RESEARCH ARTICLE

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Evaluation of indoor air quality by indoor environmental index in market places in Istanbul/Türkiye during Covid-19 pandemic

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ABSTRACT: This is the first study to evaluate the indoor air quality of markets using the “Indoor Environmental Index (IEI)”. In the study, carbon dioxide (CO_2), relative humidity, temperature, particulate matter, and total volatile organic compounds were measured as indoor air quality parameters in four different markets in Istanbul during the COVID-19 pandemic. Data were analyzed and evaluated using IBM SPSS Statistics 22 program. While CO_2, Paticulate matters ($PM_{2.5}$, PM_{10}), humidity, and temperature had a statistically significant difference in different markets, no statistically significant difference was found for NO_2 and total volatile organic compounds ($p>0.05$). Considering the different hours in a day, it was determined that there was a statistically significant difference for all parameters. The highest and strongest correlation between the parameters was found between $PM_{2.5}$ and PM_{10} ($r=0.703$, $p<0.01$). The IEI values for 4 different markets in different time intervals in a day were found as 6.862, 6.775, 8.816, and 6.244, respectively. The highest and lowest Indoor Environmental Index values were calculated in market 2 (7.525) and market 4 (4.936), respectively. Indoor air quality parameters had an impact on the IEI results as they affected the pollution index and the discomfort index. As a result of the study, it was seen that the density of customers and products, the size of the closed area of the markets, and the capacity of ventilation equipment affect the indoor air quality. All these results were evaluated and suggestions were made about the visit times to the markets.

Keywords: Indoor Air Quality, Indoor Environmental Index, Marketplaces, COVID-19.

INTRODUCTION

During the COVID-19 epidemic, people had to spend most of their time indoors due to strict quarantine laws in Turkey as well as all over the world. The first of the indoor spaces was the residences where people lived, and the second was markets (MTs) with the increase in demand for retail food products during the pandemic period (Beyhan et al., 2020). People have spent most of their time outdoors in the MTs because they can only go out for basic food needs and are worried about running out of food supplies. This has led the management of the MTs to use social distancing strategies and change in-store best practices to keep their consumers safe. Because it has been stated that indoor air quality (IAQ) is a very important indicator in the rapid transmission of COVID-19 (Agarwal et al., 2021).

It is known that there is a strong relationship between air quality and health (Seguel et al., 2017). According to the The World Health Organization (WHO), the combined effects of outdoor and indoor air pollution cause approximately seven million premature deaths each year. According to another report, indoor air pollution contributes to ailments such as asthma, allergic disorders, cardiovascular diseases, mucosal diseases, central nervous system effects and some cancers (Luengas et al., 2015). In addition, it has been stated in studies conducted during the pandemic period that there is a positive correlation between IAQ and the spread and increase of the COVID-19 virus (Agarwal et al., 2021; Comunian et al., 2020; Bashir et al., 2020). Indoor air can be polluted by a wide variety of both indoor and outdoor components (Zhang and Smith, 2003). These components are inorganic, organic, biological and even radioactive and may contain air pollutants such as nitrogen oxide (NOx), sulfur dioxide (SO_2), ozone (O_3), carbon dioxide (CO_2), total volatile organic compounds (TVOCs) (ASHRAE, 2009), paticulate matters (PM), radon and microorganisms (Settimo et al., 2020). The effects of air pollutants on humans vary according to their toxicity, concentration and exposure time and may differ between humans (Leung, 2015). CO_2, carbon monoxide (CO), formaldehyde (HCHO), nitrogen dioxide (NO_2), SO_2, black carbon (BC), polycyclic aromatic hydrocarbons (PAHs), PM_{10} (pariculate matter in 10 μm average diameter) and $PM_{2.5}$ (pariculate matter in 2.5 μm average diameter) are common air pollutants that contribute to IAQ deterioration (Seppänen et al., 1999; Kajtár et al., 2003; Lin and Peng, 2010; Satish et al., 2012; Spiru and Simona, 2017). In addition, building age, season, meteorological factors, ventilation rates and human activities are also expressed as factors affecting IAQ (Hu et al., 2014). While Mentese et al., (2015) stated that the concentrations of bacteria and molds increased in summer months due to seasonal and spatial differences in indoor air, Spiru and Simona (2017) reported that TVOCs, CO_2 and PM levels were higher in winter than in summer. In addition to the above parameters, indoor air quality parameters include factors related to the thermal comfort zone such as temperature (T) and relative humidity (RH) (Abdul-Wahab et al., 2015). Comfort factors such as T and RH are critical to maintaining healthy IAQ (Ormandy and Ezratty, 2012; Davis et al., 2016). In addition, the “acceptable

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temperature" is defined by ASHRAE Standard 55 as "80% or more of users are satisfied with the ambient temperature" (Shaharon and Jalaludin, 2012). RH measures the amount of water in the air in relation to the maximum amount of water vapor (Spengler et al., 2001). T and RH have been proven to increase air pollutant concentrations due to dense air trapping pollutants (Bentayeb et al., 2015).

Indoor measurement parameters include comfort indicators such as ambient T, RH, light, noise measured in a certain time period, and pollution indicators such as gaseous pollutants and particles in the air (Wei et al., 2016). Obtained data is converted into a value representing air quality with quality indexes (Sethi and Mittal, 2019). There are many indices developed for IAQ and indoor environmental quality (IEQ) assessment. Among these, indoor environmental index (IEI) based on analytic hierarchy process (IEIAHP) (Chiang and Lai, 2002), IEI calculated with indoor air pollution index (IAPI) and indoor discomfort index (IDI) (Moschandreas and Sofuoğlu, 2004), IEQ (Mui and Chan, 2005), IAQ (Leyva et al., 2016), IAQ and IEI calculated with Thermal comfort index (TCI) (Saad et al., 2017), IEQ calculated considering EN 15251 (Piasecki et al., 2017), IAQ based on field measurement and survey research (Wu et al., 2018), using a low-cost monitoring platform IEQ (Mujan et al., 2021) are major studies. These indices are usually based on indoor measurements and/or user opinion surveys. The values of the IAQ and IEQ indices can be calculated using complex equations, or they can be obtained by comparing the values measured in a certain time period with the threshold values recommended by various institutions and organizations or associated with the same exposure time by national regulations (Wei et al., 2016). In any case, the evaluation of the IAQ and its expression with concrete indicators appear as an important tool in determining the measures to be taken and analyzing the situation.

The literature review on the subject has shown that many studies have been achieved on the IAQ of homes, schools, offices and various workplaces, but the studies on the indoor air quality of MTs are quite limited. The work carried out in the MTs, especially during the Covid-19 pandemic quarantine period, is very rare. Also, no studies were found that previously examined the IAQ of an MT using the IEI assessment method. For this reason, it was found important to investigate the IAQ in order to protect the health of market employees and market customers. This study is a candidate to attract the attention of researchers as a study evaluating the IAQ of various MTs using the IEI method during the pandemic period in Istanbul. Considering the IEI values of the selected MTs during the Covid-19 pandemic process, it is thought that it will provide important information in terms of raising public awareness about the visiting hours and times of MTs.

