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EXPERIMENTAL STUDY ON CO_2 CAPTURE IN A RESIDENTIAL SPACE

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Abstract

The influence of Spathiphyllum "Sweet Silvio" flowers on indoor air quality (IAQ) and energy savings were studied experimentally in a bedroom, part of a 65 m^2 three-room apartment, in Brașov, Romania. We used four 14 cm pots of Spathiphyllum "Sweet Silvio" with a total leaf surface of 134.29 cm^2. The residential space has a low number of air exchange rates because exterior walls are insulated with 5 cm polystyrene, and windows have high-energy efficiency glass in PVC casement. To evaluate indoor air quality, CO_2 levels were considered as the main indicator and relative humidity (RH) as second indicator. Measurements were carried out in a three-week period plus one day in the week four, both during the day and at night. In the same period for one week, we measured also CO_2 concentration in the outside air and results show an average value of 408 ppm. The study was divided into four cases, each with a specific scenario. The results indicate a beneficial effect brought by the flower's presence inside the bedroom, but only if the door is open both day and night, to maximize the number of air exchange rates.

Key words: indoor air quality, CO_2 capture, active bio filtration, residential space

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1. Introduction

1.1. Literature review

The relationship between economic growth, environmental sustainability and energy are of great interest among researchers and policy makers (Călămar et al., 2017; Gurban et al., 2018; Vargas-Vargas et al., 2011). The progressive technological development of world countries contributed to global warming effect due to the quantities of greenhouse gases emitted (Butuc and Moldovean, 2011). Global warming is happening due to increasing level of carbon dioxide and other greenhouse gases into the atmosphere. In order to reduce the rising level of CO_2 emitted by human activities, carbon capture and storage technologies are being developed (Pădurean et al., 2013). CO_2 and thermal comfort together with a control logic that, using measured data, provide the optimal rules to actuate the control devices (ventilation, heating/cooling, windows opening, shutters operation and so on) (Revel et al., 2015). The building environmental concerns have motivated industry professionals to pursue low impact building designs and strategies. Globally the construction industry has an immense contribution to socio-economic development but is also responsible for the consumption of energy and natural resources. Ideally, a multi-disciplinary approach covering issues like emissions reductions, improved use of materials, reuse and recycling is needed to achieve the goals of building sustainability (Asif et al., 2005; Horneț et al.,

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2017; Todor et al., 2017). Buildings use a significant amount of primary energy and largely contribute to greenhouse gases emission (Gabor et al., 2017; Stojiljković et al., 2015). Most of the research has focused on reducing the operational impact of buildings, however in recent years many studies have indicated the significance of embodied energy in different building types (Rai et al., 2011). In residential building sector the primary indoor pollutant is the CO_2, from occupant respiration. The increase in indoor CO_2 concentration above the outdoor concentration is considered as a good surrogate for the indoor concentrations of bio-effluents.

The outdoor concentration of carbon dioxide can vary from 350 to 400 ppm (Apte et al., 2000) or higher in areas with high traffic or industrial activity (Manohar et al., 2018; Turanjanin et al., 2014). Ventilation is ambiguously related to the energy saving rationale originating from the mitigation of global warming, the reaching of peak oil or health concerns related to fossil fuel burning. Since it makes up for about half of the energy consumption in well-insulated buildings, it is an attractive target for energy saving measures. However, simply reducing ventilation rates has unwanted repercussions on the indoor air quality (Laverge et al., 2011). The detection of occupants in indoors can be fundamental for a correct operation of the installed engineering systems (e.g. lighting, ventilation, heating and cooling) (Cali et al., 2015). When a building is used only for intermittent occupancy, continuous operation of ventilation system is not necessary for achieving good indoor air quality during the occupation periods. Such buildings have a great energy saving potential which is not harnessed enough yet. Indeed, energy loss can be avoided by promoting natural means and managing mechanical ones.

Therefore, control strategies based on time and/or occupancy scheduled ventilation associated to pre-purge ventilation constitute a key for an energy efficient ventilation system (El Mankibi, 2009). Carbon dioxide is most of the time significantly and positively correlated with indoor air pollutants. However, the strength of the correlation is weak (Ramalho et al., 2015). Wei et al. (2015) reviewed fifty-five building schemes in 31 certifications worldwide. IAQ is included in all of the certifications as a section that evaluates the health risk of indoor occupants. In recent years, indoor air quality (IAQ) has become an internationally recognized issue that has attracted the attention of researchers and occupants towards improving the quality of air inside buildings (Al-Rashidi et al., 2012). IAQ is defined as the desire of humans to perceive the air as fresh and pleasant, with no negative impacts on their health and productivity; this is important in schools to enhance the children's learning and performance (Fanger, 2006).

In the last decade, indoor air pollution has been unanimously recognized as a public health hazard world- wide, both in developed and developing countries. Accumulation of indoor air pollutants appears to significantly contribute to ''sick building syndrome'' (SBS) and other reported diseases in affected spaces. Botanical biofiltration has received a great deal of attention in the past decade, likely due its economic, environmental and social benefits, including its potential in the near future to be incorporated in both traditional and the new trend of sustainable zero-emission green buildings (Soreanu et al., 2013). Urban people spend about 85–90% of their time indoors (residential and public spaces), which can explain the direct relation- ship between indoor air quality and public health risk (European Commission, 2007; Koistinen et al., 2008; Wang et al., 2018; Yu et al., 2009). Indoor air quality (IAQ) was ranked by the US Environmental Protection Agency in the top five public health concerns (US EPA, 2009).

