



Original Article

A long-term multi-parametric monitoring study: Indoor air quality (IAQ) and the sources of the pollutants, prevalence of sick building syndrome (SBS) symptoms, and respiratory health indicators



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ABSTRACT

Poor indoor air quality (IAQ) can cause several respiratory diseases and symptoms. In this study, IAQ of 121 homes located in 3 different towns of Çanakkale, Turkey was monitored throughout a year. Target air pollutants were particulate matter, volatile organic compounds (VOCs), bioaerosols, and Carbon dioxide (CO₂), as well as air temperature and humidity. Moreover, pulmonary functions of the occupants were measured on a monthly basis. Also, occurrence of sick building syndrome (SBS) symptoms and other health related data were gathered from the occupants by a detailed questionnaire. The SBS is a situation related to indoor air pollution in which the occupants of a building experience health or comfort related adverse effects that appear to be associated directly to the time spent in the “sick” building. Results of this study showed that the highest indoor air pollutant levels were observed in Çan town and the lowest levels were observed in Central town. Indoor levels of bioaerosols, particulate matter, benzene, *Cladosporium* spp., and *Penicillium* spp. as well as pulmonary functions of the occupants showed statistically significant differences between the locations of the homes ($p < 0.001$). Factor analysis implied that both indoor and outdoor originated sources contributed to IAQ. Even though the predominant SBS symptoms varied seasonally and spatially among the study sites, fatigue, cold-flu like symptoms, and difficulty in concentration occurred frequently. Correlations were found among the occurrence of SBS symptoms, measured IAQ parameters, and personal factors ($p < 0.05$). Performing more studies from the health and IAQ points of view improve public awareness.

1. Introduction

People spend most of their time (more than 80%) in indoor environments. Therefore, indoor air has a considerable impact on public health, at least as much as outdoor air quality. It is stated in studies conducted on this subject that poor indoor air quality (IAQ) may cause various respiratory diseases (e.g., asthma), allergic diseases (e.g., hypersensitive pneumonia) and cancer (Simoni et al., 2002; Godish, 2001; Payne-Sturges et al., 2004; Habil et al., 2015). Improving IAQ will help protecting human health and reducing the loss of work caused by illnesses and preventing economic losses caused by medical treatments.

Therefore, all stakeholders such as designers, users, building material and consumer products manufacturers, etc. should consider sustaining good IAQ for protection of public health (Mentese, 2009).

The most common indoor air pollutants monitored at the residential settings are particulate matter (PM), formaldehyde, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), carbon dioxide (CO₂) particularly for crowded micro-environments, carbon monoxide (CO) specifically for homes with solid fuel used for heating/cooking purposes, and airborne bacteria and mold (Mentese, 2009; Mentese et al., 2009, 2012a,b, 2015, 2017, 2018a; Mentese and Tasdibi, 2016, 2017; Habil et al., 2016a,b). There are several reasons why

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Fig. 1. Sampling locations: Center, Lapseki, and Çan towns.

generally those air pollutants have been monitored: *i*) sources of those pollutants are ubiquitous in the indoor environments, *ii*) they have known potential adverse health effects, *iii*) their convenience of monitoring, and *iv*) occupants and constructors of the buildings intend to achieve the limit values or recommended guidelines proposed for those pollutants, applicable at indoor settings. Studies imply the contribution of indoor air pollutants on adverse health effects such as respiratory diseases and combination of several symptoms (Pope and Dockery, 2006; US EPA, 2019; Burge, 2002; Portnoy et al., 2005; Rehwagen et al., 2003; Mentese et al., 2015; Mentese and Tasdibi, 2016). Moreover, indoor emissions from household combustion of coal is classified as human carcinogen (lung cancer) (IARC, 2012) and household use of solid fuels (biomass) is classified as probable human carcinogen (IARC, 2010).

The scope of sick building syndrome (SBS) covers unspecified, combined, adverse health effects due to poor IAQ. The SBS is called as symptoms since the causative factors or sources have not been fully confirmed yet. People who spend a long period of time in the buildings with poor IAQ may be affected by various symptoms and even diseases, depending on the intensity of the sources of the pollutants. These buildings, which cause problems, are called “sick buildings”. SBS is assumed to cause personal symptoms in a wide spectrum by exposure to indoor environmental source(s); while the exact cause of the symptoms is unidentified. The cause of SBS may be due to a single factor or a combination of multiple factors. These factors are roughly: insufficient ventilation, humidity, light, temperature; chemical pollutants from indoor sources; chemical and biological pollutants from external sources (World Health organization (WHO), 1989). The symptoms and complaints identified by WHO in the context of SBS are (World Health

organization (WHO), 1989): *i*) irritation of the eyes, nose and throat, *ii*) neurotoxic or general health problems, *iii*) skin irritation, *iv*) nonspecific hypersensitivity reactions, *v*) odors and taste sensation. Most of the symptoms related to SBS were listed in the latest studies with potential source contributors of SBS such as building products, cleaning agents, paints, pesticides, combustion of fuel etc. (Zeliger, 2011; Norhidayah et al., 2013; Mentese and Tasdibi, 2016). Studies have also identified associations between exposure to bioaerosols and SBS and other hypersensitivity reactions (ACGIH, 1989; Carrer et al., 2001; Douwes et al., 2003; Harrison et al., 1992; Mentese and Tasdibi, 2016). With this respect, some studies highlighted the importance of fungal volatiles and water-damaged and/or humid buildings (Polizzi et al., 2009, 2011, 2012a,b). Some previous studies investigated associations between adult's SBS symptoms and outdoor air pollution (SO_2 , NO_2 , O_3 , and PM_{10}), climatic factors (temperature, humidity, and wind speed), and indoor exposures (mold/dampness, renovations, microbiological factors, a sensation of dry air, and ventilation conditions) (Wang et al., 2013; Lin et al., 2014; Zhang et al., 2014; Lu et al., 2016; Huo et al., 2020). They found that outdoor air pollution could also increase the prevalence and incidence of SBS.

Since the perception and public awareness of IAQ in Turkey is quite recent, studies conducted on this issue are limited so far. The aims of this study were *i*) to estimate the variations of indoor air pollutants' levels in 121 homes located in 3 different towns of Çanakkale city with no known complaints throughout a year; *ii*) to compare outdoor air pollutants' levels with corresponding indoor levels, *iii*) to find the links between several environmental factors and SBS occurrences; *iv*) to estimate the variation of SBS symptoms among the occupants; and *v*) to estimate respiratory health indicators of the occupants. The results of

this study will help to increase public awareness for providing better IAQ in Turkey.

2. Materials and methods

2.1. Sampling sites

In this study, relationships between IAQ and respiratory health of the participants were investigated over a year (August 2013–August 2014) in Çanakkale city, Turkey as a part of Çanakkale HealthAir Project (Menteşe et al., 2018b). This study was conducted in 121 homes located in 3 different towns of Çanakkale city, namely, Center ($n = 46$), Lapseki ($n = 36$), and Çan towns ($n = 39$). Populations of Central town, Lapseki, and Çan are 149,881, 26,370, and 48,331, respectively (Turkish Statistical Institute (TUIK), 2018). Detailed information about the sampling sites is described in Menteşe et al. (2015). Fig. 1 shows the sampling locations on a map. Lapseki and Central towns are close to Dardanelles strait, while Çan town has no seashore. Central town represents an urban site; Lapseki represents a semi-rural site; and Çan represents semi-rural and industrial site characteristics (i.e., huge open-pit coal mines, a lignite-based thermal power plant, and ceramic factories). Participants of this study, occupied in Lapseki and Çan towns were mostly engaged with agriculture. Among these three study sites, Çan has a valley-shaped topography, posing a disadvantage to the majority of the local people who live at the lowest heights of the town by frequently observed temperature inversion episodes (Menteşe and Yarıntepe, 2012; Menteşe et al., 2018b). Annual average values for ambient temperature and relative humidity (RH) in each sampling site were close to each other and approximately 18°C and 65%, respectively.

