CO_2 LEVEL CHANGE WITH MOVING OCCUPANTS IN CLOSED SPACE

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ABSTRACT

Carbon dioxide (CO_2) is a colorless gas, one of the most important components of the air. The CO_2 is related to our daily lives. This report dedicated to reduce the CO_2 level in closed space. The moving occupants, green plants and carbon dioxide scrubbers will influence the CO_2 level in closed space. The report added a carbon dioxide sensor to detect the CO_2 level in the room. It evaluated the CO_2 level and figured out how the CO_2 will be reduced. The simulation showed that green plants and carbon dioxide scrubbers can absorb CO_2 in the room. Green plants only absorbed limited value of CO_2. The experiment results were shown and analyzed in the report. This report simulated the model with green plants, model with carbon dioxide scrubbers, model with carbon dioxide scrubbers and plants, original model to compare the effects of each object. The simulations imitated the CO_2 level change in closed space. The report used Cell-DEVS formalism and Cadmium as the method to simulate the model.

Keywords: CO_2, Cadmium, moving occupants.

1 INTRODUCTION

This paper provided methods for simulating the CO_2 level change in the room. The physical constructions in the room will be added in the closed space. Their influence of the CO_2 level change due to the moving occupants, different kinds of green plants, and the carbon dioxide scrubbers. These factors were considered and the corresponding influence were analyzed. I simulated four models to compare the effects of each objects. The simulation helped us figure out which object is the most effective to reduce the CO_2 in the room. The report used Cadmium as the method and the Cell-DEVS formalism. The Cell-DEVS referred to the combination of DEVS and CA with explicit timing delays. DEVS represented the discrete event systems specification. It's a set of conventions for specifying discrete event simulation models. It included the atomic model and the coupled model. The atomic model is the basic model which is automatic coupling mechanism. Each atomic model and coupled model of the closed space will be illustrated. The formalism of each cell was shown in this report as well. This report introduced the CO_2 dynamic DEVS and Cell-DEVS. It used Cell-DEVS model to simulate the diffusion of CO_2 in the closed room. The model in the report can be considered as the two dimensional Cell-DEVS model with different CO_2 levels. The system has many models including CO_2 and other gases, which were independent. For preliminary model, the averaged CO_2 levels of all cells in the local neighborhood including the center cell were calculated. The rate of diffusion was then controlled explicitly by the timing delay between each averaging event. The cell space should reflect the size of an average small office space or room. Meanwhile, multiple moving occupants were added in the room. The report added plants and carbon dioxide scrubbers in the room to see which object can absorb the CO_2 in the room. Meanwhile, the report added different kinds of plants in the room. I put some plants near the wall, they were separated randomly.

In this report, I set two carbon dioxide scrubbers in the room. One of the them was on the left side of the room, the other one was on the left side. The moving people were added to see their influence for the CO_2 level change in the room. The change of CO_2 levels was collected and analyzed. The influence of the plants and carbon dioxide scrubbers were discussed. The CO_2 sensors can detect different change of the CO_2 in closed space. For instance, when I put two carbon dioxide scrubbers in the room, the results of CO_2 level on left side and right side will decrease. They can increase the air circulation and absorb the CO_2 using NaOH solution.Green plants, carbon dioxide scrubbers, and the ventilation system can absorb the CO_2. The report will analyze the experiment results and make the conclusion about the CO_2 level change.

2 BACKGROUND

In this part, the report will introduce the background information of the experiment. The report was based on the CO_2 model offered by Professor Wainer. It's a Cell-DEVS model showing the diffusion of CO_2 produced by breathing occupants in the closed room. In the model, some factors included the room dimensions, vents, windows, doors, and moving occupants. Moving occupants can be considered as the CO_2 production source. There are two different versions of this model: one for indoor spaces and the other represents a 3D space in 2D cross sectional scenarios. In this report, the 2D cross scenarios was chose and analyzed. The report made some changes of the original model, these changes will be discussed in the report. In this report, I focused on how to reduce the CO_2 level in closed space. I added several plants, two carbon dioxide scrubbers and one CO_2 sensor in the room. In this way, I can simulate the CO_2 change in the room. The results can help us know the influence of each object ability to absorb the CO_2 including different types of plants and carbon dioxide scrubbers.

2.1 DEVS and Cell-DEVS Methodology

2.1.1 DEVS

This report dedicated to model the CO_2 dynamic DEVS and Cell-DEVS. The DEVS formalism is a set of conventions for specifying discrete event simulation models. DEVS can be applied to discrete time simulation. The CO_2 diffusion model in the report used this characteristics to simulate the real situation. The discrete event method impacted the model development process. In the basic model, it's clear to see that the time latency existed in the original model. The DEVS formalization includes the hierarchy composition of behavior (atomic) and structural (coupled) models (Warnier 2009). The time advance was considered in the model. Each Δt (time advance) was decided for each cell model, then DEVS can used coupled model to combine the models together. Meanwhile, it's independent of any tool and programming language.

The DEVS atomic models are indivisible DEVS models. The coupled models are DEVS models composed of other DEVS models. The parameters of atomic models were listed below. They can be applied to coupled models as well. The atomic models can be expressed as:

$$\mathrm{M} = < X, Y, S, \delta_{ext}, \delta_{\text{int}}, \lambda, \ \ t\alpha >$$

Where:

- X is the set of input values
- Y is the set of output values
- S is the set of states
- δ_{ext} is the external transition function.
- δ_{int} is the internal transition function
- λ is the output function

- $t\alpha$ is the time advance function

In the DEVS atomic models, the external event transition function δ_{ext} was used to transform a state and an input event into another state. The internal event transition function δ_{int} transformed the state into another state after the time has elapsed. The time advance function $t\alpha$ mapped a state into duration. The output function λ mapped the state into an output. The coupled models can be expressed as:

$$\text{CM} = < X, Y, D, \{M_i\}, \{I_i\}, \{Z_{ij}\}, Select >$$

Where:

- X is the set of input values
- Y is the set of output values
- D is an index for the components of the coupled models
- M_i is the basic DEVS model, it can be atomic model or coupled model. It can be defined as:
$$M_i = < I_i, X_i, S_i, Y_i, d_{\text{int}\,i}, d_{exti}, t_{\alpha i} >$$
- I_i is the set of influences of model i. The model i was the model that can be influenced by output of the model i.
- Z_{ij} is the i to j translation function
- Select is the tie-breaking selector

2.2 CO_2 Reduction

2.2.1 CO_2

Global warming is increasing at an alarming rate due to the tremendous increase in the concentration of carbon dioxide. Carbon dioxide is the most significant long-lived greenhouse air in Earth's atmosphere. CO_2 also causes ocean acidification because it dissolves in water to form carbonic acid (Gattuso, Pierre and Hansson 2020). These CO_2 emissions come from our daily life including food, transportation, breath and so on. We produce CO_2 directly or indirectly when we use products generated using fossil fuels. For instance, we indirectly produce the CO_2 when we turn on the heat that have been produced with fuel fossils. To reduce the global warming, we have to mitigate atmospheric CO_2 (Devi and Gupta 2018). This report dedicated to model the CO_2 dynamic DEVS and Cell-DEVS. In the closed space, the CO_2 mainly came from the breath of moving occupants. People breath in the oxygen and breath out the CO_2. In the simulation result, it's clear to see that CO_2 level increased after people entered the room. The report, tried to find the objects that can absorb the CO_2. Removal of carbon dioxide from the gases is a key measure to reduce CO_2 emission. In the coming few decades, it has huge potential for the contribution to carbon emission reduction by carbon capture and storage. Some scholars proposed the absorption methods, cryogenic methods, membrane separation and the biological fixation. The model added several components in the model to reduce the CO_2 level in the closed space. The green plants and carbon dioxide scrubbers were added in the report.

2.2.2 Green Plants

Green plants can absorb CO_2 as a part of photosynthesis. It can absorb CO_2 and generate O_2. For instance, trees have been called "woody biomass" to store CO_2. In this report, I added indoor plants which can absorb the CO_2 effectively in closed space. The indoor air quality (IAQ) became an important factor which can influence our health nowadays (Suhaimi et al.2017). IAQ is important to human health and the quality of life, work environment with consequential benefits to wellness and performance (Tham 2016). Several methods were designed to improve the air quality including having green plants in the room.

Plants need CO_2, water, sunlight to grow. They can absorb the CO_2 in the room. The problem is how much CO_2 they can absorb in limited time. Therefore, I added some plants near the wall to simulate their influence to CO_2 level change. Different plants absorb different amount of CO_2 according to scientific research. I will try to put these plants separately in the closed room and find the plant that can absorb the most CO_2 under the same time. Each simulation only tried one type of plants a time. The selected plants included: Prayer Plant, syngonium, Kadaka Fern, Golden Pothos, Dumb Cane, Spider Plant and the Anthuium. They were shown in Figure 1. The difference of the CO_2 amount they absorbed under the same time will be analyzed in the report.

