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Influence of Indoor Climate on Employees in Office Buildings—A Case Study

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Abstract: The presented research work is aimed at investigation of the influence of indoor environmental conditions on employees in office buildings. Monitoring of carbon dioxide, temperature, relative humidity and pulse, as well as subjective evaluation, was carried out in three office rooms where air conditioning systems ensured the required amount of fresh air. Investigation showed that in two offices (A and B), the amount of fresh air did not comply with EN 15251:2017. The concentration of CO_2 in office A was above 1000 ppm for 72% of the total length of stay. Respondents confirmed fatigue and headaches. In offices A and B, where CO_2 concentration was around 1000 ppm, people with a weight of up to 70 kg experienced a significant increase in air temperature as well as odor. Persons with weight higher than 75 kg experienced a slight decrease in air quality. In office C, where CO_2 concentration was around 800 ppm, respondents reported a slight decrease in air quality. According to pulse monitoring, it can be stated that in an office where there is an insufficient supply of fresh air, the pulse of a person falls or only slightly rises. A decrease in pulses may indicate the attenuation or stunning of people caused by poor air quality.

Keywords: office building; CO_2; temperature; relative humidity; pulse; questionnaire

1. Introduction

The main source of carbon dioxide (CO_2) in the indoor environment is human respiration [1]. Levels of CO_2 are often considered as an important indicator of indoor air quality as well as ventilation intensity [2]. CO_2 concentrations may vary from building to building and within one building may vary from location to location. These variations are caused by the dispersion of CO_2, which varies with room conditions and variables such as internal and external environmental conditions, the occupancy level, the air flow rate etc. [3]. The mean concentrations of CO_2 were ranged from 488 to 1164 ppm in ten office buildings in Taiwan in the study of [4]. In Delhi, the mean concentrations of CO_2 in two office buildings were 1513 and 1338 ppm [5]. According to another study [6], mean CO_2 concentrations were from 742 to 920 ppm in a Slovak office building. Levels of CO_2 normally occurring in the indoor environment do not represent a major risk to human health; however, higher levels were associated with some adverse effects [7]. Authors in study [8] observed a relationship between CO_2 concentrations and lower respiratory and mucous membrane symptoms. The generalized estimating equation models in the study of [9] showed that office workers exposed to indoor CO_2 levels higher than 800 ppm were likely to report more upper respiratory symptoms and eye irritation. A well known issue in indoor environments is sick building syndrome (SBS), which is the result of exposure to indoor air pollutants or, generally speaking, exposure to poor indoor air quality. Headache, fatigue, nausea, dizziness, eye, nose and throat irritation, sensation of dry mucous membranes, skin erythema, high frequency of airway infection and cough, hoarseness, wheezing, and unspecified hypersensitivity are the symptoms of SBS [10]. In study of [11] was investigated the relationship between indoor air quality and prevalence of SBS in old and new office buildings in Selangor. The authors proposed that an increase in ventilation rates per person would significantly reduce prevalence of SBS. Authors in study of [12] in their review observed that half of the CO_2 studies suggest that the risk of SBS continued to decease significantly with decreasing CO_2 below 800 ppm. Researchers in study of [13] performed a multiparametric analysis on environmental factors such as temperature, relative humidity and CO_2, the physiological stress reactions in the body, measured alertness and subjective symptoms during simulated office work. This study showed that high CO_2 levels can caused physiological changes such as higher CO_2 concentrations in tissues, increase of peripheral blood circulation during exposure to elevated CO_2 levels, as well as changes in heart rate variation, and noted that these physiological effects can decrease the building user's functional ability. Thus, indoor CO_2 was linked with a decrease of performance. In study of [14] was investigated the impact of different CO_2 levels on airline pilots in a flight simulator and suggested that there is a direct association between CO_2 levels above 1000 ppm and performance. A different study [15] showed that levels of CO_2 are associated with cognitive function. Study [16] assessed direct effects of increased CO_2 on decision making and found that decision-making performance in six of nine scales significantly decreased at 1000 ppm in comparison with 600 ppm, and at 2500 ppm large, significant reductions occurred in seven scales of decision-making performance. Results from the study of [17], in which the impact of CO_2 levels on intensity of mental work and human well-being were examined, showed that the capacity to concentrate attention and human well-being decline with increasing CO_2 concentration up to 3000 ppm. Sufficient ventilation intensity or proper design of the air distribution systems (diffusers) will help to create a healthy indoor environment [18]. Studies [19,20] investigated that by reorganizing the rooms in the workplace to achieve a combination of sedentary activity with physical activity, it is possible to improve the perceived indoor environmental quality. Results of the study [19] showed that the availability of space which allows people to occupy a workstation and use it as a proprietary desk, and the feeling of working in a traditional open plan layout are important features in the workplace. According this study, 44% of interviewees answered the questionnaire saying that they would appreciate the possibility to personalize their desk to feel more comfortable at work. In the study [20], the research task was focused on job satisfaction, environmental satisfaction and perceived support in the work environments. Results pointed to slightly higher average job satisfaction than environmental satisfaction and perceived support in the work environment. Further, environmental satisfaction and perceived support in the work environment were highly correlated with each other. This study also recommended an effective layout design of a sustainable building, taking into account the possible positive and/or negative impacts of active design on organization performance for better implementation outcomes. In addition to these aspects, indoor air factors also need to be investigated. As can be seen, despite the fact that CO_2 is not an indoor air pollutant of greatest concern, at high levels it has a significant influence on humans. Therefore, the aim of this study is the investigation of dynamic changes of indoor air factors in offices and their influence on employees during working shifts. An innovative approach can be considered the investigation of the relationship between indoor air parameters, the human pulse and the subjective perception of employees.

