Preliminary investigation of association between indoor air quality and emergence of depressive symptoms

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ABSTRACT

Indoor air quality may influence the health of inhabitants. Few studies have examined the role of air pollution in the etiology of depressive disorder. The purpose of this study is to further explore the relationship between the indoor air quality and depressive disorders. The mean CO_2 concentration, relative humidity and temperature were 1414 ppm, 49.1%, 24.3 ℃ in indoor air, respectively. The complaints of sick building syndrome were reported in 75.4% of the participants. 32.1% of the participants who filled in the Beck Depression inventory (BDI) questionnaire form (n = 196) reported minor depressive symptoms, 8.7% of them reported moderate depressive symptoms and 5.8% of them reported severe depressive symptoms. Moderate positive correlation was found between the carbon dioxide levels and the depressive symptoms reported in the BDI, in addition a weak positive correlation between the reported poor quality of life and sick building syndrome complaints.

These results indicate that the physical and mental health of the inhabitants of buildings with poor indoor air quality seems to be adversely affected as evidenced by increased depressive symptoms and reported poor quality of life.

INTRODUCTION

According to World Health Organization, people spend 90% of their time indoor. Indoor air is defined as the air inhaled inside of non-industrial offices and buildings [1,2]. Indoor air quality can be measured as "low" and "high" and "low quality indoor air" may cause illness and loss of productivity. "High quality indoor air" may contribute to a better work environment and promote a healthier life-style [3,4]. Indoor air quality can be evaluated by measuring the concentration of some air pollutants (air pollutants included particulate and gaseous pollutants) in the surrounding air or by measuring the CO_2 concentration only [5,6].

When the indoor air quality is compromised symptoms of "sick building syndrome" (SBS) may emerge. SBS symptoms may include mucosal irritation which could manifest as dryness and hoarseness of the throat; irritation and defluxion of the nose; itching, burning and irritation of the eyes, itching of the contact lenses and intolerance; skin symptoms such as itching, stinging, burning, drying and flushing of the skin. In SBS, respiratory

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symptoms may include, chest tightness, breathlessness, coughing, wheezing; neurological symptoms may include heavy-headedness, headaches, dizziness, fatigue and attention difficulties. These complaints may emerge in a certain building and disappear outside the building [7-10].

The CO_2 is a colorless and odorless gas produced by each living organism via breathing air is the most important source of CO_2 in the surrounding. The atmospheric value of CO_2, for the current century, is 377 ppm (0.0377%) [3,8]. The CO_2 concentration below 650 ppm is accepted normal indoors. When the CO_2 concentration reaches at 800 ppm levels, the symptoms of SBS appear; 5000 ppm is accepted as the highest tolerable CO_2 value for a healthy living environment. At 15000 ppm, the heart rate increases and difficulties in inhalation arise. At 30000 ppm muscle aches, convulsions, loss of consciousness and death risk arise [10-12]. For "high quality indoor air" the CO_2 concentration should be below 650 ppm (0.065%), temperature should between 19 and 23 ℃ and relative humidity should be between 40 and 60% [3,4]. It has been found that the CO_2 concentration is increased in surroundings with poor indoor air quality [4].

It is known that polluted air is connected to cardiovascular and respiratory illness [9,11-13]. Inhalation of air with 5% CO_2 concentration for 15 min or 35% CO_2 concentration only once with vital capacity may trigger a panic attack as defined in Diagnostic and Statistical Manual for Mental Disorder IV [11,14]. However, further adverse physiological and psychological effects of CO_2 air exposure remain unknown.

Depressive disorder is an imbalance in brain chemicals caused by biological, social and psychological factors [14,15]. According to DSM IV, some of the major symptoms of depressive symptoms are markedly diminished interest or pleasure in all or most activities, feelings of worthlessness, diminished concentration, fatigue or loss of energy, recurrent thoughts of death or suicide. Multiple etiological factors have been suggested in the emergence of depressive disorder [8,9,14,15]. In addition to many known biological contributors, it is known that psychosocial contributors also play a role in the etiology of depression. Some studies indicate that physical features of the residence and the neighbor interactions is associated with increased risk for depression and anxiety [7,15]. It has also been reported that there is correlation between certain psychosocial modifiers such as crowdedness, noisiness, indoor air quality, structure of the house with mental health [16]. However, a few studies have evaluated the association between air pollution and depressive symptoms [17-21]. But, there are not any information about the effects of indoor air quality on mental health status.

