The influence of green walls on interior climate conditions and human health

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Abstract. In recent years, many researchers have addressed the issue of interior climate and how it affects human health. Investigations performed at schools and office buildings have found that CO_2 concentrations often exceed the limit value of 1500 ppm given in Decree No. 20/2012 Coll., on technical requirements for buildings. In addition, interior space often exhibits very low relative humidity. This results in poor conditions that are detrimental to human health and not conducive to studying and work. One means of improving the interior microclimate is implementing green walls. These walls can help generate a much better climate and greatly enhance the mental well-being of the inhabitants. In addition, they greatly improve dust levels and acoustics in the room. The research compared the interior conditions in two classrooms at the Faculty of Civil Engineering, Brno University of Technology. One had a green wall installed while the other was in its original configuration. CO_2 concentration, temperature, and relative humidity were measured. A survey was conducted to assess the influence of the green wall on students and teachers (mental well-being, efficiency, productivity, creativity, etc.). Results obtained thus far show that the room with the green wall provides far better interior conditions, mainly in terms of lower CO_2 concentration and higher relative humidity, improving students' and teachers' mood and health (as confirmed by the survey as well).

1 Introduction

The indoor climate of school buildings is often lacking mainly due to high carbon dioxide concentrations, which are detrimental to the health of people inside. Other adverse factors include improper relative humidity, insufficient lighting, and poor room acoustics. These problems can be solved by installing green living features in the interior in order to improve the indoor microclimate as well as acoustics [1-5].

The paper describes the results of research which investigated the effect of living green features on the indoor microclimate of a school building.

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2 Experiment

In order to examine how green walls influence the interior conditions, including the way they affect the health of users, a survey and preliminary measurements were performed, which led to choosing a classroom of 9.9 m by 7.95 m on the 1st floor of the Faculty of Civil Engineering, Brno University of Technology. This room has had issues relating to microclimate for a long time. The preliminary measurements revealed very low values of relative humidity and very high concentrations of CO_2 throughout the academic year. These factors have an adverse effect on students and teachers alike. Both of these groups have often suffered fatigue and complained about poor lighting and acoustics, which impeded their academic performance and even health. Figure 1 shows the original appearance of the room before the green wall was installed. Another 2nd floor room was chosen as reference, as it shared the same geometry.
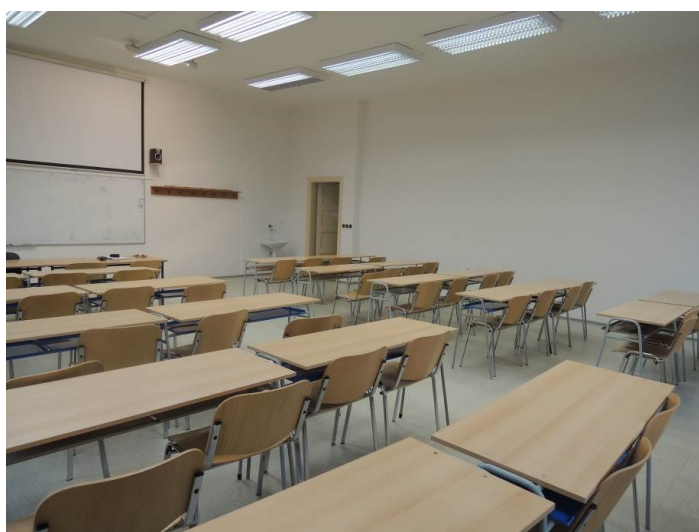

