Future Cities and Environment

The City Lung and COVID-19: Effect of Air Quality on Infection Control and Human Health

RESEARCH ARTICLE

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ABSTRACT

Throughout history, pandemics affect cities and their shapes, many health problems have been reflected in urban planning. Today, the world faces a general health crisis of COVID-19. The number of people infected by the virus and the increasing number of deaths may result in the city-design strategies. The effect of this pandemic shows the importance of urban design and its effect on viral infections and its role in the health of populations, but this relationship is unclear and ignored; that is why we face this pandemic today. In this study, we are looking to protect the environment and human health by enhancing air quality by designing a new urban space in crowded cities called 'City Lung' and green roofs to reduce the effect of air pollutions. Moreover, cleaning the air inside high-density districts by controlling pollution sources was a vital link observed between the lockdown and the reduction of CO2 emissions during the COVID-19 pandemic. This paper will start by searching for a crowded study area with high traffic density, study the impact of urban form and air quality effects on human health, and suggest solutions to this study area. In the beginning, ENVI-MET 4.4.5 software was used to simulate the carbon emission values and validate these values by CI-340 lightweight hand-held photosynthesis system device to get readings to evaluate the urban air quality and its effect. The present study reveals that algae stations improved the oxygen ratio 1.65 times in the study area than the existing values. Also, green roofing as a solution effectively affects air quality near the ground, as an alternative for the green areas in crowded cities and pedestrians areas. This study enables urban planners to determine more greening principles for better urban living environments in high-density cities. Finally, the results give guidelines on improving air quality in the surrounding environment to enhance the quality of life.

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1. INTRODUCTION

The majority of the world's population lives in cities, which are also engines of economic growth and innovation. On the other side, cities are open to many stressors such as natural and artificial disasters due to their significant concentration of people and activity (Sharifi, 2020). While pandemics had impacted cities before, there is not enough literature on cities and pandemics before the outbreak of the COVID-19 pandemic (Matthew and McDonald, 2006). The previous epidemic has pushed the question of urban pandemic risk to be an exciting subject. Because many factors like climate change and human expansion on natural wildlife habitats may increase the frequency of pandemics in the future, understanding the basic patterns and dynamics of pandemics and their effects on cities is essential (Connolly et al., 2020).

As seen in history, a disease outbreak may happen at any moment, the spread of disease can be quick and tragic. Many people died during the Spanish flu pandemic (1918–1920) than in World War II (Centers for Disease Control and Prevention, 2018). Many pandemics have influenced our history and society; in ***Figure 1***, we can see a timeline of global pandemic outbreaks from ancient times to the twenty-first century (Huremović2019).

Survivors of the 1918 pandemic virus have caused almost all seasonal influenza epidemics during the last century; all influenza viruses responsible for the pandemics of 1957, 1968, and 2009. Also, it derived from the founding 1918 virus by gene changing between human, avian, and swine influenza viruses (Morens et al., 2009), as shown in ***Figure 2***.

As several urban forms and design elements can determine pandemic dynamics, the present study has primarily concentrated on density-related aspects; The COVID-19 epidemic brought up questions about the effects of compact urban development. Due to the high level of face-to-face interaction, densely inhabited and well-connected places were thought to be hotspots for the rapid spread of the pandemic. The evidence for a link

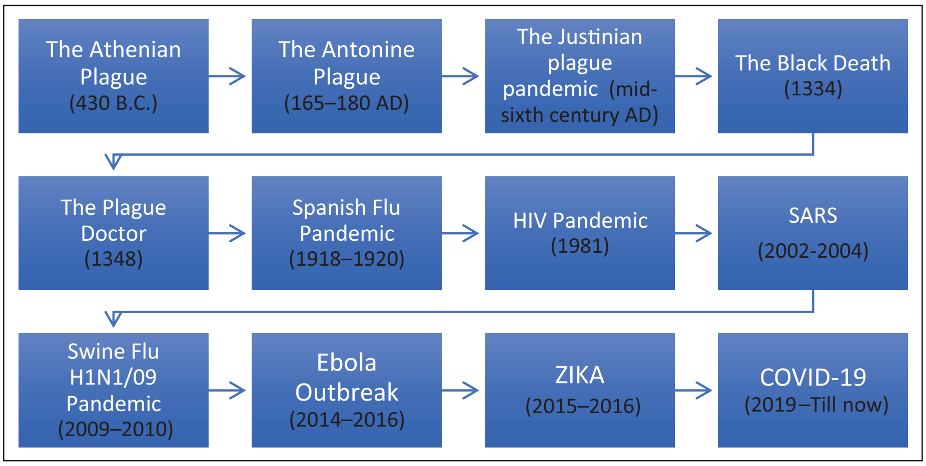

Figure 1 Timeline for the pandemics throughout history.

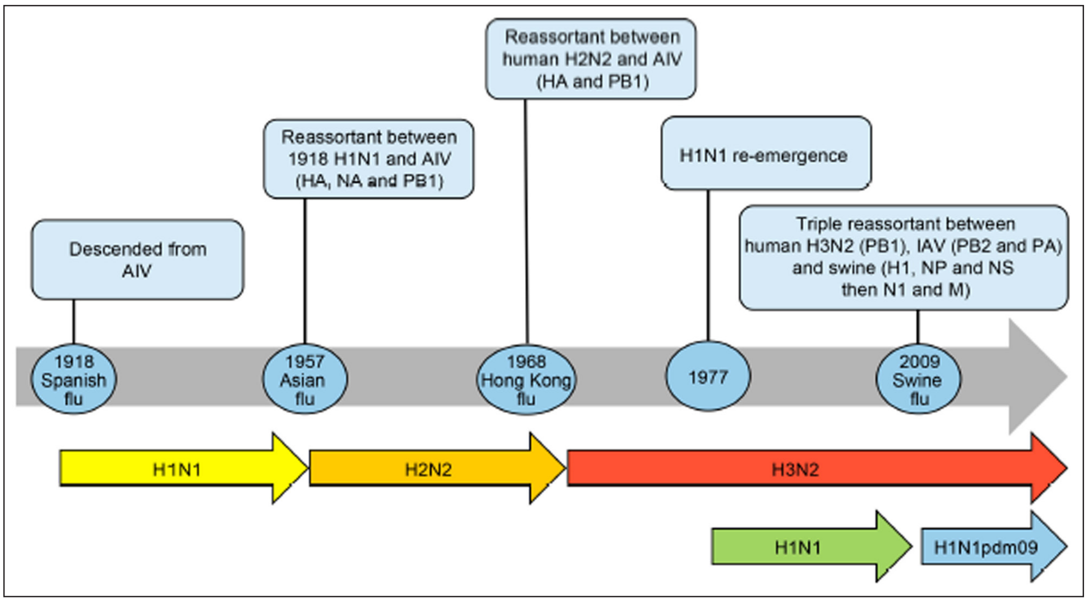

Figure 2 Timeline of influenza pandemics caused by the 1918 H1N1 virus and its descendants produced by an assortment of circulating strains with avian influenza viruses (AIV) and swine H1N1 viruses (Morens et al., 2009).

between density and COVID-19, on the other hand, is diverse and unclear. In a study of over 900 metropolitan counties in the United States (Sharifi and Khavarian-Garmsir, 2020). Unexpectedly, in many studies, they found that high-density areas had slightly lower virus-related mortality rates than broad areas. Willem R. found no significant positive link between county density and infection rate in the Netherlands, which is generally highly urbanized and densely inhabited. Boterman concludes that the public debate focuses on the high risks of infection in cities due to disruptive behaviors when controlling for age and public health factors (Boterman, 2020). On the other side, Lin et al. also discovered that the percentage of the population who came from Wuhan to other metropolitan and population densities are essential factors in explaining the COVID-19 spread rate in China. The highest scaled transmission rates were reported in densely populated urban areas and colder northern Chinese provinces. Disease spread had a non-linear connection with population density as shown in ***Figure 3*** (Lin et al., 2020).

Also, the linear link between population density and spread rate vanished after controlling the first variable, looked at the influence of population density, and found that high spread rates were not found in high-density metropolitan areas (Sharifi and Khavarian-Garmsir, 2020).