2. Materials and Methods

2.1. Site Description

An eight story office building located in Košice, Slovakia, was selected for the investigation of indoor environments and their impact on employees who carried out administrative work on personal computers. Experimental measurements were performed in three office rooms in January with outdoor air temperature ranging from −2 to 0 °C. It is important to note that the envelope of the building consisted of 90% of the transparent area and 10% of the non-transparent area.

The size and shape of the offices were different and the workplaces were arranged differently. Respondents were present during the measurements for the time of 8 h. Table 1 presents basic information about the offices.

Table 1. Basic information about monitored offices.

Room	Floor Area (m^2)	Volume of Room (m^3)	Number of Men (-)	Number of Women (-)	Volume of Room (m^3/Person)	Volumetric Air Flow Rate (m^3/(h. Person))
A	60.00	156.00	4	5	17.33	19.4
B	73.90	206.92	10	1	18.81	40.5
C	86.00	223.60	9	2	20.33	47.8

Office A was occupied by 9 employees with average age of 37 years and average weight of 69 kg. Five of them were women aged from 25 to 44 years with weight of 50–66 kg; and 4 were men aged 33 to 41 weighing from 67 to 90 kg. In office B were present 11 people, whose average age was 36 years and average weight 84 kg. One woman was aged 57 years with weight of 65 kg and 10 men aged 25 to 42 weighed 55 to 110 kg. Office C was occupied by 11 employees with average age of 28 years and average weight of 80 kg, of which 2 were women 25 years old with weight from 50 to 68 kg and 9 were men aged 25–38 with weight between 75 and 112 kg.

Mechanical rooms for air-conditioning were placed on each floor and the required amount of fresh air was adjusted by demand. Indoor air quality in office spaces was ensured through combined air and water conditioning systems. The air system provided fresh air to the room. The two-water pipe fan coil system with windscreen fan coils ensured the required room temperature.

Volumetric flow rate of inlet air and exhaust air was determined. Measurement of volumetric air flow rate was carried out by the Testo 480 anemometer, which measured flow rate of the incoming air in the air supply duct before the end element. The volumetric air flow rate was calculated on the basis of the measured air flow rate and internal cross-section of air-conditioning pipe. Air flow rate measurement was performed at a time when the air-conditioning unit was operating at 100% power. The volumetric flow rates of the intake air are shown in Table 1.

2.2. Objective Measurement

CO_2 concentration, indoor air temperature, relative air humidity and human pulse were measured in all three office rooms in which employees performed sedentary office work.