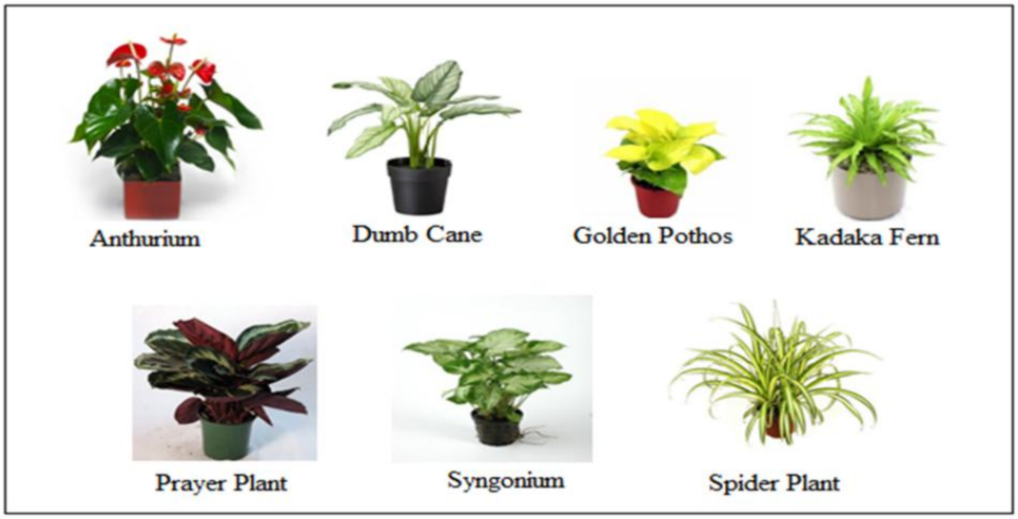

Figure 1: Plants selected for term project (Suhaimi et al.2017)

2.2.3 Carbon Dioxide Scrubber

After discussion with professor Wainer, he suggested me to learn HEPA filters. High-efficiency particulate air (HEPA) filter can be used to protect people and the environment from harmful gasses and particals. HEPA filter applications involve filter media testing, filter testing and in-place filter testing (Zhang and Jiang 2016). The fully-sealed filter system combined with an activated carbon filter and a HEPA filter. Dyson HEPA tower fan and purifier can capture 99.97% of microscopic allergens and pollutants as small as 0.3 microns. However, the traditional air purifier can't remove CO_2 in the room.

I found the carbon dioxide scrubber, it can remove the CO_2 in the room. A carbon dioxide scrubber is a piece of equipment that absorbs CO_2. The potential methodologies were concluded below.

1. The CO_2 can be absorbed by NaOH solution. It can absorb the CO_2 and generate corresponding sodium carbonate.

$$2\mathrm{NaOH(aq)} + \mathrm{CO_2}(g) \rightarrow \mathrm{Na_2CO_3(aq)} + \mathrm{H_2O(I)} \tag{1}$$

$$\mathrm{Na_2CO_3(aq)} + \mathrm{Ca(OH)_2(s)} \rightarrow 2\mathrm{NaOH(aq)} + \mathrm{CaCO_3(s)} \tag{2}$$

2. The lithium hydroxide can remove carbon dioxide by chemically reacting with it, the method can be expressed as:

$$2\mathrm{LiOH(s)} + 2\mathrm{H_2O(g)} \rightarrow 2\mathrm{LiOH} \cdot \mathrm{H_2O}(s) \tag{3}$$

$$2\mathrm{LiOH} \cdot \mathrm{H_2O(s)} + \mathrm{CO_2}(g) \rightarrow \mathrm{Li_2CO_3(s)} + 3\mathrm{H_2O}(g) \tag{4}$$

This method need can also be used to remove CO_2. The lithium orthosilicate used this methodology to capture CO_2 and store energy. However, the process need high temperature to form the carbonate. It's hard to trigger the process.

3. The activated carbon can be used to remove the carbon dioxide in the room. After people entered the closed space, the air was with high concentration of CO_2. The CO_2 can absorb the carbon dioxide through beds of activated carbon.

Using activated carbon has a disadvantage, the activated carbon bed need to be replaced when the bed is saturated with CO_2. It will regenerate by blowing CO_2 from the bed, which costs too much time. The whole process is complex.

All of these three methodologies can be used to generate the carbon dioxide scrubber. The first methodology was used in producing the advanced air purifier with function of removing the CO_2 in the room. The advanced air purifier which can remove CO_2 has similar function to the carbon dioxide scrubber. I will add the carbon dioxide scrubber in the model to see whether it will work well.

3 PROBLEM DEFINITION

In this report, I used the Cadmium as the tool to simulate the CO_2 level change in closed space. When people entered the room, the CO_2 level increased. I want to find some methods to reduce the CO_2 level in the closed room. The CO_2 sensors will be used in the model. It can detect the CO_2 level change in multiple places and different occupants. The report took advantage of the Cell-DEVS to realize the goal of the model. Some potential objects which might reduce the CO_2 level were tested and analyzed in the report. The methods included:

- The CO_2 can be absorbed by green plants. I added plants in the room to see whether the plants can reduce the CO_2 level or not. The result should also show how much CO_2 can be removed after I added the plants in the room. According to the research, only limited amount of CO_2 will be absorbed in short time, I will simulate the model and illustrate the function of plants in the closed space. Meanwhile, different plants can absorb different amount of CO_2 based on scientific background. I can simulate the model using one kind of plant a time to see which plant can absorb the most amount of CO_2.
- The carbon dioxide scrubber can be applied to improve the IAQ and remove the CO_2. The methodology was using NaOH solution to absorb CO_2. In this model, I will add two carbon dioxide scrubbers to show the change of CO_2 level.

4 MODELS DEFINED

In the paper, I limited a closed scope 63×50 cells in three dimension and set six moving occupants. The presence for CO_2 to escape included the wall, door and ventilation port, plants, air purifier and CO_2 detector. In Figure 1, the model and inputs were shown. Each cell mode was independent. In original model, the report averaged CO_2 levels of all cells in the local neighborhood including the center cell. This methodology can be used in this report as well. The rate of diffusion was then controlled explicitly by the delay between each averaging event. The cell space should reflect the size of an average small office space or room. Meanwhile, the conceptual model is shown in Figure 2.

In Figure 2:

- Pink points represent the carbon dioxide scrubber. They can absorb the CO_2 generating by moving people.
- Green points represent the green plants, they can absorb the CO_2. They were placed near the wall. Different kinds of plants were tried in the model.
- Green part at the upper right hand corner represents the door of the room.
- The blue points represent the vents of the room.
- The red points represent the moving occupants.
- The black parts represent the walls of the room.

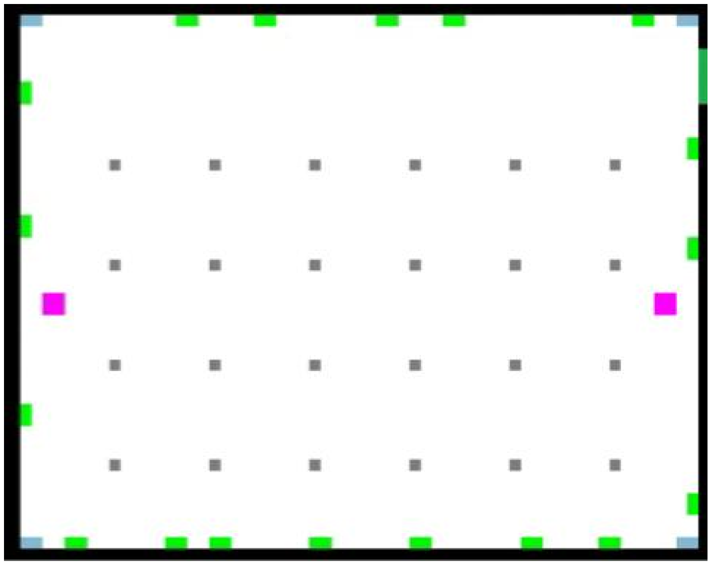

Figure 2: The closed room model

In Figure 3, the conceptual model was shown. The report used the same conceptual as the original CO_2 model as Professor provided. The original model presented the closed space as a set of neighboring cells in a two dimensional Cell-DEVS model with different CO_2 levels. Each cell in the model represents $25cm \times 25cm \times 25cm$ spaces and therefore 23.438L volume of air. It's clear to see that the window, door, ventilation port can remove the CO_2 from the room. In the report, the moving occupants all have fixed destinations. People in the room will move to the destination. The different distances between people were analyzed.