MATERIALS AND METHODS

In this study, the IAQ of the MTs was evaluated with the IEI methodology, taking into account the parameters $PM_{2.5}$, PM_{10}, NO_2, TVOCs, CO_2, T, and RH measured for 13 weeks in four different MTs in Istanbul/Türkiye during the COVID-19 pandemic. The IEIs of 4 different MTs were calculated in terms of factors such as customer density, product type, indoor area size, and MT ventilation equipment. The measured parameters were compared within 3 different categories, and it was investigated whether they had a statistically significant difference, and the correlation between the parameters was examined.

Sampling Devices

In this research, 2 devices were used, "77535 AZ" and "Flow" (Figure 1).

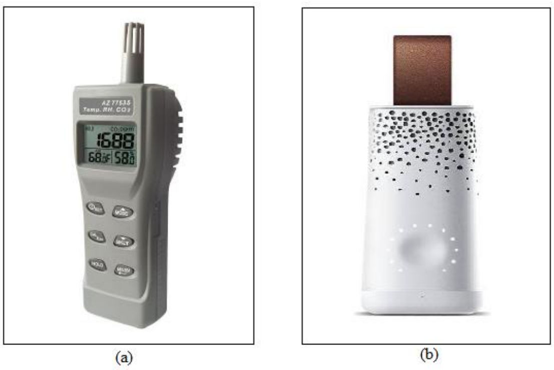

Figure 1. a) *77535-AZ,* ***b)*** *Flow tracker by plum labs*

The 77535 AZ is a portable CO_2 sensor that was used to measure CO_2 concentration, air temperature, dew point, and humidity, it can measure CO_2 in the range 0~9999 ppm, with a resolution of 1 ppm, an accuracy of ±30 ppm ±5% of reading (0~5000 ppm). It required 30 seconds for warm-up to measure CO_2. In order to minimize the standard deviations of the values obtained during the measurement, the instrument was calibrated in the laboratory at a standard concentration of 400 ppm CO_2.

For the T, it measures it within the range of -10~60℃, a resolution of 0.1℃, an accuracy of ±0.6℃, and a response time of $<$2 mins. While for the relative humidity (RH), the range was 0.1~99.9% RH, with a resolution of 0.1% RH, an accuracy of

±3% RH (at 25℃, 10~90%RH); others ±5% RH, and a response time of ＜10 mins. To minimize the standard deviations of the values obtained during the measurements, the device is calibrated in the laboratory, with 33% and 75% salt solution for the RH parameter.

"Flow" is an air pollution sensor that uses artificial intelligence and neural networks, designed to track air quality both indoors and outdoors. Every 60 seconds the device provides concentration estimates of the following pollutants: PM, NO_2, and TVOCs, with a coefficient correlation of 95% for NO_2, 68.6% for TVOCs, 95% for $PM_{2.5}$, and 88% for PM_{10}. The "Flow" device measures the following components as VOCs in any environment: 1-Butene, 1 -Pentene, 2 -Methylpentane, 1, 3 -Butadiene, 1, 3, 5 -Trimethylbenzene, 2, 2, 4- Trimethylpentane, Acetone, Acetylene, Benzene, cis-2-Butene, D4 siloxane, Dichloromethane, Ethane, Ethanol, Ethene, Ethylbenzene, Iso-butane, Iso-butene, Iso-pentane, Isoprene, Limonene, m/p-Xylene, Methanol, n-Butane, n-Heptane, n-Hexane, n-Octane, n-Pentane, o-Xylene, p-Cymene, Propane, Propene, Tetrachloroethylene, Toluene, trans-2-Butene, trans-2-Pentene, α-Pinene, β-Pinene, γ-Terpinene. Flow connects to an application installed on a mobile device (iOS) using Bluetooth to show the results in real-time, data presented in the app was using the Plume Index and was converted using the plume cloud data extraction service. The "Flow" is self-calibrating due to its machine-learning algorithms: Calibration happens automatically in the background every single time the device and app synchronize over Bluetooth. "Flow" automatically guarantees the stability of its own measurement capabilities over time.

Equipment was configured to capture a two-minute average sample, which was presented on-screen for 77535-AZ and on the mobile screen for "Flow". The data obtained were recorded on a sampling sheet. All sampling data, such as time, $PM_{2.5}$, PM_{10}, NO_2, TVOCs, CO_2, T, and RH were recorded on a single form. Each measurement was repeated 3 times and the average of the values was recorded.

All devices were tested before every session, and our modeling system was designed in a way that will minimize any faulty or extremely exceptional readings. Also, the equipment was configured to capture a two-minute average sample.

Sampling Catagories

Sampling was carried out for 13 weeks between 12/21/2020 and 3/20/2021 (winter season). The data were evaluated in 3 categories, on the basis of MTs, Weekdays/Weekend (WD/WE), and different periods (hours =Ps) during the day.

Marketplaces (MTs)

Air measurements were conducted at four MTs referenced as MT1, MT2, MT3, and MT4, all located in the Kadikoy area in Istanbul, Türkiye. Each of these MTs is connected to a wider MT chain. All MTs had similar ventilation systems (but different ventilation capacities), except for the MT_4, which had an air curtain on the door, and the ventilation systems were set at the highest level. The maximum number of individuals who can use the MT at the same time with the restriction applied (Circular Letter, 2020a) due to the COVID-19 pandemic, the surface areas of each MT, the presence of ventilation system, the door air curtain and product range information are given in Table 1.

Table 1. *Description of sampling area*

MT Reference	Area (m^2)	Capacity (person / simultaneous)	Ventilation System Capacity (BTU/h)	Curtain On The Door	Variety of Products
MT1	600	60	292500	-	**
MT2	200	20	97500	-	***
MT3	180	18	87750	-	**
MT4	580	58	282750	+	**

\+ available, - not available, * (The number of characters indicates the greater of product variety)

Weekday/Weekend (WD/WE)

Due to the curfews imposed in Türkiye during the sampling period, curfews were only allowed on weekends to meet basic needs (Circular Letter, 2020b). Apart from meeting their needs, people tended to spend WEs in MTs to take advantage of the restriction exemption. For this reason, in this part of the study, all the data obtained from the MTs were evaluated in two categories as WD and WE, and the effect of WE intensity was investigated.

Different Hours of the Day (Ps)

Guo et al., (2004) reported that IAQ depends on the population density sharing the environment, and the population density in Hong Kong MTs is experienced especially between 10:00-12:00 in the morning and 16:00-18:00 in the afternoon. For this reason, considering that the density in the MTs changes depending on time, 4 time periods are examined under this title.

The samples were collected in 4 periods for 13 weeks, taking into account the time intervals of 10:00-12:00 (P1), 12:00-14:00 (P2), 14:00-16:00 (P3), and 16:00-18:00 (P4) during the day.