A Testo 480 instrument with Testo 0635 air flow sensor was used to measure the air flow rate. The measuring range of the instrument is from 0 m/s to +20 m/s, the instrument's sensitivity is 0.01 m/s and the accuracy is ± 0.03 m/s. For measuring the CO_2 concentration, indoor air temperature and relative humidity, we used the Testo 435-4 instrument with Testo 0632 sensor. The measuring range of the instrument for temperature is from 0 to + 50 °C, the instrument's sensitivity is 0.1 °C and the accuracy is ± 0.3 °C. The measuring range of the instrument for relative humidity is from 0% to 100%, the instrument's sensitivity is 0.1 RH and the accuracy is ± 1.8 RH. The measuring range of the instrument for CO_2 concentration is from 0 to 10,000 ppm, the instrument's sensitivity is 1 ppm and the accuracy is ± 3%. The operative temperature of the measuring device is between −20 and + 50 °C. The instruments were placed in the middle of the room at a height of 1 m.

The Sanitas-SBM 42 was used to measure the human pulse. The measuring range of this device is from 30 to 180 pulses/min, its sensitivity is 1 pulse and the accuracy of the instrument is ± 5%. The operating temperature of the instrument is from −10 to +40 °C.

2.3. Subjective Evaluation

During the experimental measurement, the persons in the room performed subjective evaluation of the indoor environment through the questionnaires focused on gender, age, weight, sensation of room temperature, odor and overall air condition. Questionnaires were filled out at the beginning and at the end of the working shift.

3. Results and Discussion

Table 2 presents minimum, maximum and mean values of indoor air temperature, relative humidity and CO_2 concentrations during the total time of monitoring.

Table 2. Indoor air parameters.

Office	Indoor Air Temperature [°C]			Relative Humidity [%]			CO_2 Concentration [ppm]		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
A	22.9	25.0	24.5	20.1	26.4	23.9	374	1162	863
B	22.8	25.5	24.5	17.7	25.8	22.8	379	1006	702
C	22.2	25.3	22.4	19.6	23.7	21.6	396	869	651

3.1. Office A

The measured volumetric flow rate of supplied fresh air was 19.4 m^3/h per person in office A. This amount of fresh air does not comply with EN 15251 [21], which prescribes 42 m^3/h per person for II. category (standard level for new and reconstructed buildings) and for the given room type. Figure 1 depicts levels of CO_2 concentration, indoor air temperature and relative humidity.

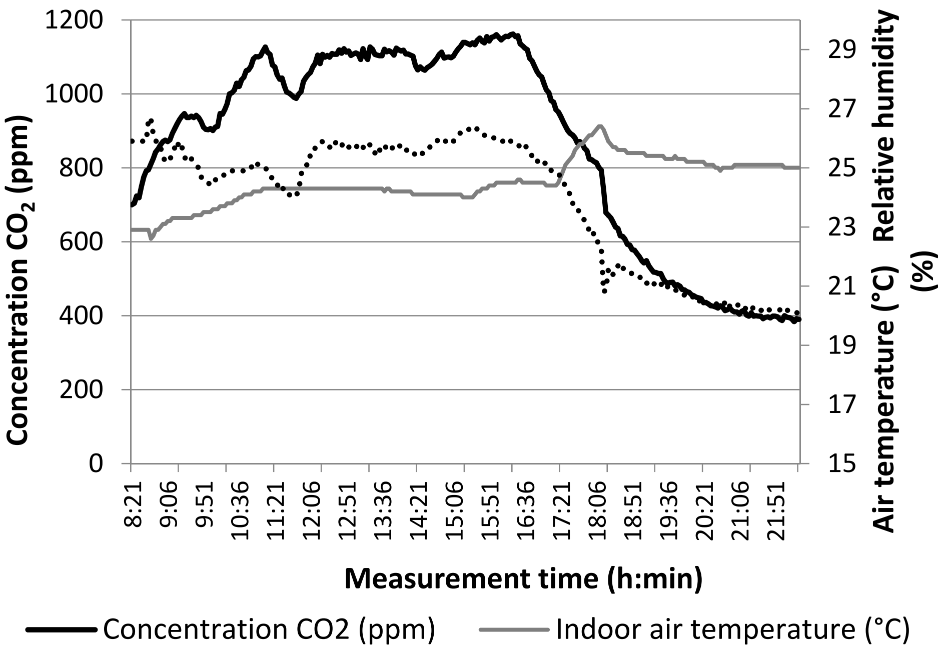

Figure 1. Indoor air parameters in office A.