4.1 Formal Model Formalism

The changed model two-dimensional Cell-DEVS space of the CO_2 model can be expressed as:

$$CO_2 = < X_{list}, Y_{list}, S, X, Y, \eta, N, \{t_1, t_2\}, C, B, Z >$$

Where:

- $X_{list} = Y_{list} = \{Ø\}$
- $X = Y = \{Ø\}$
- S = type: {-100, -200, -300, -400, -500, -600, -700,-800, -900}
- I is set of states
- X is the input events set
- Y is the output events set
- η is the neighborhood size, $\eta = 5$
- N is the neighborhood set, $N = \{(0,0), (-1,0), (0,-1), (0,1), (1,0)\}$
- $\{t_1, ..., t_n\}$ is the number of cells in each dimension, t_1=14 and t_2=20
- C is the cell shape, $C = \{Cij / i \in [0,14] \wedge j \in [0,20]\}$
- $B = \{\phi\}$ which is the unwrapped cells.
- Z is the translation function

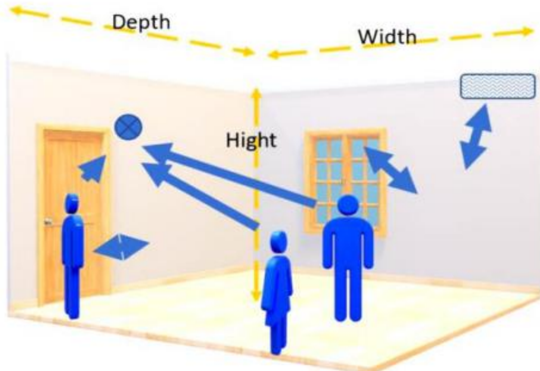

Figure 3: Conceptual model

The types were listed below:

- type -100: normal cell representing air with some CO_2 concentration
- type -200: CO_2 source, constantly emits a specific CO_2 output
- type -300: impermeable structure (Eg: walls, chairs, tables, solid objects)
- type -400: doors, fixed at normal indoor background CO_2 level (500 ppm)
- type -500: window, fixed at lower CO_2 levels found outside (400 ppm)
- type -600: ventilation, actively removing CO_2 (300 ppm)
- type -700: workstations
- type -800: plants
- type -900: carbon dioxide scrubber

The local computing function τ of the atomic model of each cell were listed in Table 1. The duration function D was also included in this report. The values of D(s) were shown in Table 2. Each types have corresponding values in Table 1 and Table 2.

Table 1: Values of τ (N).

τ (N)	N
conc = average of neighbors	type = -100
conc = neighbors average+145.92ppm	type = -200
conc = -10	type = -300
conc = 500 ppm	type = -400
conc = 400 ppm	type = -500
conc = 300 ppm	type = -600
conc = 500 ppm	type = -700
conc = average of neighbors-0.229ppm	type = -800
conc = average of neighbors-10ppm	type = -900

The cell has two state variables including the type and *conc.* Table 1 shows eight possible values of different types. conc is a double value which represents the CO_2 concentration level in ppm in each cell. The impermeable cells have the conc variable value of -10. Most of the cells in the model have the default delay of 60000ms. The CO_2 sources represented the people breathing. The cells have the value of 145.92 ppm of CO_2 added every 600000ms to intimate breath per ten minutes.

Table 2: Values of D(S).

D(S)	**S**
R0+=60000	type = -100
R0+=600000	type = -200
R0+=60000	type = -300
R0+=60000	type = -400
R0+=60000	type = -500
R0+=60000	type = -600
R0+=60000	type = -700
R0+=60000	type = -800
R0+=60000	type = -900

The types have rules in the model. The type -100 represented the open-air spaces with constant 500 ppm CO_2 level. The type -200 was the CO_2 sources with a fixed level of CO_2 added at an interval to mimic breathing of people. Additional 12.16ppm of CO_2 is added every five seconds. The type -300 was the walls that are impermeable and do not allow CO_2 to diffuse through them. Set the CO_2 level to maintain -10. The type -400 was doors with a fixed at normal indoor background CO_2 level. I set the CO_2 level to maintain 500 ppm. The type -500 was the window with a fixed at lower CO_2 levels found outside. Set the CO_2 level to maintain 400ppm. The type -600 was ventilation that actively removing CO_2. Set the CO_2 level to maintain 300ppm. The type -700 was the workstations. The type -800 was the plants which can remove the CO_2. The type -900 was the carbon dioxide scrubber, it can absorb the CO_2. The carbon dioxide scrubber removed more CO_2 than the plants absorbed.

4.2 Experimental Tools

For the term project, I chose the Cadmium to set up the model and generated the corresponding results. Cadmium is a tool for Discrete-Event modelling and simulation which is based on the DEVS formalism. DEVS is a discrete event paradigm that allows a hierarchical and modular description of the models (Wainer, 2009). This term project also realized the visualization of the model. I used the ARS Lab Simulator Viewer to finish the visualization part of the project.

5 SIMULATION RESULTS

The simulation results were visualized using ARS Lab Simulator Viewer. The videos were attached in a zip of my term project. Diffusion rules for open-air and source cells were performed by averaging the conc values of the center cell with the four neighboring cells. Open-air cells need to check the local neighborhood in case one or more wall/impermeable cells are present. If this is the case, the diffusion computation is adjusted to exclude the unwanted cells from the average calculation. There are eight cases to consider for an open-air cell: four cases when the cell was directly against a wall and not in a corner, the other four cases of being in a corner where walls met.

The color legend for CO_2 levels shown in simulation (Khalil et al. 2020).

Figure 4: Conceptual model Color legend for CO_2 levels

In this project, four major problems were analyzed:

- Does the green plants absorb the CO_2 in the closed space?
- Does the carbon dioxide scrubber absorb the CO_2 in the closed space?

5.1 CO_2 Level Change

In this part, I would like to show the CO_2 level change after adding moving occupants, green plants and two carbon dioxide scrubbers in the closed rooms. The simulation time was 1440 minutes for the whole day. The screen captures were shown to illustrate the experiment results.

In Figure 5, the right part of the picture represented the beginning situation of the room. The occupants were all outside of the room. The left part represented the routine when moving people entered the room. The image in the middle showed the carbon dioxide level of the room. The color legend was shown in Figure 4. At the beginning of the room, the positions of vents and carbon dioxide scrubber were blue. The reasons were listed below:

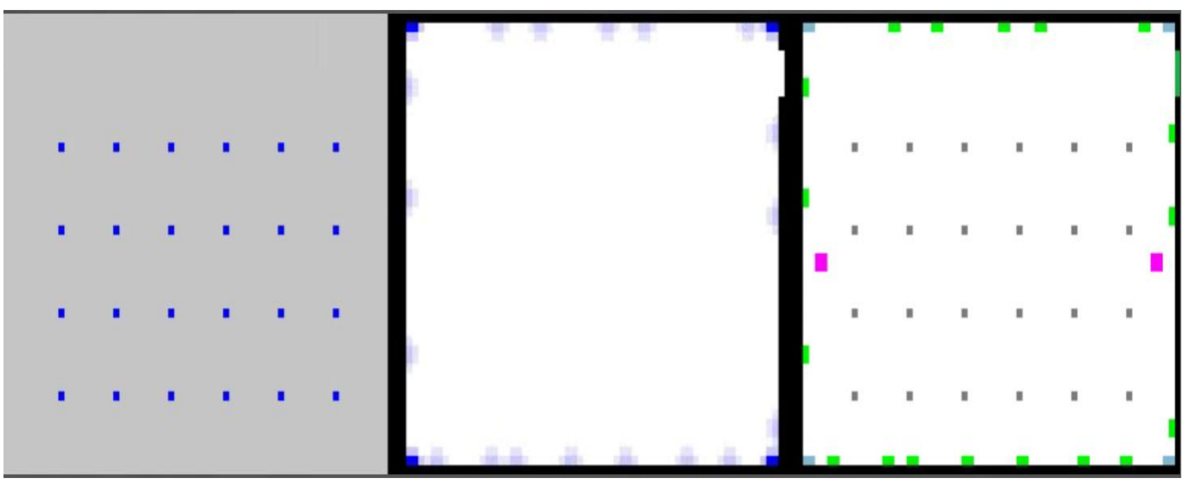

Figure 5: Beginning situation of the closed room.

1. The ventilation system in the closed room can let the gas freely move. Hence, the amount of CO_2 is lower than 500 ppm. Hence, the color of corresponding positions were blue when moving occupants have not entered the room.
2. The carbon dioxide scrubber can absorb the CO_2. Hence, the CO_2 level is low. The color of the carbon dioxide scrubber positions were blue as well.
3. I put some plants near the wall to absorb the CO_2. However, the effect was hard to see. They only generate small amount of air and remove limited amount of the CO_2. In Figure 5, I used the Prayer Plant in the room. It absorbed 215.01 ppm in 1440 minutes. However, a normal people can generate 18158.4 ppm CO_2. The effect of the plant is small according to the results.