2.2. Sampling and analysis methods

Total particulate number, volatile organic compounds (VOCs), total bacteria count (TBC), total mold count (TMC), and CO₂ measurements, together with thermal comfort parameters such as air temperature and RH were monitored in the indoor environments of those houses. Each volunteered participant's house was visited once a month for IAQ monitoring and PF measurements of the participants. Details regarding the sampling and analyzing techniques of IAQ parameters are described in Menteşe et al. (2015). Briefly, air samplings or measurements were conducted at 1.5 m above the ground and at the center of the corresponding microenvironment. In addition to the indoor measurements, outdoor sampling and measurement studies were carried out simultaneously. Outdoor samples were collected and/or measurements were carried out at least 3 m away from the buildings and any remarkable air pollution sources. Briefly, VOCs were collected on a dual-bed adsorbent tubes by a low flow sampling pump (Pocket pump, SKC Inc., flow rate = 50 ± 5 mL/min, sampling duration = 1 h, and final volume = 3–4 L) according to ISO 16017-1 (2000) and US EPA TO17 (1999) methods and measured by Thermal Desorber-Gas Chromatography-Flame Ionization Detector. Target VOCs were quantified according to 7 – points calibration by standard solutions of aromatics (DWM-588, Ultra Scientific) and paraffins (Piano-Paraffins, Supelco). To calculate the limit of quantification (LOQ), 7 replicates of calibration stock solutions were analysed. Field blanks for each sampling day and a laboratory blank for every 10 sample was analysed. Total VOCs (TVOCs) level was calculated for the compounds between *n*-hexane (C₆) and *n*-hexadecane (C₁₆), equivalent to toluene response (European Collaborative Action-IAQ (ECA), 1997; ISO, 2004). Total concentration of benzene, toluene, ethylbenzene, and xylenes (BTEX) was also calculated. Airborne bacteria and mold samples were collected by a single-stage Andersen bioimpactor on Dichloran-Rose-Bengal Agar (DRBC) and Plate count agar (PCA) culture media, respectively (NIOSH, 1998; Menteşe et al., 2015; 2017). Sampling duration for airborne bacteria and mold samples was 5 min at 28.3 L/min flow rate. Incubation

conditions for airborne bacteria and mold samples were at 37°C for 2 days at 25°C for 4–7 days, respectively. Enumeration of bioaerosols was conducted under a light microscope. Also, airborne molds were identified morphologically according to the genera (Samson et al., 2010; Sutton et al., 1998; Larone, 2011; Barnett and Hunter, 2003). Temperature, RH, and CO₂ were measured by real-time instruments (Testo 435-2 and Graywolf Advanced Sense IAQ Meter). Total PM count (#/cc) was measured by a 6-channelled real-time instrument (Lighthouse Inc.), counting the particles in 6 particle size ranges (0.3–10 µm).

2.3. Questionnaires

To estimate the relationship between IAQ and SBS occurrence, a detailed questionnaire was applied to all occupants in 4 subsequent sampling seasons: fall (Sep–Nov), winter (Dec–Feb), spring (March–May), and summer (June–August). The questionnaire included five different sections regarding the questions on (i) the factors that may affect IAQ, (ii) the characteristics of the sampled environment, (iii) socioeconomic conditions of the participants, (iv) health condition and the occurrence of SBS symptoms in the participants, and (v) the factors that may affect respiratory health and comfort. In each season, the questionnaire was completed by the same person (> 18 years old). Written informed consent was obtained from the participants. Detailed information regarding the questionnaire is given in Menteşe and Tasdibi (2016). The participants were asked to complete the SBS-related part of the questionnaire if they were not diagnosed by the doctor that could cause the symptoms used to describe the SBS. 20% of the participants in Center; 11% in Lapseki, and 26% in Çan had a disease diagnosed by the doctor that causes at least one symptom similar to any of the SBS symptoms. These participants did not fill the relevant part of the questionnaire regarding the observation of SBS symptoms. SBS symptoms in the questionnaire included headache, fatigue, eye irritation, tickly throat, sneezing, coughing, dry skin, chest tightness, dizziness, difficulty in concentration, and cold, flu-like symptoms. Since 11 SBS symptoms were taken into account in this study, the SBS score ranged from 0 (none of the SBS symptom was occurred) to 11 (all SBS symptoms were occurred).

2.4. Respiratory health indicators

Respiratory function of the occupants was measured by Spirometry on a monthly basis over the year. Pulmonary function (PF) of the participants was assessed by FEV₁/FVC ratio (%). Here, FEV₁ indicates the forced expiratory volume in 1 s (i.e., the max amount of air that you can forcefully exhale in 1 s) and FVC indicates forced vital capacity (i.e., the amount of air which can be forcibly exhaled from the lungs after taking the deepest breath possible). Details regarding the application of PF test can be found in Menteşe et al. (2015). Also, general health condition of the participants as well as doctor-diagnosed asthma prevalence was assessed in the questionnaire.

2.5. Evaluation of the data

Descriptive statistics presented in the tables and figures are calculated based on each air sample, collected for corresponding sampling duration. Spatial and temporal distribution of the data set was shown in means and 95% least significant difference (LSD) plots. ANOVA test was utilized to examine the differences among group means in a sample. Values with $p < 0.05$ were considered statistically significant for all applied tests. Correlations among the measured IAQ parameters, environmental parameters, and health indicators were done by Spearman rank correlation test.

The multivariate factor analysis method with varimax rotation was applied to whole data set to estimate factors affecting the IAQ at the study sites on the basis of measured parameters in this study. In order to facilitate the interpretation of common factors, a varimax orthogonal

rotation was performed for pairwise data. Community of each parameter used in factor analysis was more than 50%. The output of the factor analysis states that the first factor influenced the data set the most and the last factor influenced the data set the least (for details regarding the application of factor analysis, please check Mentese et al. (2012a)).

Generalized linear models (GLM) have commonly been used to estimate associations between the air pollution on health outcomes (Chen et al., 1999; Szyszkowicz, 2006). Therefore, GLM was applied to find associations between the SBS symptoms of the participants and all seasonal IAQ measurement/monitoring data of this study. Also, personal factors that can have influence on respiratory health of the individuals are taken into account such as gender, age, lifelong smoking, lifelong environmental tobacco smoke (ETS) exposure that includes exposure at home and/or workplace, season, odour perception at home, time spent at home, and residing district at the corresponding study site.

Computational analyses and statistical tests were performed by using Microsoft Excel and SPSS 19.0 programs.