Respondents stayed in the office from 9.00 a.m. to 5.00 p.m. During their work the values of CO_2 concentration, indoor air temperature and relative humidity ranged from 871 to 1162 ppm, from 23.1

to 24.6 °C and from 24.0% to 26.4%, respectively. Mean values were 1065 ppm for CO_2 concentration, 24.1 °C for indoor air temperature and 25.4% for relative humidity.

From Figure 1, we can see that the CO_2 concentration in office A was greater than 1000 ppm for 345 min, which was 72% of the total occupancy time (480 min). The highest measured CO_2 concentration was 1162 ppm. It is necessary to say that employees felt a lack of fresh air during the experimental measurement.

3.2. *Office B*

Measured volumetric flow rate of supplied fresh air was 40.5 m^3/h per person in office B. This amount of fresh air does not comply with EN 16798-1, which prescribes 42.13 m^3/h per person for the given room type. Figure 2 depicts the variation of CO_2 concentration, indoor air temperature and relative humidity with measurement time. Respondents stayed in the office from 9.00 a.m. to 5.00 p.m. During their work, the values of CO_2 concentration, indoor air temperature and relative humidity ranged from 696 to 1006 ppm, from 23.7 to 25.5 °C and from 22.4% to 25.8%, respectively. Mean values were 882 ppm for CO_2 concentration, 24.9 °C for indoor air temperature and 24.2 % for relative humidity. During the experimental measurement, staff did not feel a significant decrease in air quality. CO_2 concentration in office B was greater than 1000 ppm for 9 min, which was 2% of the total time spent by employees. The peak CO_2 concentration was 1006 ppm.

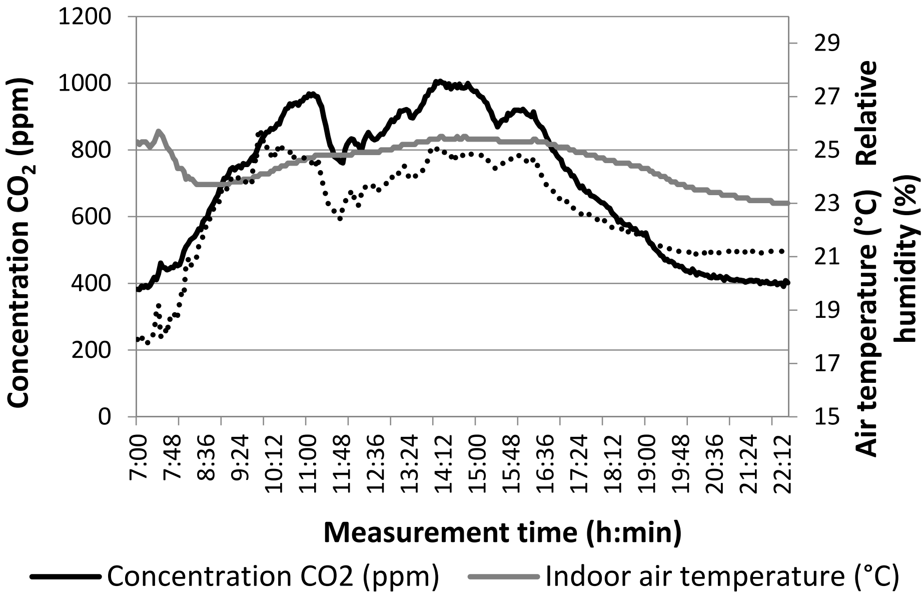

Figure 2. Indoor air parameters in office B.