As seen in the history of the effect of these epidemics on different aspects of social lives, this study depends on the impact of COVID-19 on our lives today, which started in December 2019, the Coronavirus (COVID-19) erupted in Wuhan, China. By March 2020, the virus had spread around the world. In July 2020, the World Health Organization (WHO) reported that the virus might be transmitted through the air. The virus spreads as quickly and is more deadly than the seasonal flu (World health organization, 2021b). Now, there are significant public health problems caused by air pollution. In comparison, many studies have assessed air pollution and its effect on the risk of respiratory infection by observing the Coronavirus disease dashboard and global carbon emissions map, as shown in ***Figures 4*** and ***5***. These approximate values on both maps may be relevant in specific locations and potentially during human disease outbreaks.

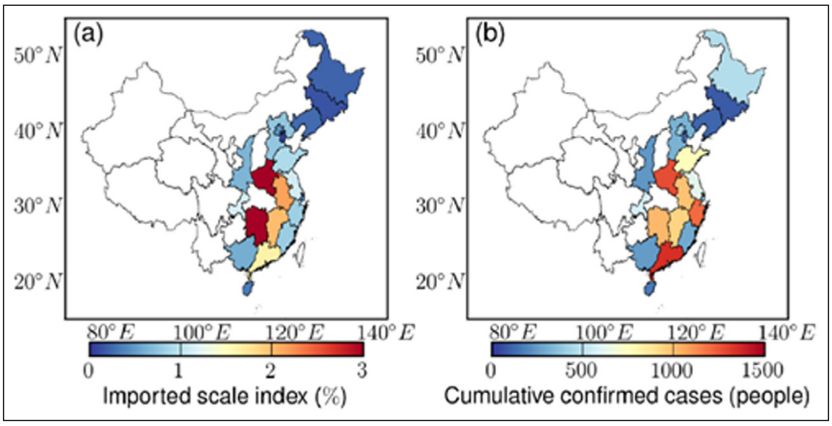

Figure 3 (a) Spatial distribution of the imported scale index for each province located on plains in China from 19 to 23 January 2020. **(b)** Spatial distribution of the cumulative number of confirmed cases of COVID-19 for each province located on plains in China on 29 February 2020 (Lin et al., 2020).

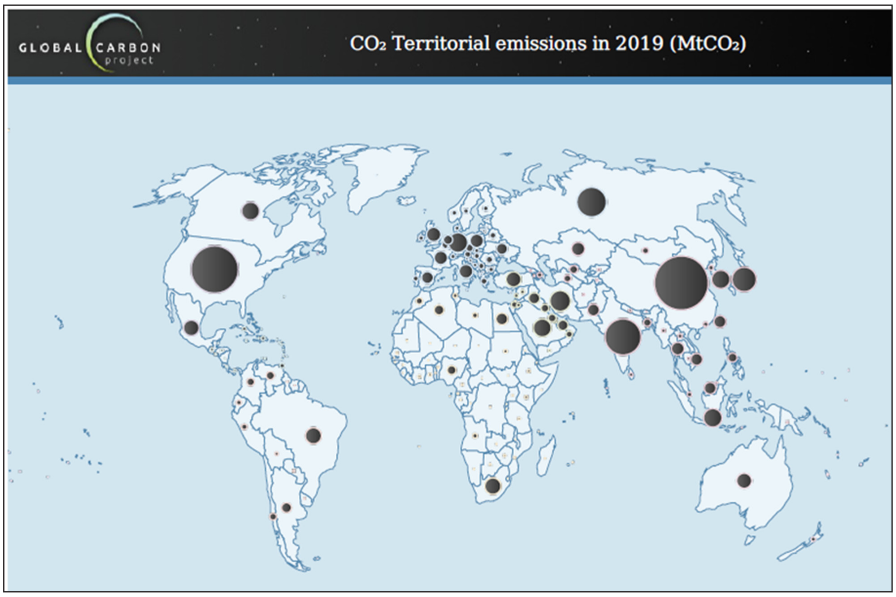

Figure 4 Carbon Dioxide emissions on the world map (Global Carbon Project, 2019).

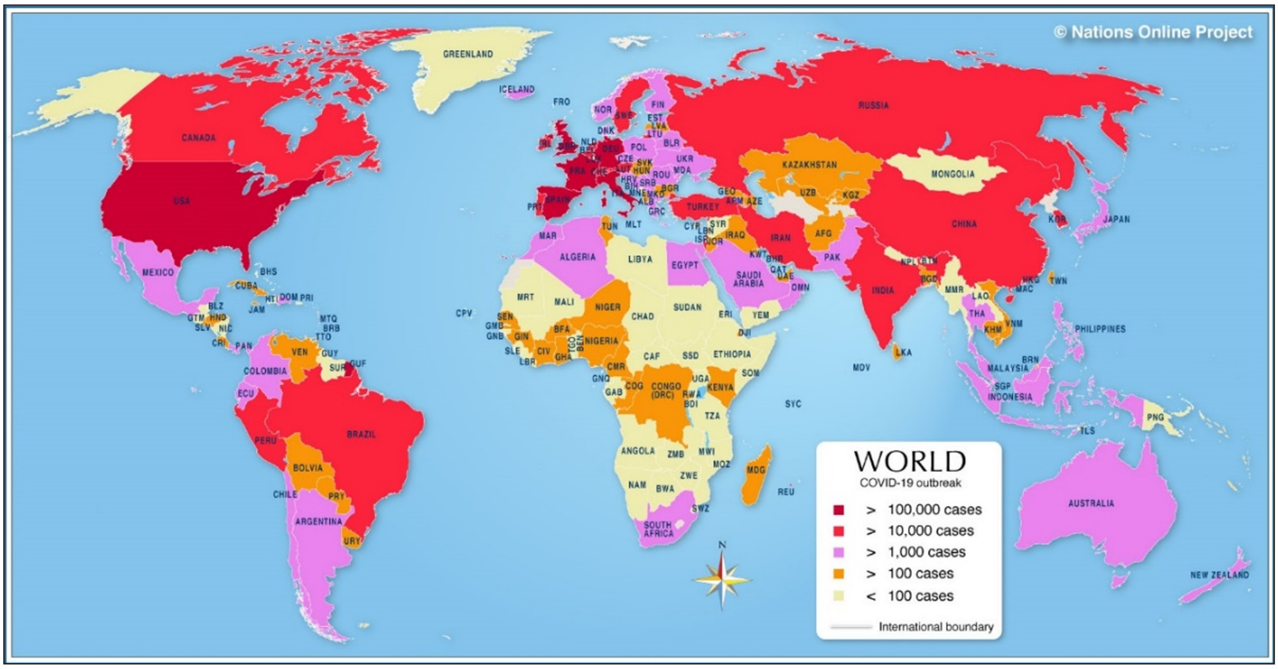

Figure 5 The updated world map of coronavirus outbreak shows countries with the number of confirmed COVID-19 cases (Nations Online, 2020).

In principle, scientific advancements have reduced infection risk and mortality related to many infectious diseases and injuries. But also the efforts of the past to control the pollution sources such as public sanitation, factory pollution, and food processing have helped to minimize the risks on urban health (Jackson, 2003).

Therefore, as mentioned in ***Figure 6***, it is essential to highlight the value of city planning and the urban environment to provide people with a safe and healthy environment. The relation between urban elements like buildings, streets, and public spaces dramatically impacts the quality of life (Kibert, 2016). The pedestrian path is one aspect of the design that is currently attracting much attention. According to the Centers for Disease Control and Prevention (CDC), physical inactivity is responsible for up to 23% of all deaths in the United States due to major chronic diseases. Physical inactivity plays a critical role, which increases the risk of many illnesses (Control and Prevention, 1998). The concept of "Lungs of the City" is about integrating an air cleaning system into strategic

