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Impact of Plants to Improve the Quality of Indoor Environment in Buildings

Vliv rostlin na zlepšení kvality vnitřního prostředí v budovách

The paper presents the potential of using vegetation for improving the indoor air quality. The influence of plants is investigated on an experimental element with greenery, which was designed as a dividing element in large offices with the condition of the minimum necessary maintenance. The article presents the proposed element and the results of measuring the basic parameters of the indoor environment (temperature, relative humidity, concentration of carbon dioxide, light intensity and air velocity) inside the element. At the end of the article, other possibilities are also summarised for its application.
Keywords: *plants, carbon dioxide, air quality, indoor environment*

Článek představuje potenciál využití vegetace pro zlepšení kvality vnitřního prostředí. Vliv rostlin je zkoumán na experimentálním prvku se zelení, který byl navrhnut jako dělící prvek do velkoprostorových kanceláří s podmínkou minimální nutné údržby. Článek představuje navržený prvek a výsledky měření základních parametrů vnitřního prostředí (teplota a relativní vlhkost vzduchu, koncentrace oxidu uhličitého, intenzita osvětlení, rychlost proudění vzduchu) uvnitř prvku. V závěru článku jsou shrnuty další možnosti pro jeho uplatnění.
Klíčová slova: *rostliny, oxid uhličitý, kvalita vzduchu, vnitřní prostředí*

INTRODUCTION

With the development of industry and civil engineering over the last two centuries, there has been a reduction in the vegetation in the cities. Green spaces were replaced with parking slots and new constructions, which has led to the present problem of an urban heat island effect. The necessity of replanting vegetation back into the city environment has, thus, become an often-addressed issue for urban planners, architects and civil engineers. In recent years, green roofs have become a nearly standard solution for roofs. Furthermore, the first constructions of green facades, i.e., vertical analogy of green roofs, are being implemented in urban environments.

The integration of plants into the construction of buildings has not only changed the aesthetic function, but the vegetation can also help decrease the thermal fluctuation, protect the roofing from UV radiation and actively consume rainfall. The vegetation integrated into building envelopes have some impact on the indoor environment, as they increase the thermal insulation of the building [1], [2] and help cool the buildings during the summer [3].

Vegetation is also important for the indoor environment, given the fact that modern humans spend approximately 80 to 90 % of their time indoors [4]. The indoor environment quality (IEQ) has a direct impact on the people's comfort, health and productivity [5], [6]. Various scientific research has confirmed the positive influence of the vegetation on the quality of the indoor environment and the human psyche.

The basic positives that plants have in the indoor environment include:

- oxygen production and carbon dioxide consumption [7], [8], [9];
- ability to clean the air from dust particles and bioaerosols [10], [11], [12];
- ability to reduce the chemical contaminants, such as formaldehyde, toluene, benzene and others volatile organic compounds (VOCs) [13], [14], [15];
- decrease the air temperature and increase the air humidity [16], [17];
- have a positive effect in reducing the risk of a sick building syndrome effect [18];
- increase a person's mental health [19], [20];
- increase the work efficiency [21], [22].

The influence of built-in vegetation cannot realistically replace modern methods of indoor air treatment. However, plants and their influence on the quality of the indoor environment and humans themselves should not be neglected. For these reasons, this article brings an experimental study offering an idea of what influence could be expected from plants on the indoor environment.

PLANTS IN THE INDOOR ENVIRONMENT

The basic type of plant placement in the indoor environment, which does not need to be introduced in more detail, is a plant grown in a pot. Newly, there has been the development of green walls for the indoor environment, just like the green walls on an exterior's facade. They are used as botanical biofilters – bioreactors, where the contaminated air or water passes through the biological active area, in which the pollutants are neutralised by a biological process.

In principle, biofiltration can be divided into two groups, active and passive. As can be expected, pot-based plants are typical examples of a passive biofilter. Several studies [14], [23], [24] have confirmed that even freestanding pots with plants can remove significant amounts of VOCs.

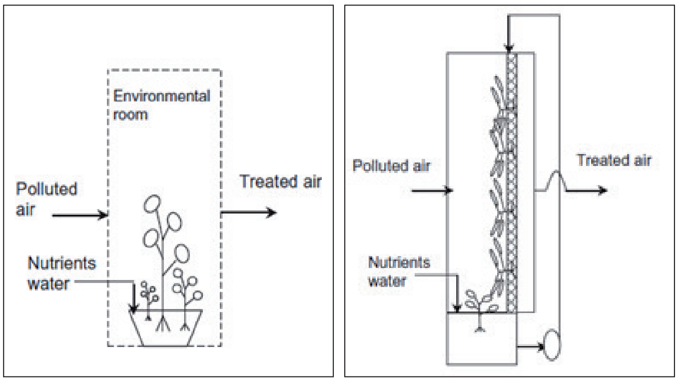

Figure 1 Representation of a passive (left) and active (right) botanical air biofiltration [7]

Active biofiltration can be defined as the use of biological processes to remove pollutants from the air or water flows that are actively conducted through the element. The processed air or water is then further used, for example, the air cleaned from pollutants is distributed throughout the room by a mechanical ventilation system. The principle of both passive and active biofiltration is shown in Figure 1.