There are many studies about IAQ, but there is no common standard index for the indoor air quality. The IAQ is usually expressed in required level of ventilation or in CO_2 concentration. To maintain a good indoor air quality (IAQ) in residential buildings and decrease the risk of health problems a ventilation system is needed, natural, mechanical or hybrid. In Romania, as in many places, most residential buildings are not designed with a ventilation system, and people resume to opening windows for natural ventilation, during the day. This is not wrong but when outside is cold, during the winter season or during the night, when we sleep, opening windows is not an option. Without a monitoring and data-acquisition system, people cannot quantify their indoor air quality parameters, and they end by having health problems. We studied different scenarios in a bedroom, to evaluate IAQ, by measuring indoor temperature, relative humidity and CO_2 concentration. Measurements were carried out in a three-week period plus one day in the week four, both during the day and at night.

The large scale "energy efficient" solutions for energetic audits in Romania include better insulation for the exterior construction elements and replacement of double glass with wood joinery with high-energy efficiency glass in PVC casement. All these measures minimize the number of air exchange rates between interior and exterior.

Because people spend usually 50% of their lives at home and mainly 30% of their lives in bedrooms arises in the need of generic control indoor air quality in these spaces, with a question of compliance with permissible CO_2 concentrations and in what conditions.

1.2. Description of the experimental space

We chose for the measurements an 11.4 m^2 bedroom inside a three-room apartment with 65 m^2 total living area (see Fig. 1), built in 1978, located in Braşov, which is in the central part of Romania (latitude 45°67′N, longitude 25°60′E, +2 h GMT). During measurements, two adults were living at the apartment, mostly from 6 PM to 8 AM in the week days and all day during weekends.

The apartment has three exterior walls (north, east and south) composed of 20 cm reinforced concrete and 5 cm of polystyrene insulation with a heat transfer coefficient U=0.7 W/m^{2}K. The windows are double glass window panes separated by argon, with a heat transfer coefficient U=2.6 W/m^{2}K. In accordance with the energetic certificate for the apartment, made on 20th of May 2013 the corresponding energetic class is C, with specific annual heat consumption between 201 and 291 kWh/m^2/year. The geometrical characteristics in terms of room height, surface and volumes for the experimental space are resumed in Table 1.

1.3. Number of air exchange rates.

Local standards (SR 1907-1,1997), (SR1907/1, 2014) and (SR 6643/1, 2014) recommend for residential sector 0.792 [m^{3}h^{-1}/m^3] air exchange rates for living rooms and 1,19 [m^{3}h^{-1}/m^3] air exchange rates for kitchens. Considering our case, the calculations show we need 23 [m^3/h] for bedroom, 93 [m^3/h] for Bedroom 2, Livingroom and Lobbies and 29 [m^3/h] for the kitchen. For the entire volume considered, we need 145 [m^3/h].

1.4. Spathiphyllum "Sweet Silvio"

The Spathiphyllum belongs within the Aracaea family; it is originally from tropical regions of the Americas and is also called the 'spoon' or 'flag' plant. In Europe, the Spathiphyllum was introduced in 1870. The Spathiphyllum, has large leaves, 12–65 cm long and 3–25 cm broad and upright white flowers.

'Sweet Silvio' is a hybrid of Spathiphyllum Schott that originated from the hybridization of the female or seed parent a proprietary Spathiphyllum Schott identified as 96341-1 (not patented) and the male or pollen parent a proprietary Spathiphyllum Schott identified as 96099-50 (not patented). The cultivar 'Sweet Silvio' was selected by the inventor P.C.M Olsthoorn in September of 1999 as a single plant within the progeny of the stated cross in Honselersdijk, The Netherlands (Olsthoorn, 2008).

For this experiment, in the week 3 and 4 we used four 14 cm pots, with a Spathiphyllum "Sweet Silvio" each. All flowers were placed on the bedroom, near the breathing zone of people, two on each side of the bed, as presented in Fig. 2. To evaluate correctly the influence of Spathiphyllum "Sweet Silvio", inside the bedroom, we collected all their characteristics and summarized them in Table 2.