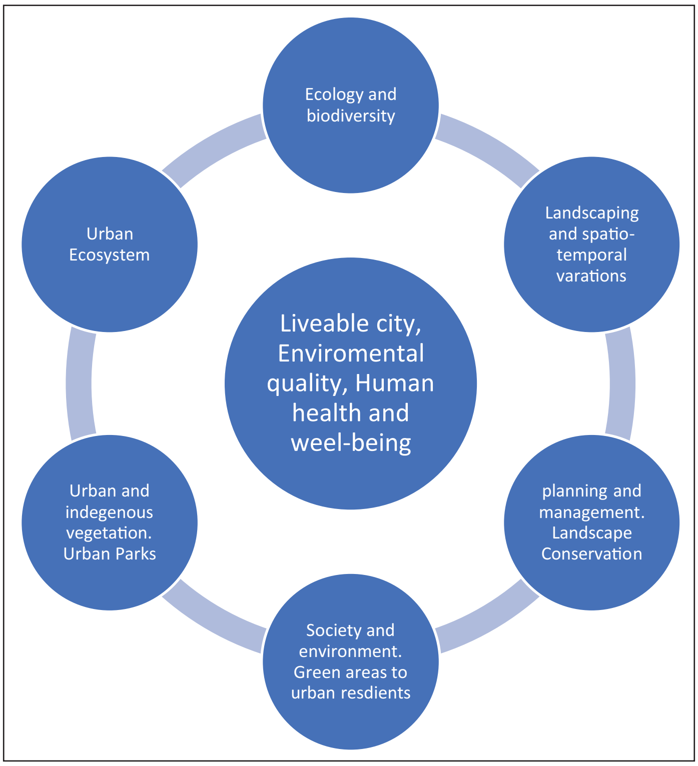

Figure 6 Livable city and environmental quality, human health and wellbeing (Duque and Panagopoulos, 2010).

urban areas to enhance the air quality at the street level. In 2016, the concept's validity was investigated; this technology can be used in different places, including busy traffic roads, train and bus stations, and even street furniture as shown in ***Figure 7a*** (Environmental Nano Solutions, 2016). These air purification systems clean fine dust and pollutants from the polluted city air on the basis of positive ionization as shown in ***Figure 7c***, and the clean air is blown back into the city (AVADA, 2016).

According to these experiences, Environmental Nano Solutions (ENS), in collaboration with the Eindhoven University of Technology, has developed a plan to implement large-scale air purification in parking garages to improve air quality substantially. By installing Aufero's device shown in ***Figure 7b*** in a car park in Cuijk and the city of Weert, the air inside the parking garage is cleaned, and a part of the surrounding city air. The air quality inside the car park in Cuijk improved due to reducing the fine dust concentration by more than 70% (Environmental Nano Solutions, 2016). Also, other studies prove that this device plays a critical role in improving outdoor air quality (Blocken et al., 2016) (Vervoort et al., 2019). It has been shown that the design of cities and urban spaces directly affects human health through air quality and the need for an urban element that should help to purify the air by using the concept of biophilic design. According to the definition of wellness architecture by the global wellness institute, human health, wellbeing, and comfort are the keys of design that create a base rooted in sustainable and regenerative design principles (Global Wellness Institute (GWI), 2017).

According to the World Health Organization (WHO), air pollution causes 4.2 million deaths per year, and 91% of the world's population lives in areas where air quality fails to meet the recommended standards (World Health Organization, 2021a). In order to design buildings and urban spaces, urban designers can control the spread of disease by designing spaces that promote health-giving features through the circulation of airflow, natural light, and biophilic elements (Garofalo, 2020). To better meet the needs of pedestrians and offer sufficient green and open areas to suit inhabitants' aspirations for outdoor exercise and enjoyment. Recently, green roofs, made up of grasses, flowers, and other plants, have been popular in city planning. It is an approach that could help in improving the urban thermal environment. In the daytime, less solar radiation is absorbed because of vegetation canopies at a green roof, which is called the shading effect of vegetation (Fioretti et al., 2010). Pollutants can be removed from the air by plants. Because of the increase in environmental pollution, plants' ability to purify the air has gotten much attention (Li et al., 2010). The different forms of vegetation like trees, shrubs, and grasses have a different proportion of land areas in cities. According to a study in Chicago, the total of annual air pollutants increased by using green roofs; 1675 kg of air pollutants was removed by 19.8 ha of green roofs in one year (Yang et al., 2008).

This paper provides enhancing scenarios for the air quality in urban areas, tested by simulation on a selected site on Aswan, Egypt. The research could serve as a foundation for evaluating recent research by Sharifi's (2020) recommendations for enhancing pandemic-proof design and policy considering the geographic distribution of Covid-19 mortality. For example, we should focus on greening, the transportation, and manufacturing sectors and increase air pollution reduction (Sharifi and Khavarian-Garmsir, 2020). Also, When the study parameters are combined by A. AbouKorin (2021), they

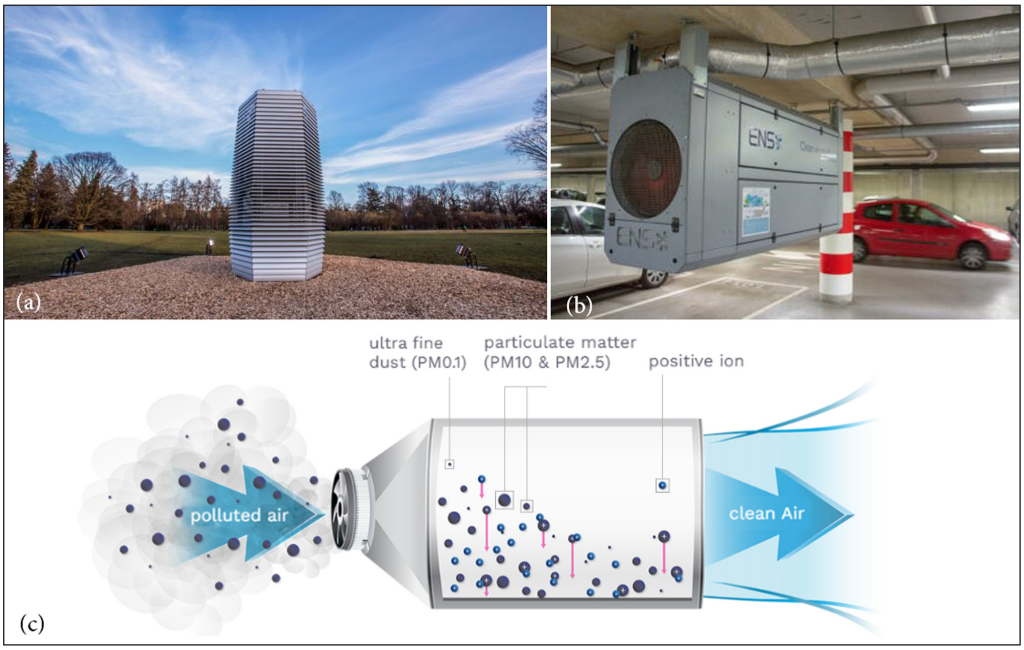

Figure 7 (a) The ENS systems outdoor application. **(b)** Aufero's device installed in a car parking. **(c)** A diagram for the positive ionization technique of ENS air purification technology (Environmental Nano Solutions, 2016).

have a considerable impact on COVID-19 spreading. They conclude that the most critical component is the intra-city connectivity provided by public transportation. As a result, and based on research findings, public transportation planning should receive a more significant proportion of future research interest. This is also necessary for a low-carbon, inclusive urban development (AbouKorin et al., 2021). From here, different helpful suggestions for limiting disease spread and reducing crowding were made in this research.

2. METHODOLOGY

The methodology of this research is adopted by the following steps displayed in the schematic diagram to achieve the main focus of the study. The adopted steps are shown in ***Figure 8***. To indicate air quality in an urban environment in this research by simulation software, ENVI-met 4.4.5 is used to model the study area as a three-dimensional model and simulate the air quality and the values of carbon emissions within the selected study area. The selected site in Aswan, Egypt, was selected according to its importance, historical background, and effect on the city's urban form. Moreover, to validate the simulation data, it was needed to record actual values of carbon emission in this area by using CI-340. Furthermore, to achieve the aim of this research, by having strategies to attain improvement and reach a good level of air quality. It suggested enhancing air quality by using algae stations to help purify the air, produce more oxygen, and see its effect simulation using SuperPro Designer software. Also, as an alternative solution, the use of a green roof was tested by simulating its effect using ENVI-met 4.4.5; the results of the two suggested solutions were different from the existing case, which modified the process of enhancing air quality.

2.1. SIMULATION SOFTWARE AND MEASURE DEVICES

2.1.1. ENVI-met 4.4.5

Different simulation software can indicate the values of carbon emission and the air quality in an urban environment. In this research, the software ENVI-met 4.4.5 is used to execute a three-dimensional model of the study area. Also, it allows to create sustainable living conditions in a constantly changing environment and simulates the outdoor microclimate for the urban environment.