3. Results and discussion

3.1. IAQ of the study sites

Descriptive statistics for IAQ parameters measured at three sampling locations over the year are given in Table 1. In general, the highest levels for the measured parameters were observed in Çan, while the lowest levels were observed in Central town. Briefly, average levels of bioaerosols were $< 10^3$ CFU/m³; total PM counts were between 15 and 228 particles/cc; TVOC was around 500–550 µg/m³; sum of BTEX was 25–32.9 µg/m³; benzene was 4–9.9 µg/m³; and both indoor temperature (22.7–23.7°C) and RH (50.4–51.5%) values were close to each other at all locations. The most predominant mold genera were *Cladosporium* spp. (46.2%), *Penicillium* spp. (32.9%), and *Aspergillus* spp. (6.3%), in descending order. *Cladosporium* is mostly known as outdoors originated, while *Aspergillus* and *Penicillium* are known indoors originated mold species (Mentese, 2009). As can be seen from Table 1, statistically significant differences were found between the sampling locations for levels of TBC, TMC, benzene, *Cladosporium*, *Penicillium*, and total PM count ($p < 0.001$). Details can be found in Suppl. Material Fig. S1.

Indoor-to-outdoor (I/O) ratios for the measured IAQ parameters are given in Table 1. I/O ratios of TVOC levels were quite high (≥ 60), followed by I/O ratios of TBC (9.3–11.5), *Penicillium* spp. (3.9–13.1), sum of BTEX (5.2–9.4), benzene (3.2–7.3), *Aspergillus* spp. (2.5–7.0), CO₂ (1.7–1.9), total PM count (1.5–1.7), TMC (1.1–1.7), and *Cladosporium* spp. (0.96–1.37). The I/O ratio that bigger than unity indicates the burden of indoor originated emissions over outdoor sources. The

lowest I/O ratios for all IAQ parameters were observed in the homes located in Central town, while the highest I/O ratios were, in general, observed in Çan town. Since both Lapseki and Çan town can be assumed as semi-rural sites, relatively higher levels of bioaerosols observed in both Lapseki and Çan than Central town is consistent. Differences in site characteristics between Lapseki and Çan towns might have affected the observed IAQ levels (Menteşe et al., 2018b). As already mentioned in the methods section, Çan town is the most industrialized place among the sampling locations of this study, in which low-quality lignite was the main fuel used for both domestic heating and in 18 Mart Çan thermal power plant, whereas Lapseki is located on Dardanelles strait seashore with relatively denser road and marine traffic than Çan.

Fig. 2 shows the monthly variations of indoor TBC and TMC levels at the study homes in each location. Higher TBC levels were observed in the summer months than other months at all locations. Accordingly, TBC levels showed statistically significant monthly variation at the homes located in Lapseki ($p < 0.001$) and Çan ($p < 0.05$). TMC levels showed statistically significant monthly variation at the homes in all sampling locations ($p < 0.001$). Other studies also found monthly and/or seasonal variations of indoor bioaerosols (Mentese et al., 2009, 2012a,b, 2018a; Mentese and Tasdibi, 2016).

Monthly variations of TVOC and sum of BTEX levels at the study sites are given in Fig. 3. Accordingly, TVOC levels were, in general, higher during the heating period than warmer months. A statistically significant monthly variation for TVOC levels was observed merely at the homes located in Çan ($p < 0.05$). Sum of BTEX levels showed monthly variations in all sampling sites ($p < 0.05$). Observation frequencies (%), indoor levels, and I/O ratios of individual VOCs covered in this study are given in Table S1. Even though no standard guideline value for TVOC is available worldwide, some organizations and studies have recommended different limit values for the residential settings. Ad-Hoc working group of German Indoor Air Committee recommended TVOC levels between 1 and 3 mg/m³ for the homes and ideally, 200–300 µg/m³ on average for long-term exposure (Umwelt Bundesamt, 2020). Another study has proposed a TVOC target value of 300 µg/m³ for indoor air (Tuomi and Vainiotalo, 2016), whereas annual average TVOC levels of our study sites were around 500–550 µg/m³.

Among VOCs, benzene is of concern due to its adverse health effect found in exposure assessment studies and thus classified as known human carcinogen (IARC, 1987; US EPA, 2002). In order to protect the human health, the EU has set an annual limit value for benzene as 5 µg/m³ in the European Council air quality directive (2008/EC/50) as from 2010 (European Union (EU), 2008). As can be seen from Table 1, the highest annual average benzene levels were found in Çan (9.9 µg/m³), Lapseki (8.4 µg/m³), and Center (4.0 µg/m³), in descending order. Therefore, benzene limit value was exceeded in Çan and Lapseki towns. Furthermore, I/O ratio for benzene was more than 3 at the sampling

Table 1

Descriptive statistics for annual levels of IAQ parameters^a at the sampling locations.

Parameter	Center	Lapseki	Çan	Significance
TBC (CFU/m ³)	485 ± 384 (9.3)	852 ± 782 (11.5)	907 ± 730 (10.7)	< 0.001*
TMC (CFU/m ³)	566 ± 592 (1.1)	865 ± 843 (1.5)	958 ± 783 (1.7)	< 0.001*
TVOC (µg/m ³)	509 ± 384 (60.0)	528 ± 431 (109.5)	547 ± 428 (64.6)	> 0.05
Benzene (µg/m ³)	4.0 ± 5.6 (3.2)	8.4 ± 10.3 (6.4)	9.9 ± 15.1 (7.3)	< 0.001**
Sum of BTEX (µg/m ³)	25.1 ± 48.1 (5.2)	27.2 ± 43.4 (9.4)	32.9 ± 46.3 (7.2)	> 0.05
Total PM count (#/cc)	159 ± 158 (1.7)	213 ± 190 (1.5)	225 ± 222 (1.6)	< 0.001*
CO ₂ (ppm)	787 ± 483 (1.7)	808 ± 314 (1.8)	951 ± 1900 (1.9)	> 0.05
<i>Cladosporium</i> spp. (CFU/m ³)	298 ± 406 (0.96)	394 ± 463 (1.01)	430 ± 472 (1.37)	< 0.001*
<i>Penicillium</i> spp. (CFU/m ³)	170 ± 376 (3.9)	286 ± 520 (13.1)	359 ± 601 (6.8)	< 0.001*
<i>Aspergillus</i> spp. (CFU/m ³)	65 ± 196 (2.5)	62 ± 101 (4.7)	91 ± 252 (7.0)	> 0.05
Temperature (°C)	23.7 ± 3.7	23.6 ± 3.5	22.7 ± 3.0	> 0.05
RH (%)	50.4 ± 8.9	51.2 ± 9.1	51.5 ± 9.6	> 0.05

*Indicates a statistically significant difference between the sampling sites at $p < 0.001$.

^a Values are given as mean ± standard deviation and average I/O ratio in the bracket.