Among the first prototype active botanical biofilters were CLER [25], which was used in a conference room ventilation system in a Toronto building, and a Darlington biofilter, which was further patented and commercialised [26]. Another example is the research conducted by Davis and Hirmer [17], which examined ways to supply air to a room through an active green wall. The most efficient way turned out to be supplying the air between the substrate and the wall. There are several large-scale installations in the world, which, in addition to the aesthetic aspect, also fulfil the function of active air biofiltrations.

In addition to the positive benefits of indoor vegetation, it is also necessary to mention its ability to reduce the CO_2 concentration. The consumption of carbon dioxide is a key aspect of photosynthesis, which depends, above all, on the light conditions of the environment. In fact, in low light conditions, a plant can be a CO_2 producer. Some research has shown that plants (with typical C3 photosynthesis – e.g., *Chlorophytum comosum*) can efficiently use CO_2 with sufficient light gain, but cannot do so in low light, where they can generate high concentrations of CO_2 [27]. It follows from the above that not all plants are suitable for such an installation and their choice should be carefully considered.

CONCEPT OF THE EXPERIMENTAL GREEN PARTITION

The goal of the presented research was to create a maintenance-free element with vegetation, which is designed to be used as a dividing partition between workplaces, for example in large open space offices. The partition should be able to create suitable conditions for the plants' growth, with the essential condition of a minimum necessary maintenance. Maintenance, i.e., irrigation and plant waste disposal, is a typical issue for free-standing vegetation. The element, should only be dependent on supply of electricity. The necessary irrigation water should be supplied at multiple intervals.

Beside the space division function, the element provides a positive influence of the inner vegetation to the indoor environment of a room. For control reasons, it is equipped with a monitoring system gathering data of the air conditions inside the partition and in the environment of the surrounding room.

The construction of one green partition consists of two parts. The lower part ensures the maintenance-free operation of the entire system. Besides the water tank, this part contains a distribution system for the irrigation and a system to regulate conditions inside partition and to measure the outside boundary conditions. The system controls these subsystems:

1) irrigation subsystem that processes data from the sensors in the soil,
2) subsystem of artificial lighting, necessary in the case of insufficient solar radiation,
3) air exchange system supplying filtered air into room, the exchange interval depends on the measured values of the air in the upper chamber.

The upper transparent part of the partition is intended for the vegetation. It is made of glued plexiglass and defines the outer dimensions of the element, i.e., the plants will not overgrow the predefined space.

The choice of plants is largely influenced by their demands for irrigation, the amount of plant waste and ability to fill the space evenly over a certain height. The potential suitable plants were discussed with experts from the Department of Botany and Plant Physiology at the Czech University of Life Sciences in Prague. The plant used in the experimental partition is *Rhapis excelsa* (Lady Palm). These resilient plants use C3 photosynthesis, thus, in appropriate conditions, they should increase the quality of the surrounding air during the daytime.

An experimental light is located at the highest plane of the partition, which is designed to simulate natural sunlight with the possibility of the dynamic adjustment of the power and light spectrum (very similar to a solar spectrum).

EXPERIMENTAL SETUP

The partition was monitored by two systems, its own air measuring system and Lumasense Innova analyser instruments (1412i and 1303) for

Table 1 Main sensors important for the vegetation impact analysis

Sensor name	Range	Accuracy
Moisture Guard HT01485	−40 to +125 °C, 0 to 100 % RH	±0.3 °C, ±2 % RH
Lumasense Innova 1412 gas monitor and 1303 multipoint sampler	Dynamic, 4 orders of magnitude	temperature dependence: 0.3 % /°C pressure dependence: 0.01 % /mbar reference conditions: 20 °C, 1013 mbar, RH 60 %.