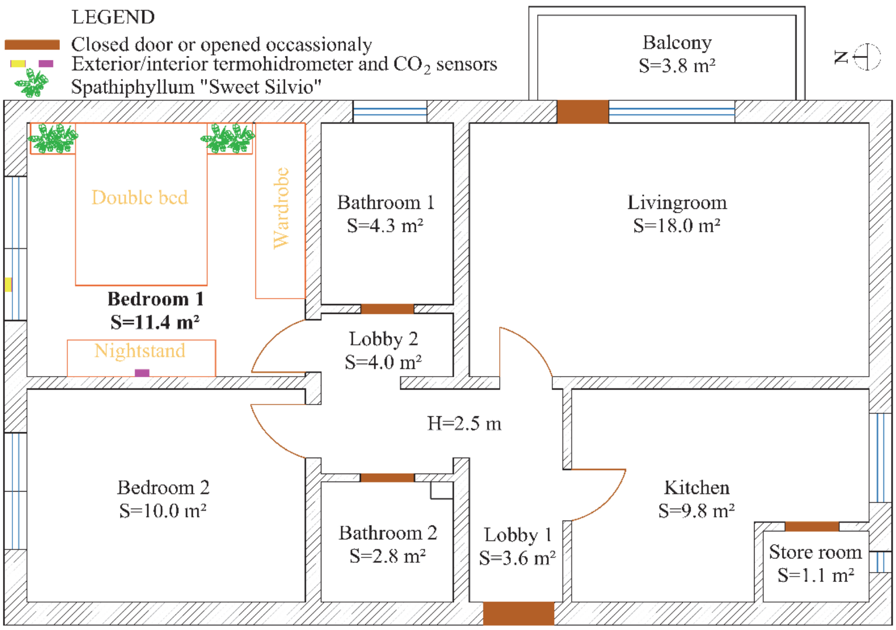

Fig. 1. Three-room apartment selected into the study

Fig. 2. The position of Spathiphyllum "Sweet Silvio" used for the experiment, inside the bedroom

Table 1. Geometrical characteristics of the experimental space

Rooms	Bedroom 1			Bedroom 1, 2; Lobby 1, 2; Livingroom and Kitchen		
Dimension	Height	Surface	Volume	Height	Surface	Volume
U.M.	[m]	[m^2]	[m^3]	[m]	[m^2]	[m^3]
Values	2.5	11.4	28.5	2.5	56.8	142

Table 2. Spathiphyllum "Sweet Silvio" characteristics

Plants	Leafs	Leaf surface	Bloomed flowers	Buds
	[PCs]	[cm^2]	[PCs]	[PCs]
Spathiphyllum Sweet Silvio no. 1	27	35.24	1	1
Spathiphyllum Sweet Silvio no. 2	27	29.28	3	2
Spathiphyllum Sweet Silvio no. 3	31	32.84	4	2
Spathiphyllum Sweet Silvio no. 4	33	36.93	2	3
Total	**118**	**134.29**	**10**	**8**

If the bedroom surface is 11.4 m^2, and the total leaf surface inside the bedroom is 0.013429 m^2, the leaf surface per square meter is 0.0012 m^2 leaf/m^2.

2. Methodology

To evaluate indoor air quality CO_2 level was considered the main indicator and relative humidity (RH) as second indicator. Because measurements were made in winter, the indoor temperature was relatively constant because of the room thermostat that adjusts the gas boiler. The average temperature during measurements was 23 ^oC for comfort reasons and to provide an optimal temperature level for the flowers.

2.1. Measuring instruments

To check the level of pollution inside experimental space we used a CO_2 datalogger, type Wöhler CDL 210. The Wöhler CDL 210 can record readings of CO_2, temperature and humidity for long time environment monitoring. The memory capacity is 16 000 points. The user can set up the sampling rate from 1 second to 4:59:59 hours. The data logger and a screenshot of the related software are shown in Fig. 3.

The data logger has an LCD display that allows instant readings for the three measured parameters. Related software enables instantaneous values and possibility of creating reports for a certain predetermined time.

The data logger was positioned as presented in Fig. 1 and Fig. 3, on the nightstand in front of the bad, inside the bedroom, at 70 cm from the floor.

To evaluate the concentration of CO_2 in the outside air, next to experimental space, we used a portable measuring instrument, Testo 480, equipped with IAQ probe (Fig. 4). Testo 480 is a high-performance measuring instrument, for measuring climate-related parameters relevant when desired for measuring, monitoring, adjusting of ventilation and air-conditioning systems in residential, office and industrial buildings. The instrument was places in the north orientation, outside the bedroom window, at 10 m above the ground, as presented in Fig. 4.

The device has USB output for PC Connection and memory card slot for local storage of the measurements made. EasyCLIMATE software for Testo 480 devices simplify the task of measuring, and data acquired processing in clear and concise reports for a rapid and complete assessment of the relevant parameters for the study.

2.2. Case's description

For this study, we considered four cases, each with a different scenario, summarized in Table 3. Easily to observe the differences arising from measurements, after the presentation of four cases results, we did a comparison of them. The comparison is presented in charts with average values for the whole period or for certain times.

The comparison will include also other related results obtained in this study, such as values of the CO_2 concentration in the outside air, at the location of the experiment.

3. Results and discussions

3.1. CO_2 concentration in the outside air

Normally, the level of CO_2 in a given region tends to remain constant if we refer to a short period of time, one-year maximum, for example. This is because the CO_2 molecules, as well as other gas molecules tend to diffuse and to equalize in the atmosphere.

For one-week period, we measured the CO_2 concentration in the outside air at the location of the experiment. The measurements were taken at five-minute intervals, for 24 hours each day, from 9 AM on 15 December until 10 AM on December 22, and the results are shown in Fig. 5.

The CO_2 concentration in the outside air fluctuated from 383 up to 443 ppm. The average value from the measurements was 408 ppm and the largest variation of CO_2 in the atmospheric air was 60 ppm. Daily week average measured value coincides with all week averages and with weekday average, 408 ppm, while the nocturnal week average was 407 ppm. The weekend average of CO_2 concentration in the outside air was 405 ppm and fluctuations were smaller than during the week.

