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Exposure of Indoor Air Quality in Office Environment to Workers and its Relationship to Health

Kemalettin PARMAKSIZ[1a], Tuba RASTGELDI DOGAN[1b*], Mehmet Irfan YESILNACAR[1c]

Department of Environmental Engineering, Faculty of Engineering, Harran University, Şanlıurfa/Turkey
trastgeldi@harran.edu.tr

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Abstract: Indoor air quality (IAQ) is a growing concern, as people spend about 80–90 percent of their time indoors. It is known that IAQ in office buildings influences people's health. Employment agencies are one of the most important institutions, where more than 1000 people visit and hold interviews every day. Measurements were made to assess the IAQ that staff and visitors to the building are exposed to, and the findings were compared to WHO and ARSHAE standards. Two questionnaires were applied to the staff to have an insight into their exposure and determine their effects on health. The mean PM_{10} was found to be 67.73 µg/m³; $PM_{2.5}$ was 35.95 µg/m³ and sound was 67 dBA, which may pose risks for health. The first questionnaire was to measure the exposure of indoor air pollutants to individuals, who reported that ventilation is frequently inadequate (42%) and the office environment is always noisy (57%). In the second questionnaire, the participants complained of dry and sore throat (42%), frequent tearing and redness in eyes (60%).These have been considered to result from the fact that the building is an old one, there is a lack of ventilation and air conditioning system, an open office system is used without insulation system like folding screens, and the the building is not big enough considering the number of daily visitors. The results of the study are expected to enhance the indoor air quality of similar public buildings into higher standards and to ensure the satisfaction of the employees.

Keywords : Particulate Matter (PM); Indoor Air Quality (IAQ), Personal Exposure, Respiratory Effect

Ofis Ortamında Çalışanların İç Hava Kalitesine Maruziyeti ve Sağlıkla İlişkisi

Öz: İnsanlar zamanlarının yaklaşık %80-90'ını kapalı alanlarda geçirdiklerinden, iç hava kalitesi (IAQ) büyüyen bir endişe kaynağıdır. Ofis binalarındaki IAQ insanların sağlığını etkilediği bilinmektedir. İş bulma kurumları, her gün 1000'den fazla kişinin ziyaret ettiği ve görüşme yaptığı en önemli kurumlardan biridir. Personel ve binaya gelen ziyaretçilerin maruz kaldığı iç hava kalitesi değerini değerlendirmek için ölçümler yapılmış ve bulgular WHO and ARSHAE standartlarla karşılaştırılmıştır. Personel maruziyetlerini anlamak ve sağlık üzerindeki etkilerini belirlemek için iki anket uygulandı. Değerler ortalama PM10 67,73 µg/m³; PM2.5 35.95 µg/m³ ve gürültü 67 dBA bulundu, bu değerler sağlık açısından risk oluşturabilir. İlk anket katılımcıları iç hava kirleticilerinin maruziyetini ölçmek içindi; havalandırmanın sıklıkla yetersiz (% 42) ve ofis ortamının her zaman gürültülü (% 57) olduğunu bildirdiler. İkinci ankette katılımcılar boğaz kuruluğu (% 42), gözde sık sık yaşarma ve kızarıklıktan (% 60) şikayet ettiler. Bina, havalandırması ve kliması olmayan eski bir bina olup, günlük ziyaretçi sayısının fazla olması ve elde edilen sonuçlardan sorumlu olduğu düşünülen yalıtım sistemi olmadan açık ofis sistemi kullanılmaktadır. Çalışmanın sonuçlarının benzer kamu binalarının iç hava kalitesini daha yüksek standartlara yükseltmesi ve çalışanların memnuniyetini sağlaması beklenmektedir. Çalışmanın sonuçlarının benzer kamu binalarının iç hava kalitesini daha yüksek standartlara yükseltmesi ve çalışanların memnuniyetini sağlaması beklenmektedir.

Anahtar Kelimeler: Partikül Madde (PM); İç Hava Kalitesi (IAQ), Kişisel Maruziyet, Solunum Etkisi

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ORCID ID : [a]0000-0002-3512-0294, [b]0000-0002-8246-388X; [c]0000-0001-9724-8683

1. Introduction

Today, people spend most of their time in their workplaces. According to the studies of EPA (United States Environmental Protection Agency), "Sick Building Syndrome, which ranks 4th among the top 10 health problems to be dealt with, is mostly seen in office workers [1-4]. Indoor air pollution (IAP) is defined as gas, chemical, and particles entering a structure's atmosphere that lead to unhealthy air and causes short- and long-term diseases, breathing problems, and allergies. These pollutants can harm people from spending a lot of time indoors compared to those who spent more time outdoors [5]. Emissions caused by consumer products, construction materials, and printers can also be an important source of aerosol in offices [6,7]. Moreover, a number of people are exposed to indoor pollutants as a result of activities like cooking, house cleaning and smoking, using traditional methods for heating (wood and coal stove), harmful gases such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen dioxide (NO_2), volatile organic compounds (VOC) and particulate matter (PM) [8].