Figure 2 Visualisation of a dividing green partition with vegetation in an office environment

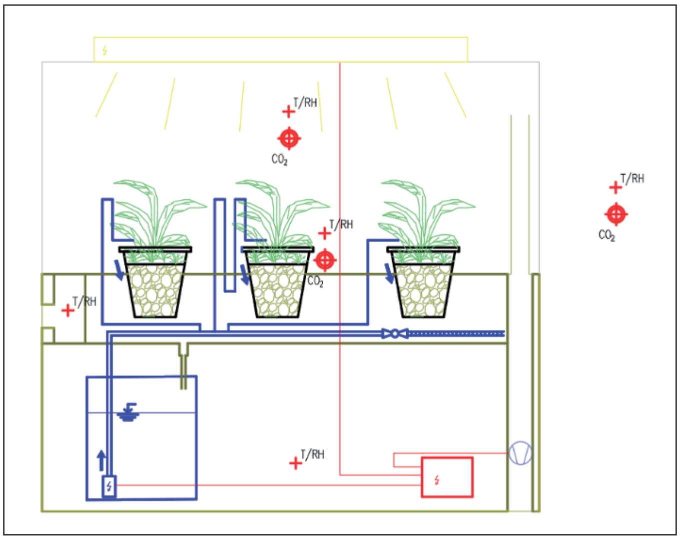

Figure 3 Location of the main sensors for the measurement and control of the green partition

Figure 4 Experimental green partition in a meeting room with an extra Lumasense Innova measuring device for the air analysis

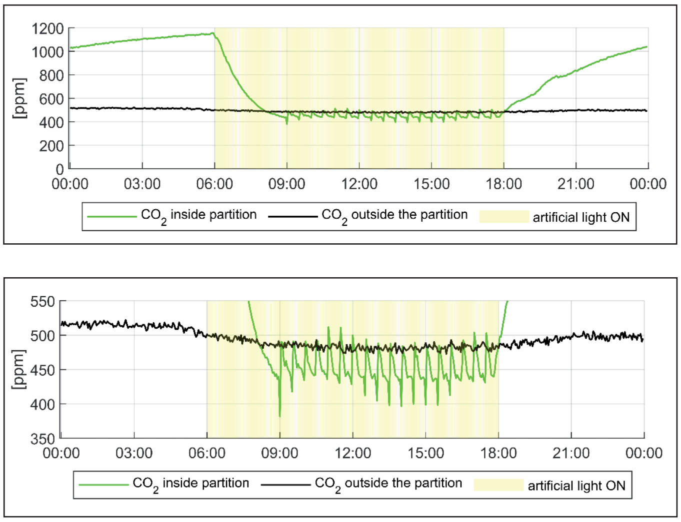

Figure 6 Example of the daily course of the CO_2 concentration in a partition placed in a dark unoccupied room. The bottom graph is the detailed CO_2 consumption with periodical ventilation during the day.

monitoring the air quality. Their specifications are summarised in Table 1. The usage of this precise device, which analyses the air with a photoacoustic method, turned out to be the key for validating the experiment. Typical CO_2 concentration measuring devices do not provide sufficiently accurate data. For a closer idea of the location of the sensors in the device, their positions are shown in Figure 3.

Over the course of several weeks, a series of measurements were performed, which gradually improved the design and performance of the partition at different boundary conditions. This development was necessary to achieve the expected properties of the element. The first measurements were held in the CVUT UCEEB facility meeting room. This larger room (approx. 5 × 10 m) has a fully glazed northeast wall. First, the partition was placed approximately 4 meters from the glazed wall. After the performance was measured, another measurement was held with the partition moved as close as possible to the glazed wall. In the end, the partition was moved to a dark room, which has no solar radiation or occupancy, thus, it offered stable boundary conditions and it was, therefore, ideal for measuring the effect of the element on its surroundings.

RESULTS AND DISCUSSION

Carbon dioxide consumption – Photosynthesis performance

The main aim of the experiment was to design a device that will provide the conditions for the plants to thrive in a deep open space. These rooms are often dark and insufficiently lightened. To evaluate this condition, the measurable photosynthesis ability was used, in which the plant processes carbon dioxide and produces oxygen. It was found that plants located 4 meters from the glazed northeast wall do not use photosynthesis, but rather photorespiration. This phenomenon is (except for the CO_2/O_2 ratio) directly dependent on the amount of radiation reaching the plant's surface. The photorespiration was suppressed by placing the element closer to the glazed wall.