3.3. *Office C*

In office C, measured volumetric supplied air flow rate was 47.8 m^3/h per person. This amount of air complies with EN 16798-1, which prescribes 44.90 m^3/h per person for the given room type. Figure 3 illustrates the variation of CO_2 concentration, indoor air temperature and relative humidity with measurement time. Respondents stayed in office from 8.45 a.m. to 4.45 p.m. During their work, the values of CO_2 concentration, indoor air temperature and relative humidity ranged from 689 to 869 ppm, from 23.6 to 25.3 °C and from 20.9% to 23.5%, respectively. Mean values were 783 ppm for CO_2 concentration, 24.9 °C for indoor air temperature and 22.5% for relative humidity. During the experimental measurement, the employees did not feel a significant decrease in air quality.

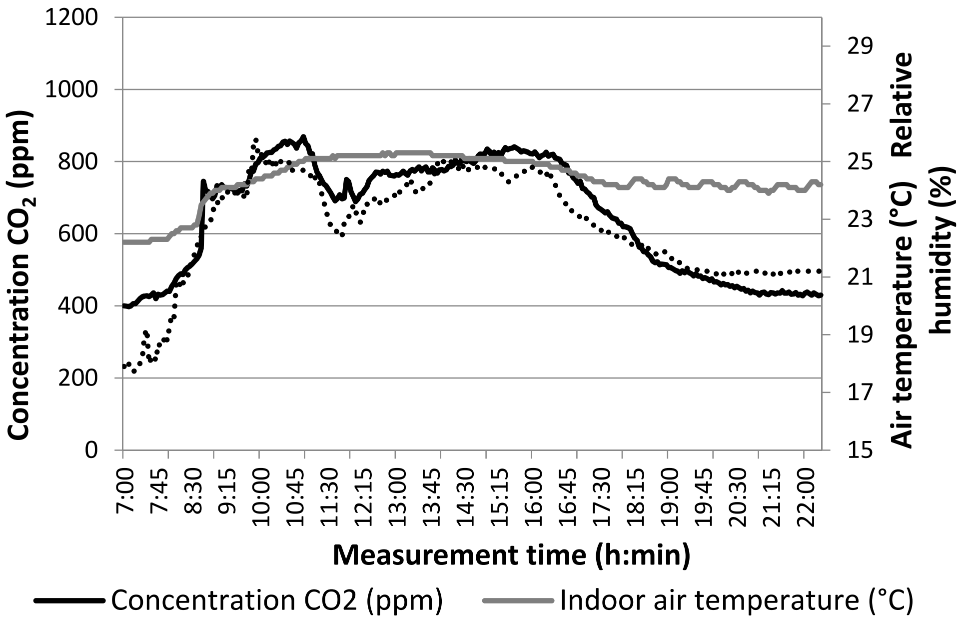

Figure 3. Indoor air parameters in office C.

Figure 3 shows that CO_2 concentration did not exceed the value of 1000 ppm. From the indoor air parameters, it can be stated that the indoor air temperature was relatively high but still acceptable. Outdoor air temperature and sun's intensity ranged from −2 to 0°C and from 40 to 100 W/m^2, respectively. As the envelope of the building was predominantly glazed, the interior was overheated by sunlight. In all three offices, the relative humidity values were below the permissible minimum, which makes it possible to conclude that air conditioning did not provide air humidification.

Room A, where 9 people worked, had the smallest floor area as well as air volume per person. The volumetric flow rate of fresh air supplied per person was 19.4 m^3/h, which absolutely does not meet the hygienic minimum. Rooms B and C, where 11 people worked in each office, had a larger floor area as well as volume of air per person than room A. The volumes of fresh air of 40.5 m^3/h per person (office B) and 47.8 m^3/h per person (office C) met the hygienic requirement.

The concentration of carbon dioxide in office A was above 1000 ppm for 72% of the total length of stay. Although this is not a large increase in carbon dioxide, it can be said that the environment was inadequate.

3.4. Human Pulse

During the working shift, pulse measurements of the respondents were performed. The pulse measurement was done a few minutes after the employees arrived in the office room to calm them down. Next pulse measurements were performed before people left for a lunch break, after a lunch break and before leaving the workplace at the end of the shift. Table 3 presents the recorded pulses of the respondents.