Fig. 1. Classroom wall designated to hold the living wall

A green living wall of 4 x 2.5 m and 4 smaller green features (3 green panels of 85 cm x 85 cm + 1 moss panel of 64 cm x 94 cm) were installed in the classroom. The following plants were used on the green vertical wall and panels: Scandens, Chamadorea, Anthurium pink, Aglaonema cutlass, Maranta tricolor, Calathea lancifolia, Calathea zebrina, Monstera deliciosa, Nephrolepis exaltata Green Lady, Asplenium nidus, Chamadorea, Anthurium red, Aglaonema maria, Aglaonema silver, Aglaonema jubilee compacta, Aglaonema anymanee, Croton, Ananas, Chlorophythum, Maranta tricolor, Calathea makoyana, Ficus benjamin, Calathea rose, Calathea lancifolia, Aglaonema white lance, Spathiphilum, Imperial red, Asplenium osaka, Aglaonema butterfly, Calathea sanders, Calathea pinstride, Calathea white star. The following mosses were used on the moss panel: Royal Pole Moss, Flat moss, Reindeer Moss, Forest Moss, Spanish Moss, Mountain Moss. The wall used conventional soil as substrate; the panels contained Seramis, a combination of Seramis and Zeoponic, and soil. The wall and panels were watered manually using a system of irrigation channels to deliver the necessary amount of water to all plants. During the day (8:00 to 18:00) the green features were lit by LED lamps to provide the plants with sufficient light. Figure 2 below shows the classroom with the green wall and 3 panels installed. The moss

panel was installed in a wall opposite the green wall and is not pictured. The goal was to improve the interior microclimate and thus cater to the health of people using the room.

Fig. 2. Classroom with the green features

The following parameters were measured: carbon dioxide concentration, air temperature, relative humidity, air flow rate. This article presents results of measurement from 28. 8. 2018 to 7. 12. 2018. In the case of a reference room, a pause has been made in October due to the misalignment of the measuring devices. The sensors were mounted onto an independent Raspberry Pi platform, and connected individually to a WiFi network. Temperature, relative humidity, and carbon dioxide concentrations were measured by a Sensirion SCD30. A thermo-anemometer measured the air flow rate. The Raspberry PI ran on the RASPBIAN JESSIE operating system. Sensor data was read by a Python script. The Sensirion SCD data was read using a library written in C++, which had direct access to I2C ports and read data according to the sensor's manufacturer's specifications. Readings by the Honeywell HPMA115S0 sensor were carried out using a Python library. The measured data was sent directly to a server, where it was logged in a database.

The occupancy rate of both classrooms was monitored during the measurements. Ventilation was performed regularly three times a day at given time intervals. The evaluation of results for selected parameters was carried out with respect to the number of persons staying in classrooms, day / night mode.

2.1 Carbon dioxide concentration

An important factor when assessing the interior air quality is carbon dioxide concentration. Even at very low concentrations it can have a marked effect on the health of people inside. Its natural concentration is around 400 ppm, and recommended indoor concentration should not exceed 1000 ppm. The legal CO_2 limit is 1500 ppm as stated in Regulation No. 20/2012 Coll [6]. Carbon dioxide concentration presents a major problem in school buildings especially during the winter season because maintaining a comfortable temperature and keeping heating costs low does not allow for sufficient ventilation. High CO_2 concentrations markedly increase fatigue and impede concentration, greatly reducing the

mental well-being and harming the health of the room's users. Figure 3 below shows the progress of carbon dioxide concentration over the second half of 2018 in both rooms.

The results show that the green features help maintain an optimal CO_2 concentration in the room fitted with them as opposed to the reference; see Figure 3. The lower CO_2 values in the start-up period were due to the holiday season when the classrooms were almost unused.
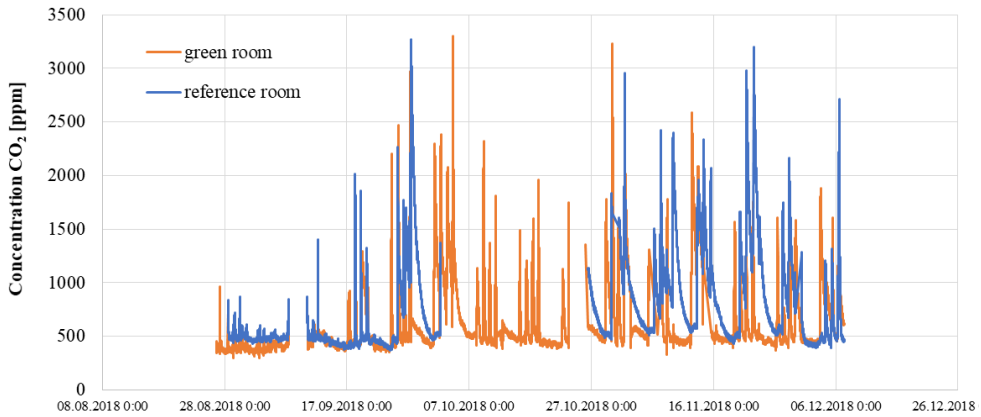