Fig. 3. Indoor CO_2, temperature and relative humidity data logger (left) and related software screenshot (right)

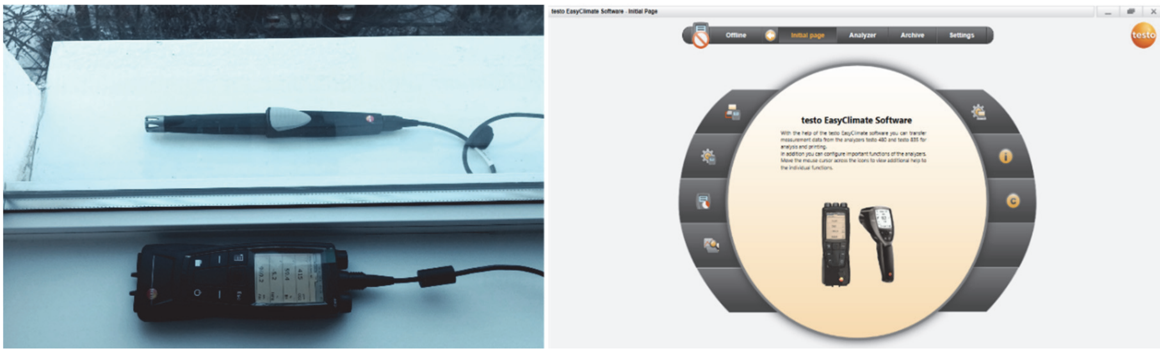

Fig. 4. Testo 480 with IAQ probe measuring CO_2 concentration in the outside air next to the experimental space (left) and EasyCLIMATE software screenshots (right)

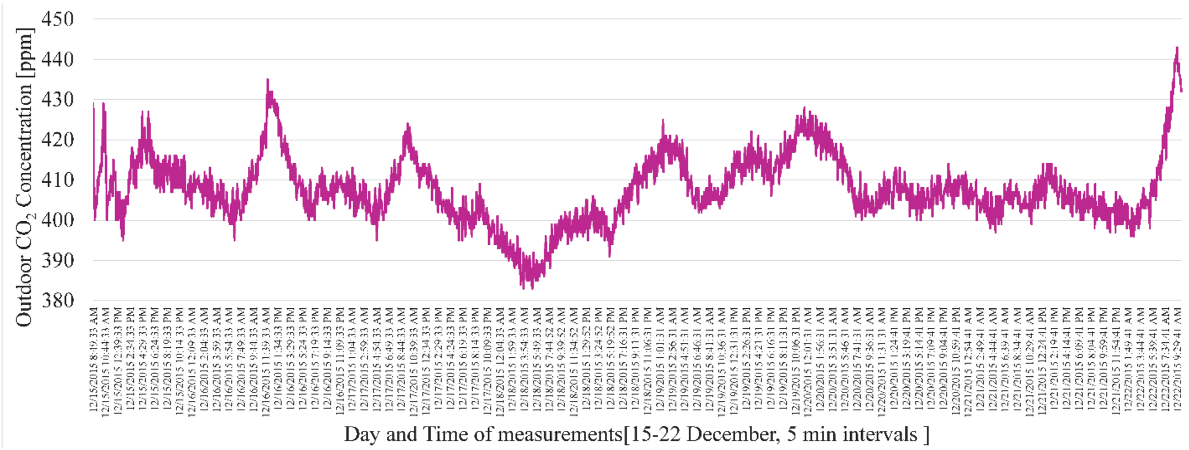

Fig. 5. Outside air CO_2 concentration [ppm]

Table 3. Proposed cases with related scenarios

Proposed cases	Scenarios			
	Bedroom door	Flowers inside Bedroom	Measurement period	
Case I	Closed	NO	1 week	7-14 December, 2015
Case II	Open	NO	1 week	14-21 December, 2015
Case III	Open	YES	1 week	21-28 December, 2015
Case IV	Closed	YES	1 day	28th of December, 2015

Buildings with natural ventilation systems must be designed according to location, region, specific statistical data of solar radiation and wind, in the days and years, to maximize occupant comfort and minimize energy costs. As buildings with natural ventilation systems must respond to the location and microclimate conditions, it is no set of specific criteria applicable to each naturally ventilated building. However, by choosing natural ventilation for a building, a variation of carbon dioxide in the outside air up to 100 ppm have no significant influence.

3.2. Case I

In this scenario, during the nights, starting usually from 8 PM until 8 AM, the bedroom door was kept closed. As it can be seen in Fig. 6 the CO_2 concentration in the bedroom air reached values close and over 6000 ppm, in 10 hours, while asleep. The weekly average concentration of CO_2 in the air inside the bedroom, before closing the door was 1353 ppm. This leads us to a difference of 4646 ppm of CO_2 accumulated in the air inside the bedroom within 10 hours, from two persons breathing, while asleep. If the difference is divided by time and the number of persons inside the bedroom, the carbon dioxide exhaled hourly by a person during sleep was 232.3 ppm. In the second day, the measurements did not reach a high value of CO_2 concentration because we tested the bedroom with door open. The maximum value of the CO_2 concentration in the bedroom air was 1726 ppm in that test day, recorded at 7:56 AM. The weekly average value of the CO_2 concentration in the bedroom air was 2355 ppm, while the average temperature was 22°C and the average relative humidity was 46 %. Daily week average measured of the CO_2 concentration in the bedroom air was 1187 ppm, while the nocturnal week average was 3399 ppm. Daily week average measured of the relative humidity in the bedroom air was 40.9%, while the nocturnal week average was 50.5%. Weekly values of minimum, maximum and average for case I are summarized in Table 4.