Indoor air quality, might affect people's health and functioning in public areas, schools and working environments. Thus, researchers are working on preventing the increase in CO_2 and CO_2 eliminate systems [22,23]. The aim of this study is to investigate the effects of CO_2 levels of the buildings on the quality of life, emergence of depressive symptoms and SBS in the inhabitants.

MATERIALS AND METHODS

The students and the staff of Dokuz Eylul University have voluntarily participated in this study between April and May. The temperature, humidity and CO_2 levels of the closed areas were measured with a temperature humidity CO_2 sensor (Sense Air, Sweden). The measurements have been conducted between 10 am and 12 pm. At the time of the CO_2 assessment, the SBS Questionnaire, Quality of life Survey Form (SF-36) and the Beck Depression Inventory (BDI) were filled by the participants at their location (office or classroom). The measurement performed in 15 physician offices, 18 hospital offices, 9 dean's offices, 11 small classes, 2 lecture rooms. 344 people participated in the study. This study was conducted in accordance with the ethical principles as suggested by Declaration of Helsinki. Approval was obtained from the Local Independent Ethics Committee.

1. BDI

BDI attempts to subjectively measure physical, emotional, cognitive symptoms of depressive syndrome [24]. A validated Turkish version of BDI was used [25]. BDI consists of twenty one questions about how the subject has been feeling in the last week. Each question has a set of at least four possible answer choices, ranging in intensity. (0) I do not feel sad. (1) I feel sad. (2) I am sad all the time and I cannot snap out of it. (3) I am so sad or unhappy that I cannot stand it. Then the test is scored, a value of 0 to 3 is assigned for each answer. The total score is gives the severity of depression. The standard cut-offs are: 0-13: indicates not any depressive complaints, 14-19: indicates mild depression, 20-28: indicates moderate depression, 29-63: indicates severe depression.

2. Quality of Life Scale

SF-36: It is a general survey form with a common use to measure the multi-faceted health status of people. This survey evaluates 8 aspects of life. 1) Physical functions: Limitation of physical daily activities due to health problems; 2) Social function: Limitation of social activities due to physical and emotional factors; 3) Physical role limitation: Physical health problems caused by work or daily

activities; 4) Emotional role limitation: The effect of emotional problems such as depression or anxiety on working or daily activities; 5) Mental health: General mental health related to psychological anxiety or well-being; 6) Liveliness: Objective assessment of energy and fatigue levels; 7) Pain: The level of pain, and how it affects working; and 8) General health perception: Evaluations of a person's own feelings on his health. The subscales evaluate health between 0 and 100, and higher score is associated with better quality of life [26].

3. SBS Questionnaire

This questionnaire was formed by the authors based on NIOSH's indoor air-quality and work place symptoms. It consisted of 34 items that were generated by converting SBS symptoms into dichotomous variables. Sociodemographic information, medical and psychiatric history were also obtained [27,28].

Described symptoms of SBS were collected under 6 main categories. 1) Physical: Headache, fatigue, heavy-headedness, tingling sensation in the body, sleepiness; 2) Cognitive: Concentration deficit, clouding of consciousness, dizziness; 3) Eyes: Burning, dryness, itching, fluxion; 4) Anxiety: Nervousness, restlessness, excitability, irritability, tachycardia, boredom; 5) Respiration: Sneezing, stuffed nose, nasal fluxation, nasal obstruction, itching and pain in the nose, itching, burning and irritation in the throat, uneasiness in breathing, wheezing, chest tightness, chest ache, coughing; and 6) Sensory: Dryness and irritation in the skin, stomach-ache, numbness and tingling in the body, general ache and pain, tinnitus, cramps in the legs, backache and sweating.

Differences in the behavioral parameters were performed using the Chi-square test. Correlations between groups were calculated using Pearson correlation analysis. Reported responses were converted into numeric data by assigning 2 to "existent symptoms", 0 to "non-existent symptoms" and 1 to "sometimes", which were then correlated with the measured CO_2 levels using Pearson Correlation. Results are presented as mean ± standart error and $p < 0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

A total of 344 people participated in the study; 259 of them (75.3%) were students and 85 of them (24.7%) were staff. All participants were given the SBS questionnaire, 196 of the participants completed the questionnaire in full and 198 of them did so for the SF-36 scale. The mean age of participants was 23.3 ± 8.4 (youngest 18, oldest 54). 93.3% of the participants were under 40. 38.1% of the group was male and 61.9% of the group was female. The mean indoor CO_2 level were assessed 1414 ± 198 ppm (882 ppm lowest; 2159 ppm highest); the mean relative humidity level was 49.0% (38.8% lowest; 57.2% highest); and mean temperature was 23.3 ℃ (21.1 ℃ lowest; 24.4 ℃ highest) (Table 1).