Fig. 3. Determination of CO_2 concentration

2.2 Temperature

Besides air temperature the indoor climate also depends on the mean radiant temperature. Hygienic requirements dictate a range of air temperatures and black ball thermometer temperatures. Regulation No. 343/2009 Coll [7]. stipulates this temperature between 20 and 28 °C with a recommended optimum of 22 °C +/- 2 K. This temperature assumes a clothing thermal insulation value of 0.75 clo (underwear, shirt, trousers, socks, and slippers) for work class I with minimal overall body movement. Air temperature is measured by a dry-bulb thermometer and the final temperature by a black ball thermometer. This measurement required the sensors to be shielded from direct sunlight to avoid any distortion of results. Figure 4 shows the progress of the temperatures measured in both classrooms.
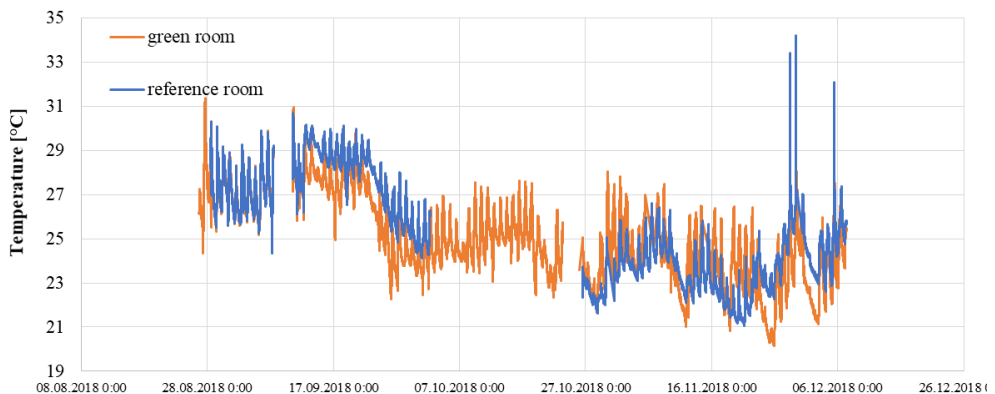

Fig. 4. Determination of air temperature

The measured values of temperature show that the green wall and panels managed to cool the room in summertime, compared to the reference; in addition during cooler periods they had the opposite effect; see Fig. 4. The recording of higher temperatures at the reference room at the end of the measurement period was caused by a failure of the measurement technique and the following illustration.

2.3 Relative humidity

Relative humidity has a dramatic effect on the quality of the indoor microclimate. Both high and low humidity cause difficulties and health problems. High relative humidity may cause the growth of moulds. Low humidity, on the other hand, raises dust levels, and causes drying of the skin and mucous membranes in humans. Regulation No. 343/2009 Coll. stipulates relative humidity for residential rooms at 30–65 % [7]. Figure 5 shows the measured values of relative humidity.
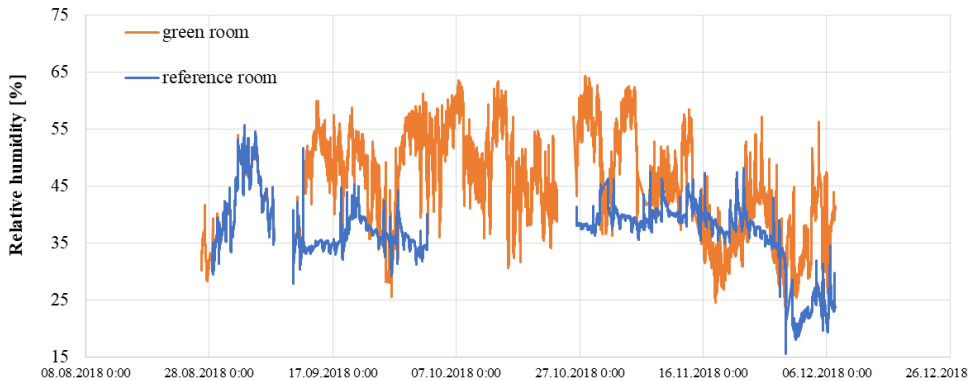

