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Assessment of CO_2 Reduction Potential of Indoor Plants Using Artificial Neural Network in Classrooms

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Abstract: Carbon dioxide gas (CO_2) is one of the critical factors used to measure indoor air quality that affects the well-being of school building occupants daily. Therefore, efforts to reduce the indoor-CO_2 amounts have been made by adding indoor plants to absorb the CO_2. The critical knowledge is to understand the factors affecting the rate of CO_2 adsorption. This research aims to study the relationship between indoor CO_2 reduction using trees and environments. First, a flowerpot with snake plants is placed in a room of 24.5 m^2 for the data collection of the temperature, the relative humidity, light intensity, and the amount of CO_2 using sensors. Then, the data were used to create a forecast model using the Artificial Neural Network (ANN) technique, which its accuracy was 99.64%. The results showed that the snake plants could reduce 2.13% of the indoor CO_2. The suitable environment for plant photosynthesis is a temperature of 25 to 30°C and relative humidity of 40% at a light intensity of 200 Lux. The results can be used as data in the design of rooms in educational institutions to effectively increase the air quality in response to building occupants' health.

Keywords: indoor plants, indoor air quality, CO_2, artificial neural network.

在课堂上利用人工神经网络评估室内植物的二氧化碳减排潜力

摘要：二氧化碳气体是用于测量室内空气质量的关键因素之一，它每天都会影响校舍住户的健康。因此，通过增加室内植物来吸收二氧化碳气体，已经做出了减少室内二氧化碳气体量的努力。关键知识是了解影响二氧化碳气体吸附率的因素。本研究旨在研究利用树木减少室内二氧化碳排放量与环境之间的关系。首先，在 24.5 平方米的房间内放置一个种有蛇类植物的花盆，用于使用传感器收集温度、相对湿度、光照强度和二氧化碳气体量的数据。然后，将这些数据用于使用人工神经网络技术创建预测模型，其准确率为 99.64%。结果表明，蛇类植物可以减少 2.13%的室内二氧化碳气体。植物光合作用的适宜环境是温度为 25 至 30°C，相对湿度为 40%，光照强度为 200 勒克斯。研究结果可作为教育机构房间设计的数据，以有效提高空气质量以响应建筑物居住者的健康。

关键词：室内植物，室内空气质量，二氧化碳，人工神经网络。

1. Introduction

Carbon dioxide gas (CO_2) is one of the critical factors used to measure indoor air quality that affects the well-being of school building occupants daily, such

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as classrooms, offices, and living rooms. Therefore, they should be in places with good weather; otherwise, they are harmful to the occupants [1]. Trees can reduce CO_2 and increase oxygen (O_2). Generally, trees are all around in the nature outside. However, few places use trees as air purifiers for occupants or visitors. Therefore, efforts to reduce the indoor-CO_2 amounts have been made by adding indoor plants to absorb the CO_2. The critical knowledge is to understand the factors affecting the rate of CO_2 adsorption. Many trees are suitable for indoors depending on the appropriateness or preferences, such as snake plants, Syngonium, and yellow palm. However, the O_2 production and CO_2 reduction capabilities of each tree type are different, so some plants are suitable for offices or classrooms but not bedrooms.

Photosynthesis is a crucial process for trees to reduce CO_2. In this process, CO_2 and water are precursors used to react with other factors contributing to the rate of photosynthesis, like light intensity, temperature, and air humidity [2]. It is interesting to study these factors because it is challenging to analyze the suitability of trees and their environment, which may take a lot of analytical procedures and multiple trials to determine the proper environment. Nowadays, computer technologies are advanced and are helpful for more straightforward and more accurate analysis.

Machine learning processes allow computers to learn experiences from past data and create algorithms that can forecast future data. Applying this process to the study of photosynthetic factors yields fast and accurate results, as the simulations do not require actual experimentation. However, precise data collection methods are needed to obtain accurate equations from the forecast.