Particles are common in indoor and outdoor settings, and there are numerous sources of particulate matter (PM). It is possible to distinguish aerosol particles into coarse, fine, and ultrafine particles. Particles greater than 10 μm in diameter are referred to as coarse and those which are greater than 2.5 μm in diameter, but less than 10 μm are referred to as fine particles. Ultrafine particles range from 0.001 μm to 0.1 μm in diameter [9].

Particulate air pollution seems to be the reason for many health effects. Indoor exposure to airborne pollutants is not only dependent on pollution from different indoor sources, but also on pollutants coming from outdoors which are intensified by ventilation and filtration. Regional aerosol sources in urban areas involve road and soil dust, combustion of automotive gas, industrial processes, and processing of energy [10-12]. It has been indicated in several studies that fine particulate matter coming from outdoors influences indoor air and personal exposure [13,14]. It was reported in the field study conducted by Wal et al. (1991) that indoor concentrations of CO, CO_2, NO, NO_2, PM and HCHO can efficiently be decreased by ventilation [15]. In another study on urban houses in Australia, Molloy et al. (2012) reported a reverse relationship between the indoor concentrations of air pollutants and time in which the building was constructed [16]. Branco et al. (2014) found that PM concentrations exceeded the corresponding limits urban nursery study rooms in Porto resulting from the poor ventilation [17]. Indoor air quality of rural houses particularly in an extreme cold area in China were investigated in the field study carried out by Wang et al. (2014). It was reported that the national standard values were greatly exceeded in terms of PM, CO, NO_X and SO_2, which were primarily released by Chinese kang [18].

Office workers' exposure to health-related air pollutants is still not completely defined; however, recent research has attempted to investigate issues on indoor air quality in offices [18-23]. OFFICAIR (on the reduction of health effects from combined exposure to indoor air pollutants in modern offices) is the first primary project conducted worldwide the main purpose of which is to evaluate the quality of indoor air in modern offices throughout countries in Europe and to seek explanations for several problems about offices [24-25]. It has been reported in this project that approximately 66% of the indoor particle mass originate from such outdoor sources as secondary sulfate, long-range transport, oil combustion, and traffic. Burning and traffic produce most of the fine particles. Traffic levels were found to have a strong correlation with, and particle counts and exposures [26].

Another reason for the transportation of outdoor particles indoors is using cracks in the building shell and crevices in the windows and doors. On the other hand, the most significant factor in the transportation of outdoor particles indoors is thought to be ventilation systems [27-29].

In recently built intelligent buildings, open-plan offices are developed rather than enclosed offices to ensure flexibility and to decrease the level of costs for space and maintenance. In the study conducted by the International Facility Management Association (IFMA), it has been reported that 61% of the office workers in North America prefer open-plan offices and the number is on the rise [30-31]. IAQ is considered to have a great influence on people's comfort, efficiency, well-being, capacity, and issues about saving energy as indoors are where people spend 90% of their time [31-36].

Harmful gases or aerosol particles can both lead to indoor air pollution. Particulate pollution has been reported in many studies to correlate with numerous health indicators [37-38]. It has also been shown that increased amounts of particle air pollution lead to reduced lung functions and increases in respiratory problems including coughing, shortness of breath, wheezing, asthma, chronic obstructive pulmonary disease, cardiovascular diseases, and lung cancer. Such factors as how big the airborne particles are and what they consist of are important in terms of health. The particles are deposited in specific areas in the respiratory tract depending on their sizes, and an increased level of problems in the respiratory system is thought to be related to the composition of particles [39-40].

Prevalence of symptoms, recall period and office type; Symptoms caused by work in offices have been divided into four main categories in the light of several studies. Additionally, buildings were also grouped based on the office type (private, shared, and open-plan offices).For instance, at least one health symptom related to work was reported by 45% of the workforce in 100 US public buildings and 20% of them indicated that had symptoms within the following categories [41]:

- Mucosal irritation, in eyes, and upper airways.
- Low respiratory symptoms, e.g. coughing.
- Central nervous system (neuropsychological) symptoms (CNS); e.g. headache.
- Tiredness (fatigue).