2.1.2. CI-340 lightweight hand-held photosynthesis system

CI-340 lightweight hand-held photosynthesis system is a portable device (***Figure 9***) designed for field use to

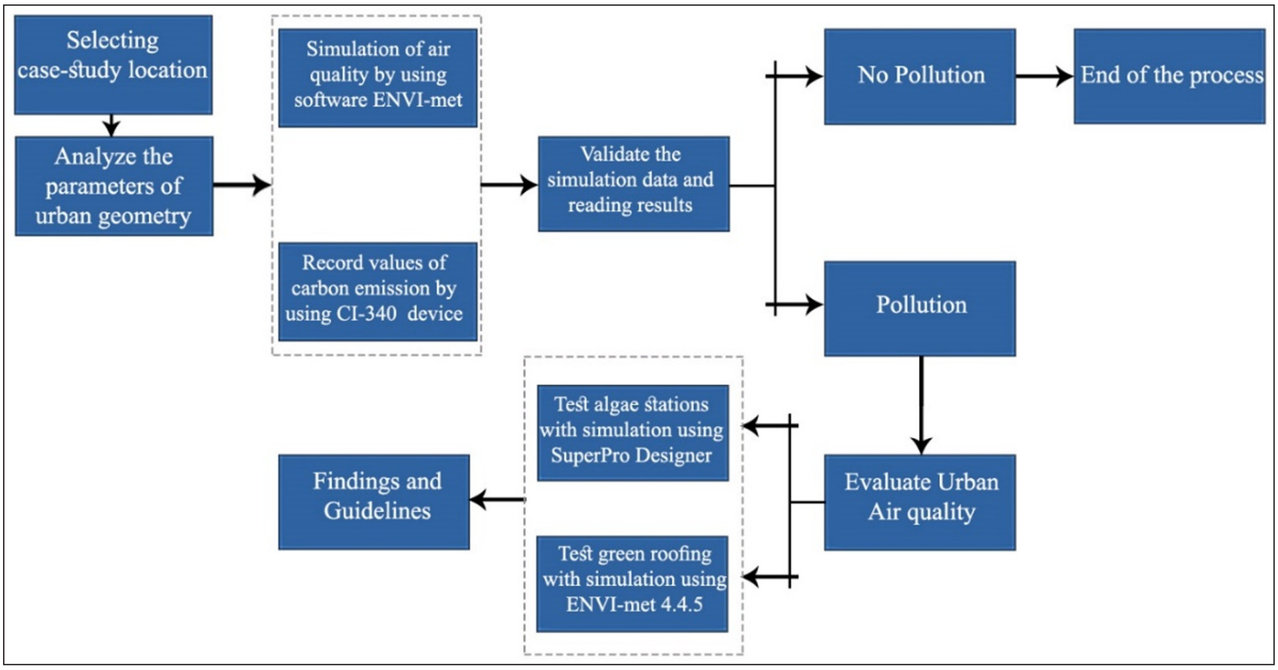

Figure 8 Research methodology diagram.

Figure 9 CI-340 lightweight hand-held photosynthesis system device.

measure photosynthesis, respiration, transpiration, stomatal conductance, PAR, and CO2. In this research, the device quantifies the carbon emission at different points in the study area.

2.1.3. Superpro Designer

SuperPro Designer is an excellent tool for engineers and researchers in process development, engineeing, and manufacturing. It enables the user to optimize manufacturing and discover the treatment processes and helps in pollution prevention and control. In this research, this software is used to simulate algae production and achieve the following results.

3. STUDY AREA

The case-study district at Aswan, Egypt, as shown in the location in ***Figure 10***, the case-study covers a 35,492.35 m² area shown in ***Figure 11***, with a built-up area of about 85% and heights between 12–18 m. (Starts from 24°05′25.8″N 32°53′43.5″E to 24°05′20.6″N 32°53′54.6″E).

This quarter is an important area around a street considered as an artery between the two main streets in Aswan; this street links between Cornish street, the Nile-front in Aswan, and another main street parallel to the Cornish, as seen in ***Figure 12***.

As shown in ***Figures 13*** and ***14***, This street was not that wide before 2006. It was a residential area filled with buildings and houses. It became wider to solve the problem of slum area, but it caused traffic jam problems. Which affected the environmental quality because of the creation of many air polluting sources and little ventilation; improving air quality, especially in these critical streets in Aswan city, positively influences the residents' health.

Figure 10 Site location.

Figure 11 Case-study urban block.

Figure 12 Photo for the street that leads to the Nile front view.

Figure 13 Photo for the street before 2006.

Figure 14 Photo for the street after 2006 until now.

4. RESULTS AND DISCUSSION

4.1. SIMULATION OF AIR QUALITY IN THE DEFAULT SCENARIO

The first step in this research is to indicate the air quality of the urban area; the simulation shown in ***Figures 15***, ***16***, and ***17*** is an average during mid-day of the mid-month of summer and winter. The evaluation happened according to the values at 09:00–11:00 AM, 2:00–4:00 PM and, 8:00–10:00 PM.

According to the simulation, the study selects three different times to visualize the flow of carbon emission. As shown in ***Figure 18***, the carbon emission values during the mid-day (at 2:00–4:00 PM) are higher than the early morning and the night values because of the traffic volumes and higher human activity at this time of the day.

4.2. RECORDS OF CARBON EMISSIONS UNDER THE CURRENT CIRCUMSTANCES

As shown in ***Figure 19***, CO2 values are recorded at different points in the study area by using the CI-340 device to validate simulation results at different times of the day.

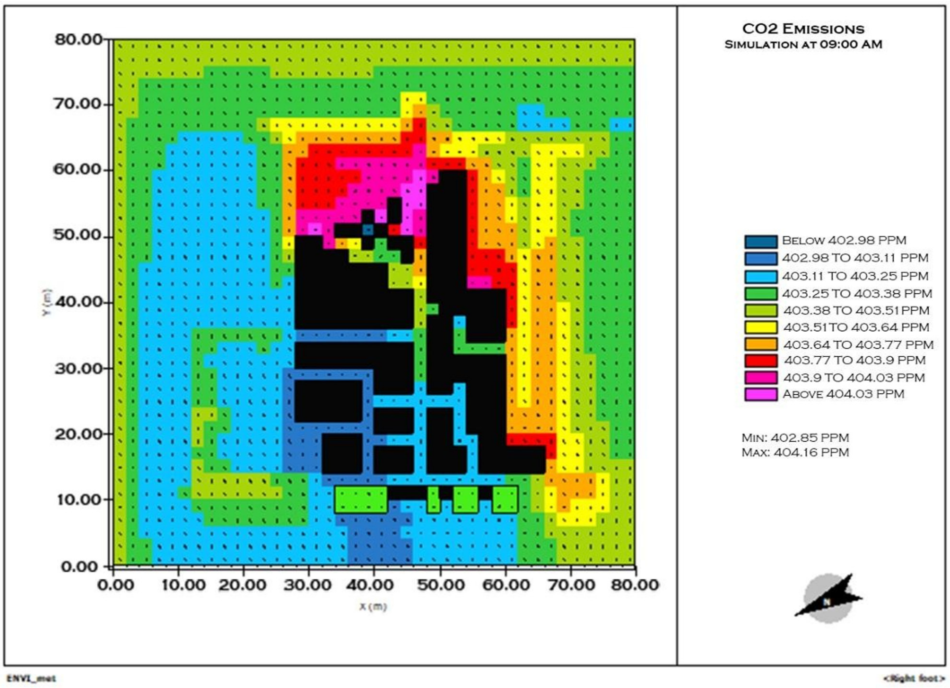

Figure 15 Simulation of CO2 emission at 09:00 AM.