For residential buildings humidification or dehumidification is usually not needed. Short-term exposure to very low or high values of humidity can be accepted.

3.3. Case II

In this case, during the nights, from 8 PM until 8 AM, the bedroom door, together with other room doors were kept open, as represented in Fig. 7. The CO_2 concentration in the bedroom air reached values close and over 1400 ppm, in 10 hours, while asleep. The weekly average value of the CO_2 concentration in the bedroom air was 1218 ppm and does not include the sharp rise in the penultimate day of measurement. The 4-hour rise on that day is explained by the fact that the bedroom was occupied by a person who kept the door closed. The weekly average temperature was 23 °C and the average relative humidity was 41 %. Daily week average measured of the CO_2 concentration in the bedroom air was 905 ppm, while the nocturnal week average was 1404 ppm.

Daily week average measured of the relative humidity in the bedroom air was 32.8%, while the nocturnal week average was 42.2%. Weekly values of minimum, maximum and average for case II are summarized in Table 5.

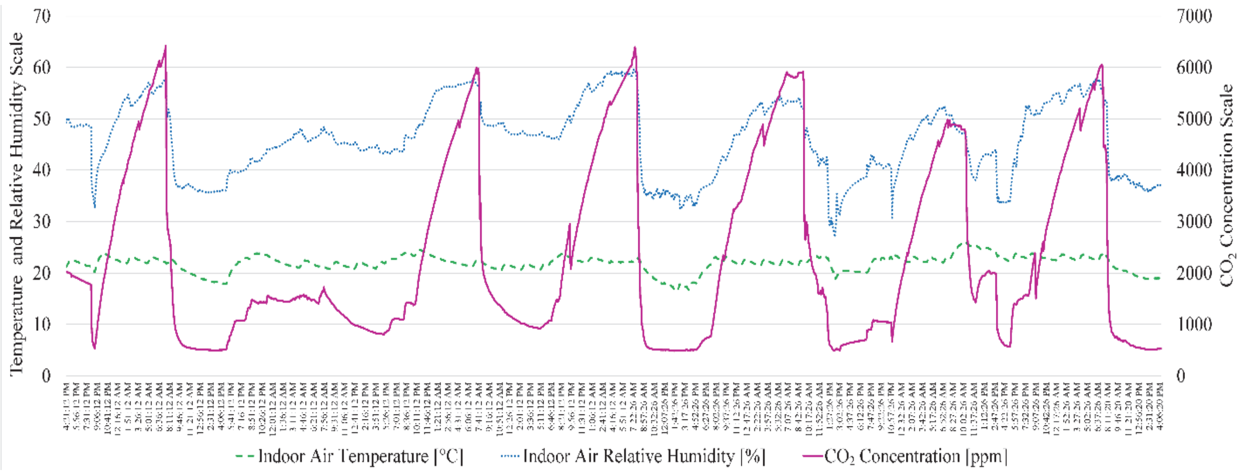

Fig. 6. Indoor air parameters for the first case

Table 4. Weekly minimum, maximum and average parameter values for case I

Parameter	*CO_2 Concentration [ppm]*	*Temperature [°C]*	*Relative Humidity [%]*
Weekly minimum values	486	17	27
Weekly maximum values	6418	26	60
Weekly average values	2355	22	46
Weekly night average values	3720	23	51

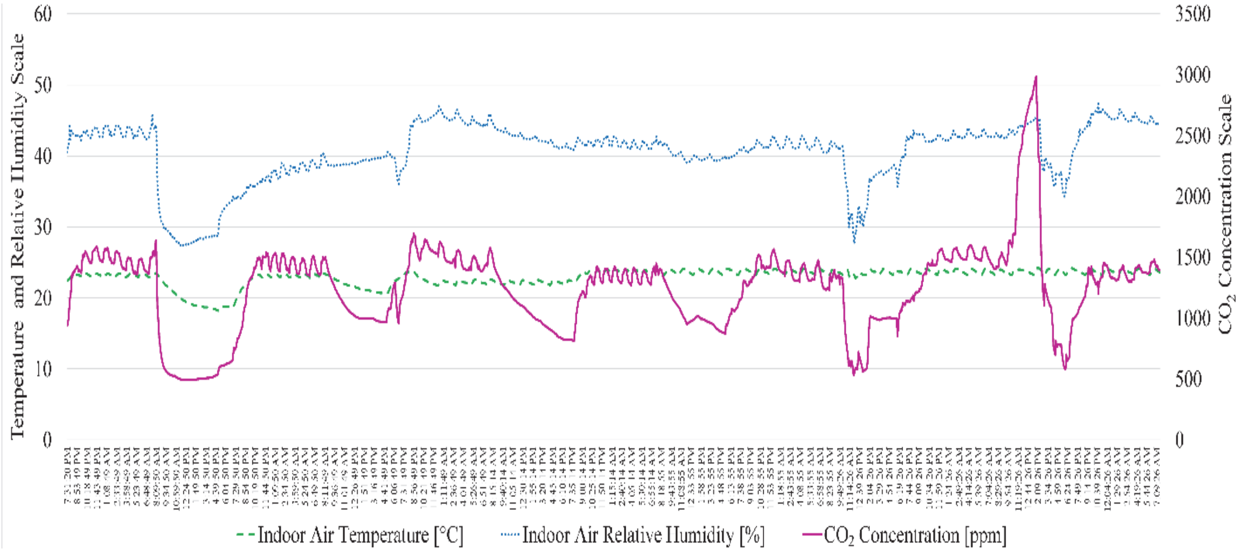

Fig. 7. Indoor air parameters for the second case

Table 5. Weekly minimum, maximum and average parameter values for case II

Parameter	*CO_2 Concentration [ppm]*	*Temperature [°C]*	*Relative Humidity [%]*
Weekly minimum values	493	18	27
Weekly maximum values	2985	24	48
Weekly average values	1218	23	41
Weekly night average values	1404	23	42