Many studies have been carried out in national and international contexts to investigate and improve air quality in indoor environments. These studies have often been carried out in homes, schools, hospitals and offices. However, it is known that the number of studies on office environments where people spend a lot of time is limited. In this study, the most crowded public institution applied for a job in Turkey has been chosen which is located in Sanliurfa. The indoor air quality (PM_{10}, $PM_{2.5}$, temperature and relative humidity, noise), which all affect the employees and the people in the office environment, was measured and compared with WHO (World Health Organization) and ASHRAE (The American Society of Heating, Refrigeration and Air Conditioning Engineers) standards. Fine particulate matter ($PM_{2.5}$) 10 μg/m³ annual mean is 25 μg/ m³ is 24-hour mean, Coarse particulate matter (PM_{10}) 20 μg/ m³ is annual mean; 50 μg/ m³ is 24-hour mean. Moreover, interim targets for concentrations of PM_{10} and $PM_{2.5}$ are provided in WHO air quality guidelines to promote a gradual shift from high to lower concentrations [42]. Two questionnaires were applied to 40 employees working at the institution to have an insight into their exposure and determine its effects on health due to high values. The first questionnaire was implemented to a total of 40 employees to determine the effect of personal exposure on employees and those coming to the institution.

To determine the impact on health, the second questionnaire was administered to find out complaints about the health of the same 40 employees. The results were evaluated, and indoor air quality was found to exceed WHO and ASHRAE standards. It has been considered that the lower indoor air quality results from the building, which is old, and the lack of ventilation. In light of the questionnaire findings, it has been determined that the employees in the office environment are negatively affected in terms of health and this situation causes health problems such as lack of concentration in particular. Recommendations have been provided accordingly.

2. Materials and Method

The properties of the indoor environment and the selection of the measurement points are the most significant factors for indoor air quality. Information about the measurement points, measurement time and the devices used are provided in this section.

2.1. Study Area

The building of the Provincial Directorate of Employment Agency, which is located in the city center of Sanliurfa and has streets around it, was chosen as the study area. The building was built in 1999, each floor is 573 m² and has 5 floors (Figure 1). The reason why this building was chosen is that it does not have the characteristics of modern buildings in terms of material and insulation as it is an old building. The exterior of the building is covered with mineral paint on rough plaster and the walls are made of classical bricks. The exterior of the building is covered with mineral paint on roughcast and the walls are made from standard bricks. The building has curtain concrete, plasterboard and brick interior walls. The floor is covered with tiles. The building has an office type suspended ceiling and there is no mechanical ventilation system. The facade opening to the west and to the east are 10 and 37 meters respectively. The other facades are wide except the first floor that cannot receive sunlight for a long time because of the neighboring building on the west facade. Such buildings are common in many cities of Turkey.

The employees in the institution work in an open office system and about 500 people visit this institution, the most important establishment in Turkey, daily to be employed. At the time of the interviews, this number is around 1000 people. The building is heated by a central heating system in winter and cooled by air conditioning in summer. There is no mechanical ventilation system (Figure 2).