From Table 3, where the individual pulses were recorded, it was observed that pulses were dropping in all persons during the morning worked in office A. Pulses dropped in 82% and 55% of the total number of people in offices B and C, respectively. After a lunch break in all three offices, pulses were mostly elevated, which can be explained by the walk they had to take to the restaurant. For people who were not out of the room during the lunch break and resting in the room, pulses continued to fall slightly. During the afternoon, pulses sharply declined in 44% of the total number of people who worked in office A. Among others, pulses increased only slightly. In office B, pulses dropped in 36% of the total number of people, but less than those in office A. In office C, pulse dropped in 82% of the total number of people but also less than those in room A. From pulse levels, it can be stated that in an office where there is an insufficient supply of fresh air, the pulse of a person falls or only slightly rises. A decrease in pulses may indicate the attenuation or stunning of people caused by poor air quality. In the afternoon, when the CO_2 concentration was above 1000 ppm, the pulse drop was more pronounced, especially for those with a higher weight. In rooms where there was the required fresh air supply, the pulses fluctuated.

Table 3. Heart-beat intensity (pulse) of occupants in offices.

Office	Sex	Weight of Person [kg]	Heart-Beat Intensity (Pulse) of Occupants in Offices [pulse/min]				Increase/Decrease of Pulse [%]
			Coming into the Office	Departure for Lunch	Return from Lunch	Departure from the Office	
A	Woman	50	75	74	76	77	2.67
	Woman	51	82	81	82	84	2.44
	Woman	60	65	63	60	56	−13.85
	Woman	66	69	62	62	77	11.59
	Woman	66	64	63	70	65	1.56
	Man	67	70	71	71	72	2.86
	Man	85	96	90	107	76	−20.83
	Man	87	63	71	72	60	−4.76
	Man	90	87	66	92	63	−27.59
B	Man	55	78	55	64	57	−26.92
	Woman	65	68	71	69	90	32.35
	Man	80	67	62	75	65	−2.99
	Man	80	57	57	61	61	7.02
	Man	83	98	95	93	84	−14.29
	Man	85	65	53	60	55	−15.38
	Man	86	76	76	94	108	42.11
	Man	90	65	60	58	63	−3.08
	Man	93	60	66	54	56	−6.67
	Man	97	87	85	84	86	−1.15
	Man	110	95	86	84	87	−8.42
C	Woman	50	72	73	80	70	−2.78
	Woman	68	64	70	77	72	12.50
	Man	75	72	66	75	61	−15.28
	Man	76	80	88	75	65	−18.75
	Man	80	78	60	74	62	−20.51
	Man	80	75	69	91	88	17.33
	Man	81	60	67	78	66	10.00
	Man	86	76	88	79	86	13.16
	Man	87	98	93	96	96	−2.04
	Man	90	85	66	74	63	−25.88
	Man	112	72	71	98	82	13.89

3.5. Subjective Evaluation

Subjective evaluation of the indoor environment through the questionnaires, which focused on indoor air temperature and odor, showed that odor proportionately increased as a by-product of the presence of people with the increase of the carbon dioxide concentration. Experimental measurement was carried out in normal workplace conditions, with as few staff as possible to perform their duties. For this reason, the questions were simple and concise. From the point of view of the indoor air temperature, respondents could choose one of the possible answers: cold (−2), slightly cold (−1), neutral (0), slightly hot (+1) and hot (+2). The odor intensity scale was: odorless (0), weak odor (+1), slight odor (+2) and strong odor (+3). The results of the questionnaires are shown in Figures 4–9, with the male and female responses being shown separately.

From the subjective evaluation, we can say the air quality in all three offices got to be worse at the end of working hours. Significant air quality downgrades of up to 2 levels (from weak odor up to strong odor) were found in office A, where the smallest flow of fresh air was also measured. In offices A and B, where the carbon dioxide concentration was around 1000 ppm, people with a weight of up to 70 kg experienced a significant increase in air temperature as well as odor. Persons weighing more than 75 kg experienced a slight decrease in air quality. In office C, where the carbon dioxide concentration was around 800 ppm, respondents reported a slight decrease in air quality. From subjective evaluation, we can see that the quality of indoor air was getting worse during the stay of the persons in the room. Women responded to the increase in temperature and odor more than men. Respondents noted that they were extremely tired after the end of their working shift and that some of them had headaches. It can be said that workers during the day adapted to their environment, but symptoms appeared after hours spent in an unhealthy environment.