Therefore, this research aims to study the relationship between indoor CO_2 reduction using trees and the environment related to various factors. The snake plants were used in the experiment because they could photosynthesize under indoor temperature, humidity, and light intensity of 200 Lux, which is convenient to simulate the research environment [3].

2. Literature Review

Due to weather conditions, there is a growing awareness of using potted plants to reduce the amount of indoor CO_2 nowadays [4]. One of the popular houseplants for indoor decoration is snake plants. Besides being beautiful, it can grow in an indoor environment.

The snake plant has its scientific name Sansevieria, in the Agavaceae family. Bowstring Hemp, Devil Tongue, and Mother-in-law's Tongue are common names. The genus is distributed in tropical and subtropical Africa, Madagascar, India, and the East Indies, with about 70 species discovered. It is an herbaceous plant with longevity, rhizomes slithering along the soil surface, precise joints, succulence in all parts, easily breaking, circulating, or paralleling simple leaves, many types of leaves, hard or wavy edges, and different colors and patterns. In nature, snake plants can grow in arid places, under intense sunlight, and on cold nights. It is also a crassulacean acid metabolism plant. This plant closes its stomata during the day in strong sunlight to reduce water loss. However, it opens at night to absorb the moisture of dew or air vapor and CO_2 for use in daylight photosynthesis, considered a defense mechanism. National Aeronautics and Space Administration (NASA) has recognized this genus as a sound toxin absorber in the atmosphere [5].

Therefore, in studying CO_2 reduction using houseplants, it is essential to know the variables involved in CO_2 reduction. In addition, plants use CO_2 for photosynthesis, making the factors in the room necessary to collect data for analysis.


Fig. 1 Sansevieria (snake plant)

2.1. Photosynthesis

Photosynthesis is how plants convert energy from light to chemicals in the form of food stored in the tissues, such as carbohydrates, protein, and fat. In addition, O_2 and water vapor are returned to the ecosystem by exiting the leaves into the air. CO_2 and water CO_2 and water are the precursors as reactants in the photosynthesis process, as shown in Equation 1 [6]. Therefore, plants are helpful in terms of reducing CO_2 as well as providing O_2, the gas for human respiration [7].

$$6CO_2 + 12CH_2O \xrightarrow[Chlorophyll]{Light} C_6H_{12}O_6 + 6H_2O + 6O_2 \qquad (1)$$

CO_2 is one of the greenhouse gases in nature and is not dangerous if it is in small amounts. However, there is a massive increase in CO_2 until reaching a level that affects natural changes. It is a chemical compound composed of two O_2 atoms covalently bonded to a single carbon atom. CO_2 is one of the world's most essential gases because it is part of the photosynthesis process of plants. So, this means that plants can live on CO_2 just like humans can live on O_2. Without CO_2, plants cannot survive [8]. Usually, CO_2 should be 400 parts per million (ppm) in the air. If it is indoors, it can be up to 1,000 ppm, but not more than 1,500 ppm, because if it exceeds this value, it is dangerous to humans, such as excessive sweating, tachycardia, and shortness of breath. Therefore, it is necessary to have a sound ventilation system in buildings; otherwise, it will harm the occupants and affect children's growth.

2.2. Factors Affecting CO_2 Reduction

According to the process discussed in Section 1, photosynthesis also depends on factors other than CO_2, like light and water. In addition, critical factors for indoors are temperature and humidity, which affect the process.

2.2.1. Light Intensity

Light is an essential factor for plants as they need energy for photosynthesis. The light requirements of each type of plant are different. Plants with more green leaves with a high chlorophyll can photosynthesize more than plants with fewer green leaves. Some plants try to reduce chlorophyll by themselves, depending on the amount of light they absorb.