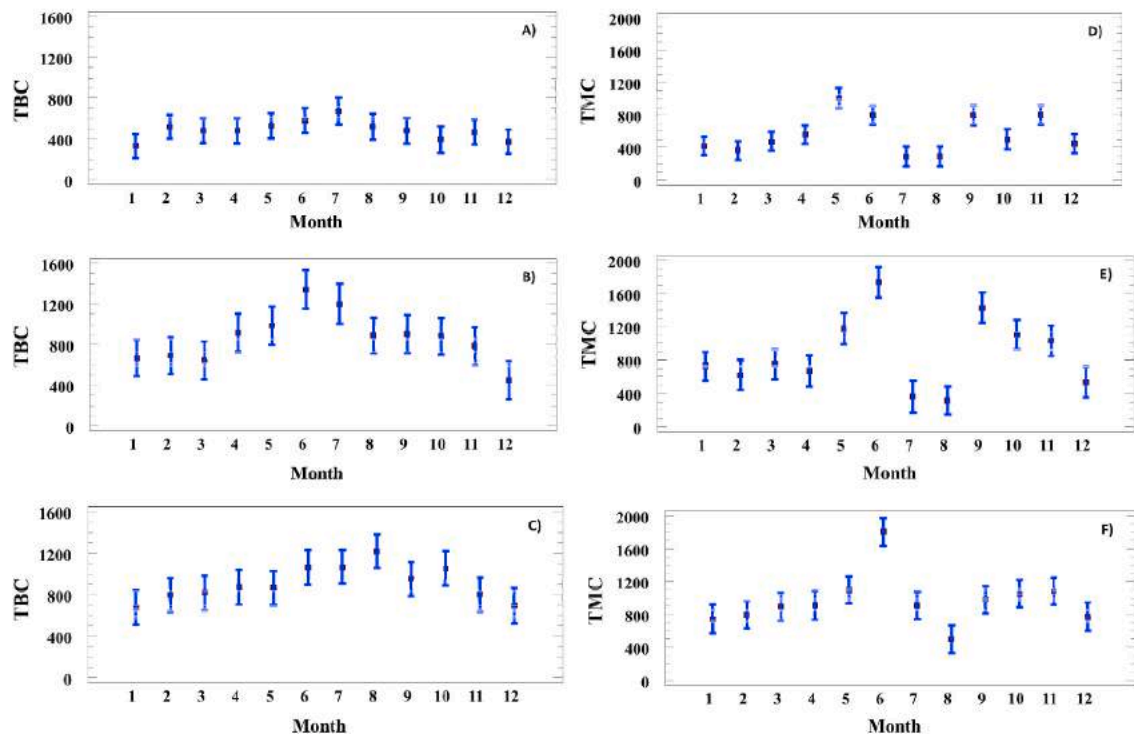


Fig. 2. Monthly variations of levels of TBC (CFU/m³) at A) Center ($p > 0.05$), B) Lapseki ($p < 0.001$), and C) Çan ($p < 0.05$) and TMC (CFU/m³) at D) Center ($p < 0.001$), E) Lapseki ($p < 0.001$), and F) Çan ($p < 0.001$). Note: $\overline{}$: upper confidence interval; $\underline{}$: lower confidence interval; $\blacksquare$: mean of 95% LSD interval.

sites, indicating abundant indoor benzene sources in addition to outdoor originated benzene entrance into the indoors through ventilation. Similar to this study results, indoor levels of benzene are commonly higher than those outdoor air due to the presence of indoor sources

(e.g., smoking, inappropriate heating/cooking, solvent use, building materials, human activities, etc.) and outdoor sources (e.g., traffic or industrial plants) (World Health organization (WHO), 2010; Mentese and Tasdibi, 2017).

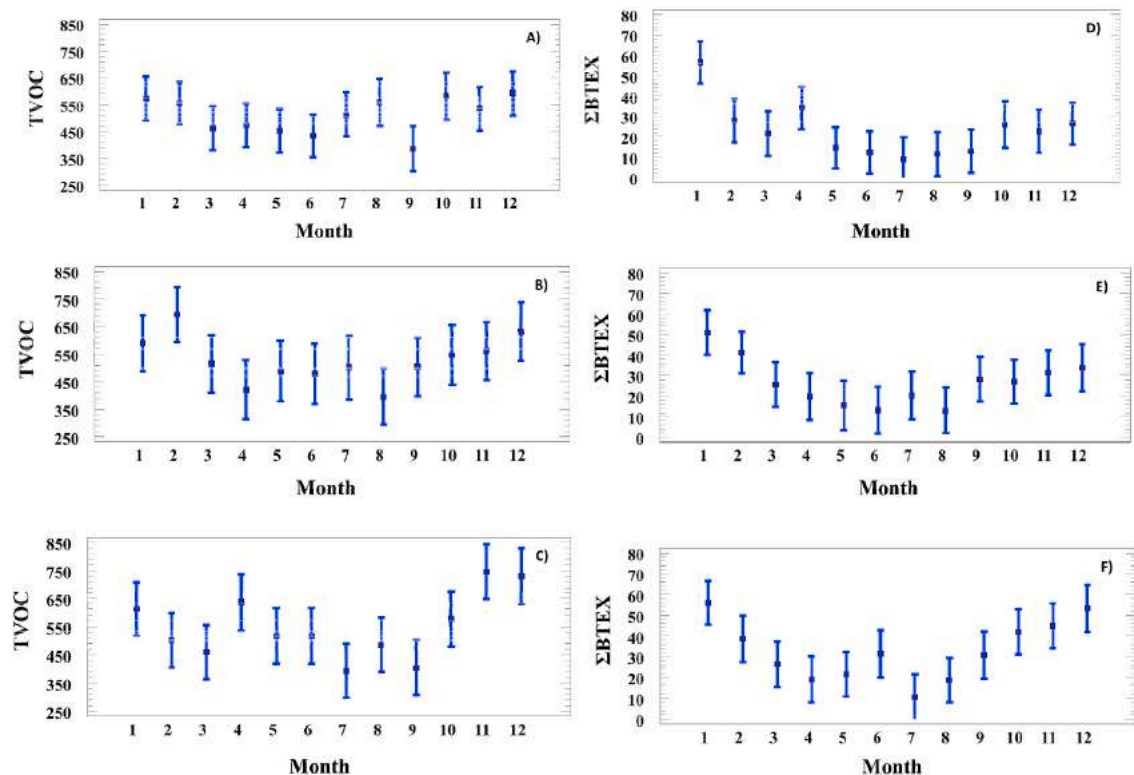


Fig. 3. Monthly variations of indoor concentrations of TVOC (µg/m³) at A) Center ($p > 0.05$), B) Lapseki ($p > 0.05$), and C) Çan ($p < 0.05$) and sum of BTEX (µg/m³) at D) Center ($p > 0.05$), E) Lapseki ($p > 0.05$), and F) Çan ($p < 0.001$).