A positive correlation was found between the CO_2 levels and particular SBS symptom categories including, physical, cognitive, eye, anxiety and emotional symptoms ($p < 0.001$) (Table 2).

It was found that 75.4% of the participants (76.8% of the students and 74.1% of the staff) reported physical complaints. 78.2% of the participants with physical complaints reported that their complaints disappeared in outdoor settings. 50.6% of the staff reported eye complaints attributable to SBS ($p < 0.040$). More physical and emotional complaints were reported by women compared to men ($p < 0.020$, $p < 0.001$, respectively). The eye, respiratory and sensory complaints were found to be positively correlated with individuals who were allergic to dust ($p < 0.001$). Participants who were allergic to animals reported more physical complaints ($p < 0.040$). It was found that individuals who were sensitive to cigarette smoke reported more eye and respiratory complaints ($p < 0.001$). Physical, cognitive, anxiety, eye and respiratory complaints in participants with air pollution sensitivity were found to be more prominent than others ($p < 0.001$, < 0.010, < 0.030, < 0.001, and < 0.040, respectively) (Table 3). There was a weak positive correlation between the surrounding CO_2 levels and the complaints of SBS ($p < 0.001$, $r = 0.202$).

BDI revealed various symptoms of depression in 45.4% of participants. Responses of the participants were rated using the recommended scale in BDI. 32.1% of the responses (n = 196) were consistent with minor depression, 8.7% of them were consistent with moderate depression and 5.8% of them were consistent with severe depression (Table 4). A moderate positive correlation was found between CO_2 levels of the surroundings and the results of BDI ($p < 0.001$, $r = 0.317$).

The subcategory score averages for the SF-36 scale of the participants were 89 ± 14 for physical function, 69 ± 36 for role limitations due to physical problems, 61 ± 42 for role limitations due to emotional problems, 57 ± 20 for vitality, 617 ± 19 for mental health, 70 ± 22 for social function, 71 ± 22 for bodily pain, and 60 ± 17 for general health (Table 5). A weak positive correlation was found between the CO_2 levels of the surroundings of the participants and physical function and ache perception subcategories of the SF-36; and a weak negative correlation was found between the CO_2 levels and physical and emotional role limitation ($r = 0.228$, $p < 0.001$; $r = 0.142$, $p < 0.05$; $r = -0.255$, $p < 0.001$; $r = -0.211$, $p < 0.003$, respectively) (Table 5).

Table 1. Descriptive statistics of environmental parameters

	Number of person	Size of the room (m^2)	Carbon dioxide (ppm) Mean ± SD	Relative humidity (%) Mean ± SD	Temperature (°C) Mean ± SD
Management offices	2-3	24-30	974 ± 68	38.8 ± 2.3	26.4 ± 1.0
Hospital offices	2-3	24-30	882 ± 10	39.1 ± 1.5	25.6 ± 1.1
Dean's offices	5-6	24-30	1068 ± 294	47.0 ± 2.7	23.0 ± 0.7
Small classes	11-12	24-30	1532 ± 456	55.8 ± 2.6	24.5 ± 0.8
Lecture room 2	276	375	2159 ± 416	57.0 ± 2.9	23.0 ± 0.7
Lecture room 1	150	280	1872 ± 365	56.0 ± 2.8	23.0 ± 0.8
Mean			1414 ± 198	49.0 ± 2.0	24.3 ± 0.6

Table 2. The correlation between CO_2 measurement results and SBS complaints

	Sick Building Syndrome Complaints					
	Physical	Cognitive	Eyes	Anxiety	Ventilation	Emotional
Correlation values	r = 0.202	r = 0.113	r = 0.112	r = 0.108	r = 0.032	r = 0.145
	p = 0.001*	p = 0.036*	p = 0.039*	p = 0.046*	p = 0.553	p = 0.007*

Table 3. The socio-demographic and health features of the participants, and the rates of SBS syndromes prevalence