Data Collection

Sampling sessions were chosen to collect data during periods of possible high activity and a period of low activity for the baseline. The four-time periods (Sampling Sessions) were as follows:

1. Morning baseline: approximately 10:00-12:00, marketplaces opened their doors at 10:00 during the lockdown, samples were collected earliest possible.
2. Noon lunchtime: approximately 12:00-14:00, most employers' lunch break occurs at this time period.
3. Afternoon baseline: approximately 14:00-16:00.
4. Evening: approximately 16:00-18:00 mostly the time around closing hours, usually a time when shoppers rushed to obtain their groceries before stores closed, this period has been replaced by an average of the three other weekend periods due to earlier lockdown hours.

All calibrations were carried out in accordance with the manufacturer's specifications. All equipment was mounted on a shopping cart at roughly waist level, All equipment's inlets were positioned far from all walls and corners and toward the middle of the marketplace.

Equipment was configured to capture a two-minute average sample, which was presented on-screen for 77535-AZ and on the mobile screen for Flow.

The data obtained were recorded on a sampling sheet. All sampling data, such as location, weather conditions, time, $PM_{2.5}$, PM_{10}, NO_2, TVOCs, CO_2, T and RH, were recorded on a single form.

Data Analysis

All analyzes were performed using the IBM SPSS Statistics 22 program. The data obtained from the measurement of air pollution parameters were first examined in terms of normality and homogeneity. Shapiro-Wilk test was used for the normality test, and Levene's test was used for homogeneity (Madureira et al., 2015; Abdullah et al., 2018; Abdullah et al., 2019). Since the data of all air pollution parameters are not normally or log-normally distributed ($p<0.05$) (Shrestha et al., 2019), the median instead of the mean in this study; Instead of minimum and maximum values, 25th and 75th percentiles of the data were taken into account, respectively. (Madureira et al., 2015; Abdullah et al., 2019). The non-parametric Kruskal-Wallis H test was used for the statistical comparison of median pollutant concentrations at different MTs and times (Ps). The Bonferroni-correction Mann-Whitney U Test was used to evaluate the intra-group comparison of the MTs and period in pairs (nmarkerplace and nperiod = 4, Mann-Whitney U test, p=0.0083 after Bonferroni correction). Other statistical analyzes were assumed for the 95% confidence level. The Mann-Whitney U Test was performed to compare the differences between the WD and WE measurements. The Spearman correlation coefficient was used to examine the correlation between parameters determining air quality.

IEI Approach

In this study, according to pollutant and comfort parameters, modified IEI was used. The structure of the IEI is shown in Figure 2. The IEI approach was used as it is one of the measurement-based IAQ indices (Wei et al., 2016; Gunes et al., 2022; Walker, 2022; Cabovská et al., 2022) that was originally proposed for office buildings but has also been applied to various indoors.

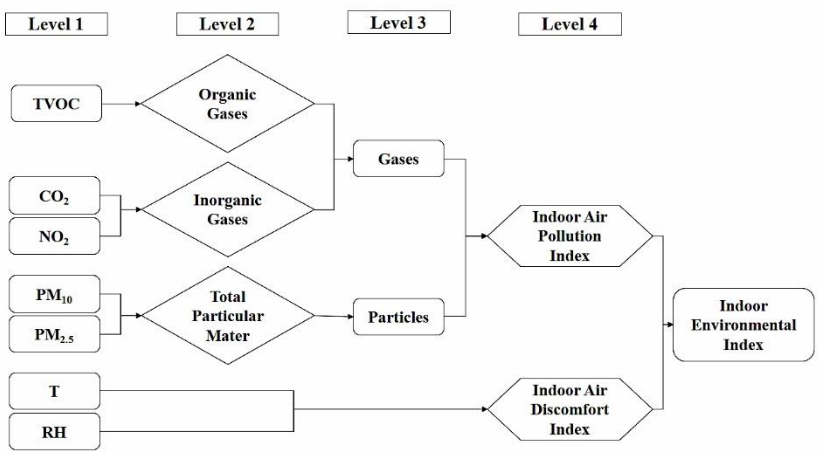

Figure 2. *Tree Structure for the determination of IEI Modified from Moschandreas and Sofuoglu (2004) taking into account the parameters measured in our study.*

IEI is a function that combines pollutant concentrations (organic/inorganic gases, total/biological particulate matter) and comfort variables (temperature and humidity) and is calculated as in Equation 1 (Moschandreas and Sofuoglu, 2004).

$$\text{IEI} = \frac{(\text{IAPI}) + (\textit{Indoor Air}\ \text{IDI})}{2} \qquad (1)$$

Calculated as the arithmetic average of the IAPI and the IDI, the IEI is a unitless number from 0 (excellent) to 10 (worst). IAPI is a composite index and a linear function including sub-indexes are used in its calculation (Equation 2) (Moschandreas and Sofuoglu, 2004). In this study, five pollutant parameters were included in the calculations: CO_2, NO_2, $PM_{2.5}$, PM_{10}, and TVOCs.

$$\text{IAPI} = \frac{1}{I}\sum_{i=1}^{I}\frac{1}{J}\sum_{j=1}^{J}\frac{1}{K}\sum_{k=1}^{K} 10\left[1 - \frac{C_{i,j,k}^{max} - C_{i,j,k}^{obs}}{C_{i,j,k}^{max} - C_{i,j,k}^{min}}\left(\frac{C_{i,j,k}^{dmc} - C_{i,j,k}^{obs}}{C_{i,j,k}^{dmc}}\right)\right] \qquad (2)$$

Where I, J, K are the number of parameters in each category and $C_{i,j,k}^{max}, C_{i,j,k}^{obs}, C_{i,j,k}^{min}, C_{i,j,k}^{dmc}$ are the maximum, observed, minimum, and limit concentrations of pollutants, respectively (Moschandreas and Sofuoglu, 2004; Moschandreas et al., 2006; Wei et al., 2016).

IDI is calculated as in Equation 3, using temperature and relative humidity, which are indicators of indoor comfort. The absolute distance of the observed value to the optimum value (T: 22 °C and RH: 45%) defined according to the preset comfort range is used to estimate the IDI. The index is a unitless number ranging from 0 to 10, with high index values indicating high discomfort and low index values indicating low discomfort (Moschandreas and Sofuoglu, 2004).

$$\text{IDI} = \frac{1}{L}\sum_{i=1}^{L} 10\,\frac{\left|CA_{i,opt} - CA_{i,obs}\right|}{CA_{i,ucl} - CA_{i,lcl}} \qquad (3)$$

Where *CA* is the comfort agent, *opt* is the optimum comfort agent value; *ucl* is the upper comfort level, *lcl* is the lower comfort level and *obs* is the measured comfort agent value in the MTs (Moschandreas and Sofuoglu, 2004; Moschandreas et al., 2006; Wei et al., 2016).

RESULTS and DISCUSSION

Statistical Evaluations

Statistics of all samples depending on the MTs variant

The MTs included in the study are different from each other in terms of ventilation, product capacity and, size (Table 1). The minimum and maximum of the comfort parameter values with the pollution concentrations measured in MTs during the sampling period the 25th percentile and 75th percentile values of the rectangle medians (line inside the rectangle) and outliers are shown in box plots (Fresán and Sabaté, 2019) were shown in Figure 3-8.