3.4. Case III

The third case is similar to second case, but with the difference that we put the flowers inside the bedroom, as represented in Fig. 8. The CO_2 concentration in the bedroom air reached values close and over 1200 ppm, in 10 hours, while asleep. The weekly mean value of the CO_2 concentration in the bedroom air was 1165 ppm. The weekly average temperature was 23 °C and the average relative humidity was 43%. Daily week average measured of the CO_2 concentration in the bedroom air was 884 ppm, while the nocturnal week average was 1283 ppm. Daily week average measured of the relative humidity in the bedroom air was 35.6%, while the nocturnal week average was 44.4%. Weekly values of minimum, maximum and average for case III are summarized in Table 6.

3.5. Case 4

This last case is similar to the initial case, except that we have left the four flowers inside the bedroom. Because of the high concentrations of CO_2 recorded in the primary case, we decided that in this case the measurement period to be narrower. We considered so, minimizing health problems for the occupants. This last measurement took place in the night of 28th to 29th of December 2015 from 7:52 PM until 7:42 AM. As displayed in Fig. 9, the presence of the four flowers in the room, during the night, with two persons asleep and the room door closed had a serious influence on the CO_2 concentration. We all know flowers as all other plants produce oxygen during the day and release CO_2 during the night. This is because plants photosynthesize in the presence of daylight, which adds oxygen and purifies the air. However, at a night time, in the absence of light plants respire and absorb the oxygen.

In the night of the measurements, the CO_2 concentration reached the value of 6969 ppm inside the bedroom. Probably the value would have been higher, maybe over 7000 ppm if it were not the two small reductions at 2:12 AM and 5:22 AM. In the indicated moments, the bedroom door was briefly ajar, because one of the occupants has left the room. In the first moment, at 2:12 AM the CO_2 concentration dropped 161 ppm in 5 minutes and lasted 15 minutes to raise 166 ppm. In the second moment, at 5:22 AM the CO_2 concentration dropped 329 ppm in 10 minutes and lasted 20 minutes to raise 324 ppm.

In the morning, the bedroom door was open for 21 minutes and indoor air CO_2 concentration dropped from the maximum value 6969 ppm to 2280 ppm. After that, the persons left and the bedroom door was closed and for 10 minutes indoor air CO_2 concentration raised from 2280 ppm to 2515 ppm. The raise was 235 ppm and after the CO_2 concentration slowly decreased in 645 minutes to 1738 ppm, during the day. The decrease was 777 ppm, with the door closed, and no persons inside.