	Sick Building Syndrome Complaints					
	Physical n (%)	Cognitive n (%)	Eye n (%)	Anxiety n (%)	Respiration n (%)	Emotional n (%)
Male	91 (69.5)	34 (26.0)	49 (37.4)	75 (57.3)	92 (70.2)	62 (47.3)
Female	171 (80.3)a	73 (34.3)	93 (43.7)	134 (62.9)	161 (75.6)	64 (30.0)a
Dust allergy (+)	124 (77.0)	49 (30.4)	86 (53.4)b	102 (63.4)	135 (83.9)b	118 (73.3)b
Animal allergy (+)	91 (82.7)c	32 (29.1)	38 (34.5)	67 (60.9)	82 (74.5)	70 (63.6)
Cigarette smoke sensitivity (+)	152 (79.6)	64 (33.5)	90 (47.1)d	123 (64.4)	150 (78.5)d	127(66.5)
Air pollution sensitivity (+)	190 (82.6)e	82 (35.7)e	104 (45.2)e	151 (65.7)e	177 (77.0)e	153 (66.5)

a: $p < 0.05$ compared with the males
b: $p < 0.05$ compared with the people who are without dust allergy
c: $p < 0.05$ compared with the people who are without animal allergy
d: $p < 0.05$ compared with the people who are not sensitive to cigarette smoke
e: $p < 0.05$ compared with the people who are not sensitive to air pollution.

Table 4. Beck Depression Scale Results of the Participants

	n	%
Not any depressive complaints	107	54.4
Minor depressive complaints	63	32.1
Moderate depressive complaints	17	8.7
Severe depressive complaints	9	5.8

In this study, it was found that 32.1% of the participants who filled in the BDI questionnaire form reported symptoms that are consistent with minor depression, 8.7% of them reported symptoms that are consistent with moderate depression and 4.6% of them reported symptoms that are consistent with severe depression. A positive correlation was found between CO_2 concentration and BDI results. A positive correlation was found between the reported depressive symptoms and the indoor air quality. To our knowledge, this is the first study in the literature which attempts to investigate the potential role of the indoor CO_2 concentration in the etiology of depressive

Table 5. Distributions of Average Scores for SF-36 Subcategories, and the correlation of CO_2 measurement results and SF-36 Life Quality Scale Subcategories

Life Quality Scale Subcategories	Mean ± SD	Correlation values
Physical function	88.6 ± 14	r = 0.228, p = 0.001*
Role limitations due to physical problems	69.2 ± 36	r = - 0.142, p = 0.046*
Role limitations due to emotional problems	60.6 ± 42	r = - 0.255, p = 0.001*
Vitality	56.8 ± 20	r = 0.108, p = 0.132
Mental health	60.7 ± 18	r = 0.074, p = 0.298
Social function	69.6 ± 22	r = 0.041, p = 0.565
Bodily pain	70.8 ± 22	r = 0.211, p = 0.003*
General health	60.2 ± 17	r = 0.004, p = 0.950

disorders. In previous studies, it was argued that the air pollution due to industrial and environmental toxins triggered an increase in the frequency of depressive episodes [17]. In a recent study conducted in Canada, it was found that the number of people who presented to hospital emergency departments with depressive complaints increased in the setting of increased air pollution [18]. It was also indicated that, compared to normal population, the prevalence of anxiety and depressive disorders was higher in people with chronic compromised respiratory functioning such as in asthma and chronic obstructive pulmonary disease; and people with chronically high levels of blood CO_2 [19,20]. In addition, in another study, increased concentration of particulate matter, nitrogen dioxide and ozone concentration in air may increase depressive symptoms among the elderly [21].

Exposure to polluted air and high CO_2 levels may affect an individual's mental health. It is widely accepted that changes in the monoamine metabolism in the brain, of serotonin and norepinephrine in particular, play a significant role in the etiology of depressive disorders. One of the biological factors that cause depressive complaints is the change in the sensitivity of the receptors of monoamines such as norepinephrine and serotonin, and the treatment is planned toward increasing these neurotransmitters [29]. In diseases such as asthma and obstructive sleep apnea accompanied by high CO_2 levels, it was found that the activity of serotonin containing neurons decreased, and in diseases like prolonged sleep apnea such as sudden infant death syndrome, with an increase level of blood CO_2, the adrenergic and noradrenergic receptors were decreased [30]. Evidence suggests that high levels of CO_2 may increase the risk of depression by affecting the metabolism of norepinephrine and serotonin.