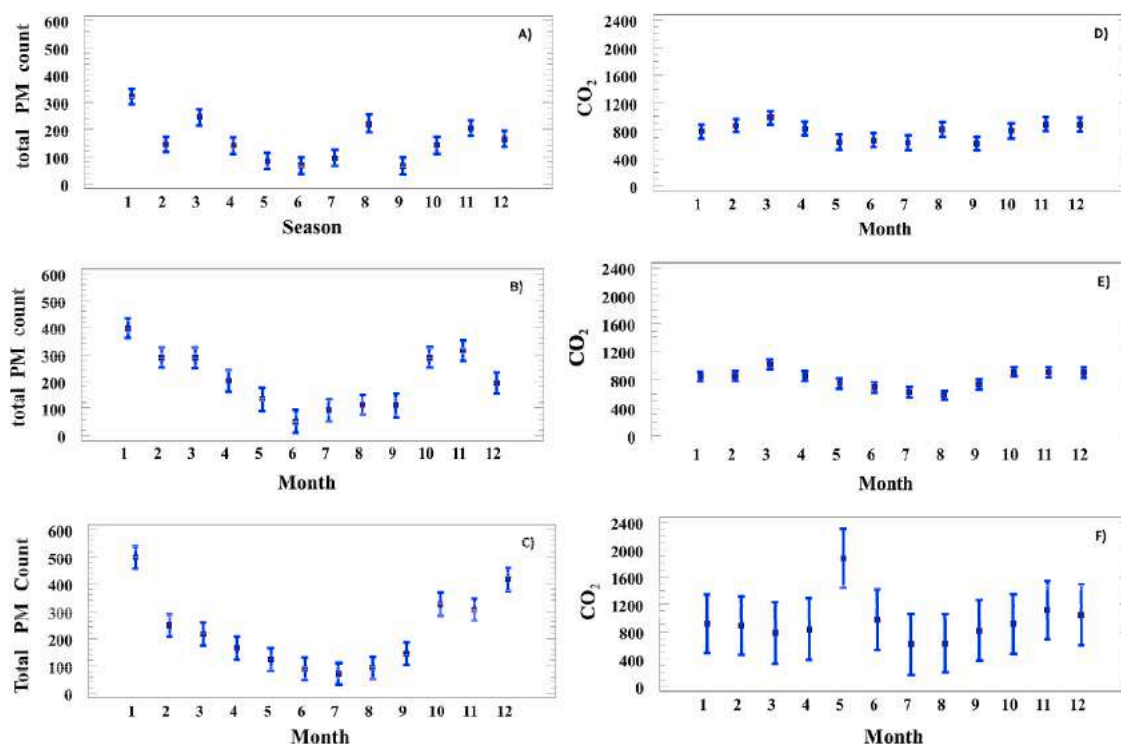


Fig. 4. Monthly variations of total particle counts (#/cc) at A) Center ($p < 0.001$), B) Lapseki ($p < 0.001$), and C) Çan ($p < 0.001$) and CO₂ concentrations (ppm) at D) Center ($p < 0.001$), E) Lapseki ($p < 0.001$), and F) Çan ($p > 0.05$).

Fig. 4 shows monthly variations of indoor total particle counts (#/L) and CO₂ levels (ppm) at the study sites. The highest particle numbers were seen during the winter and particle levels decreased gradually from heating period to summer season. Total particle numbers showed statistically significant monthly variations at the homes of all sampling locations ($p < 0.001$). Similar to the PM count, in general, lower CO₂ levels occurred in the summer than colder periods. Statistically significant difference in indoor CO₂ levels was seen at the homes located in Center ($p < 0.05$) and Lapseki ($p < 0.001$). Even though some extremely high CO₂ levels were observed at the homes probably due to use of solid fuel for domestic heating and/or high occupancy density (Mentese et al., 2012a,b), annual average indoor CO₂ levels were less than 1000 ppm at the sampling sites. CO₂ levels are mostly used as an indicator of adequate ventilation for sustaining the comfort level of the occupants. The fact that CO₂ is a bio-effluent of living beings through exhalation, indoor CO₂ levels are linked with the occupancy (Mentese et al., 2009, 2012a,b; Mentese and Tasdibi, 2016, 2017). Indoor CO₂ levels are associated with the discomfort level of the occupants, causing dissatisfaction (Lee and Chang, 2000; Olesen, 2004; Heudorf et al., 2009; Mentese et al., 2009; Mentese and Tasdibi, 2017; ANSI/ASHRAE, 2016a,b). A European standard, EN 13779, considers the human comfort level for CO₂ by comparing indoor CO₂ levels with reference to outdoor CO₂ levels at the time of measurement (EN, 2007).

Monthly variations of the measured IAQ parameters covering all study homes are given in Suppl. Material Figs. S2 and S3.

3.2. Sources of IAQ

A multivariate factor analysis with varimax rotation was performed on IAQ data set to evaluate the potential source contributors of the pollutants at each study sites thoroughly. As can be seen from Table 2, four factors for all locations were selected based on a cutoff of the eigen values declining to below unity. Source contributors of the IAQ based on input parameters were explained with over 64% variance. Once the factor loadings of the source contributors were evaluated, it appeared to

be that the potential sources of all factors had similarities at certain degree. Besides, I/O ratios of the corresponding parameters were also taken into account while identifying the potential sources. Four potential factors explained IAQ of the homes located in Central town: Outdoor related mold propagation through ventilation represented the first factor (F1) due to contributions of mold and RH levels. Also, I/O ratios for mold and *Cladosporium* were around unity (see Table 1). A strong link between the indicators of organic air pollutants such as BTEX and TVOC found in the second factor (F2) indicated the use of organic solvents indoor environments. Third factor (F3) included contributions of airborne bacteria, CO₂, total PM count, and RH, implying the human activities due to occupancy (Mentese et al., 2009, 2012a,b; Mentese and Tasdibi, 2017). Fourth factor (F4) defined as airborne bacteria propagation at warm climatic conditions. Factors affecting the IAQ of homes located in Lapseki are as follows: First factor (F1) indicated the use of organics indoor environment and occupancy due to positive contribution of CO₂ levels. As already mentioned earlier, Lapseki was a semi-rural site and the participants from Lapseki spent more time at home than Central town. Second factor (F2) represented indoor emissions due to relatively high I/O ratios of the factor contributors related to mold propagation and combustion (i.e. heating and/or cooking). Third factor (F3) indicated bioaerosol propagation, mostly outdoor originated. Fourth factor (F4) defined as PM accumulation at cold climatic conditions. IAQ of homes located in Çan were affected from four factors: First factor (F1) included the contributions of organics, PM, and *Cladosporium* levels from mixed indoor sources such as solvent use and solid fuel (i.e., mostly low quality, high sulphur-content lignite) use for domestic heating and/or cooking (Ma et al., 2017; Xu et al., 2000). Second factor (F2) represented mold propagation at cold and humid environmental conditions. Third factor (F3) had contribution of indoor bioaerosols. Since the merely source contributor of the fourth factor (F4) is CO₂, human occupancy (i.e. by respiration) and domestic heating and/or cooking assumed to be the potential sources of this factor. Another study conducted in different indoor environments in Ankara, Turkey, also found similar source contributors (Mentese

Table 2Factor loadings^a and variance apportionments obtained by factor analysis with varimax rotation for components of IAQ of the study sites.

Factor – Potential Source	Contributors (Factor Loadings)	Variance explained (%)
Central Town		67.4
F1 – outdoor related mold propagation	<i>Cladosporium</i> level (0.91), TMC (0.90), RH (0.30)	21.4
F2 – organics (solvent use)	Sum of BTEX (0.83), TVOC (0.81)	20.7
F3 – human activity	TBC (0.75), CO ₂ (0.59), total PM count (0.55), RH (0.43)	13.0
F4 – bacteria propagation at warm climatic conditions	Temperature (0.86), RH (–0.59), TBC (0.36)	12.3
Lapseki		64.3
F1 – indoor sources (solvent use) and occupancy	TVOC (0.76), sum of BTEX (0.74), CO ₂ (0.72), benzene (0.34)	26.1
F2 – indoor emissions (mold and combustion)	<i>Penicillium</i> level (0.81), benzene (0.68), total PM count (0.61), TMC (0.38)	16.4
F3 – bioaerosol propagation (mostly outdoor originated)	TMC (0.82), <i>Cladosporium</i> level (0.78), TBC (0.54), <i>Penicillium</i> level (0.31)	12.4
F4 – PM accumulation at cold climatic conditions	Temperature (–0.84), RH (0.75), total PM count (0.35), TBC (–0.35)	9.4
Çan		67.3
F1 – mixed indoor sources (solvent and solid fuel use)	<i>Cladosporium</i> level (0.84), total PM count (0.81), sum of BTEX (0.76), TVOC (0.50)	26.3
F2 – mold propagation at cold and humid environmental conditions	RH (0.80), temperature (–0.78), TMC (0.41)	16.6
F3 – indoor bioaerosols	TBC (0.81), TMC (0.55), TVOC (0.43)	13.2
F4 – domestic heating/cooking and occupancy	CO ₂ (0.97)	11.2

Notes.