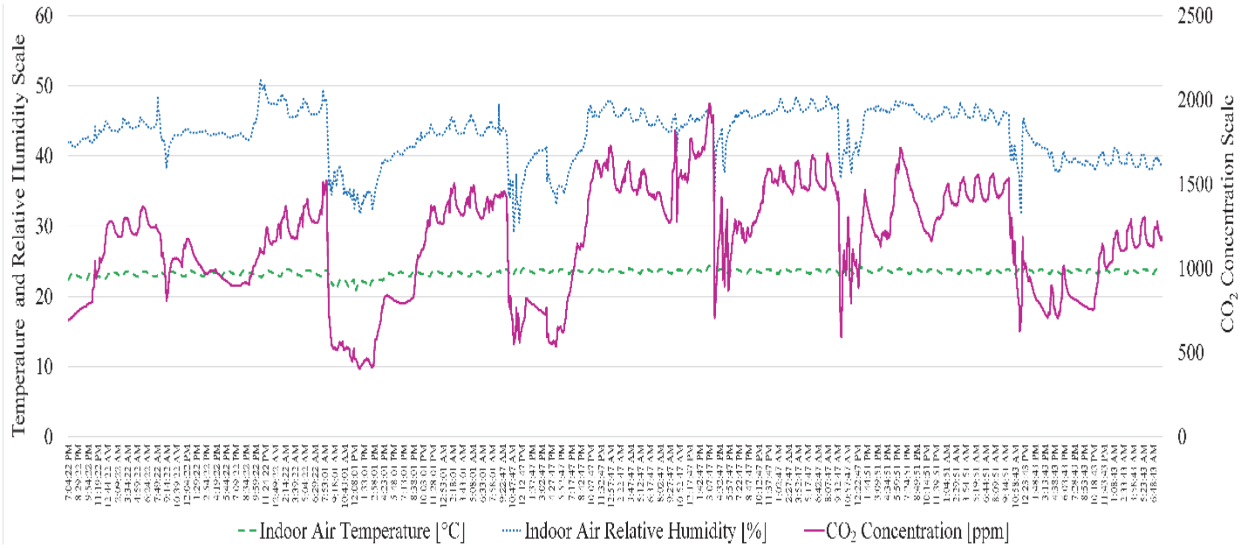

Fig. 8. Indoor air parameters for the third case

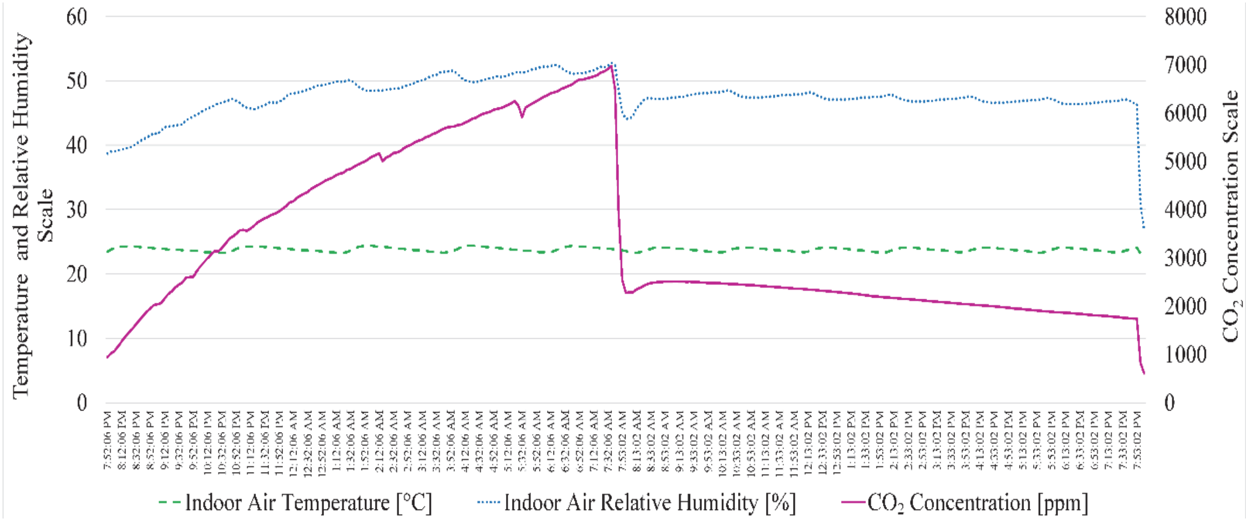

Fig. 9. Indoor air parameters for the fourth case

Table 6. Weekly minimum, maximum and average parameter values for case III

Parameter	*CO_2 Concentration [ppm]*	*Temperature [°C]*	*Relative Humidity [%]*
Weekly minimum values	404	21	29
Weekly maximum values	1979	24	51
Weekly average values	1165	23	43
Weekly night average values	1283	24	44

3.6. Case comparison

The average values of CO_2 concentration in the outside air, for one week, between 15th to 22nd of December 2015, in Braşov, Romania are presented in Fig. 10. The highest values were recorded in the week days, in the daytime, while the lowest values were during the night, in the weekend.

In general, day values are higher than night values, for the entire week. This is explained by the fact that in the daytime all activities (industry, vehicle movement, etc.) are more intense than during the nights.

For weekly average values of CO_2 concentration for the first three cases, the results indicate the highest values in the primary week (Fig. 11). The lowest values were in the third case, with the flowers inside the bedroom and the bedroom door open. To create a comparison for all four cases, we considered one day, in each of the first three cases, similar to cause four. We divided the results in two, diurnal mean values, presented in Fig. 12 and nocturnal average values, presented in Fig. 13.

The results indicate that both day and night the highest average indoor air CO_2 concentration was in case IV, while, the lowest values were in the third case, for both situations.

We compared also average indoor air relative humidity for all cases (Fig. 14) and results indicates highest values in the primary case. In the fourth case, with conditions similar to the first case, but with the flowers inside the bedroom, the values were lower.

In the other two cases (II and III) the average indoor air relative humidity was the same both day and night in case II and slightly higher in case III.

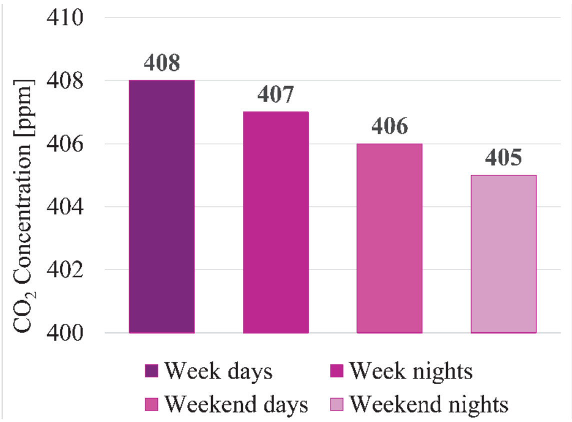

Fig. 10. Average values of CO_2 concentration in the outside air 15-22 December 2015, Brașov, Romania