It is known that experimental exposure to high levels of CO_2 of doses of 5-35% concentration increased anxiety symptoms in people diagnosed with an affective disorder and triggered panic attacks in people diagnosed with panic disorder [31]. However, it can be argued that general population is exposed to lower levels of CO_2 in daily routine. The mean CO_2 level of the surroundings in this study was found 1414 ± 198 ppm (lowest 882; highest 2159 ppm).

High levels of psychosocial stress in cities with large population might increase the frequency of depressive complaints [32,33]. In this study, it was found that high CO_2 levels due to the number of people occupying and insufficient ventilation of the habitat, influenced the physical health of the people. This finding may indicate that depressive symptoms captured by BDI could be a result of poor indoor air quality. After all, a positive correlation was found between the ambient CO_2 and physical complaints resulting from high levels of CO_2.

It was also found that participants report SBS complaints when the ambient CO_2 level reaches 800 ppm. The SBS symptoms attributable to indoor air deterioration were also detected in this study. 78.2% of the people with complaints reported that their complaints disappeared in outdoor settings. In previous studies, it was argued that one of the criteria for diagnosing SBS was the alleviation of the complaints with the evacuation of the building [34]. Norback and Edling found that the prevalence of the SBS symptoms was between 10 and 30% [35]. Reported SBS symptoms in this study might be explained by high CO_2 levels in working areas.

75.4% of the participants reported symptoms in the physical category and 44.4% of them reported symptoms in the eye category. In previous studies it was stated that the indoor air triggered the physical and eye complaints [34]. It is also known that high ambient CO_2 level is associated with the increase of SBS prevalence [7,8,10]. In our study, various levels of statistically significant correlations were found between the CO_2 levels and the reported complaints of SBS.

It was found in one study that prevalence of SBS in women is greater than in men [35]. In our study, the reported symptoms of SBS in women were higher than in men. In one study conducted on women working in problematic buildings in Sweden, it was discovered that eye, nose, throat, skin, headache and fatigue complaints were more prominent, and in men only the eye, throat and skin complaints were prominent [36]. In a study conducted in schools, it was shown that the complaints of headaches, eyes and nose increased in female teachers compared to male teachers [37].

It is also known that the SBS complaints were seen in people with asthma and other respiratory tract diseases [35]. In our study, none of the participants were diagnosed with any respiratory tract disease. However, it was seen that the eye, respiratory and emotional complaints were reported more by participants who were allergic to dust and physical complaints were reported more by participants who were allergic to animals. Participants who had cigarette-smoke sensitivity reported more eye and respiratory complaints. People who had sensitivity to air pollution reported more physical, cognitive, anxiety, eye and respiratory complaints. It was also found that physical complaints such as headache, fatigue, numbness and sleepiness were seen more in participants who were allergic to dust, animals and who were sensitive to cigarette-smoke and air pollution [35].

When the SF-36 scale score was examined in the study, it was found that the physical function and ache score were higher. A weak positive correlation between the CO_2 levels and the physical function and ache perception subcategories of the SF-36 scale was

found; Also, a weak negative correlation was found between CO_2 levels and the physical limitation and emotional limitation categories. Higher scores were obtained since the negative answers increased in physical function and ache perception as the CO_2 level in the habitat increased. Although age was declared as one of the most significant factors affecting life quality, a statistical correlation could not be found [38]. 93.3% of the participants of the study are below 40 early adults. It was found elsewhere that the life quality of men is higher than women globally [39]. In this study, it was also found that the life quality of women is lower compared to men.

CONCLUSIONS

Current research on air pollution and human health seems to focus on indoor air quality rather than outdoor weather conditions. This preliminary study suggests that indoor air quality has an effect on the physical and mental health. Depressive disorders are clinical syndromes can be diagnosed with comprehensive psychiatric examinations which would require a full clinical history along with a mental status examination. Accurate diagnosis will also depend on patient reported symptoms many of which could be captured by screening questionnaires such as BDI. In this study it is shown that low quality indoor air could trigger or intensify depressive complaints which could, as a result, play a role in the etiology of clinical depression. Further studies are needed to reveal the mechanisms of the relationship between depressive complaints and indoor air quality.

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Discussions of this paper may appear in the discussion section of a future issue. All discussions should be submitted to the Editor-in-Chief within six months of publication.

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