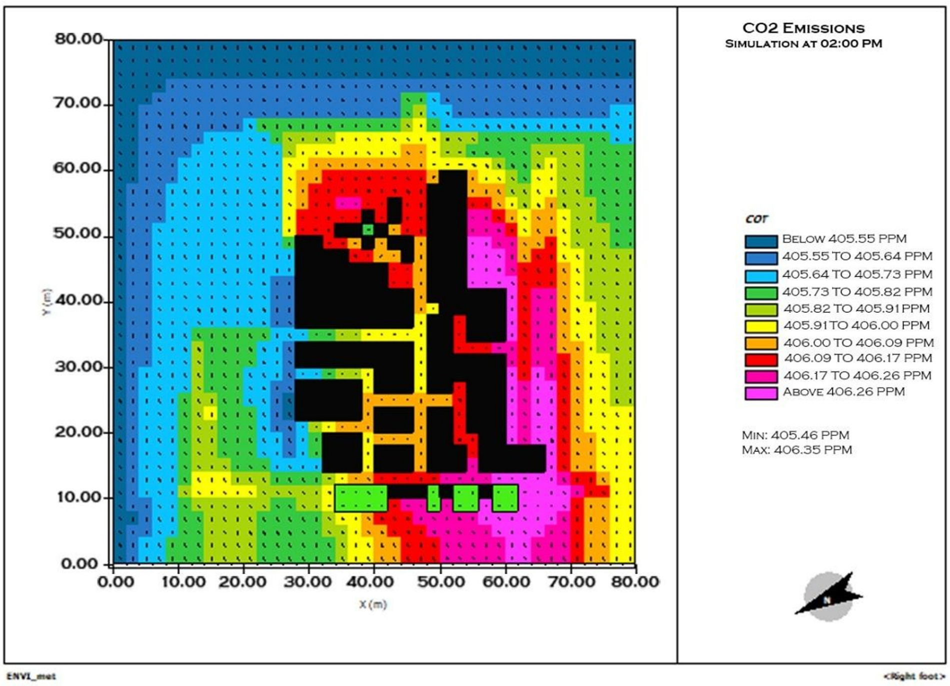

Figure 16 Simulation of CO2 emission at 02:00 PM.

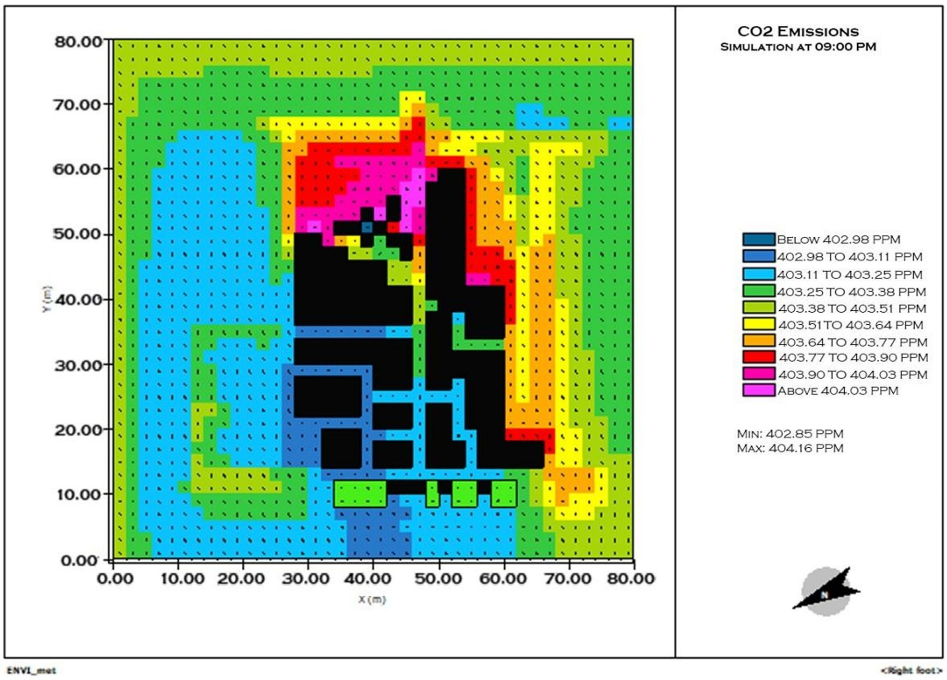

Figure 17 Simulation of CO2 emission at 09:00 PM.

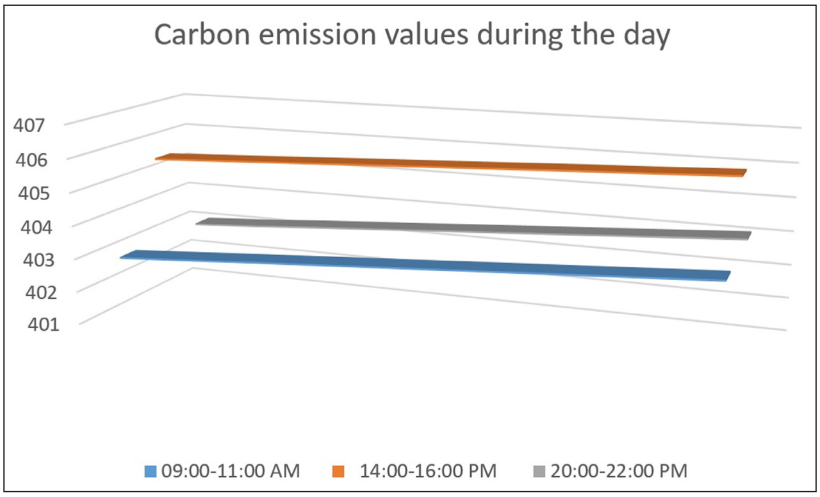

Figure 18 Graph for carbon emission values during the day by ENVI-met 4.4.5 simulation.

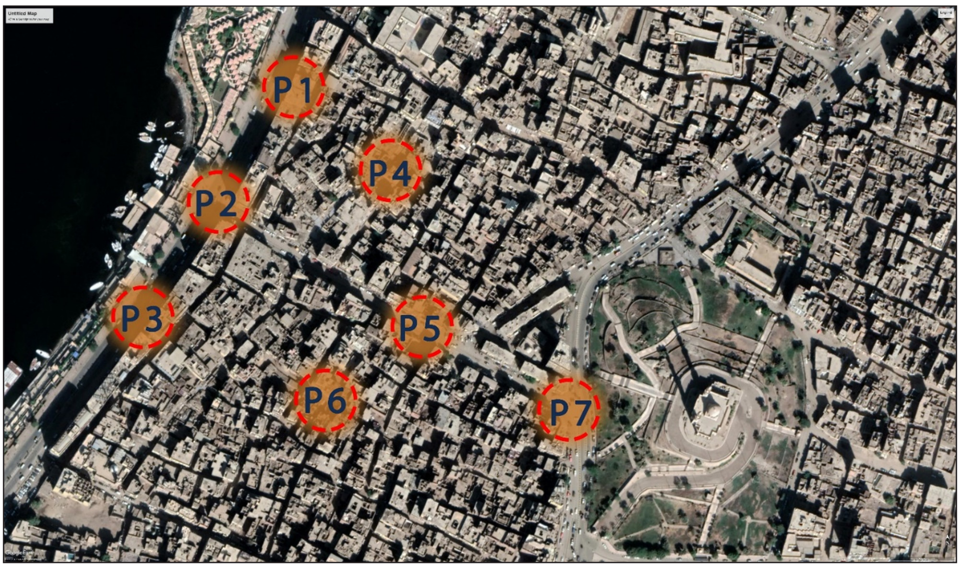

Figure 19 Measurements location on the case study map.

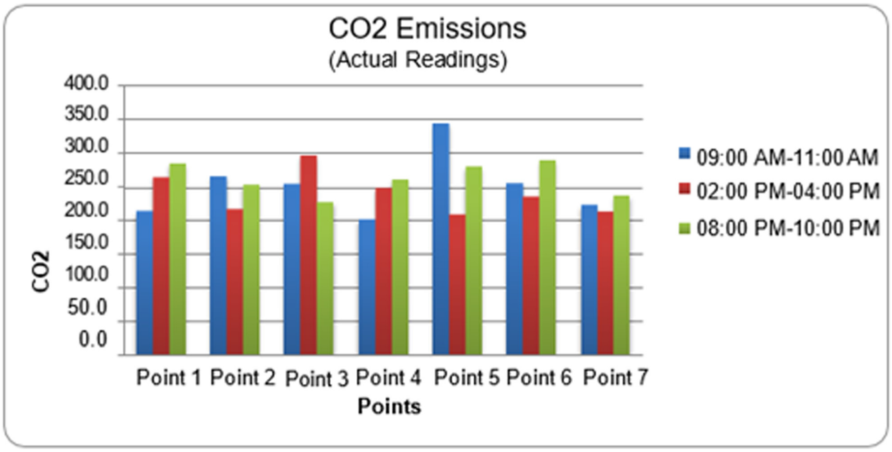

Figure 20 Graph for carbon emission values according to the readings.