In Figure 6, the moving occupants entered the room. The red points represented the moving occupants. The left part of the image showed the routine of each moving people. They entered the room and went to their corresponding destinations. The gray points represented workstations. In the model, moving people have their workstations, they went to their unique workstations.

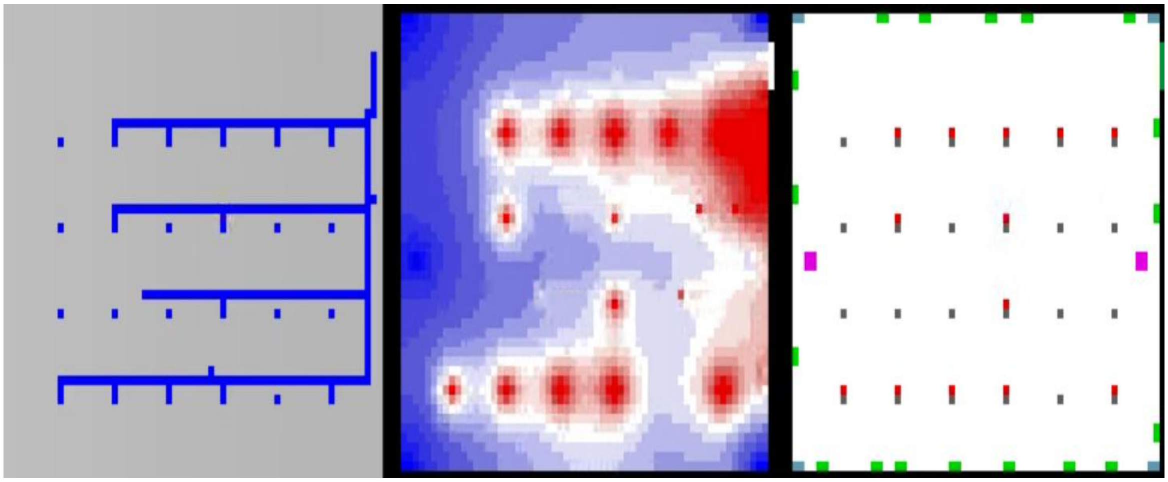

Figure 6: Moving occupants entered the room

At the same time, the red field appeared and increased when moving occupants moved into the room. Meanwhile, it's clear to see that each people has different sizes of red fields. This showed that moving occupants have different breathing rates themselves. The breathing rate of each person was generated randomly. As the time increased, the red field increased as moving people breathed in the closed space. The result was shown in Figure 6, which can illustrate that as the time increased, the CO_2 level in the room increased. In Figure 7, we can see that the position of carbon dioxide scrubber turned blue since it can reduce the CO_2 level as time increased.

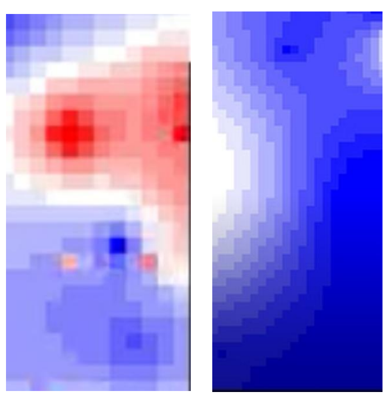

Figure 7: The simulation results of carbon dioxide scrubber position at different time.

As we can see in Figure 8, all the moving people entered the room. The red points and the gray points were gathering together. This showed that moving people all went to their workstations in the closed space. Compared to Figure 6, the red field in Figure 8 enlarged. Moving people with higher breathing rate would cause larger red circle in the simulation. As the amount of people in the room increased, the CO_2 level increased. Meanwhile, we can see that the darker blue points represented the vents and carbon dioxide scrubbers. They increased the air circulation and absorbed the CO_2 in the room. The center area had larger size of red parts than the peripheral area. I didn't set any vents or carbon dioxide scrubber in the middle of the room, the CO_2 can't be removed. The peripheral area have products that can remove the

CO_2, the red fields were smaller than the middle part of the room. For the plants in the room, it's hard to see the changes since they only observed little CO_2 in the room.

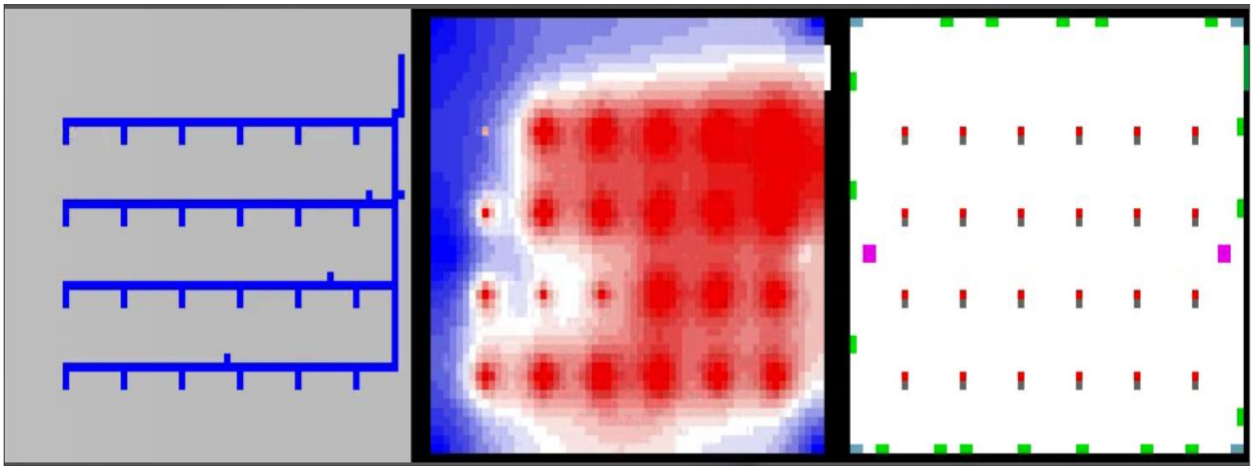

Figure 8: The simulation results of carbon dioxide scrubber position at different time

In Figure 9, we can see that some red points disappeared in the model. This showed some moving people left the room. As people left the room, the area of the red parts represented the CO_2 caused by moving people. The CO_2 will be absorbed by vents, plants and carbon dioxide scrubbers in the room. The same trend appeared as Figure 8. The center area had larger size of red parts than the peripheral area. It's because there was no objects can remove the CO_2. The points near the wall didn't become blue or have any evident change. Hence, the green plants didn't cause great change to the CO_2 level. It's reasonable since the plants can't absorb large amount of CO_2.

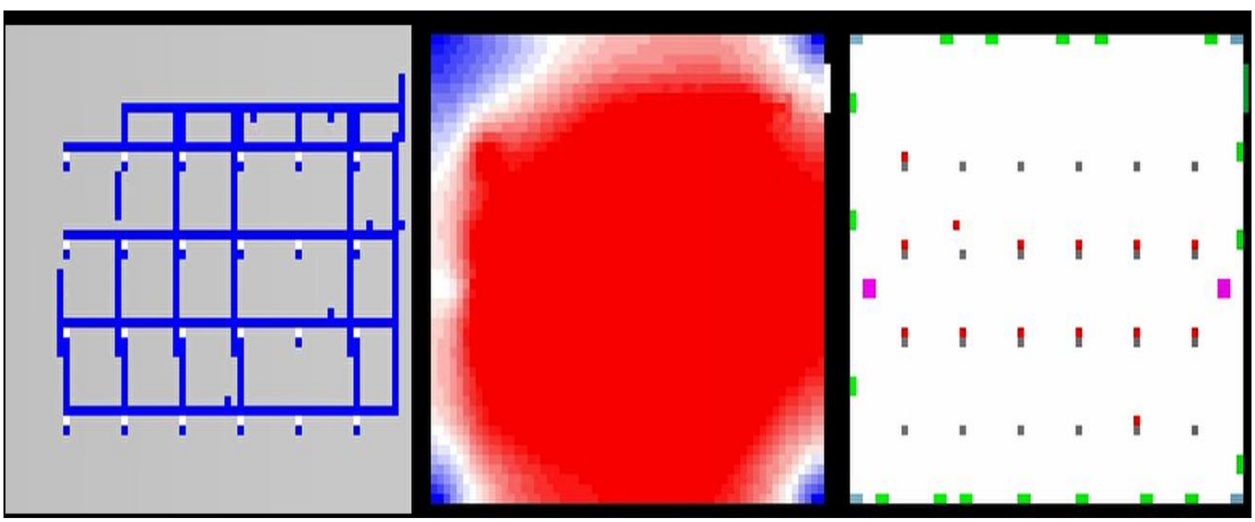

Figure 9: Part of the moving occupants left the room

The Figure 10 showed the situation when all the moving people left the room. The capture was gained after Figure 9. As the time increased, the size of blue field increased and the size of the red field in the picture was reduced. It can be concluded that CO_2 level decreased when moving occupants left the room. The room didn't have the CO_2 source at that time. Meanwhile, carbon dioxide scrubbers and ventilation can remove the CO_2 in the room.