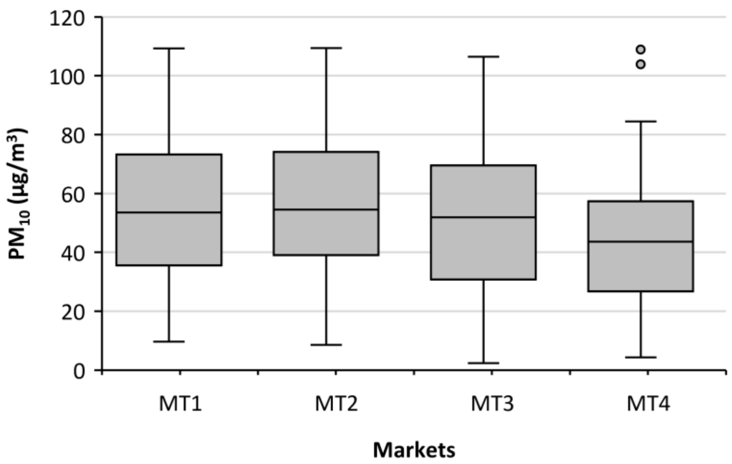

Figure 3. *Boxplot graphs of PM_{10} concentrations measured in MTs*

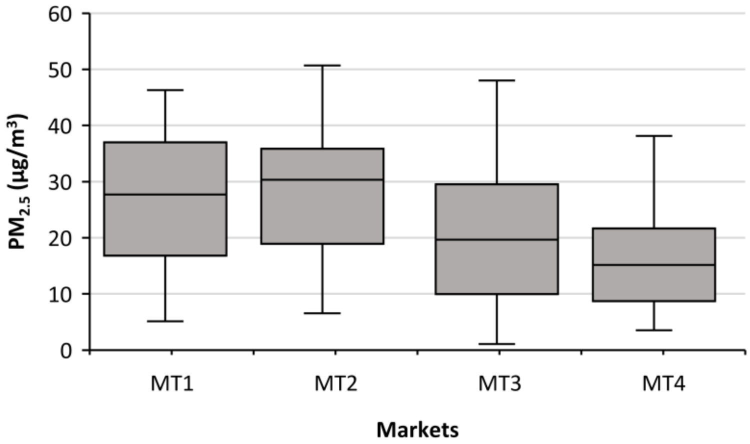

Figure 4. *Boxplot graphs $PM_{2.5}$ concentrations measured in MTs*

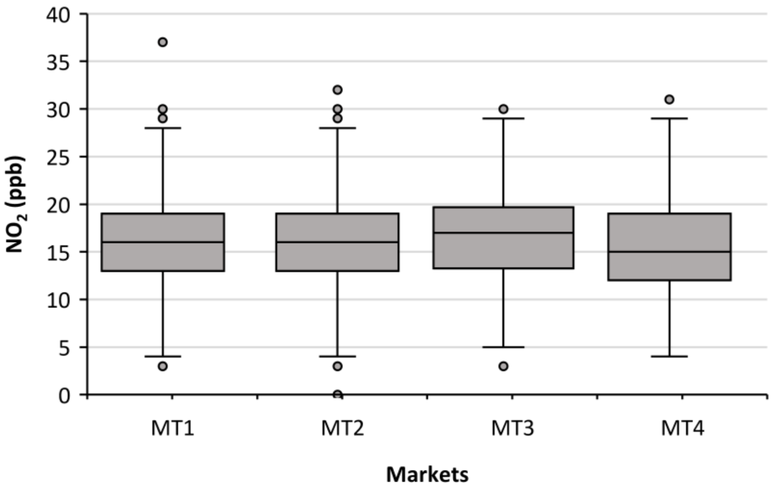

Figure 5. *Boxplot graphs of NO_2 concentrations measured in MTs*

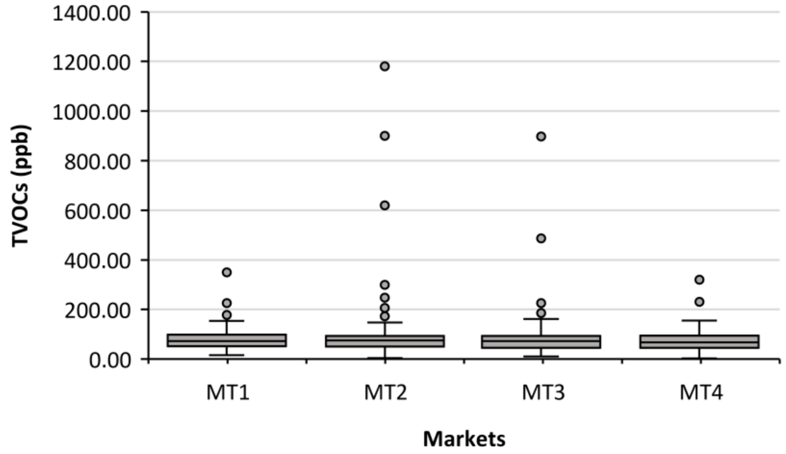

Figure 6. *Boxplot graphs of TVOCs concentrations measured in MTs*

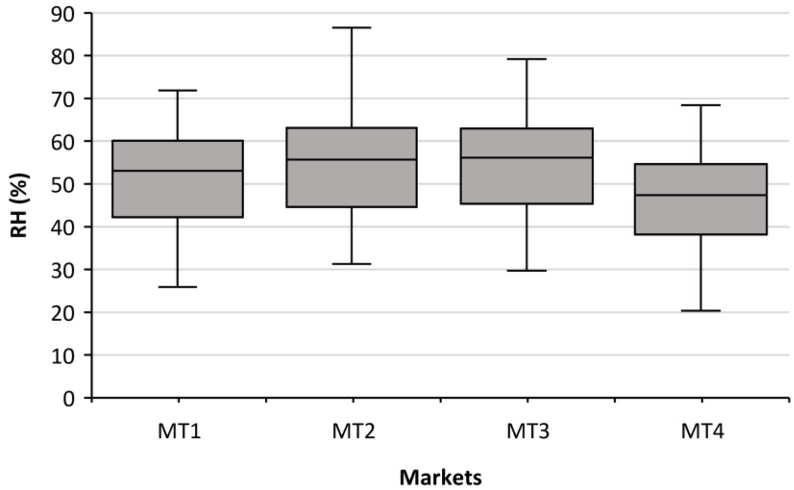

Figure 7. *Boxplot graphs of RH values measured in MTs*

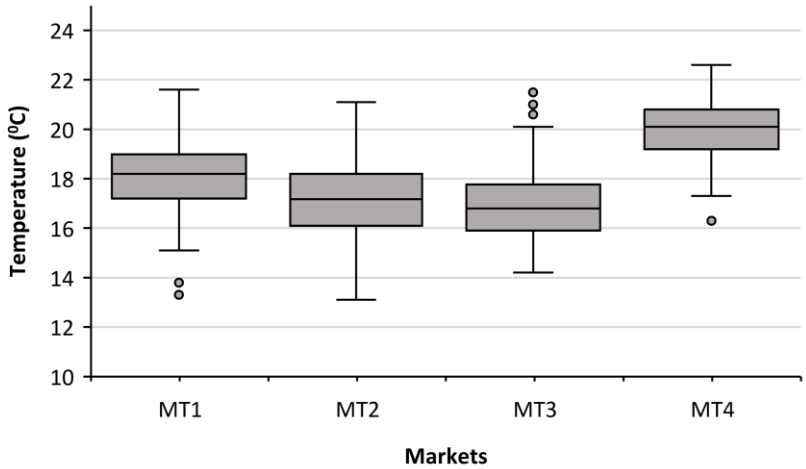

Figure 8. *Boxplot graphs of temperatures measured in MTs*

The median, 25th, and 75th percentiles, standard deviation, and Kruskal-Wallis H test results for each pollutant and discomfort parameter used in the IEI calculations in the MTs category are presented in Table 2.