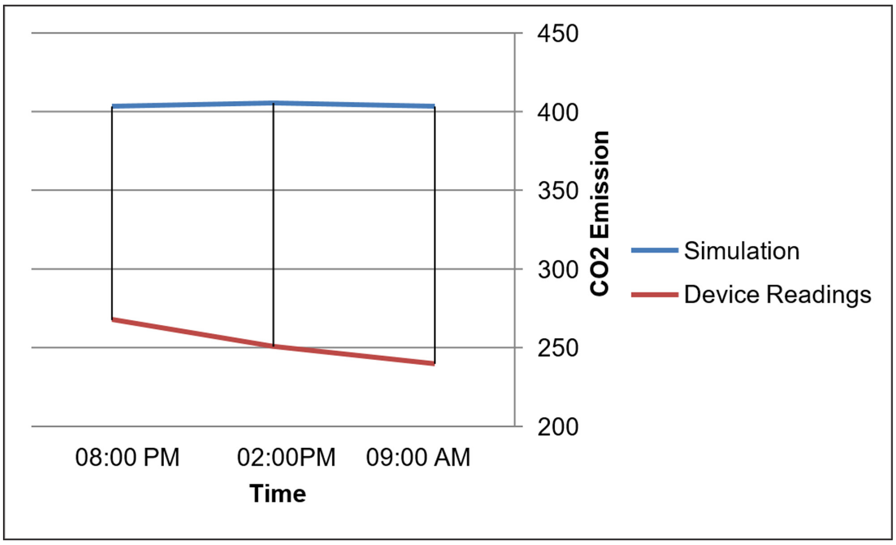

Figure 21 Comparison between the actual records for co2 emission and the simulation results.

According to the readings within two days, these are the values of CO2 emission shown in ***Figure 20***.

A comparative analysis between the simulation results and the records from the site was made (***Figure 21***) to validate the carbon emission values and their effect on the air quality before proceeding to the aim of this research, which is to enhance the air quality.

According to the comparison, the carbon emission values indicate an effect on human health in this area, so it was important to search for strategies to improve and reach a better degree for human health conditions by testing the upcoming strategies.

4.3. SPIRULINA ALGAE STATION

As shown in ***Figure 22***, a system comprises a culture tank filled with a culture fluid including the algae, an air supply unit for forcing the polluted air into the culture fluid. To dissolve carbon dioxide, nitrogen oxide, Sulfur oxide in the culture fluid, and a lighting unit for radiating light to the culture fluid. The photosynthesis of the algae is aided by directing light into the culture fluid in the presence of carbon dioxide into oxygen. In addition, during photosynthesis, the algae use nitrogen oxide and Sulphur oxide as nutrients. Consequently, the current system will effectively purify toxic air to produce filtered, oxygen-rich air (Keiun Kodo, 2000).

4.3.1. Simulation of Algae Station using Superpro Designer Software

The results in ***Figure 23*** are where the algae stations will be installed at the pedestrian level. The stations will be covered with an envelope that allows air to flow through them. The results are achieved using SuperPro Designer to simulate the algae production, which is a beneficial tool for scientists and engineers in process development, process engineering, and manufacturing.

These graphs in ***Figure 24*** show the changes between CO2 and oxygen values before the algae station's production and output. By applying these stations in the chosen points in the study area, as shown in ***Figure 23***, the oxygen ratio will improve 1.65 times than the existing values, which will help enhance the air quality in the site.

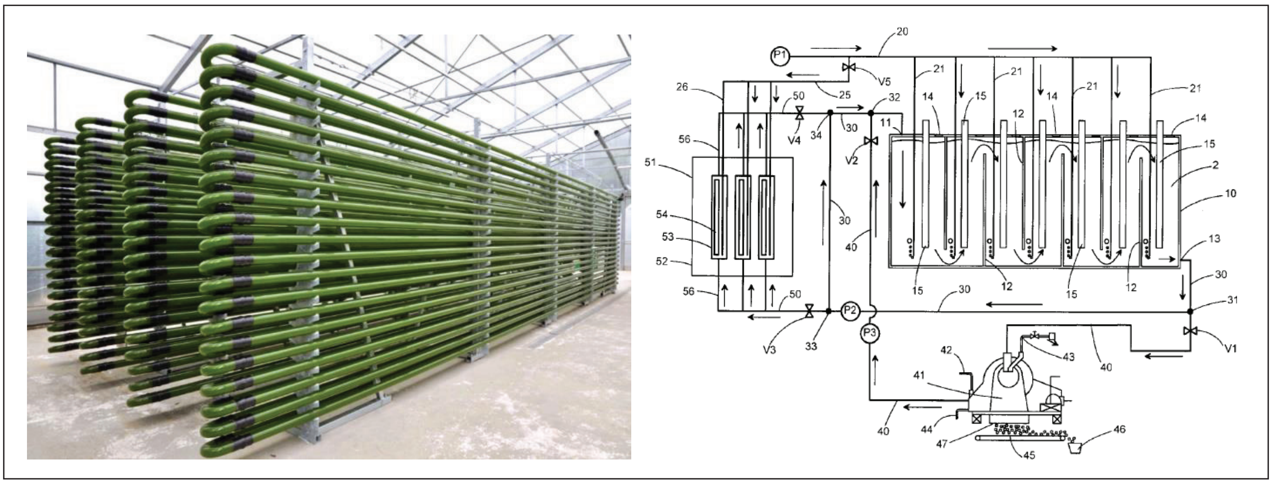

Figure 22 Algae Station (Keiun Kodo, 2000).

Figure 23 Map for algae stations proposed location on the study area.

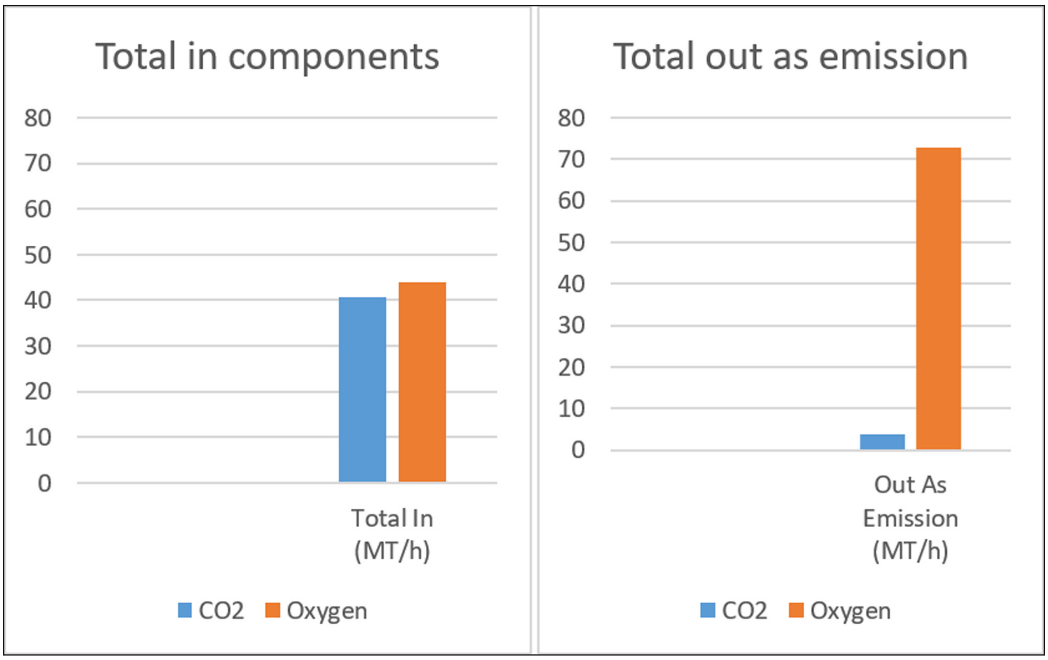

Figure 24 graphs of carbon dioxide and oxygen production from algae station.

4.4. GREEN ROOFING

As shown in previous studies, greening the roofs of the buildings helps improve the air quality, protect against radiation and isolate the noise, which helps to improve human health.

In the upcoming simulation, shown in ***Figures 26***, ***27***, and ***28***. We tested the effect of green roofs, which was applied to all buildings in the selected case study, using the layers of materials illustrated in ***Figure 25*** to determine their effect on air quality and carbon emissions.