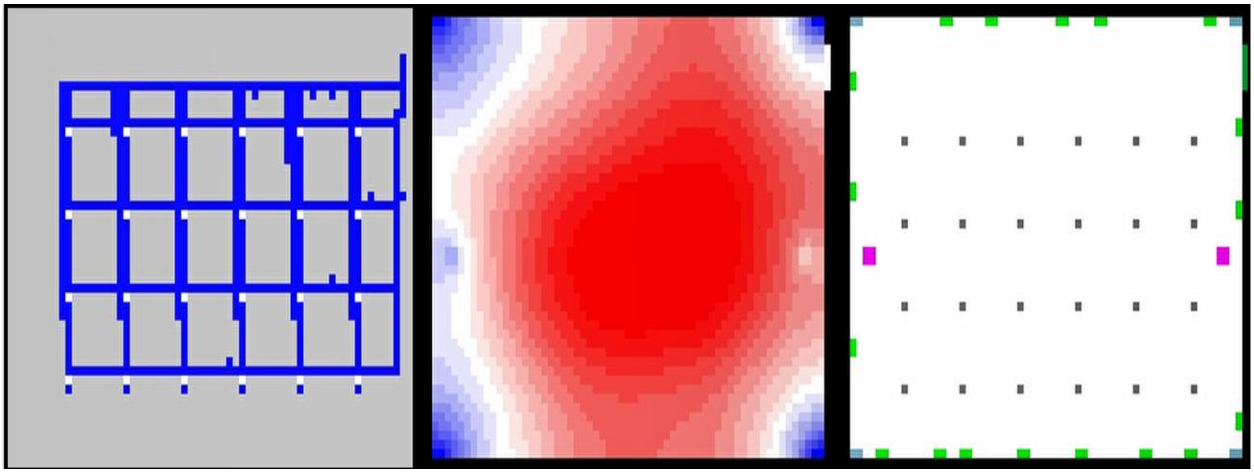

Figure 10: Moving occupants all left the room

As we can see in Figure 11, the result showed the CO_2 can be absorbed by ventilation system, carbon dioxide scrubbers and plants. But plants didn't remove large amount CO_2 in the room. Only small size of red parts in the middle of the room still can be seen in the room. This is because I didn't put vents, carbon dioxide scrubbers in the center of the room.

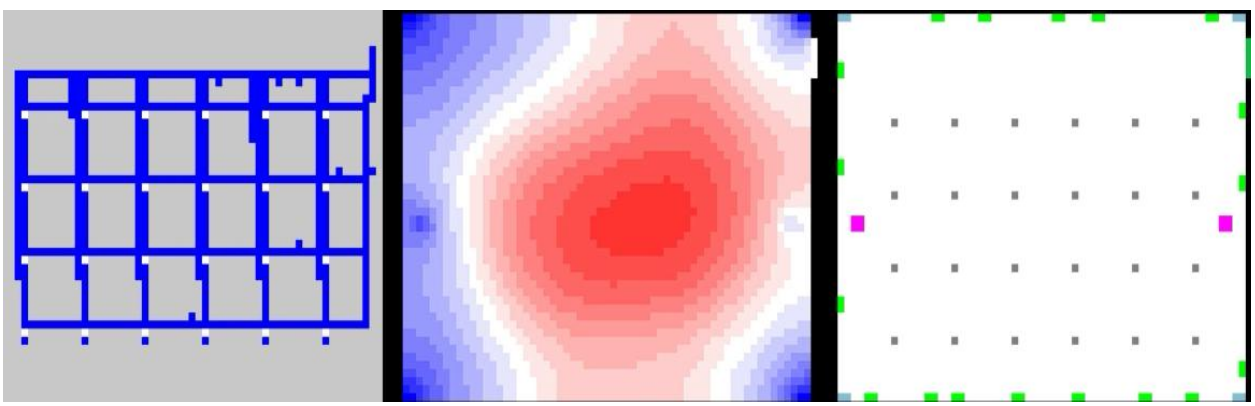

Figure 11: End of the simulation

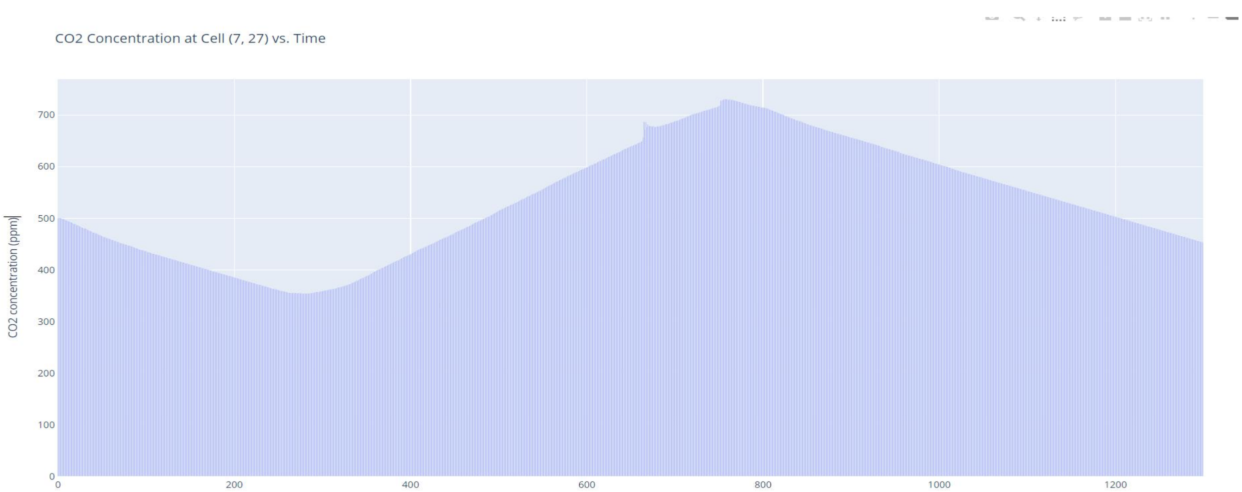

Figure 12: Simulation result after adding plants and carbon dioxide scrubber

The CO_2 sensor was at the position (7,27,0). It can detect the CO_2 level change in the room. The position was near the carbon dioxide scrubber, so the beginning state of CO_2 level was 500 ppm. As we can see in Figure 12, the highest CO_2 concentration level was about 700 ppm when all the people entered the room. After they left the room, the amount CO_2 in the room were reduced by carbon dioxide scrubber and ventilation system. From the Figure 12, we can see that the CO_2 level near the carbon dioxide scrubber would become 500 ppm approximately after people left. The carbon dioxide scrubber absorb the CO_2 generated by moving people and make the CO_2 level stable again. The plants only removed limited value of CO_2.

5.2 Effect of the Plants

In the model, I added some plants in the room and put them near the wall. The plants were not evenly separated in the room. All indoor plants in Figure 1 will be tested individually. I want to figure out whether green plants can remove the CO_2 or not, how much CO_2 can be absorbed. I tried several types of plants to see the CO_2 level change in the model. The simulation results were shown below.

Table 3: Values of CO_2 that each plant can absorb per day.

Plant Type	**Value of CO_2**
Spider Plant	0 ppm
Prayer Plant	215.01 ppm
Syngonium	200.01 ppm
Kadaka Fern	19.38 ppm
Golden Pothos	182.01 ppm
Dumb Cane	166.2 ppm
Anthurium	71.01ppm

- Not all kinds of green plants can absorb the CO_2. The spider plant is not able to reduce the CO_2 level in the room.
- Most green plants can absorb the CO_2 in the closed space. They can't remove large amount of CO_2 in short time. The results of plants which can absorb the CO_2 were listed in Table 3. It showed the amount of CO_2 that each plant can absorb per day. The values were based on scientific research (Suhaimi et al. 2016).