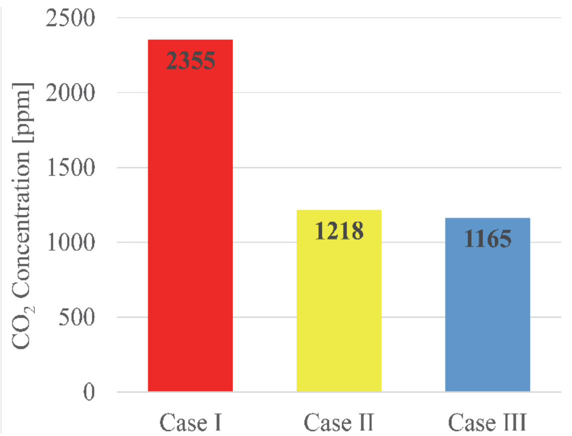

Fig. 11. Weekly average values of indoor air CO_2 concentration for the first three cases

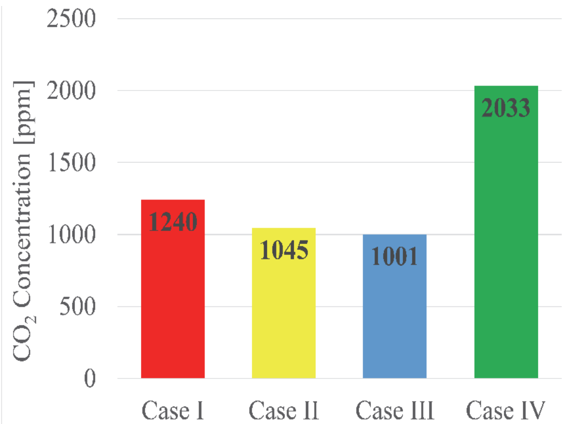

Fig. 12. One-day results on average indoor air CO_2 concentration in all cases, in similar conditions

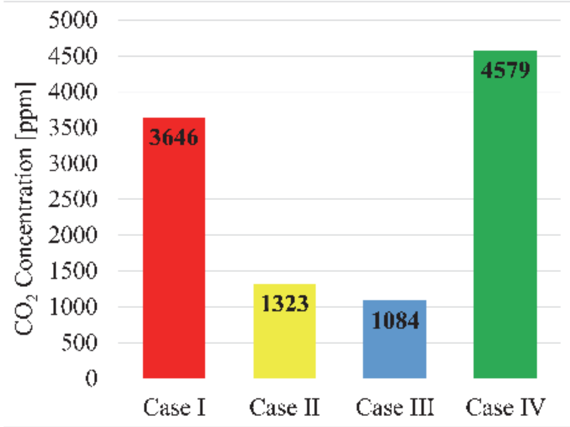

Fig. 13. One-night results on average indoor air CO_2 concentration in all cases, in similar conditions

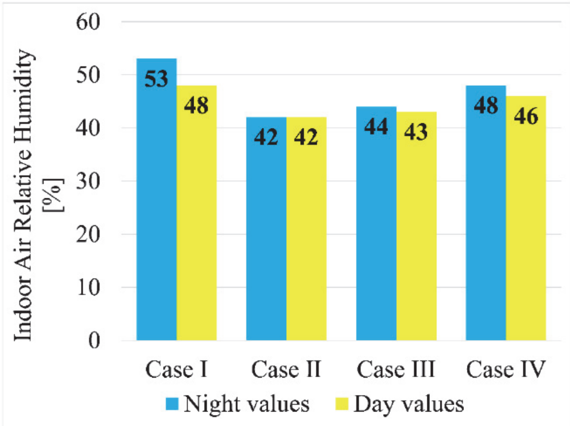

Fig. 14. One day/night results on average indoor air relative humidity for all cases, in similar conditions

4. Conclusions

In this study, we analyzed the effect of Spathiphyllum “Sweet Silvio” flowers over IAQ parameters, mostly the CO_2 and relative humidity, inside a bedroom. The study was divided into four cases, each with a specific scenario. The results indicate a beneficial effect brought by the flowers' presence inside the bedroom, but only if the door is open both day and night. The measurements indicate nearly 4% reduction on CO_2 concentration inside the bedroom over one week. In the same cases (II and III) the indoor air relative humidity was almost 5% higher during the nights and closely 4% higher during the days with the flowers inside.

The CO_2 concentration inside the bedroom with the door closed (case I and IV), while two people asleep reaches values near and over 6000 ppm, without the flowers inside and values close to 7000 ppm with the flowers inside. This means four 14 cm pots of Spathiphyllum “Sweet Silvio” placed in a 11.4 m^2 bedroom added almost 1000 ppm in CO_2 concentration by plant respiration in the night time. In this cases the indoor air relative humidity is higher than in, we considered the bedroom door open.

The measurements indicate that the four flowers inside the bedroom reduced the indoor air relative humidity, both during the days and nights, in last case if compared with the first.

Many people sleep with the bedroom door closed, without realizing how much CO_2 accumulates in 8-hour time. Some of them have also flowers in their bedroom, for their nice aspect but their presence does nothing but worsened the situation. These two situations can lead to adverse health effects, which include headache, general drowsiness, stiffness, odors and the sensation of reduced oxygen level. All these symptoms were felt by the two people who slept in the bedroom during the case I measurements.

It is good to have flowers inside the house, but their place is in living room or in kitchen, and no one should sleep with the bedroom door closed because of the CO_2 accumulation inside.

Energy reduction obtained by adding flowers in a living space it is directly proportional to the CO_2 captured from that space by the flowers. In the case of the present study, the reduction was of almost 4%.

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