of trees:* Hedgerow • *Avenue-tree layout:* CVF: 21.3%	• Pattern A can disperse CO_2 by 34.1% at an altitude of 1.8 metres. • CO_2 concentrations in the simulation results range from 0–0.82% (0–8,200 ppm) at an altitude of 1.8 metres. • The study area with a poor air quality level, which has CO_2 concentration by >0.1% (>1,000 ppm) is 4.35% of the total area at an altitude of 1.8 metres.
	• *Position of trees row:* Double rows • *Space of trees:* Hedgerow • *Avenue-tree layout:* CVF: 26.6%	• Pattern A can disperse CO_2 by 28.6% at an altitude of 1.8 metres. • CO_2 concentrations in the simulation results range from 0–0.78% (0–7,800 ppm) at an altitude of 1.8 metres. • The study area with a poor air quality level, which has CO_2 concentration by >0.1% (>1,000 ppm) is 3.86% of the total area at an altitude of 1.8 metres.
	• *Position of trees row:* Double rows • *Space of trees:* Hedgerow	• Pattern A can disperse CO_2 by 30.1% at an altitude of 1.8 metres. • CO_2 concentrations in the simulation results range from 0–0.77% (0–7,700 ppm) at an altitude of 1.8 metres.

Table 3 Analysis of CO_2 dispersion in the different characteristic of trees planting pattern at an altitude of 1.8 metres (continued) (see online version for colours)

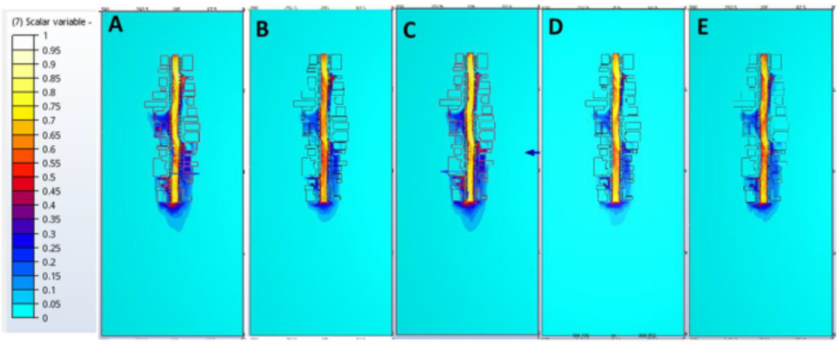
The scenario of trees planting pattern	*Parameters of trees planting pattern*	*CO_2 dispersion at an altitude of 1.8 m*
	• *Avenue-tree layout:* CVF: 28.8%	• The study area with a poor air quality level, which has CO_2 concentration by >0.1% (>1,000 ppm) is 3.86% of the total area at an altitude of 1.8 metres.
	• *Position of trees row:* Double rows • *Space of trees:* Hedgerow	• Pattern A can disperse CO_2 by 32.3% at an altitude of 1.8 metres. • CO_2 concentrations in the simulation results range from 0–0.79% (0–7,900 ppm) at an altitude of 1.8 metres.
	• *Avenue-tree layout:* CVF: 29.8%	• The study area with a poor air quality level, which has CO_2 concentration by >0.1% (>1,000 ppm) is 3.82% of the total area at an altitude of 1.8 metres.
	• *Position of trees row:* Double rows • *Space of trees:* Hedgerow	• Pattern A can disperse CO_2 by 30.06% at an altitude of 1.8 metres. • CO_2 concentrations in the simulation results range from 0–0.79% (0–7,900 ppm) at an altitude of 1.8 metres.
	• *Avenue-tree layout:* CVF: 32%	• The study area with a poor air quality level, which has CO_2 concentration by >0.1% (>1,000 ppm) is 4.0% of the total area at an altitude of 1.8 metres.

4.2 The dispersion of CO_2

CFD simulation shows the dispersion of CO_2 in five trees planting patterns. Dispersion happens as a result of an unequal concentration. This simulation uses a scalar mixing analysis to mix two-fluid, which is air and CO_2 in the study area. 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%). Figure 10 shows the CO_2 dispersion on various trees planting pattern at an altitude of 1.8 metres. This height is according to the average pedestrian height. Based on that figure, it can be seen that trees planting patterns influence the CO_2 dispersion because the scalar of fluid distribution also different in every pattern. The analysis of the simulation results is explained more clearly in Table 3. This table describes CO_2 dispersion and concentration in every design of trees planting patterns.

Table 3 shows the analysis of simulation results in every design of trees planting patterns. This table shows the dispersion of CO_2, the concentration of CO_2, and the air quality at an altitude of 1.8 metres. Based on the total CO_2 dispersion, pattern B is a pattern that can hold CO_2 distribution than other designs. 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 can disperse CO_2 by 30.1%. Pattern D and E can disperse CO_2 by 32.3% and 30.06%. Based on Table 3, the concentration of CO_2 in the area at an altitude of 1.8 metres almost the same. Pattern B, C, D, and E have CO_2 concentrations below the value of 8%. But, some areas at an altitude of 1.8 metres in pattern A has a concentration above 0.8%. CO_2 concentrations in pattern A range from 0–0.82% (0–8,200 ppm). So based on that concentration, it can be concluded the level of road-air quality for pedestrians. Poor air quality is an area that has a concentration of > 0.1% (> 1,000 ppm). The area in patterns B, C, and D that have CO_2 levels >1,000 ppm are still carried at 4%. This value is better than pattern A, and E. 4.35% of the total area in pattern A has poor air quality, while poor air quality in pattern E spreads in 4% of the total area.

Figure 10 CO_2 dispersion at an altitude of 1.8 metres in 2D modelling (see online version for colours)



5 Conclusions

This research creates five scenarios of tree planting patterns. These scenarios are according to 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 metre because this value is an average of pedestrian height. The conclusion of the result is pattern B can maintain road-air quality for pedestrians better than other patterns. This pattern can decrease CO_2 dispersion by 28.6%, which is the lowest than the different designs.

On the other hand, pattern A is a tree planting pattern that is generally planted in urban areas. But based on the simulation results, this pattern is less effective in maintaining air quality because it has a high value of CO_2 distribution. It indicates that this design cannot enough protect pedestrians from the CO_2 dispersion emitted from transportation. This pattern has the highest CO_2 dispersion, which is 34.1%.

Accordingly, pattern B can maintain road-air quality by suppressing the CO_2 distribution by up to 8%. So, 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.

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