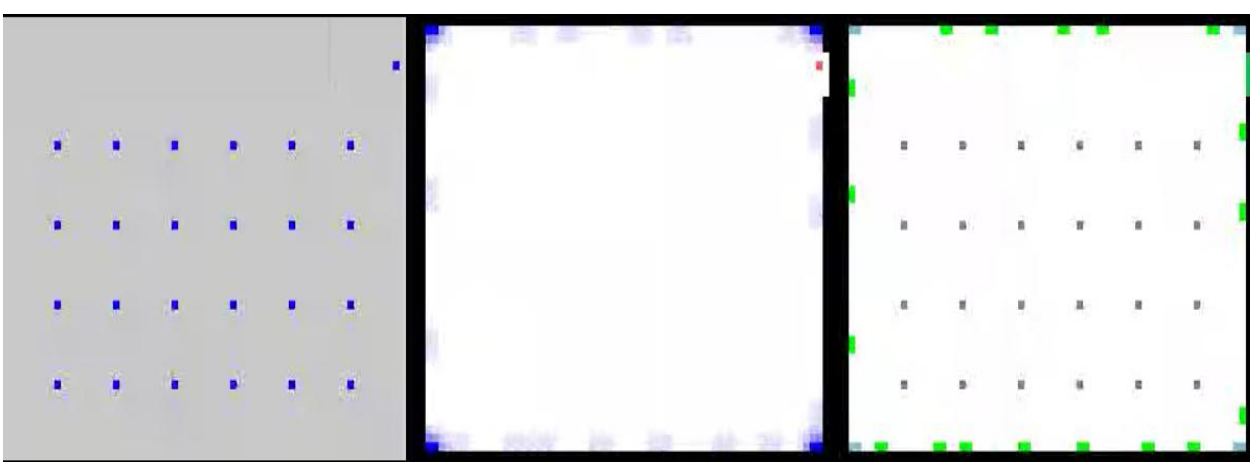

Figure 13: Beginning of the simulation without carbon dioxide scrubber

In the model, people breathed out 2.432 ppm CO_2 per second. In Table 3, we can see that Prayer Plant is the most effective plant to reduce CO_2, it can remove 0.0025 ppm CO_2 per second. The indoor plants can reduce the CO_2. However, only limited CO_2 can be absorbed, the influences of the green plants are too small for the closed room.

I simulated a model without the carbon dioxide scrubbers, I want to see whether green plants can remove the CO_2. As we can see in Figure 13, only green plants and ventilation system of the original model were added in the room. I put the he green plants randomly in the closed space. The amount of moving occupants and workstations didn't change in the model.

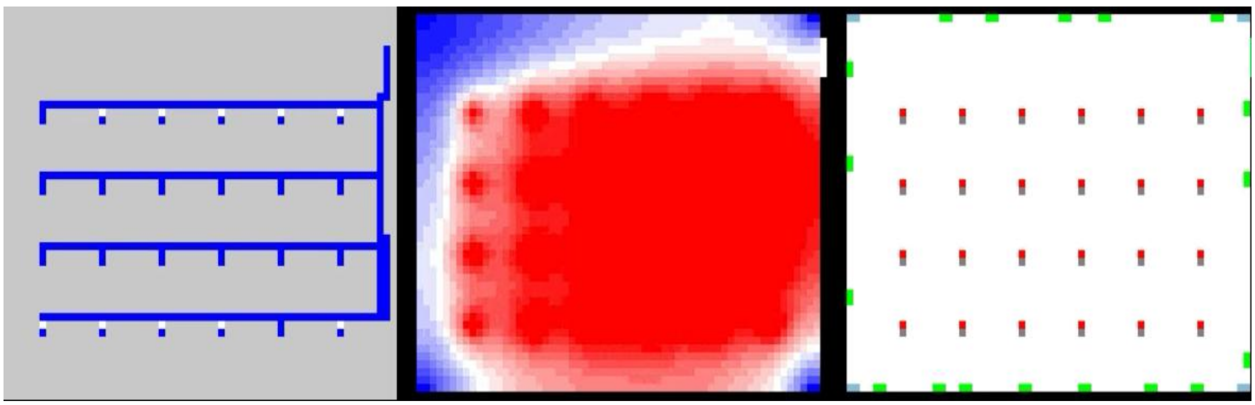

Figure 14: Simulation result of the model without carbon dioxide scrubber

As we can see in Figure 14, the red part of the image were increased. Each people have different breathing rates as well. The positions of green plants didn't turn to blue or have evident change in the result.

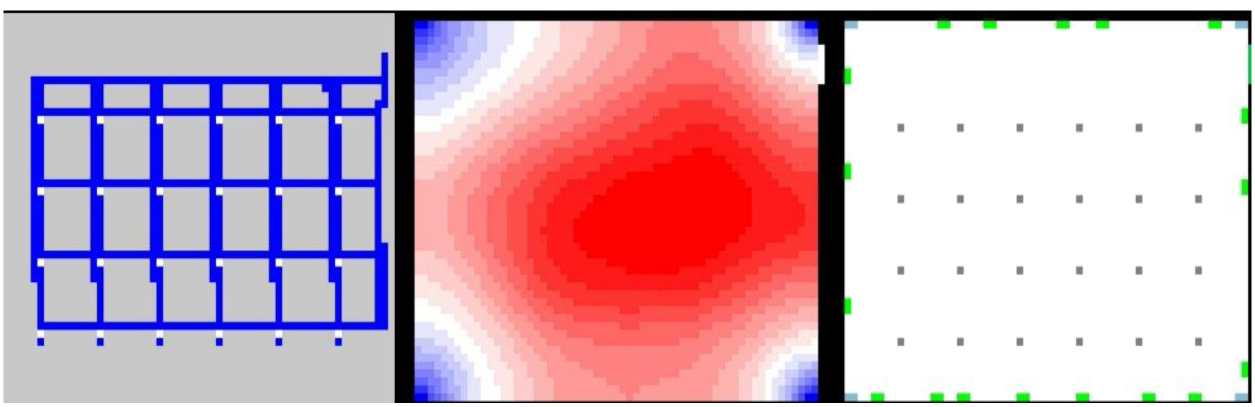

Figure 15: The end of simulation without carbon dioxide scrubber

Compared to Figure 11, the simulation result in Figure 15 has larger red space in the room. This showed that more CO_2 were absorbed by carbon dioxide scrubbers.

I also simulated the original model, the model doesn't have green plants and carbon dioxide scrubbers in the room. Only ventilation system of original model were added in the room. I will compare the result of Figure 15 and Figure 16 to show that plants didn't cause any evident change in CO_2 level. The original model was shown in Figure 16, the simulation result was shown in Figure 17. The parameters of the closed space were same. I put ventilation system and moving people in the room, other objects were not included.

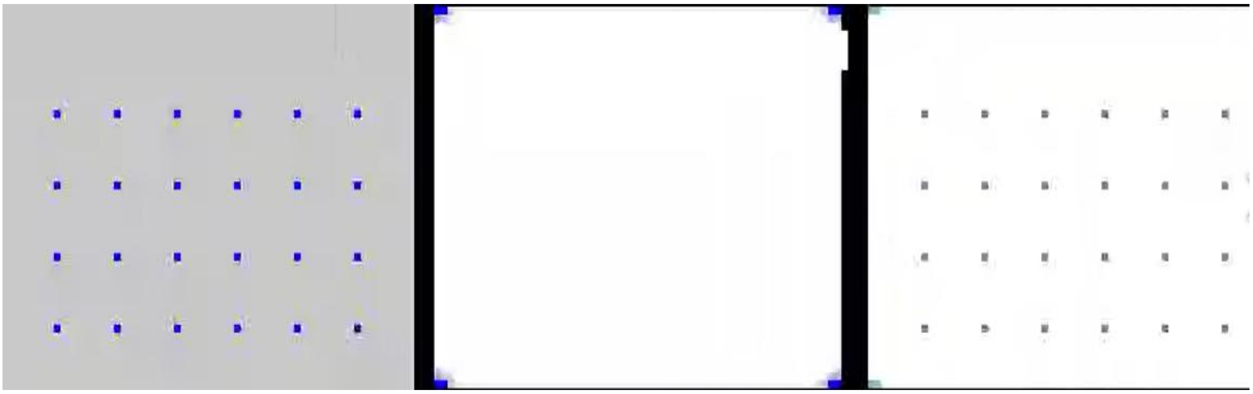

Figure 16: Beginning of the simulation without carbon dioxide scrubber

As we can see in Figure 17, the red space of the result was same as the result of Figure 15. They have almost the same CO_2 level and CO_2 diffusion patterns. This showed that green plants didn't change large amount of CO_2 level. The detailed data were shown in Figure 18.