The light requirements of plants can be divided into three groups. Firstly, the low-light indoor plants grow indoors, primarily in dimly lit rooms or office buildings with suitable low weather. Then, the medium-light plants - those tolerant of sunlight and placed in a room or office building near a window or balcony where they get some sunlight, especially in the morning and afternoon. Lastly, the high-light plants - outdoor plants commonly placed outdoors or on lawns that need full sunlight throughout the day. If the plants are in a dark place like the nook and cranny, lights from the bulb help the plants survive, but not too close to the bulb as it will dry out the leaves. Lighting is possible in the daytime or at night as the houseplants can adapt themselves. The ideal lighting value for plants is 2,400 candela or approximately 223 Lux. In high light intensity, lighting in a short period is adequate; besides, long period lighting is fine [9].

2.2.2. Temperature

Temperature is a crucial factor that influences photosynthesis. Generally, the rate of photosynthesis increases as the temperature rises to 25°C. However, a temperature above 25°C begins decreasing the rate of photosynthesis. This rate at high temperatures depends on duration, another factor. At a temperature above 40 °C, the photosynthetic rate declines. The temperature range of 25–30°C is comfortable for humans and is typical for classrooms. Thus, the indoor plants that photosynthesize at this range are suitable for interior decoration [10]. Comfort conditions are essential to human habitation. Therefore, for the interior and exterior design, they need to be considered under the suitability of temperature and comfort.

2.2.3. Relative Humidity

Water is necessary for photosynthesis. It is transported through the phloem to the leaves for photosynthesis. The amounts of soil and air humidity affect the leaves to open or close their stomata, resulting in in- and out-diffusion of CO_2 and O_2. When a plant does not get enough water, the photosynthesis rates decrease because the stomata close to slow the transpiration down, leading to the more difficult CO_2 diffusing to the cells. If terrestrial plants are in a flooded area or the saturated-with-water soils, the roots are deprived of O_2 for respiration, causing the reduction of photosynthesis rate [11].

Low humidity or a dry atmosphere causes the stomata to close to prevent water loss and decrease the rate of photosynthesis because it is difficult for CO_2 to diffuse into cells. Besides, high humidity causes the stomata to open and increases the diffusion efficiency of CO_2 into cells, resulting in more photosynthesis.

Regarding the literature reviews, key factors affecting CO_2 reduction are light intensity, temperature, and humidity. These factors are applied as the independent variables in Artificial Neural Network (ANN) modeling to forecast the CO_2 values for various environmental analyses.

2.3. Artificial Neural Network (ANN)

Modeling using computational principles to forecast data comes in a variety of formats: Linear Regression (LR), Decision Trees (DT), Random Forest (RF), Gradient Boosted Trees (GBT), Support Vector Machine (SVM), and Artificial Neural Network (ANN); each of which is applied as appropriate for the data type and output. ANN is one of the most well-known forecasting models. Its principle mimics the nervous system of the human brain [12]. The neural interface acts as a decision-making mechanism to weigh each piece of data to form a mathematical equation for future predictions. The ANN itself learns from the data and results that have already occurred and uses the experience to create forecasts with exact results [13, 14].

The ANN consists of 3 layers: the input layer, hidden layer, and output layer. At the start, the input layer receives data from various variables. Then, the output layer receives the data from experiences to analyze and find the hidden layer in which each variable is weighted. In this process, the data are divided into two sets: training data and testing data. Finding a hidden layer typically divides the data into 70 % by 30 or 80 % by 20 for the most accurate results. As a result, hidden layers usually do not have a single layer; they can change the number of layers and the node. As for the data weighting, it is likewise a simulation of human decision-making. Therefore, it remains doubtful how many hidden layer layers and nodes should be appropriate for the data and results [15].

According to the finding methods of the number of layers and nodes of a hidden layer proposed by Ranjan [16], the number of hidden layers should be approximately two. It can help the model's decision-making for a more diverse node weighting, leading to various possible outcomes where one finds a viable path with the highest precision. After that, the number of nodes in the first hidden layer should be approximately half the number of independent variables, and the number of nodes in the next hidden layer should be halved from the first hidden layer. However, the number may not be the most accurate form of such a proposal for finding results. Therefore, it is necessary to experiment with reducing or increasing the number of nodes in each hidden layer to determine the appropriate number of layers and nodes for the data [17].