***Table 2.** Kruskal-Wallis H test summary table for pollutant concentrations and discomfort parameters values comparison by MTs*

Pollutan/ Discomfort index		MTs				Test Statistic	Sig. (p)
		MT1	MT2	MT3	MT4		
$PM_{2.5}$ (µg/m^3)	Median±SD	27.69±11.60	30.32±11.05	19.64±11.78	15.13±7.88	138.70	**0.00**
	25th percentile	16.82	18.93	9.94	8.73		
	75th percentile	39.99	35.87	29.51	21.67		
PM_{10} (µg/m^3)	Median±SD	53.52±24.38	54.49±24.96	51.91±23.90	43.64±21.04	28.09	**0.00**
	25th percentile	35.61	39.10	30.81	26.79		
	75th percentile	73.22	74.07	69.52	57.36		
NO_2 (ppb)	Median±SD	16.00±5.40	16.00±5.43	17.00±4.91	15.00±4.97	3.93	0.26
	25th percentile	13.00	13.00	13.25	12.00		
	75th percentile	19.00	19.00	20.00	19.00		
TVOCs (ppb)	Median±SD	73.00±42.06	74.50±80.13	72.00±73.75	67.50±40.33	2.58	0.46
	25th percentile	52.25	50.25	45.00	45.25		
	75th percentile	98.00	93.00	93.00	94.00		
CO_2 (ppm)	Median±SD	778.00±205.97	930.50±186.78	668.00±151.71	657.50±126.96	223.47	**0.00**
	25th percentile	645.00	809.25	611.25	589.00		
	75th percentile	941.50	1077.00	792.75	754.75		
RH (%)	Median±SD	53.10±10.96	55.69±11.80	50.25±18.98	42.84±16.74	90.702	**0.00**
	25th percentile	42.23	44.58	34.98	26.45		
	75th percentile	60.08	63.13	61.72	52.65		
T (C^o)	Median±SD	18.20±1.48	17.16±1.49	16.80±1.41	20.10±1.16	367.379	**0.00**
	25th percentile	17.20	16.10	15.90	19.20		
	75th percentile	18.98	18.20	17.77	20.80		

Bold: Statistically significant difference

Table 2 shows that for CO_2, $PM_{2.5}$, PM_{10}, RH, and T there is a statistically significant difference because all p-values are less than 0.05. However, NO_2 and TVOCs results are not statistically significant across the MTs.

NO_2 measured indoors can be of both internal and external origin. NO_2 released by the burning of fossil fuels, including sources such as transportation, combustion processes, and industrial activities (Salonen et al., 2019), can enter indoor spaces through indoor and outdoor air exchange, which may include mechanical ventilation, natural ventilation, and infiltration. However, it can be caused by indoor emissions such as cooking, smoking, heating, and chemical reactions occurring inside (Hu and Zhao, 2020). The NO_2 measured in MTs is thought to be of external origin, due to the imposition of a smoking ban indoors, the absence of cooking processes, and the provision of heating processes by air conditioners. The fact that there was no statistically significant difference between the MTs, and the lowest NO_2 value was measured in the MT4 with the door air curtain, supports this view.

It has been reported that consumables such as perfume, deodorant, soap, detergent, shampoo, air deodorizing sprays, coating materials such as paint/varnish, adhesives, and building materials such as flooring, and office machines such as photocopiers and faxes are the main sources of TVOCs in indoor environments (Lee et al., 2006; Bralewska et al., 2022). Considering the variety of products sold in the MTs, there are many stands where the products and materials listed above are exhibited. In addition, the obligation to have hand disinfectants applied in all MTs in Türkiye within the scope of COVID-19 regulations and to use them by visitors (EMSG, 2020) has caused an increase in TVOCs concentrations due to disinfectant products (Virji et al., 2019). In addition, products with similar properties are used in the cleaning of MTs. It is difficult to identify the main source of TVOCs in MTs, given the wide variety of products and other influences.

Bonferroni-correction and Mann-Whitney U Test were achieved for five parameters (CO_2, $PM_{2.5}$, PM_{10}, RH, and Temperature) that were statistically different between MTs and the results are given in Table 3.

Table 3. *Bonferroni-correction Mann Whitney U Test for MTs*

		p-values for pollutant concentrations			p-values for discomfort parameters	
		CO_2	$PM_{2.5}$	PM_{10}	RH	T
MT1	MT2	**0.000**	0.301	0.508	0.018	**0.000**
	MT3	**0.000**	**0.000**	0.246	0.122	**0.000**
	MT4	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
MT2	MT3	**0.000**	**0.000**	0.080	**0.000**	0.018
	MT4	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
MT3	MT4	0.097	**0.000**	**0.002**	**0.000**	**0.000**

From Table 4, we can conclude that for CO_2, the only pair with no statistically significant difference is MT3 vs MT4 ($p>0.0083$), all the other pairs are statistically significant different ($p<0.0083$). Chen et al., (2022), reported that classrooms in schools with ventilation had better air quality in terms of CO_2 than classrooms without ventilation, although they could not meet national and WHO quality standards. According to this, ventilation in crowded environments is not sufficient to meet the CO_2 standards in terms of IAQ. Although there is ventilation in all of the MTs discussed in our study, the differences in the capacities and/or working efficiency of the ventilation equipment are thought to be the reason for the statistically different CO_2 values between the MTs. In addition, the current customer densities in the measurement period may have been effective in the formation of this difference.

However, the highest CO_2 concentrations were measured in MT2, followed by MT1 and MT3, while the lowest concentrations were in MT4. Because not all organizations see CO_2 as a pollutant, there is no clear indoor standard. On the other hand, Zhu et al. (2021) reported that PM and CO_2 pollution in indoor environments during teaching hours, especially in primary schools, is a serious problem. According to the opinions on CO_2 presence and concentration stated in the studies, we can be sure that the values observed in this study have a negative effect on IAQ. For $PM_{2.5}$, the only pair with no statistically significant difference is MT1 vs MT2 ($p>0.0083$), all the other pairs are statistically significant different. For PM_{10}, we have three pairs with a statistically significant difference, MT1 vs MT4, MT2 vs MT4, and MT3 vs MT4 ($p<0.0083$).
Considering the quarterly values in Table 2, it is seen that the RH varies between 26.45% and 63.13%, and the T varies between 15.90 °C and 20.80 °C. According to the research results of Zoran et al., (2020) negative correlation between COVID-19 with RH, showing that dry air supports viral ongoing diffusion, and a positive correlation with T, supporting the hypothesis that the warm season will not stop COVID-19 spreading. Therefore, it seems that if the T decreases in the MTs, this may stop the spread of COVID-19, but if the RH is lowered, this may increase the spread of the virus.