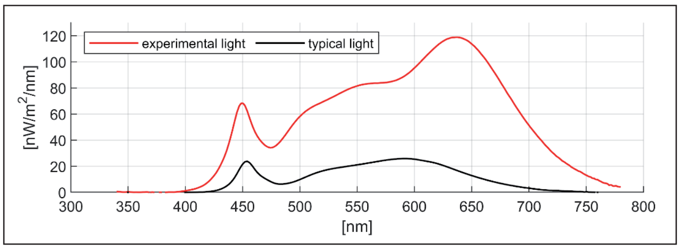

Figure 5 Comparison of the light spectrum of a typical light and the used experimental light

However, this solution is unsustainable in practice. Therefore, several types of lighting were tested on the experimental sample, while the currently used experimental light (a comparison of the light parameters is shown in Figure 5) produces light with a spectrum closer to natural light and is capable of producing an environment suitable for photosynthesis even in a room without daylight.

As can be seen in Figure 6, the experimental green partition creates ideal conditions for growth in any conventional steadily heated environment. When the artificial light is turned on, the plants located in the element begin to absorb CO_2, i.e., the C3 photosynthesis cycle starts. At the same time, the graphs show the interval after which the upper part of the partition was ventilated. This interval was 30 minutes. On the graphs, the consequence of this ventilation is the return of the CO_2 concentration inside the partition to the values of the surrounding environment. From the presented measurements in the dark unoccupied room, it can be deduced that due to the ability of the device to create sufficient conditions for photosynthesis to take place in such extreme conditions, it can be safely expected that it will be able to create suitable conditions in normal office conditions.

At the same time, however, it should be added that the mass of CO_2 consumed is negligible in terms of improving the air quality in the room. The plants can reduce the CO_2 level in the element by approximately 180 ppm in 30 minutes, which is 144 mg of CO_2 in 0.62 m^3 of air (the volume of the upper part of the partition). This means, with 18 air exchanges per day, one partition (with three medium-sized plants) consumes approximately 2 grams of carbon dioxide daily. For a comparison, a person produces approximately 1 kg of CO_2 daily by breathing.

Humidity production

The second observed phenomenon was the specific humidity of the ventilated air. The evapotranspiration of the moisture from the soil and plants should, especially in the winter months, positively affect the indoor environment of the buildings. It was found that the air in the upper chamber has a significantly higher humidity, the difference between the supply and exhaust air is approximately 5 g of water vapour per kilogram of dry air. Therefore, with 18 air changes per day, one partition is able to increase the humidity in a room with a volume of 48 m^3 by approximately 1 gram per kilogram of dry air.

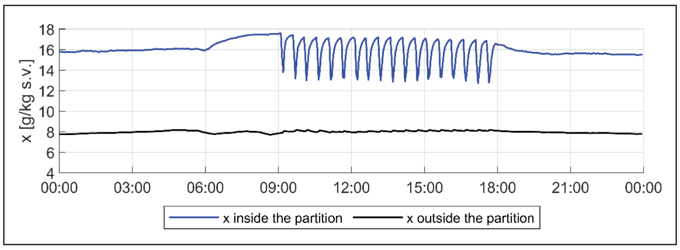

Figure 7 Daily course of the specific humidity in the partition placed in a dark unoccupied room

CONCLUSION

Plants are an important part of an outdoor and indoor environment. The article outlined the possibilities of using their potential to increase the quality of the indoor environment which may promise, at the same time, a reduction in a building's energy consumption. Thanks to their capabilities, such as lowering the ambient temperature and humidity production, they can help increase the air humidity in the buildings in the winter and reduce the need for energy for cooling in the summer. From a district's perspective, they can reduce formation of heat islands in cities and improve the air quality.

The experiment introduced an element with the function of a dividing green partition, which also contributes to improving the quality of the indoor environment. It has been proven that the system is able to create ideal conditions for vegetation growth, with minimal maintenance. In terms of the quality of the indoor environment, the element with plants primarily has an effect on the indoor humidity, its increase is desirable in the winter in our climatic conditions. On the other hand, the reduction in CO_2 was not as significant as initially assumed. Therefore, the expectation of a decrease in the ventilation rate proved to be false.

At the same time, the testing has shown that if we supplement the system with suitable lighting, it is possible to place the partition in rooms with no natural sunlight. The possibilities of using the element have, therefore, spread to shady spaces, for example, in the environment of an underground station. The variability and mobility of the developed element has the potential to be used in many other cases. The whole concept offers a wide range of variants from a solitary element, through a separating element to a partition between rooms. After the necessary adjustment (filters at the inlet and outlet of the air from the element), it should be possible to use it in areas requiring a higher degree of cleanliness, for example, in hospital buildings. Another possible use is a school environment, where it could also have, apart from the discussed benefits in this paper, an educational function.

Acknowledgment: This work has been supported by the Ministry of Education, Youth and Sports within National Sustainability Programme I (NPU I), project No. LO1605 - University Centre for Energy Efficient Buildings – Sustainability Phase.

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