^a Loadings ≥ 0.30 are given in the table, loadings > 0.7 are shown in bold. F1–F4: factors 1–4; communality of the parameters included in the model was 0.50–0.99%.

et al., 2012a).

In addition to IAQ monitoring, it is important to find the sources of measured IAQ parameters since the composition and the abundance of the air pollutants are strictly related with the several building and environmental factors (Mentese and Gullu, 2006; Mentese and Tasdibi, 2017). Several associations were found between indoor air pollutants and building/environmental factors ($p < 0.05$). In Lapseki, both TBC and TMC levels were found to be higher in older houses than new ones; higher TMC levels were observed in homes far from the traffic sources (e.g. semi-rural sites); levels of xylenes were lower in homes where visible mold growth or dampness are more frequently observed (e.g., in non-renovated homes); indoor benzene levels were higher in newly painted homes; and indoor *n*-hexane levels were high in newly renovated homes. In Çan, indoor toluene levels were higher in new homes and indoor mold levels were higher in homes where visible mold growth or dampness occurred. The main sources of indoor air pollutants are building construction materials and decoration materials, such as carpet, pressed wood, floor coverings, wall paint (Mentese and Gullu, 2006; Mentese, 2009; Mentese and Tasdibi, 2017; Salthammer and Mentese, 2008; Salthammer et al., 2010; Gunchera et al., 2013). In a study conducted in the classrooms of schools in Korea during summer season, the TVOC level was found to be 577 $\mu\text{g}/\text{m}^3$ and higher VOC levels were observed in newly built (< 1 year) schools (Yang et al., 2009). It is stated in another study that the emissions started to spread within the first 4 h and 99% of the emission was released after about 10 days (Cox et al., 2002). In addition, when high dye adsorption capacity is used, VOC emissions are releasing secondarily and cause prolonged accumulation of VOCs (Cox et al., 2002). Thus, it is expected to observe lower indoor volatile emissions, where, in contrast, higher levels of airborne bacteria and mold as well as visible mold growth or dampness records listed by the occupants of older homes than new ones. TBC, TMC, and benzene levels were higher in the homes located at Lapseki and Çan where solid fuel (wood and/or coal) were used than those natural gas was used. Similarly, another study conducted in Çanakkale found a linkage between indoor bacteria levels and type of the heating fuel (Mentese and Tasdibi, 2016). Also, TBC and TMC levels were lower in homes where more likely natural gas was used as a cooking fuel in Çan.

Moreover, several occupant activities showed linkage with some of the VOCs, e.g., as home cleaning frequency increased, the levels of xylenes and *n*-hexane increased ($p < 0.05$) and use of air fresheners or room deodorants were linked with benzene and toluene levels ($p < 0.05$). *n*-hexane is found in liquid cleaning agents (Knöppel and Schauenburg, 1989; Sack et al., 1992). Another study states that the

occurrence of childhood asthma is associated with the use of various cleaning agents and aromas (Sherriff et al., 2005).

Another factor which has lowering effect of indoor air pollutants is ventilation. Home ventilation duration of the participants (hour/day) was assessed seasonally by the questionnaire. It was found that as home ventilation duration increased, the levels of indoor total particle count, CO₂, and TVOC decreased ($p < 0.01$). A study conducted in homes in Tianjin, China found that low ventilation rates in bedrooms caused elevated concentrations of formaldehyde and VOCs and an increased prevalence of SBS (Sun et al., 2019). In terms of the pollutants, ozone and ultrafine particles (i.e. secondary aerosols) were significant risk factors for dermal symptoms, whereas formaldehyde and total VOCs had no significant linkages with SBS symptoms (Sun et al., 2019). Another study carried out at the same region showed relationships between increased reporting of general and skin SBS symptoms and an air exchange rate of less than 0.7 h^{-1} (Sun et al., 2013).

3.3. Respiratory health indicators of the participants

Asthma prevalence and FEV₁/FVC (%) ratio for pulmonary function (PF) were used as respiratory health indicators of the participants of this study. Asthma prevalence among the participants of this study was higher in Çan than other study locations (one-third in Çan vs. one-sixth of the participants living in Lapseki and Center). PF of the participants (FEV₁/FVC ratio) varied between 49 and 81%. As can be seen from Fig. 5, FEV₁/FVC ratio showed a statistically significant difference between the sampling locations ($p < 0.001$). The participants living in Lapseki had the highest PF, whereas lower ratios occurred in participants, living in Çan and Central towns. PF of the healthy individuals are assumed to have FEV₁/FVC ratio of more than 70% (Mentese et al., 2018b; Sahlberg et al., 2012; Lim et al., 2015; Lu et al., 2016). Although

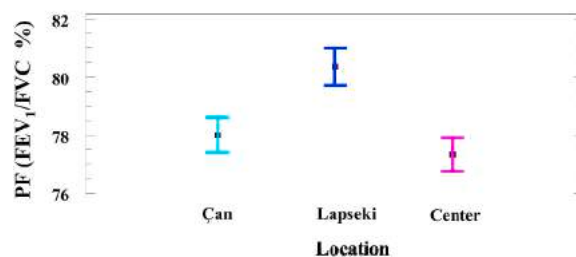


Fig. 5. Comparison of PF (FEV₁/FVC%) of the participants according to the sampling locations ($p < 0.001$).

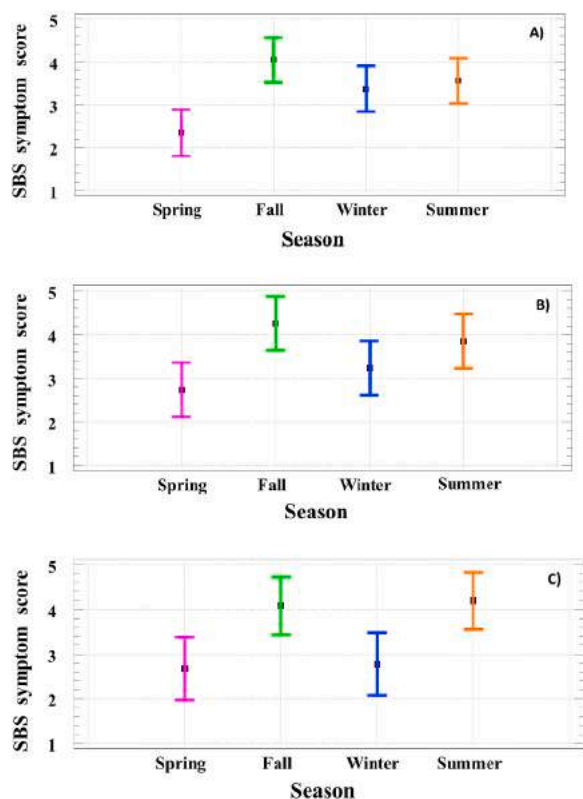


Fig. 6. Seasonal variation of SBS symptom score at a) Center ($p < 0.05$), b) Lapseki ($p < 0.05$), and c) Çan ($p < 0.05$).

slightly lower PF was observed in both Lapseki and Çan towns in some months, probably due to more time spent indoors together with the contribution of domestic heating by solid fuels, no statistically significant monthly variation was found for FEV₁/FVC ratios of the participants living in each town ($p > 0.05$) (see Suppl. Material Fig. S4).