3. Methodologies

There are two critical processes for studying the relationship between reducing indoor CO_2 using trees and the environment correlates with various factors. The first part is data collection with sensors, and the second part is machine learning, creating a forecast model to predict data for effective planning, as shown in Fig. 2.

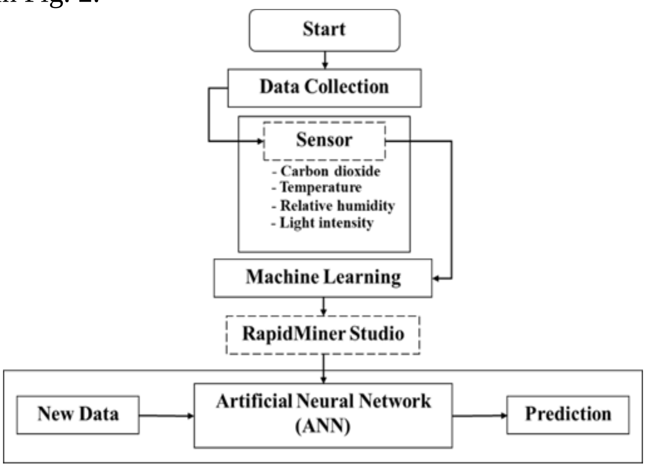

Fig. 2 Research procedures

3.1. Data Collection

In the experiments, the data of temperature, relative humidity, light intensity, and amount of CO_2 are collected by sensors [18]. The experimental area is an empty room area of 24.5 m^2, and a pot of snake plants is set in the middle of the room. In addition, four sensors are installed, 1 in the middle of the room and 3 in different corners, as shown in Fig. 3. After that, the data will be collected in real-time into the Google Cloud Platform before exporting as forecast modeling data in the next section.

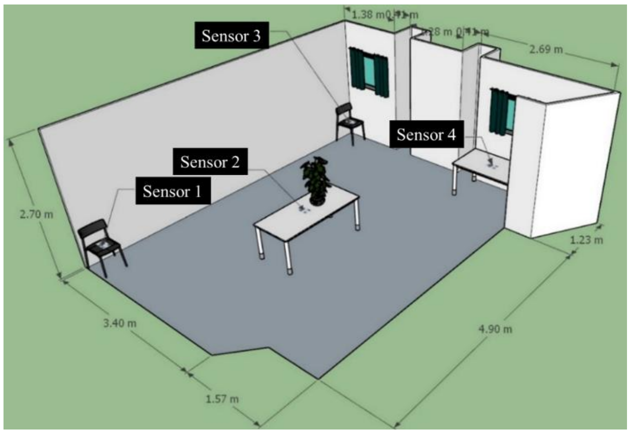

Fig. 3 Data collection via sensors within the room

3.2. Machine Learning

Predicting future outcomes requires computer skills and knowledge to create algorithms or source code for models capable of leading the data to accurate and precise results. However, creating source code might be difficult for non-coding staff, so researchers chose RapidMiner Studio, a semi-finished software able to create uncomplicated and straightforward source code.

Çelik [19] used the RapidMiner Studio to analyze various data, whether statistical analysis, data correlation, or forecasting modeling, to predict the future, such as sales, usage, customer services, and even the desired results available data. This software is applied for various forecasting modeling as well. Moreover, Sitthikankun [20] also adopted the RapidMiner Studio to develop an ANN model to forecast construction costs, proving that the software is practical.

With the easy-to-use functionality of RapidMiner Studio, it is not necessary to be an expert in source code to create usable and practical forecast models, only relying on basic knowledge of forecasting modeling. The software processes are created from junction boxes; each has pre-written source codes available for users to use.