Considering the median values on the basis of MTs, the values of MT2 IAQ parameter values are higher than other MTs. This may be because the MT2 area is small, but the customer density is high due to the product variety and selling affordable products. MT4, on the other hand, has the lowest pollutant concentrations and differs significantly from the other 3 MTs according to pollutant concentration values (Table 2). The fact that the MT4 has a large area and the presence of a door air curtain is thought to be the main reason for this difference. Fermo et al. (2021), concluded that air purifiers can be used for the improvement of the IAQ, with regard the reduction of both PMs and TVOCs, that may be present as pollutants emitted by various activities such as cleaning operation, personal cleanliness, use of beauty products, etc.

Statistics of all samples depending on the WD/WE variants

The median, standard deviation, 25^{th}, and 75^{th} percentile values for each pollutant and discomfort parameters by WD/WE are presented in Table 4. When Table 4 is examined, it is seen that the median values of all pollutant concentrations are higher at WEs than during the WDs. In addition, according to the results of the Mann-Whitney U Test used to compare the differences between WD-WE, there is a statistically significant difference between WD-WE for all parameters ($p<0.05$).

Table 4. *Mann-Whitney U Test summary table for pollutant concentrations and discomfort parameters values comparison by Weekday/Weekend*

Pollutant/ Discomfort index		WD	WE	Test Statistic	Sig. (p)
$PM_{2.5}$ (µg/m^3)	Median±SD	21.41±2.68	31.41±5.12	14.00	**0.00**
	25th percentile	18.60	25.54		
	75th percentile	22.65	33.07		
PM_{10} (µg/m^3)	Median±SD	44.13±6.31	71.19±11.40	18.00	**0.00**
	25th percentile	41.42	58.85		
	75th percentile	51.80	75.79		
NO_2 (ppb)	Median±SD	14.83±0.97	19.33±1.14		
	25th percentile	14.58	18.25	1.00	**0.00**
	75th percentile	16.11	20.20		
TVOCs (ppb)	Median±SD	76.58±10.63	83.58±22.64		
	25th percentile	66.65	80.87	36.00	**0.012**
	75th percentile	80.97	92.42		
CO_2 (ppm)	Median±SD	767.24±31.02	869.75±73.63		
	25th percentile	729.24	779.49	23.00	**0.002**
	75th percentile	789.48	911.41		
RH (%)	Median±SD	47.76±7.89	51.64±10.23		
	25th percentile	42.24	38.15	68.00	0.397
	75th percentile	54.38	56.97		
T (C^o)	Median±SD	18.10±0.57	18.06±0.80		
	25th percentile	17.63	17.15	77.00	0.724
	75th percentile	18.48	18.50		

Researching IAQ in nurseries and primary schools, Branco et al. (2019) reported that the pollution parameter values were statistically different on WDs and WEs depending on the intensity of use ($p<0.05$). Branco et al., (2014) also stated in another study that PM concentrations in kindergartens are lower on WE than during the WD with intense activities. According to the data obtained in this study, the reason for the high WE pollution parameter values is that the MT visits are carried out more intensively on the WEs than during the WDs, for the reason explained in sections 1.1.2 and 1.1.3.. Because visitors have a more limited time to visit MTs (between 10:00 and 17:00). However, there was no significant observational and statistical difference between WD-WE for comfort parameters (RH and temperature) ($p>0.05$). The necessity of keeping the T and RH in a certain value range in order to protect the products in the MT from deterioration (Sridhar et al., 2021; Farooq et al., 2021) is thought to be the reason why this difference does not occur. Because in all MTs, two related parameters are constantly controlled by means of T and RH sensors, and necessary adjustments to air conditioning equipment are made depending on automation.

Statistics of all samples depending on the Ps variants

In order to see how the indoor air quality of the MTs changed in which time period, Ps were evaluated by considering the data in all the MTs. The median, standard deviation, 25th/75th percentile values and Kruskal-Wallis H test results for each pollutant and discomfort parameters by Ps are presented in Table 5.

Table 5 shows that for all pollutant concentrations and discomfort parameters values there is a statistically significant difference, all p-values are less than 0.05. Bonferroni-correction Mann-Whitney U Test was achieved for all parameters were statistically different between Ps and the results are given in Table 6.

Table 5. *Kruskal-Wallis H test summary table for pollutant concentrations and discomfort parameters values comparison by periods (Ps)*

Pollutant/ Discomfort index		Ps				Test Statistic	Sig. (p)
		P1	P2	P3	P4		
$PM_{2.5}$ ($\mu g/m^3$)	Median±SD	15.61±9.95	24.47±11.63	21.65±11.75	25.41±11.67	64.52	**0.00**
	25th percentile	8.57	16.29	11.55	16.83		
	75th percentile	25.31	35.64	32.78	35.52		
PM_{10} ($\mu g/m^3$)	Median±SD	35.55±19.67	56.33±23.28	46.49±25.63	57.93±22.46	84.78	**0.00**
	25th percentile	22.65	42.44	27.36	44.41		
	75th percentile	53.24	75.21	68.14	73.47		
NO_2 (ppb)	Median±SD	14.00±4.27	17.00±4.63	15.50±5.69	18.00±5.17	81.41	**0.00**
	25th percentile	12.00	13.00	13.00	15.00		
	75th percentile	16.00	19.00	19.00	21.00		
TVOCs (ppb)	Median±SD	49.50±52.49	78.00±87.26	75.50±38.00	79.50±69.60	68.33	**0.00**
	25th percentile	34.00	56.00	51.25	62.00		
	75th percentile	78.75	97.00	98.75	98.00		
CO_2 (ppm)	Median±SD	644.50±159.09	806.50±187.38	748.50±194.08	819.00±208.77	104.66	**0.00**
	25th percentile	564.25	679.25	621.00	672.25		
	75th percentile	762.75	975.75	872.25	993.25		
RH (%)	Median±SD	55.19±12.13	52.44±11.39	35.15±20.13	50.96±11.16	114.98	**0.00**
	25th percentile	43.80	42.47	14.58	41.96		
	75th percentile	63.45	59.93	53.51	59.31		
T (Cº)	Median±SD	17.30±1.66	18.00±1.90	18.20±1.78	18.50±1.88	33.33	**0.00**
	25th percentile	16.20	16.80	17.02	16.90		
	75th percentile	18.57	19.57	19.60	19.99		

Bold: Statistically significant difference

Table 6. *Bonferroni-correction Mann-Whitney U Test for Periods (Ps)*

Ps		p-values for pollutant concentrations					p-values for discomfort parameters	
		VOCs	CO_2	NO_2	$PM_{2.5}$	PM_{10}	T	RH
P1	P2	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.038
	P3	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
	P4	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.008**
P2	P3	0.962	**0.000**	0.180	0.014	**0.001**	0.295	**0.000**
	P4	0.232	0.412	**0.004**	0.981	0.649	0.099	0.509
P3	P4	0.168	**0.000**	**0.000**	0.016	**0.000**	0.472	**0.000**

Bold: Statistically significant difference

From the Table 6, we can conclude that for all pollutant concentrations, the pair with the statistically significant difference is P1 vs P2, P1 vs P3, P1 vs P4 ($p<0.0083$). For all pollutant concentrations except CO_2 and PM_{10}, the pair with no statistically significant difference is P2 vs P3 ($p>0.0083$). For NO_2, the only pair with statistically significant difference is P2 vs P4 ($p<0.0083$). For all pollutant concentrations except VOCs and $PM_{2.5}$, the pair with statistically significant difference is P3 vs P4 ($p<0.0083$).