3.4. Occurrence of SBS symptoms among the participants

In this study, it was determined that more SBS symptoms were observed in Çan according to the scores of SBS symptoms which were used to define the SBS among the participants of this study. As can be seen from Fig. 6, SBS symptoms showed seasonal variations in each sampling site ($p < 0.05$). In general, the SBS symptoms were found to be widespread among the participants and some of the symptoms had seasonal variations, whereas some of the SBS symptoms were observed in the participants throughout the year. Seasonal and spatial changes of SBS symptoms according to the type of observed symptoms were investigated (see Table 3). The most common symptoms were, in general, fatigue, cold, flu-like symptoms, and difficulty in concentration. Kishi et al. (2018) found mucosal symptoms as the most common SBS symptoms with a prevalence of 17.4% in children and 12.3% in adults and more than half of the participants in both groups had at least one or more doctor-diagnosed allergies. Similarly, higher SBS prevalence was observed in children than in adults (Wieslander et al., 2010). Another study, conducted to investigate thermal conditions and SBS symptoms in three air-conditioned engineering education laboratories in Malaysia, showed that majority of the students in each lab have experienced all the SBS symptoms. Among the SBS symptoms, dry skin (40.9%), runny nose (31%), dry eyes (29.6%), blocked/stuffy nose (28.2%), tiredness (26.8%), and flu-like symptoms (21.1%) were observed in descending order (Amin et al., 2015).

Table 4 presents the seasonal and temporal change of SBS symptom score frequency. The highest frequency for the participants living in the

Central town with no SBS symptoms was observed in the summer (20%) and the least frequency was observed in the winter (4.7%). None of the participants living in the Center showed all SBS symptoms. The highest percentage for the participants living in Lapseki with no SBS symptoms was observed in the winter (14.3%) and summer (14.3%), while the least percentage was observed in the fall (9.1%). None of the participants living in Lapseki had all or 10 symptoms of SBS. The percentage for the participants living in Çan with no SBS symptoms was highest in the fall (11.8%) and least in the winter (5.9%). All SBS symptoms were observed in 4% of the participants living in Çan in the summer. The highest frequencies of SBS symptoms according to symptom scores were mostly observed in Çan.

3.5. Associations among IAQ, SBS symptoms, and respiratory health indicators

Contribution of monitored levels of IAQ parameters with the score of occurred SBS symptoms among the participants were investigated. SBS symptom score was positively correlated with total particle count ($p < 0.01$) and temperature difference between indoor and outdoor (ΔT ; $p < 0.05$) in both Center and Çan and indoor CO₂ levels in Center ($p < 0.05$). High CO₂, CO, and total bacteria concentration as well as lower RH contributed the SBS symptoms (Shan et al., 2016; Mentese and Tasdibi, 2016; Maula et al., 2017).

In terms of respiratory health indicators, indoor CO₂ and TBC levels were negatively correlated with PF of the participants ($p < 0.05$). Also, asthma prevalence of the participants was found to be more in the homes in which indoor TBC and CO₂ levels were higher than those in non-asthmatic participants' homes ($p < 0.05$). Moreover, as the respiratory symptoms increase, PF of the participants showed a decreasing trend ($p < 0.05$). The CO₂ level in the indoor air is considered as an important indicator for sufficiency of the ventilation (Mentese, 2009; Heudorf et al., 2009). Also, duration of home ventilation was positively linked with FEV₁/FVC ratio, indicating that the level of air pollutants decreased by ventilation impacts the pulmonary function of the individuals.

Generalized linear model (GLM) was applied to all IAQ measurement data to estimate the significant factors affecting on occurred SBS symptom scores of the participants based on seasonal data. Additionally, several personal factors that can influence the SBS symptom occurrence, residing district, and season were taken into account while performing the model. Table 5 shows the output of GLM applied for each study site. Least square means with 95.0 percent confidence intervals of GLM output for SBS score of the participants living in three towns are presented in Suppl. Material Table S2–S4. As significant factors; residing district, lifelong smoking and ETS exposure, temperature, and RH affected the SBS symptom occurrence of the participants living in Central town (adjusted $R^2 = 0.18$ and $p < 0.001$). Therefore, personal factors and climatic conditions of the indoor environment had contributions of SBS symptoms. More factors had contribution on SBS symptom occurrence in participants living in Lapseki, which were residing district, season, lifelong ETS exposure, gender, sum of BTEX levels, and bioaerosol levels (adjusted $R^2 = 0.24$ and $p < 0.001$). Merely season and odour perception at home were found to have significant influences on occurred SBS symptoms in participants living in Çan (adjusted $R^2 = 0.10$ and $p < 0.05$). The fact that relatively low correlation was found among the considered input parameters of GLM representing Çan, compared to other sampling locations, other parameters such as outdoor air pollution (*i.e.*, by sulphur dioxide, nitrogen oxides, and ozone) and the emissions related to ongoing industrial activities in Çan town (Mentese et al., 2018b) might have influenced the perceived IAQ of the participants living in Çan.

It has been known that smoking and or ETS exposure are one of the major leading factors of the respiratory system disorders (Nathell, 2002; Eisner et al., 2005). An interesting finding was shown in a study conducted in Shanghai, China, indicated that SBS symptoms in urban area

Table 3

Seasonal observation frequencies (%) of the most frequent 3 SBS symptoms at the sampling locations.

Season	Observation frequency of the first three SBS symptoms (%)		
	Center ^a	Lapseki ^b	Çan ^c
F	<ul style="list-style-type: none"> fatigue (50%) cold, flu-like symptoms (50%) thickly throat (49%) 	<ul style="list-style-type: none"> fatigue (65%) cold, flu-like symptoms (52%) difficulty in concentration (47%) 	<ul style="list-style-type: none"> fatigue (72%) difficulty in concentration (66%) eye irritation (47%)
W	<ul style="list-style-type: none"> fatigue (72%) difficulty in concentration (63%) cold, flu-like symptoms (61%) 	<ul style="list-style-type: none"> difficulty in concentration (59%) cold, flu-like symptoms (56%) fatigue (50%) 	<ul style="list-style-type: none"> difficulty in concentration (73%) cold, flu-like symptoms (64%) fatigue (46%)
Spr.	<ul style="list-style-type: none"> fatigue (66%) difficulty in concentration (63%) cold, flu-like symptoms (51%) 	<ul style="list-style-type: none"> difficulty in concentration (61%) fatigue (43%) difficulty in concentration (61%) 	<ul style="list-style-type: none"> cold, flu-like symptoms (68%) difficulty in concentration (66%) fatigue (48%)
S	<ul style="list-style-type: none"> difficulty in concentration (51%) fatigue (41%) thickly throat (33%) 	<ul style="list-style-type: none"> fatigue (54%) headache (36%) 	<ul style="list-style-type: none"> difficulty in concentration (56%) fatigue (48%) thickly throat (32%)

Note: SBS symptoms were recorded for the participants who have not been diagnosed by the doctor, having any disease that can show any of the SBS symptoms.