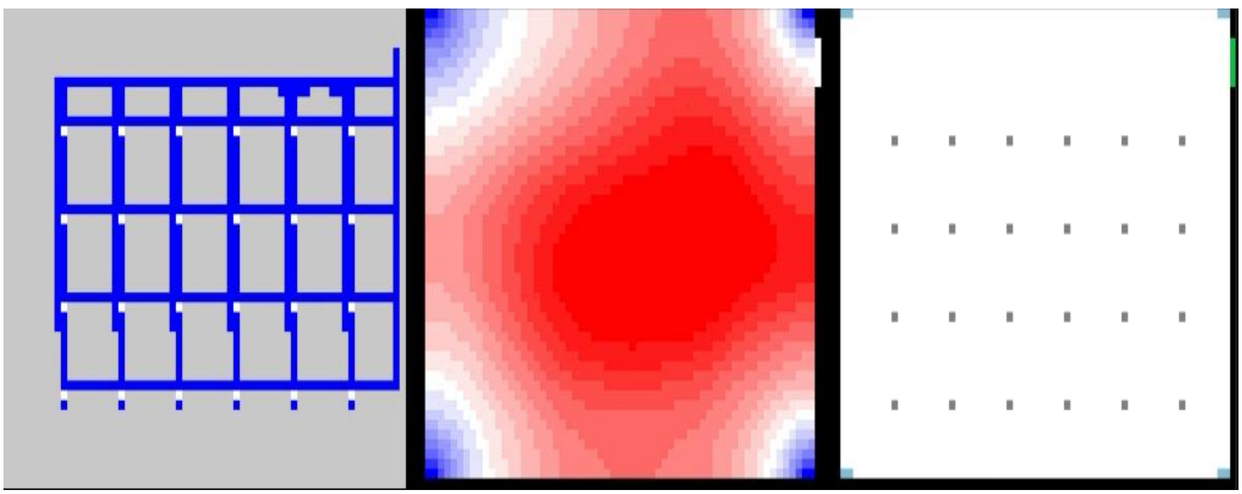

Figure 17: Result of the simulation without plants and carbon dioxide scrubber

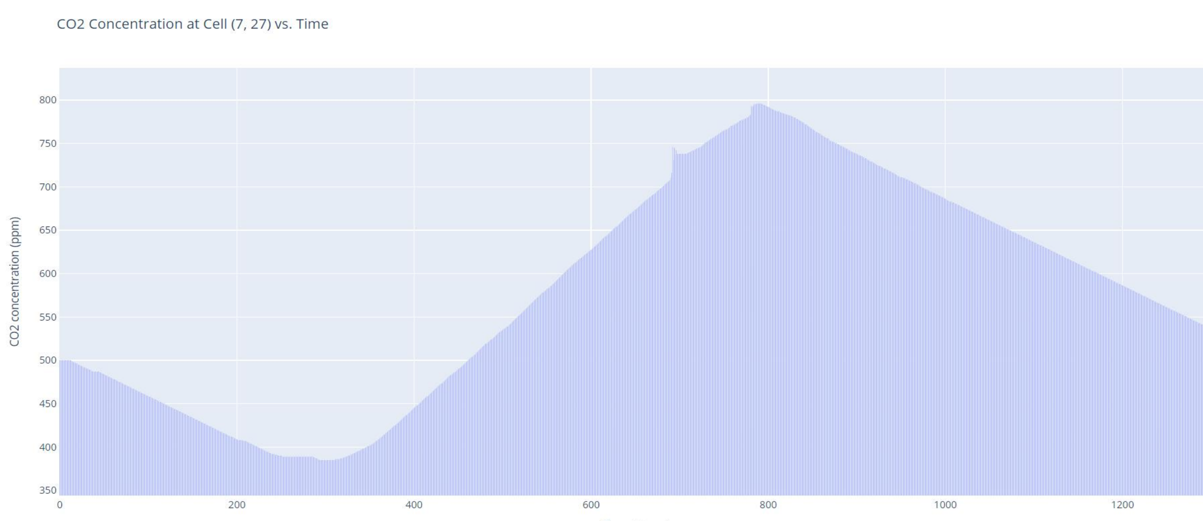

Figure 18: Simulation result with green plants

The CO_2 sensor was at the same position (7,27,0). As we can see in Figure 18, the highest CO_2 concentration level was about 800 ppm when all the people entered the room. The value was higher than the model with carbon dioxide scrubbers. After people left the room, the amount CO_2 in the room were reduced by ventilation system. The CO_2 level became 540 ppm approximately after people left. It's clear to see that the CO_2 concentration level increased after I deleted the carbon dioxide scrubbers.

Figure 19 showed the original model simulation result. As we can see, the peak of CO_2 level was 800 ppm. The carbon dioxide level didn't have evident change after I added the green plants. After people left the room, the CO_2 level became 550 ppm approximately in the original model. The green plants remove the CO_2 in closed space, 10 ppm CO_2 was removed by green plants.

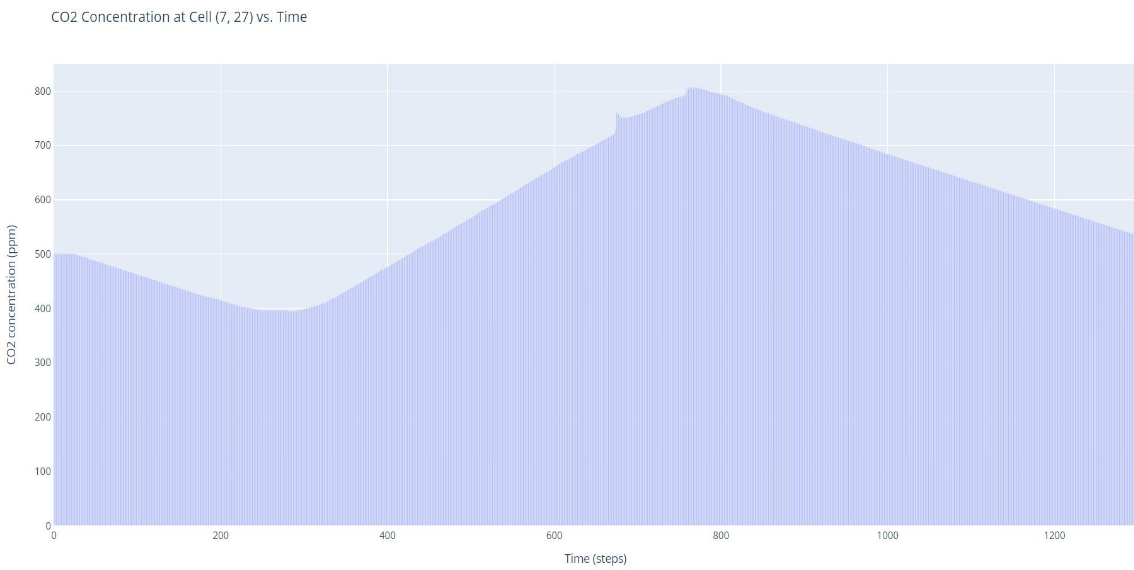

Figure 19: Simulation result of original model without plant and carbon dioxide scrubbers

5.3 Effect of Carbon Dioxide Scrubber

I simulated the model with two carbon dioxide scrubbers, ventilation system, workstations, same amount of moving people, door in the closed space and the size of the room was the same. The plants were not added in the model. In this way, the effects of the carbon dioxide scrubbers will be clear to see. The model was shown in Figure 20.The pink points in the model represented the carbon dioxide scrubbers.

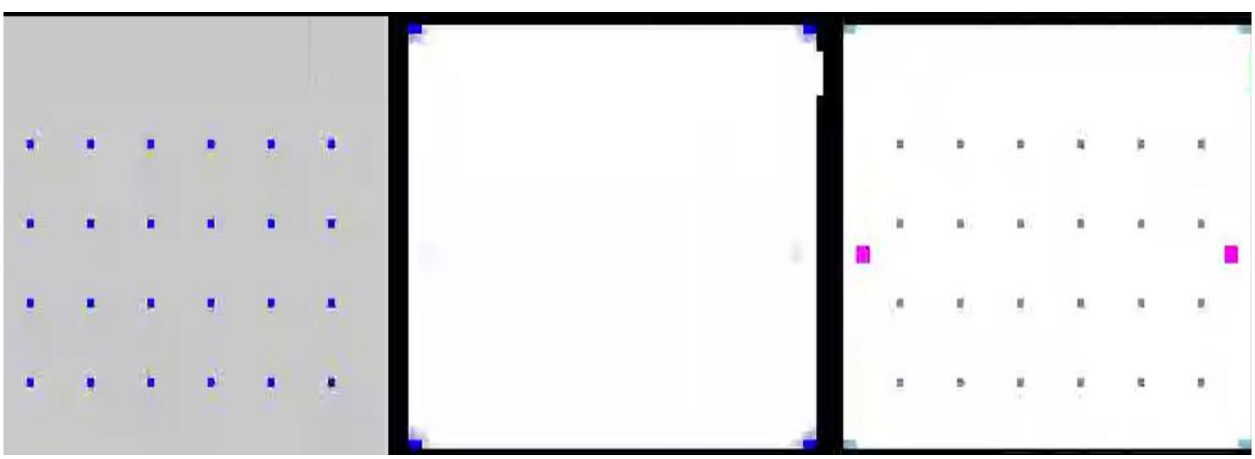

Figure 20: The model without green plants

After the simulation, it's clear to see that carbon dioxide scrubber can remove the CO_2 in the room. Before people enter the room, the carbon dioxide scrubber position showed blue color. After people entered the room, they absorbed the CO_2 effectively. In the result, the red parts in the middle of the room didn't fade away since I didn't put any objects to remove the CO_2.