When the discomfort parameters were examined, it was observed that the morning hours (P1), which are the working hours, were statistically different from other periods on the basis of temperature. However, there was no significant change in the T parameter in the following periods (P2, P3, P4) until the closure of MTs. It is thought that the increase in the density of MT visits after the opening causes an increase in the indoor temperature, both due to the mobility in the MT and an increase in the frequency of opening the doors. For RH, it is seen that the couples with statistically significant differences are P1 and P3, P1 and P4, P2 and P3 and P3 and P4 ($p<0.0083$). While RH was more stable in the morning hours (P1), it changed with the effect of temperature increase in the following hours.

Examining the correlation between indoor air quality parameters

Spearman correlation coefficient was used to show the correlation between air quality parameters. In cases where the factor value is greater than 0.50, in the range of 0.40-0.49, and less than 0.30, the correlation is considered strong, moderate and weak, respectively (Awang et al., 2015; Abdullah et al., 2019). Table 7 shows the Spearman correlation coefficient (r) between IAQ parameters.

Table 7. *Spearman correlation coefficient (r) between IAQ parameters*

Parameters	NO_2	$PM_{2.5}$	PM_{10}	VOCs	CO_2	RH	T
NO_2	1						
$PM_{2.5}$	0.237**	1					
PM_{10}	0.276**	**0.703****	1				
VOCs	0.099**	0.213**	0.223**	1			
CO_2	0.200**	0.430**	0.383**	0.231**	1		
RH	-0.012	0.126**	0.091**	-0.085*	0.103**	1	
T	-0.090**	-0.069*	0.003	0.062	-0.096**	-0.202**	1

*****:p<0.01, *:p<0.05***

As can be seen from Table 7, the highest correlation was found between $PM_{2.5}$ and PM_{10}, and this correlation was statistically significant (r=0.703, p<0.01). It has been reported in various studies that these two parameters have a high correlation in different indoor environments (Abdullah et al., 2018; Abdullah et al., 2019). On the other hand, there was a statistically significant but moderately correlated CO_2-$PM_{2.5}$ couple (r=0.430, p<0.01). There is a low correlation between other parameters. Another remarkable point is the negative correlation between T and NO_2, $PM_{2.5}$, CO_2 and RH, albeit low. The same situation exists between RH and NO_2 and TVOCs. Although the effect is low, it seems possible to change all pollutant concentrations by adjusting the comfort parameters (T and RH).

Evaluation by Indoor Environmental Index

When calculating IEI, pollutant concentrations and comfort variables are hierarchically ordered through a tree structure (Cabovská et al., 2022). The modified IEI approach according to the pollutant and comfort parameters measured in this study is shown in Figure 1. Five pollutant parameters (CO_2, NO_2, $PM_{2.5}$, PM_{10} and TVOCs) and two discomfort parameters (RH and T) were included in the formulation in calculating the IEI.

In the present study, $CA_{i,opt}$, $CA_{i,ucl}$, $CA_{i,lcl}$ and $C_{i,j,k}^{dmc}$ were retrieved from the previous studies and guidelines for the IEI index while $CA_{i,obs}$, $C_{i,j,k}^{max}$, $C_{i,j,k}^{obs}$, $C_{i,j,k}^{min}$ were calculated from the dataset measured in the study (Table 2, 4 and 5). WHO (2021) guidelines (for PM_{10}, $PM_{2.5}$), ASHRAE Standarts (for NO_2) and data from previous studies (for CO_2) were used as the limit values (Table 8) (Cabovská et al., 2022; Zhao et al., 2022; Goshua et al., 2022). On the other hand, WHO (2021) is presented as a guide to decision makers for both indoor and outdoor air quality (Goshua et al., 2022). Hori (2020), reported that there is no toxicological standard limit value for TVOCs. Breakpoints reported for TVOCs in previous studies also differ (Ugranli et al., 2015; Fromme et al., 2019; Gunes et al., 2022). Since there is no standard limit value currently applied for TVOCs, the relevant part of Equation 2, $[(C^{dmc} - C^{obs})/C^{dmc})]$ was numerically evaluated as 1 in the calculation of TVOCs in this study, as suggested by Moschandreas and Sofuoglu (2004). Although the ASHRAE standard is shown as the source for the limit value of CO_2 in many studies (Moschandreas and Sofuoglu 2004; de Gennaro et al., 2014; Sahu and Gurjar, 2021), it is stated that there is no limit value reported by ASHRAE for the CO_2 parameter (Ng et al., 2011; Persily, 2020). On the other hand, since 1000 ppm was accepted as the limit value for CO_2 in previous studies on IAQ, the limit value was taken as 1000 ppm in this study.

Table 8. *Limit values of pollutant parameters for IAPI calculation*

Pollutant Parameters	**Limit Values**	**References**
$PM_{2.5}$ (µg/m^3)	5/15	Annual / 24 h exposure, WHO (2021); Goshua et al., (2022)
PM_{10} (µg/m^3)	15/45	Annual / 24 h exposure, WHO (2021); Goshua et al., (2022)
NO_2 (ppb)	53/100	Annual / 1 h, ASHRAE Standard 62.1 (2019); Zhao et al., (2022)
CO_2 (ppm)	1000	Zhang et al., (2017); Fromme et al., (2019); Fernández-Agüera et al. (2019); Stamatelopoulou et al., 2019; Sui et al., (2021); Cabovská et al., (2022)
TVOCs (ppb)	Not available	-

Since the discomfort parameter numbers that creating the IDI value are T and RH, L value is 2. In addition, Upper comfort level (ucl), Lower comfort level (lcl) and opt values for T and RH are given in Table 9.

Table 9. *Values of discomfort parameters for IDI calculation*

Discomfort parameters	Upper comfort level (ucl)	Lower comfort level (lcl)	Optimum	Reference
RH (%)	55.0	35.0	45.0	(Moschandreas and Sofuoglu, 2004; Moschandreas et al., 2006; Wei et al., 2016).
T (C°)	25.0	19.0	22.0	

In the calculation of IDI and IAPI values, the median values in the relevant category for C_{obs} and $C_{i,j,k}^{obs}$, the 75th percentile, and 25th percentile values in the relevant category for $C_{i,j,k}^{max}$ and $C_{i,j,k}^{min}$, and the short-term exposure limit values given in Table 8 based on the $C_{i,j,k}^{dmc}$ value for the time spent in the MTs were used. In cases where the $C_{i,j,k}^{obs}$ exceeds $C_{i,j,k}^{dmc}$, $C_{i,j,k}^{obs}$ is replaced by $C_{i,j,k}^{dmc}$ ($C_{i,j,k}^{obs} = C_{i,j,k}^{dmc}$) (Moschandreas and Sofuoglu, 2004; Cabovská et al., 2022). The results obtained are given in Table 10.