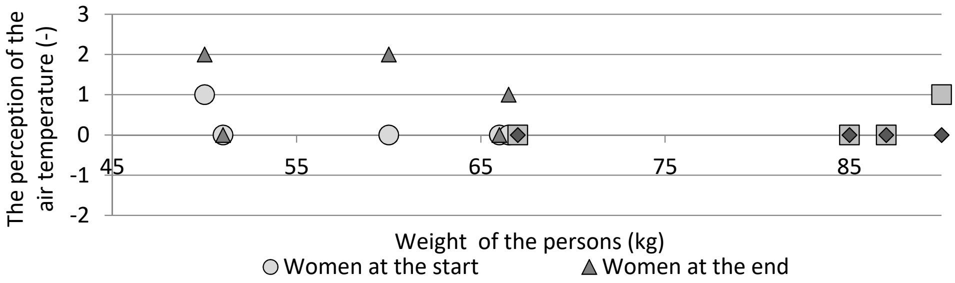

Figure 4. Perception of air temperature in office A.

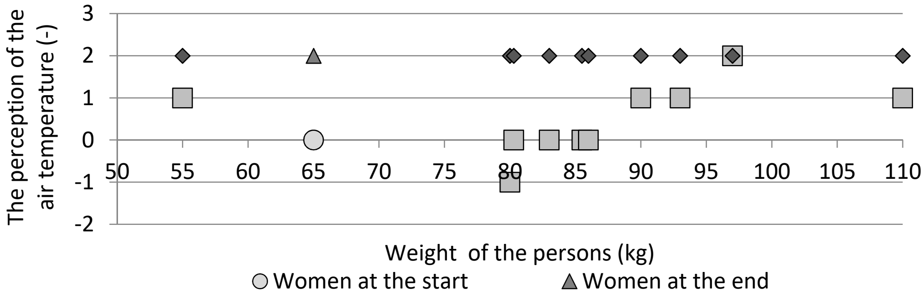

Figure 5. Perception of air temperature in office B.

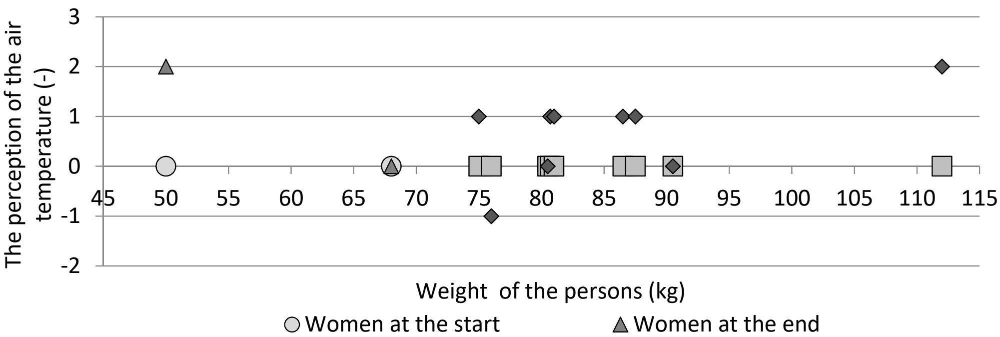

Figure 6. Perception of air temperature in office C.