In forecasting modeling of CO_2, the RapidMiner Studio is utilized to analyze the ANN models and interface with other operations according to the works and needs of users. Once a suitable ANN model is carried out, new data can be used to forecast effective planning or decision-making. In this research, CO_2 data from various environments are forecasted to test for rooms with friendly environments for plants and building occupants.

4. Results

4.1. CO2 Amounts by Sensors

According to the data collection using the sensors of the snake plants and the empty room, each situation's average indoor CO_2 data were plotted on the graph to determine the relationship between the data collection period.

The empty room data collection period was from January 21, 2021 (3.50 p.m.) to January 26, 2021 (12.20 p.m.). As a result, the average CO_2 amount of the empty room was 440.03 ppm, as presented in Fig. 4. Besides, the data on snake plants were collected from February 8, 2021 (8.32 a.m.) to February 15, 2021. The results showed that the average CO_2 amount of snake plants was 430.66 ppm, as shown in Fig. 5.

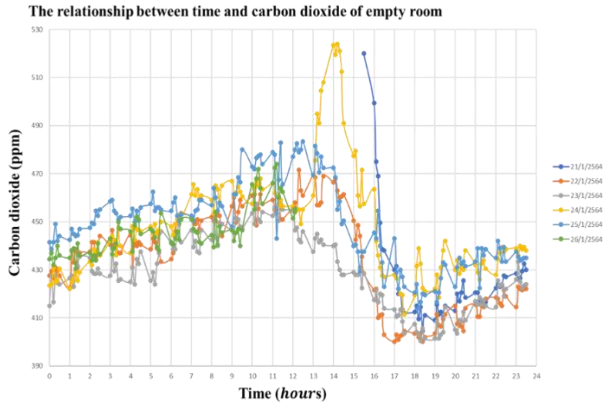

Fig. 4 Relationship between time and CO_2 in the empty room

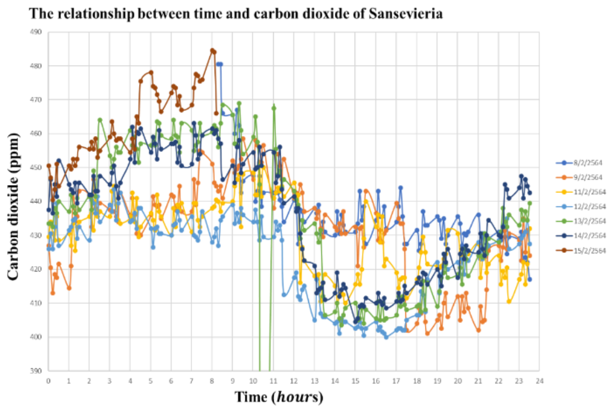

Fig. 5 Relationship between time and CO_2 of snake plants

4.2. Node Number Test in Hidden Layer

Once the ANN forecast model was created in RapidMiner Studio, it was necessary to test the number of hidden layers and nodes suitable for the model using the principle 'Rules of Thumb' by Ranjan [16] to divide hidden layers into 2. After that, perform trial-and-error to find the number of nodes in each hidden layer. For example, in the first hidden layer, three nodes were used equal to the number of independent variables, and in the second hidden layer, the nodes were reduced or halved from the first hidden layer. Therefore, the trial-and-error was performed nine times to figure out the minimum Root Mean Square Error as shown in Table 1.

Table 1 Trial of root mean square error

Root Mean Square Error			
H.L. 1 H.L. 2	1 node	2 nodes	3 nodes
0 node	16.030	14.270	15.548
1 node	15.395	14.003	14.964
2 nodes	15.018	14.981	15.092

Note: H.L. - hidden layer of ANN model

The trial-and-error results showed that the minimum Root Mean Square Error was 14.003, using two hidden layers. The first one contained two nodes, while the second had one node, as presented in Fig. 6.