^a n = 37.^b n = 31, and^c n = 26; F: Fall, W: winter; Spr.: spring, and S: summer seasons.

were all higher than that in the sub-urban area (Sun et al., 2018). SBS incidents most commonly occur in tight buildings which were new or newly renovated (Zeliger, 2011). Some earlier findings showed that emissions from newly painted indoor surfaces or renovations in homes were linked with SBS symptoms (Takaoka and Norback, 2011; Sahlberg et al., 2012, 2013). Chemicals emitted from renovations in newly built house coating materials and VOCs were all associated with the risk of SBS symptoms (Takigawa et al., 2010; Kanazawa et al., 2010). Similar to our findings, another study carried out in Malaysia indicated that crucial predictors of SBS are ventilation and accumulation of possible contaminants in the indoor environment (Norhidayah et al., 2013). In another study conducted in Çanakkale, the relationship between indoor bacterial levels and SBS symptoms was investigated (Mentese and Tasdibi, 2016). Accordingly, it was found that the frequencies of SBS symptoms vary seasonally and factors such as time spent at home and amount of daily cigarettes consumed increase the risk of SBS symptoms. Also, they found the occurrence of general SBS symptoms (headache, fatigue, and dizziness) more often in females than male occupants. Another study found a positive correlation between SBS symptom frequency and bacterial levels (Harrison et al., 1992). Other studies have also identified associations between exposure to bioaerosols and SBS and other hypersensitivity reactions (ACGIH, 1989; Carrer et al., 2001;

Douwes et al., 2003).

4. Conclusions

According to the results of this study:

- Indoor levels of bioaerosols, PM, and VOCs showed spatial variation among the study sites.
- In general, the highest indoor pollutant levels were observed in Çan, while the lowest levels were observed in Central town.
- Pulmonary function of the occupants varied according to the residing district ($p < 0.001$).
- Even though the predominant SBS symptoms varied seasonally and spatially among the study sites ($p < 0.05$), fatigue, cold-flu like symptoms, and difficulty in concentration were the most frequent SBS symptoms.
- Correlations were found among the occurrence of SBS symptoms, measured indoor pollutants, and comfort parameters ($p < 0.05$).
- Daily ventilation amount of the houses was negatively correlated with CO₂ levels ($p < 0.05$), which used to be an indicator of adequacy of ventilation or fresh air intake.
- Also, high levels of indoor air pollutants were linked with increase

Table 4

Seasonal and temporal change of SBS symptom score frequency (%).

SBS Symptom Score ^a	Center ^b				Lapseki ^c				Çan ^d			
	F	W	Spr.	S	F	W	Spr.	S	F	W	Spr.	S
0	15.4	4.7	2.9	20	9.1	14.3	10	14.3	11.8	5.9	8.7	8.0
1	10.3	2.3	5.7	17.5	9.1	5.7	6.7	10.7	8.8	14.7	8.7	16.0
2	12.8	18.6	11.4	22.5	6.1	8.6	20	17.9	8.8	8.8	21.8	28.0
3	10.3	11.6	31.4	12.5	3.0	5.7	10	21.4	5.9	11.8	4.4	4.0
4	7.7	20.9	14.3	7.5	21.2	22.9	16.7	3.6	8.8	8.8	13.1	16.0
5	12.8	16.3	11.4	12.5	21.2	11.4	13.3	7.2	17.7	14.7	21.8	8.0
6	10.3	7.0	5.7	7.5	18.2	8.6	10	14.3	8.8	8.8	13.1	12.0
7	15.4	11.6	8.6	–	9.1	8.6	6.7	3.6	11.8	14.7	4.4	4.0
8	2.6	2.3	8.6	–	–	8.6	6.7	3.6	8.8	5.9	–	–
9	–	2.3	–	–	3.0	5.7	–	3.6	5.9	5.9	4.4	–
10	2.6	2.3	–	–	–	–	–	–	2.9	–	–	–
11	–	–	–	–	–	–	–	–	–	–	–	4.0

Note: F: Fall, W: winter; Spr.: spring, and S: summer seasons.

^a SBS symptom score ranged from 0 (none of the SBS symptom was occurred) to 11 (all SBS symptoms were occurred among the participants who have not been diagnosed by the doctor having any disease that can show any of the SBS symptoms).^b n = 37.^c n = 31, and^d n = 26.

Table 5

GLM for occurred SBS symptom score of the participants residing at the study sites, based on personal variables and measured IAQ parameters.

Source	Type III SS	df	MS	F	Significance
Central town ($R^2 = 0.25$ and R^2 - adjusted for $df = 0.18$)					
Corrected model	253.93	13	19.53	3.80	< 0.0001
District ^a	85.20	4	21.30	4.14	0.0033
Lifelong ETS exposure ^b	37.91	1	37.91	7.38	0.0074
Lifelong smoking ^b	24.70	1	24.70	4.81	0.0299
Temperature	29.58	1	29.58	5.76	0.0177
RH	23.82	1	23.82	4.63	0.0329
CO ₂	19.99	1	19.99	3.89	0.0505
TBC	15.52	1	15.52	3.02	0.0843
Residual	770.95	150	5.14		
Total (corrected)	1024.88	163			
Lapseki ($R^2 = 0.30$ and R^2 - adjusted for $df = 0.24$)					
Corrected model	273.70	11	24.88	4.77	< 0.0001
District ^a	103.05	3	33.35	6.58	0.0004
Season	79.03	3	26.34	5.04	0.0025
Lifelong ETS exposure ^b	41.61	1	41.61	7.97	0.0056
Gender ^c	33.16	1	33.16	6.35	0.0130
Sum of BTEX	55.79	1	55.79	10.68	0.0014
TBC	38.64	1	38.64	7.40	0.0075
TMC	27.73	1	27.73	5.31	0.0229
Residual	637.05	122	5.22		
Total (corrected)	910.75	133			
Çan ($R^2 = 0.17$ and R^2 - adjusted for $df = 0.10$)					
Corrected model	188.2	12	15.69	2.12	0.0200
Season ^d	81.05	3	27.02	3.66	0.0145
Odour perception at home ^e	48.51	2	24.25	3.28	0.0409
District ^a	53.34	3	17.78	2.41	0.0706
TMC	11.11	1	11.11	1.50	0.2227
Total PM count	9.19	1	9.19	1.24	0.2669
Gender ^c	6.91	1	6.91	0.93	0.3355
Temperature	6.11	1	6.11	0.83	0.3649
Residual	901.50	122	7.39		
Total (corrected)	1089.73	134			

Note: Seasonal average values are used; parameters with the statistical significance at $p < 0.05$ are shown in bold; df: degrees of freedom; MS: Mean square; SS: sums of square; R^2 : correlation coefficient.

^a Name of the residing district.

^b Coded as yes or no.

^c Female and male.

^d Season was coded as winter, spring, summer, and fall.

^e Coded as none, rarely, and mostly.

of respiratory symptoms of the occupants ($p < 0.05$).

- Both indoor and outdoor originated air quality parameters had contribution on IAQ.
- In addition to IAQ parameters, other factors, such as smoking and/or ETS exposure, temperature, humidity, gender, season, and odour perception at home influenced the occurrence of SBS symptoms in at least one of the study sites ($p < 0.05$).
- Moreover, several occupant activities showed linkage with some of the VOCs, e.g., as home cleaning frequency increased, the levels of xylenes and n-hexane increased ($p < 0.05$) and use of air fresheners or room deodorants were linked with benzene and toluene levels ($p < 0.05$).

Overall, performing more studies from the health and IAQ points of view improve public awareness of indoor environmental comfort.

Credit author statement

Sibel Mentese: Conceptualization, Methodology, Resources, Project administration, Supervision, Formal analysis, Investigation, Writing - Review & Editing. Nihal Arzu Mirici: Investigation, Validation. Tolga Elbir: Formal analysis, Validation. Elif Palaz: Investigation, Analysis. Deniz Tasdibi Mumcuoğlu: Investigation, Sampling. Osman Cotuker: Investigation, Sampling. Coskun Bakar: Formal analysis, Methodology.

Sibel Oymak: Formal analysis. Muserref Tatman Otkun: Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.apr.2020.07.016>.

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