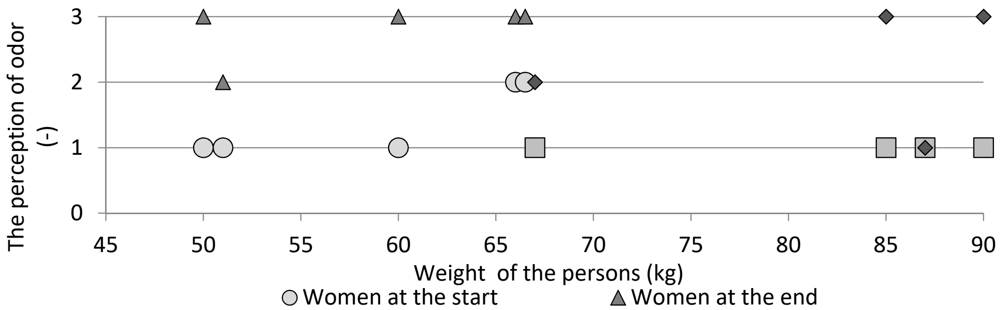

Figure 7. Perception of odor in office A.

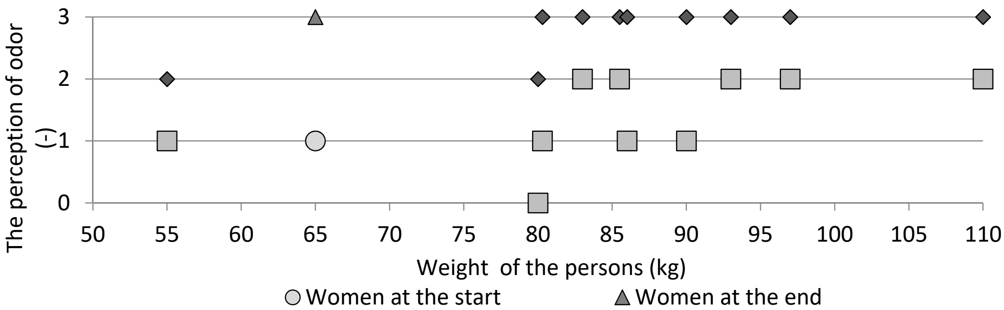

Figure 8. Perception of odor in office B.

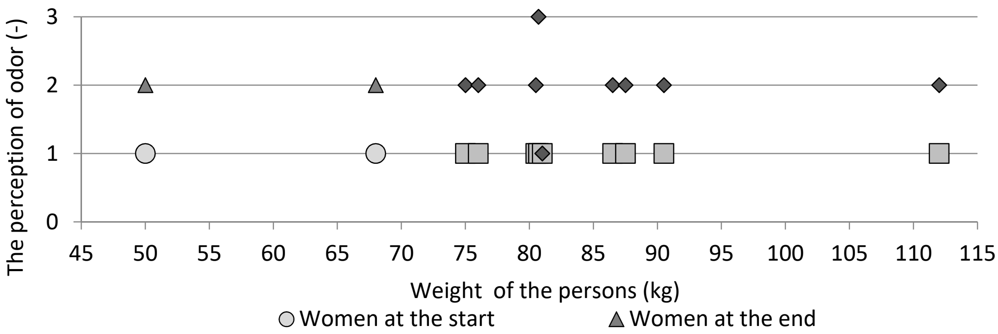

Figure 9. Perception of odor in office C.

4. Conclusions

When insufficient fresh air is supplied to a room, building users have to make more effort to perform their tasks and feel more fatigue. The performed experimental measurements and subjective evaluations showed the need to ensure the maximum CO_2 concentration of 1000 ppm in office rooms. When the CO_2 concentration increases above this value, adverse effects begin to occur, reducing the performance of employees. Tired people need more time to regenerate than those who work in a room with a sufficient amount of fresh air. In the absence of fresh air in the room, with increasing weight, the pulse difference increases by approximately 20% compared to a room where sufficient fresh air is supplied. Research shows that even a small increase in CO_2 concentration, in our case office A (1.162 ppm) in an enclosed ventilated space, causes undesirable discomfort. Lack of fresh air caused a slight change in heart rate in people, which may indicate attenuation or stunning. Subjective evaluation by questionnaires showed that women reacted more precisely to the change of indoor air temperature than men. Further, men with lower weight were more sensitive to changing air temperatures than men with a higher weight. It was similar in the perception of odors. On the basis of our experimental measurements, it is possible to conclude that the indoor air temperature and the carbon dioxide concentration in a room are suitable parameters for demand-controlled ventilation in order to guarantee indoor air quality.

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