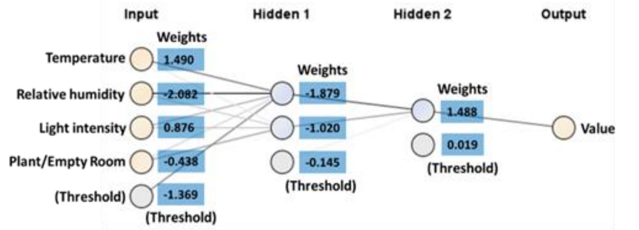

Fig. 6 Number of hidden layers and nodes of the ANN model

Consequently, the ANN model, with an accuracy of 99.64 %, created via RapidMiner Studio was utilized to forecast the amount of CO_2, which its results are presented in the next section.

4.3. Results

According to the results of the ANN model, the research applied new sets of data to figure out the reduced CO_2 amount from the houseplants and to forecast the CO_2 values at a different range of temperature and humidity by setting a constant light intensity of 200 Lux, the average intensity of standard rooms [3].

The ANN model could forecast the CO_2 data in various environments, showing the graph of the relationship between temperature and CO_2 at 200 Lux light density divided into five groups with relative humidity at 40 %, 45 %, 50 %, 55 %, and 65 % as shown in Fig. 7.

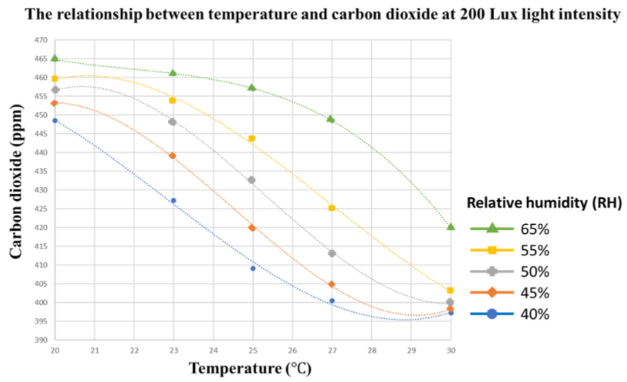

Fig. 7 Relationship between temperature and CO_2 at 200 Lux light intensity

Regarding the graph, when the temperature increased, the forecasted volume of CO_2 of 20 - 30°C decreased, varying with relative humidity. Besides, when the RH was high, the rate of CO_2 reduction was lower, and a higher temperature was necessary to reduce the proper amount of CO_2.

5. Discussion

Regarding Fig. 7, the snake plants can reduce the amount of CO_2 when the temperature increases. This type of plant photosynthesizes between 25-30°C [21].

The graph also shows that the forecasted minimum amount of CO_2 is at 25-30°C with 40% relative humidity. Moreover, when the relative humidity increases, the temperature rises, resulting in a lower rate of photosynthesis and CO_2 amount.

Considering the room usage activities, it should have a temperature of about 25-30°C with a relative humidity of 40%-50%, according to the indoor comfort. Therefore, the snake plants are suitable for temperature and light intensity at 200 Lux, making the plants most effective in photosynthesis in such an environment.

6. Conclusion

According to the experiments, the snake plants can reduce the CO_2 practically compared to the amount of CO_2 in an empty room. The average CO_2 content of a room with snake plants is 430.66 ppm, while an empty room is 440.03 ppm. The snake plants averagely, reduce 2.13% of the amount of CO_2 in the room. As a result, only one pot of snake plants is sufficient for a room of 24.5 m^2. By applying machine learning to data forecasting, results are achieved quickly because the simulations are performed only in the computer system, and there is no need for an actual experiment. The CO_2 forecasting in the room, the ANN model from RapidMiner Studio with an accuracy of 99.64%, was used. It is found that the optimum temperature and humidity range for photosynthesis of the snake plants is 25–30°C and 40%, respectively, by considering the average light intensity in the room, 200 Lux, as it is the standard intensity of available rooms [3].

For the interior and exterior design, they need to be considered under the suitability of temperature and human comfort. Apart from the experiments, such processes can be analyzed together with room or space design planning to effectively optimize the air quality and respond to the well-being of users [22].

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