Fig. 5. Determination of relative humidity

The values of relative humidity measured in the room with the green wall and panels were higher than in the reference; see Figure 5. It is thus safe to assume that the green features substantially increased relative humidity and improved the well-being of the users. The values stayed within the required range of 30 to 65 %. Nowadays relative humidity tends to be low in buildings, typically around 30 %, causing respiratory difficulties and drying of mucous membranes.

2.4 Air flow

Indoor climate is also affected by the airflow rate. Regulation No. 343/2009 Coll. and Government Decree No. 361/2007 Coll. state a value between 0.1 to 0.2 m/s [7, 8].
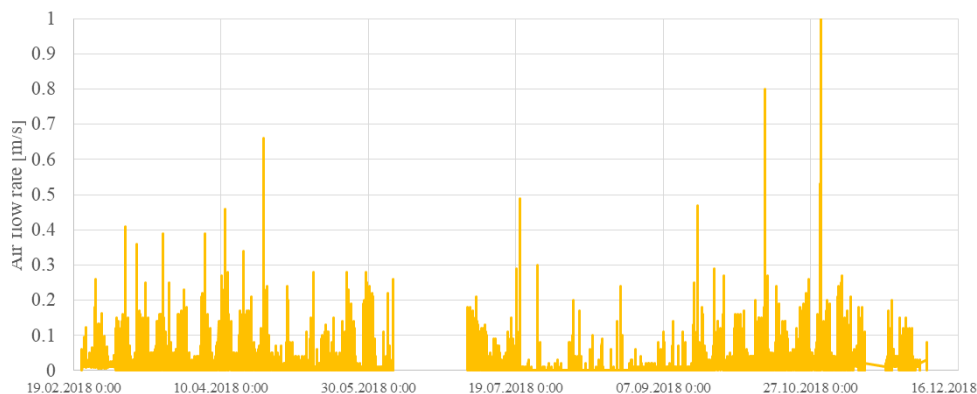
Fig. 6. Determination of air flow rate

The air flow measurements show that the required air flow rate requirements were met. They stayed between 0.1 and 0.2 m/s, See Figure 6. The fluctuations were caused by open windows.

3 Conclusion

The research into the influence of green walls and green features on the indoor climate has provided positive findings. The paper presents mainly the results of an analysis of carbon dioxide concentrations, relative humidity, air temperature, and air flow rate.

Comparing the measurements made in the classroom fitted with the living elements and the classroom without them, the following can be stated: The green features can be very effective in regulating indoor CO_2 concentrations. Air temperature measurements showed that the room with the green wall and green panels experienced a marked cooling in the summer season compared to the reference; while in winter the opposite had happened. The values of relative humidity in the classroom with the green wall and panels were higher than in the reference. It is therefore safe to assume that the green elements significantly increased the relative humidity, which also had a positive influence on the health of the room's users. The air flow rate remained within the required interval of 0.1 to 0.2 m/s.

In general, it can be said that green elements have a strong influence over the indoor microclimate, which in turn affects the mental well-being and health of the users. By extension, they contribute to the efficiency, productivity, and creativity of the people working inside and improve the study performance of students. The results of the survey showed that 66.7% of the surveyed employees and 68.3% of the students feel the positive impact of green elements on their psychological well-being and in both groups more than 50% of the respondents felt an increase in their productivity and creativity.

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