After comparing the simulation results of the existing case and the simulation using a green roof, the values of CO2 emission reduced after using a green roof on the top of buildings, affecting the study area's air quality, as shown in ***Figure 29***.

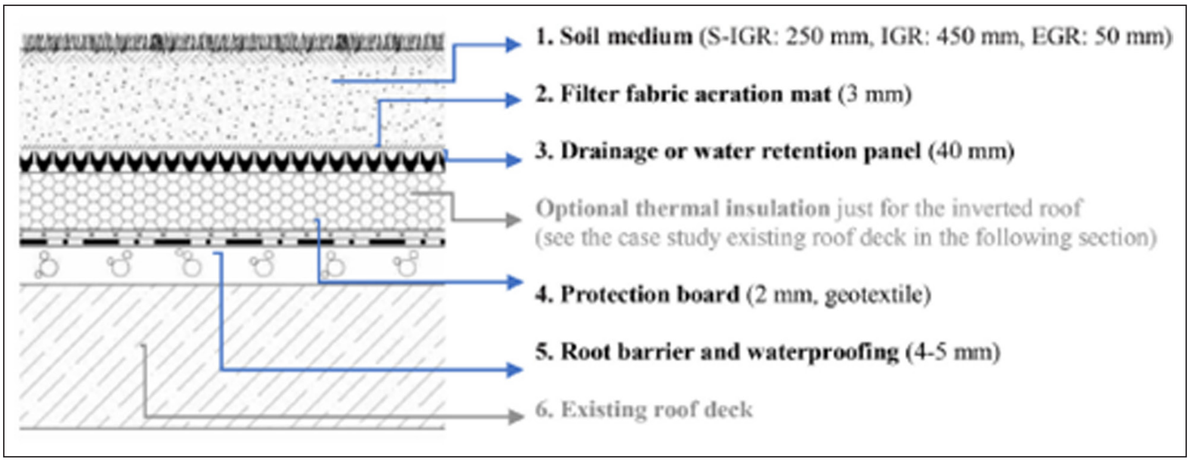

Figure 25 Layers of green roof used in the simulation (Motlagh et al., 2021).

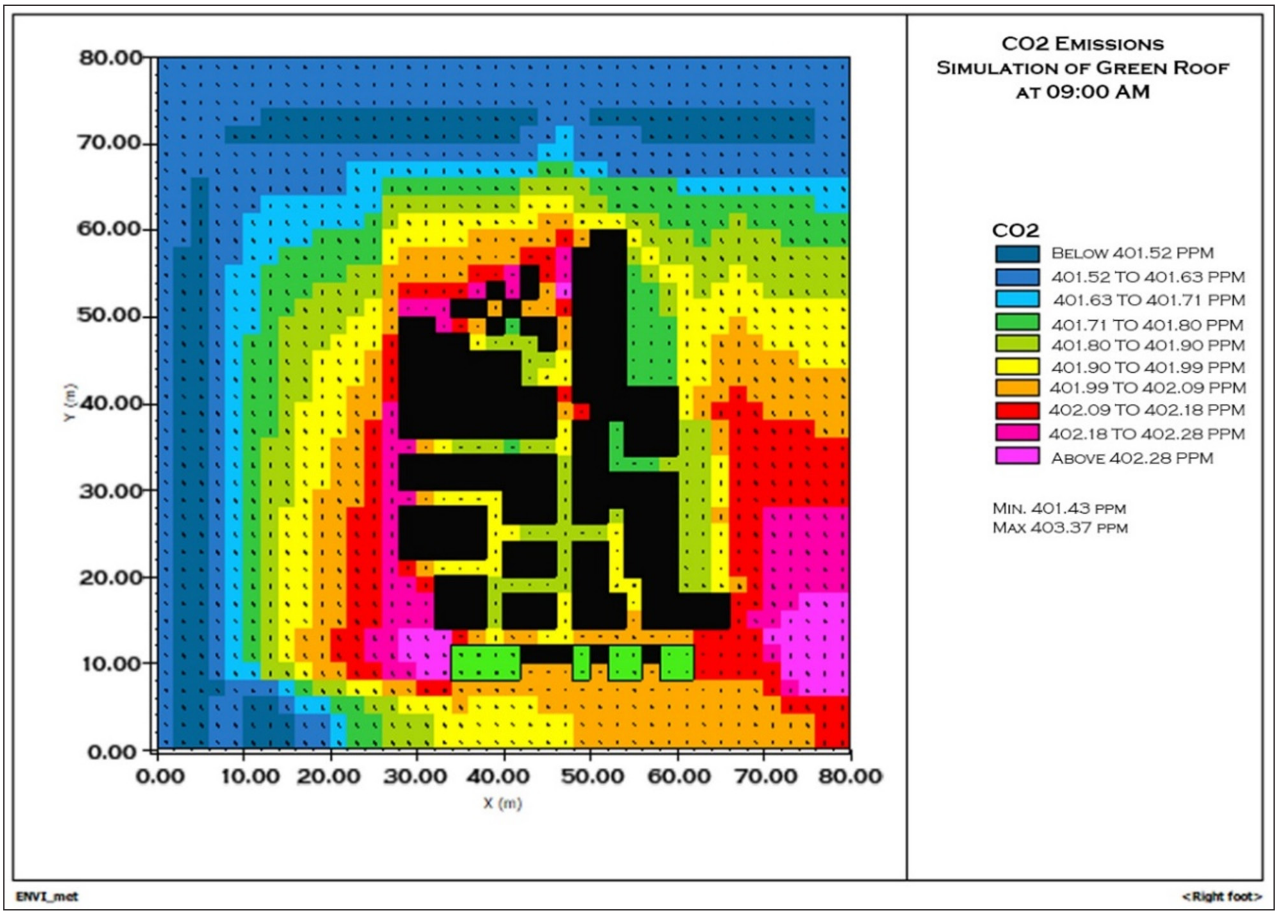

Figure 26 Simulation of CO2 emission at 09:00 AM.