The left part shows the routine of the moving occupants. The middle image showed the CO_2 level change. The right part showed the moving occupants in the room. The blue points in the right image represented the ventilation parts. The gray points were the workstations of the model. The simulation result was shown in Figure 21.

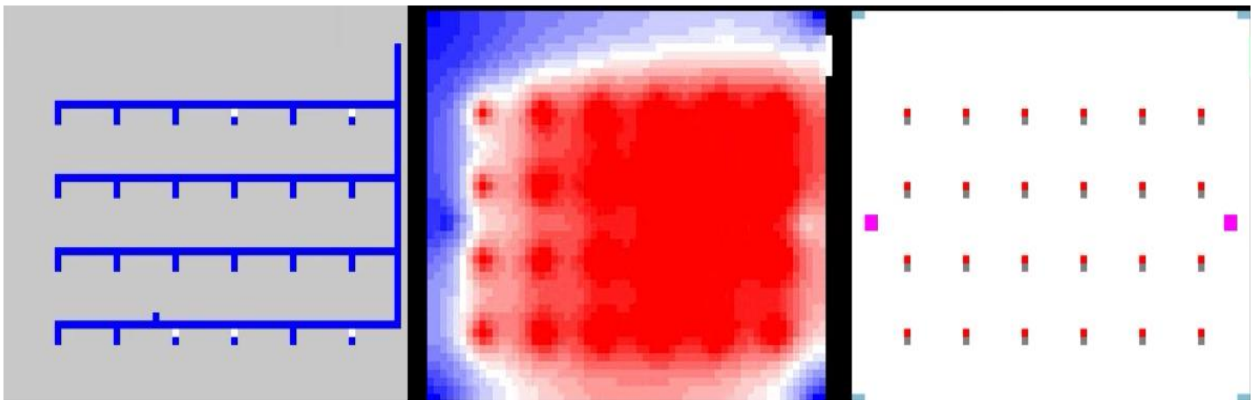

Figure 21: All the moving occupants entered the room of the simulation without plants

As we can see in Figure 21, the red points were gathered in their corresponding workstations. It showed that all the occupants entered the room. Each people has different breathing rates. The CO_2 was generated by moving occupants. Four small blue parts were shown in the corner. These were the ventilation system and carbon dioxide scrubbers in the room. They can remove the CO_2 in the room.

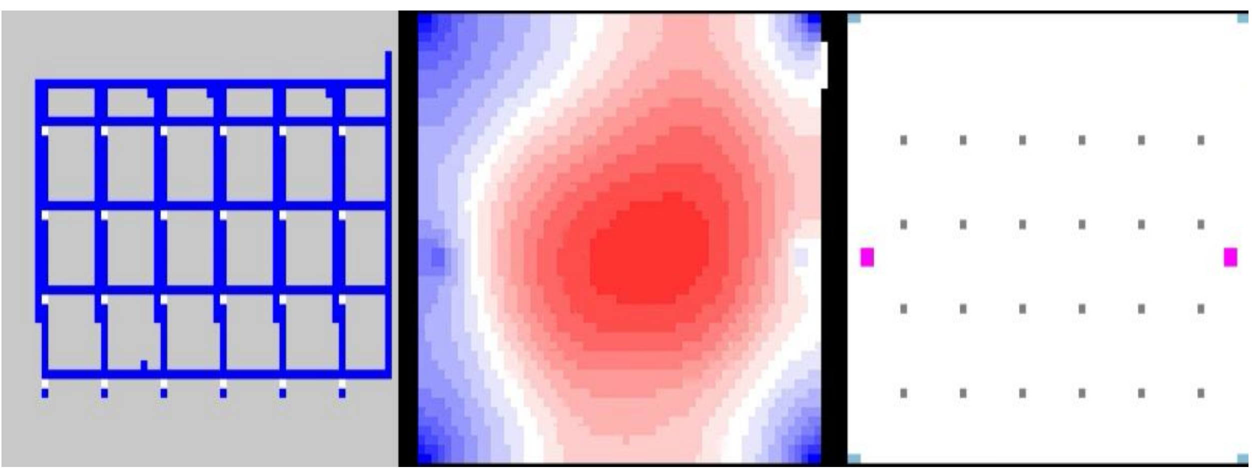

Figure 22: The end of the simulation without plants

In Figure 22, the red points disappeared. It showed that all the occupants left the room. The size of red field was almost same compared to the result in Figure11. In Figure 9, two carbon dioxide scrubbers and some plants were added to remove the CO_2 in the room. Large amount of CO_2 in simulation without carbon dioxide scrubbers (Figure 15) was not absorbed if I didn't put the carbon dioxide scrubbers in the room. The carbon dioxide scrubbers can CO_2 in closed space.

The simulation result of model with carbon dioxide scrubbers was shown in Figure 23. The peak of the CO_2 level was 700 ppm around. The value of CO_2 was almost the same as simulation result of model with plants and carbon dioxide scrubbers. The CO_2 level in Figure 23 reduced the CO_2 compared to original model. This showed that carbon dioxide scrubbers reduced the CO_2 in the room.

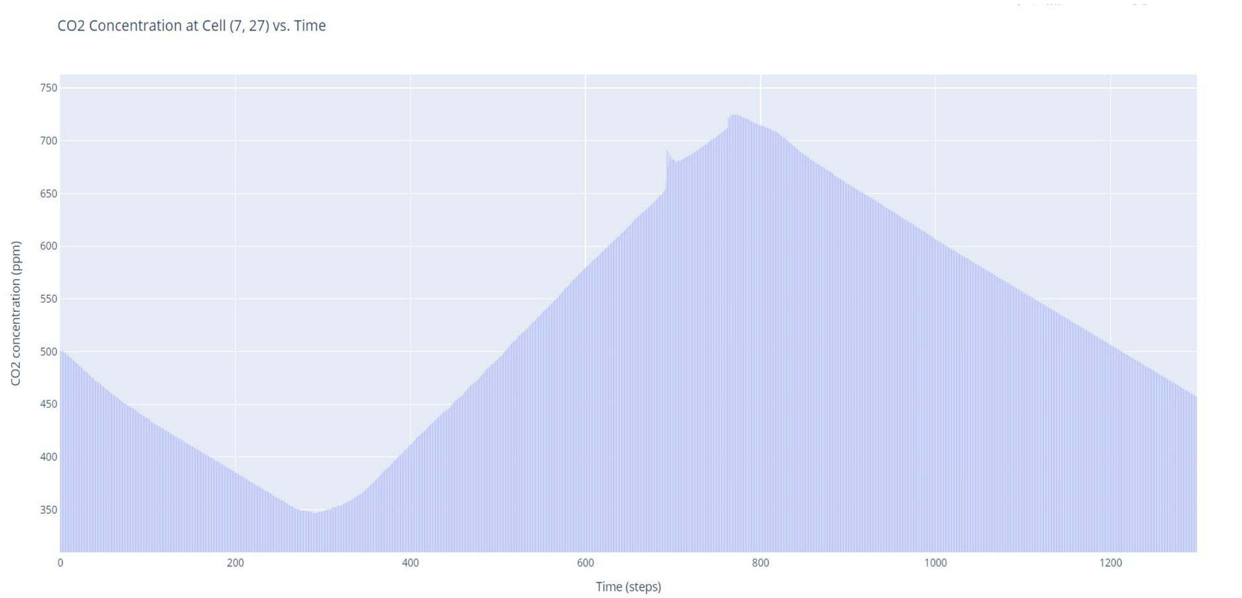

Figure 23: Simulation result of model with carbon dioxide scrubbers

CONCLUSIONS

The report dedicated to reduce the CO_2 in closed space. I added two carbon dioxide scrubbers and green plants to absorb the CO_2 generated by moving occupants in the room. The CO_2 in the room was reduced after making these changes. The results were shown and analyzed in the report. Based on the result, it's evident to see that moving occupants generated the CO_2 in closed space. I added the two carbon dioxide scrubbers and some plants in the model. The result showed that carbon dioxide scrubber can absorb the CO_2 in the room. Indoor green plants can absorb limited value of carbon dioxide. Not all of the green plants can absorb the CO_2, only some green plants are effective in removing the CO_2 in closed space. The Prayer Plant is the most effective plant in absorbing the CO_2 in the room.

ACKNOWLEDGMENTS

The report added the carbon dioxide scrubber and green plants to reduce the CO_2 in closed space. The process of finishing the term project was full of challenges. I made lots of efforts to realize the goal. I learned practical knowledge from the term project. Thank you professor Wainer fro giving me advice and help during the process.

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