Table 10. *IAPI, IDI and IEI calculation results by categories*

	Marketplace				Weekday/Weekend		Periods (Ps)			
	MT1	MT2	MT3	MT4	WD	WE	P1	P2	P3	P4
IAPI	8.206	8.345	8.095	7.749	8.170	7.659	7.260	8.357	8.003	8.080
IDI	5.192	6.706	5.646	2.123	3.940	4.943	6.464	5.193	5.629	4.407
IEI	6.699	7.525	6.870	4.936	6.055	6.301	6.862	6.775	6.816	6.244

It is seen that IAPI values are high for all categories (close to 10). The fact that the median values of $PM_{2.5}$ and PM_{10}, which were taken into account in the IAPI calculations, were higher than the limit values ($C_{i,j,k}^{dmc}$) given in Table 8, were effective in the formation of this situation. Although IDI values varied between 2.123 and 6.706, they played a decisive role in the calculation of IEI. The MTs with the highest and lowest IEI in the MTs category are MT2 and MT4, respectively. IEI values also described in detail in Section 3.1.1.

Considering the pollution parameters in the WD/WE category, WD has a higher IAPI value than the WE, while the opposite is true for the IDI value calculated according to the comfort parameters. Since a cleaner environmental quality value is calculated on WDs according to IAPI and IEI, it is recommended to go to all MTs on WDs with less intensity. Although the IAPI value of P1, which expresses the first opening hours of the MTs is the smallest, the IEI value is the highest since its IDI value is the highest. The time limitation has reduced the customers' time between arrivals, and the determination of the MT capacity as 10 m^2/person caused queues to form at the MT gates. In the following hours, the customer density in the MT continued steadily until close to the closing time (P4). This situation is thought to cause an increase in IAPI values. The increase in the IAPI value at P2 after the opening hour (P1) and the relatively constant at P3, P4 supports this view. After the P1 period, RH decreased below the upper limit (ucl) indicated in Table 8 and the temperature approached the lower limit (lcl), resulting in an improvement in IDI values.The results of the IEI calculations made in various indoor spaces are given in Table 11. When compared with the IEI values of other indoor types, it is possible to say that the indoor air quality of the MTs, which is the subject of our study, has the worst value after libraries.

Table 11. *Comparison of different indoor types in terms of IEI values*

References	Indoor Type	Detail	Parameters taken into account in the calculation	IDI	IAPI	IEI
Cabovská et al., (2022)	School buildings	Measurements of thermal environment and IAQ were performed over 5 school days in 45 primary school classrooms in Gothenburg, Sweden.	$PM_{2.5}$, PM_{10}, TVOCs, Formaldehyde, Ozone, NO_2, T and RH	3.04 (Average	5.16 (Average	4.10 (Average)
Walker (2022)	Homes	IEI has been served as a tool to quantify of 28 homes.	$PM_{2.5}$, CO_2, TVOCs, T and RH	3.6 (Mean)	6.7 (Mean)	5.1 (Mean)
Gunes et al., (2022)	University libraries	IAQ was investigated in two libraries of Bartin University	$PM_{2.5}$, PM_{10}, TVOCs, CH_2O, T and Humidity	-	-	9.5 (Library 1) 8.4 (Library 2)

Table 11 continuing...

References	Indoor Type	Detail	Parameters taken into account in the calculation	IDI	IAPI	IEI
Langer et al., (2018)	Residental houses	Comparison with the Swedish residential housing stock and new conventional buildings (Total 41 buildings)	T, RH, NO_2, Formaldehyde, TVOCs	-	-	It ranges from 2 to 7
Langer et al., (2017)	Dwellings	A pilot study on indoor air quality in energy efficient dwellings has been performed in 10 apartments in the district Töfsingdalen, Norra Djurgårdstaden in Stockholm.	CO_2, NO_2, ozone, TVOCs, formaldehyde, PM_{10}, $PM_{2.5}$, T, RH	-	-	It ranges from 4-6
Gomes and Esteves (2016)	University buildings	University buildings in downtown Lisbon, Portugal	PM, TVOCs, CO, CO_2, T and RH	3.742 (Average)	2.442 (Average)	3.092 (Average)
Moschandreas and Sofuoglu (2004)	Office building	Total of 100 buildings were investigated from 10 predetermined geographical areas (climaticregions)	$PM_{2.5}$, PM_{10}, TVOCs, CO, CO_2, HCHO, Bacteria, Fungi, T and RH	5.1 (median)	3.3 (median)	3.9 (median)
This Study	Marketplace	Different categories of 4 markets	$PM_{2.5}$, PM_{10}, TVOCs, NO_2, CO_2, T and RH	It ranges from 2,123-6,706	It ranges from 7.260-8.345	It ranges from 4.936-7.525

CONCLUSION

In this study, the indoor air quality of MTs that people use and spend time in their daily lives during the COVID-19 pandemic was evaluated using the IEI approach and various statistical analyzes. As indoor air quality parameters, CO_2, PM2.5, PM10, TVOCs, NO_2, RH, and T measurements were made. The highest correlation between parameters was found between PM2.5 and PM10 ($r=0.703$, $p<0.01$). IEI evaluation of the data was made in 3 categories as MTs, WD/WE and Ps. IEI values for MT1, MT2, MT3 and MT4 were calculated as 6.699, 6.8705, 7.525 and 4.936, respectively. Although WD's IAPI was found to be higher in the WD/WE evaluation (8.170), the comfort indicator IDI value (3.940) was lower than WE's IDI (4.943). Therefore, it was observed that WE (6.301) had a higher IEI value than WD (6.055). In the Ps category, although indoor air quality parameters do not show a statistically significant difference, they are effective on IEI results as they affect IAPI and IDI. Compared to other indoor environments calculated with the IEI approach, the MTs considered in the study were found to have the worst indoor air quality after libraries.

Here are some suggestions for managers and customers to improve the IAQ of MPs and shop in a cleaner IAQ:

- If air cleaners are used in all markets, a serious improvement in air quality can be achieved.
- Performing shopping activities in WDs and in the morning when there are fewer people in the markets will reduce exposure to pollution parameters. Particularly, the distribution of air pollutants in the form of particles, which have settled in the morning hours, increases with the increase in mobility in the following hours.
- The use of local ventilation in the stands where the products (cleaning and hygiene materials) specified as the source of TVOCs are predominantly used will prevent the dispersal of pollution.

The IAQ has a very important role in protecting human health. Determining the indoor air pollution level qualitatively and expressing it with a quantitatively understandable value will enable us to determine and implement the necessary preventive actions to reduce and eliminate the harmful effects caused by pollutants.

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CONFLICT OF INTEREST

There is no conflict of interest between the authors

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