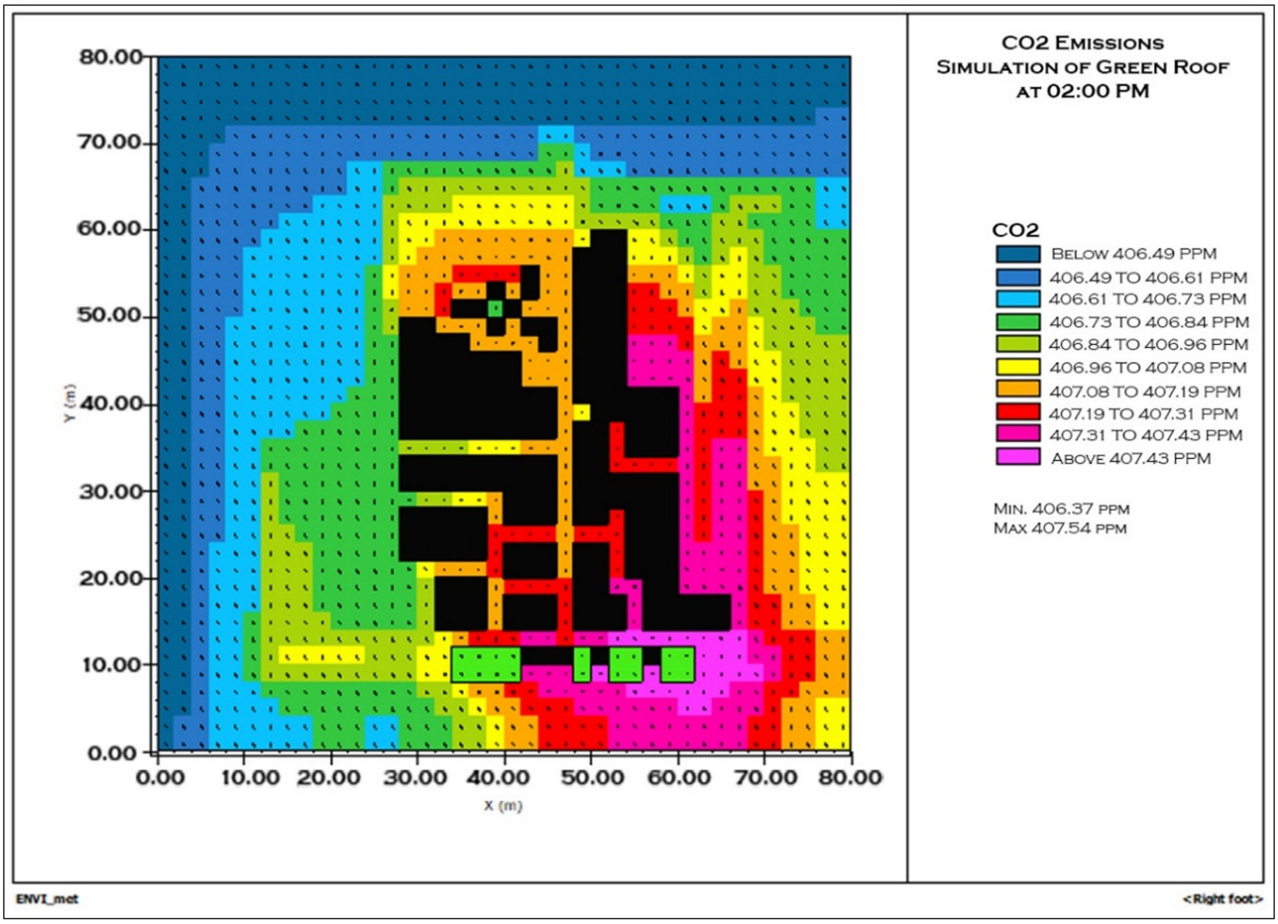

Figure 27 Simulation of CO2 emission at 02:00 PM.

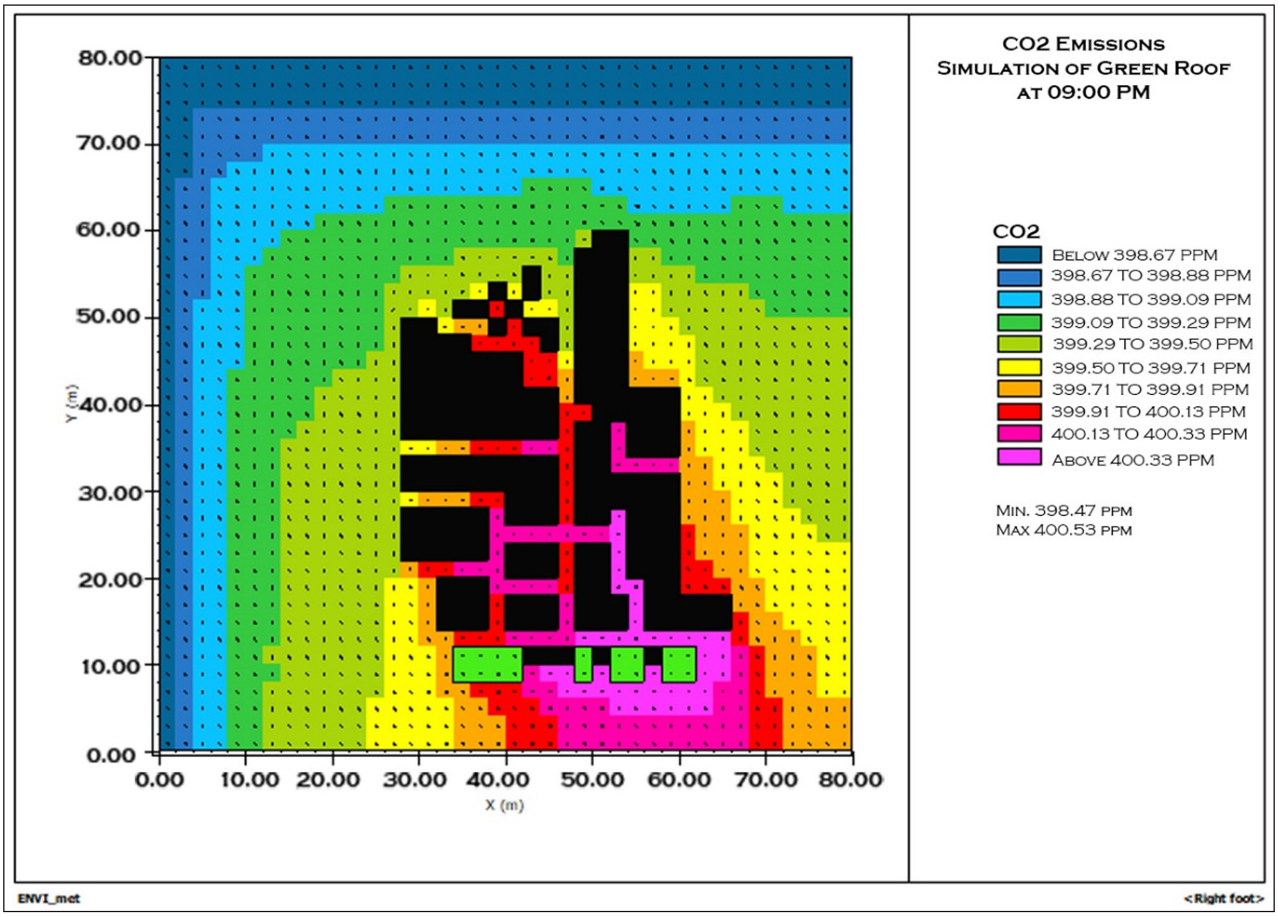

Figure 28 Simulation of CO2 emission at 09:00 PM.

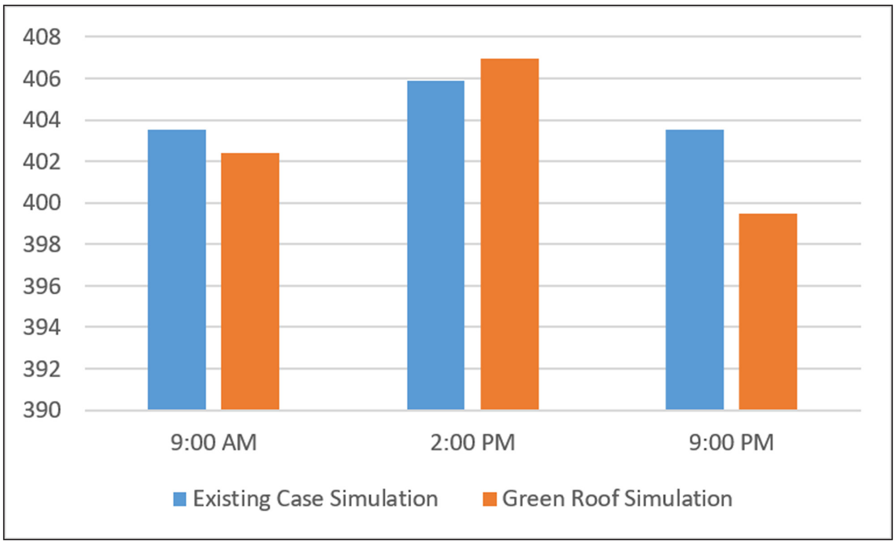

Figure 29 Comparison between records of CO2 emission before and after using a green roof.

5. CONCLUSIONS AND FUTURE WORK

The pandemic of COVID-19 impacted negatively on many countries throughout the world in early 2020. Since then, daily life in many cities has been disrupted; the scientific community has been working on casting more insight on the underlying dynamics of the COVID-19 epidemic, which is still wreaking in many world regions. So, it was essential to look for some modifications to enhance the existing urban environment, such as using algae stations and green roofs and test its effect by simulation. The validation between the simulation results and records of carbon emission from the study area proved that the urban environment has a vital role in achieving a safe environment for the users with healthy air quality. The simulation process proved that the use of algae stations as an air purifying system and green roofs in high-density urban blocks could help in the improvement of air quality and reduce the number of carbon emissions, according to the previous studies. More research is needed to improve disease prevention and infection management through urban design. In this research, the evaluation of pandemics' effects on various urban forms was necessary. Also, suggest key elements that should be considered for better preparation and reaction to such future situations, and indicate gaps that need to be further researched in future research, based on early evidence presented in the literature. It could change the perspective of planners and designers to find new solutions to achieve a safe environment for the users. These characteristics will make the cities ready for any future pandemics, and the suggested guidelines may be followed to reach a sustainable, safe city with good air quality.

COMPETING INTERESTS

The authors have no competing interests to declare.

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