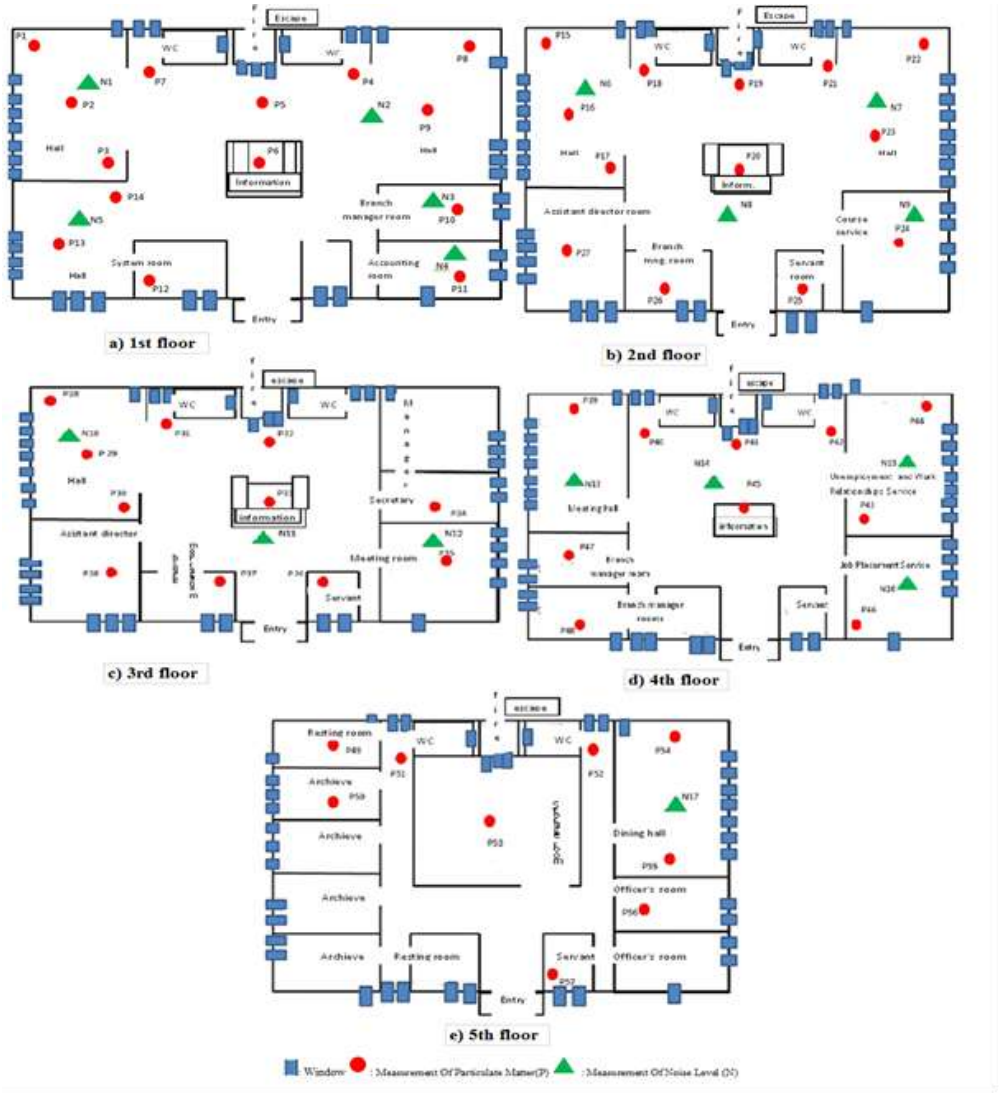

Figure 1. Work Area, Employment Agency Building Sketch and Measurement Points

Figure 2. a. Internal view of the building, b. Indoor window system of the building, c. Entrance to the building on the day of interviews, d. Exterior view of the building

2.2. Method and Tools of Measurement

The indoor air quality (PM_{10}, $PM_{2.5}$, noise, temperature, relative humidity) measurements were made at selected points in the Sanliurfa Employment Agency building (Figure 1). The values obtained from the measurements were compared to WHO and ASHRAE standards.

There are 3 types of offices in the building:

Type 1: private office
Type 2: shared office
Type 3: open-plan Office

Rooms and corridors from each office type were selected as PM measurement points. In addition, the questionnaires given to employees were also taken into consideration. Therefore, PM measurement was made in the location where employees work and in conditions where there is no air flow. Measurement points of noise included rooms and corridors as well.

PM_{10} and $PM_{2.5}$ measurements at 57 points were made with the pDR-1500 device which works with EPA standards in this 5- story building marked with a P-code in Figure 1. For sound level measurement, the Testo 816-1 was used in 17 points with an N code in this 5- story building. Moreover, Testo 440 was used for temperature and relative humidity measurements. A total of 267 measurements made in the study area. The measurements were made between February-March 2017 (winter-spring) and August-November 2017 (summer-autumn). In order to reduce the negative effects of air flows on measurements, all windows near the measurement points were kept closed and the effect of outdoor air was minimal. According to daat taken from http://index.havaizleme.gov.tr/Report/Station, measurements were made during the times when the outdoor PM average was the lowest and on days when the outdoor air quality was high.

3. Results and Discussion

Bu çalışmada binada yapılan ölçüm sonuçları WHO ve ARSHAE standartları ile karşılaştırılmış, çalışanların bu durumdaki şikayetleri ve yaşadıkları sağlık sorunları için 2 ayrı anket yapılmıştır.

3.1. PM_{10} and $PM_{2.5}$

The inhalable particles in PM_{10} and $PM_{2.5}$ can go through the thoracic region of the respiratory system. The influences of these inhalable PM on health have been identified to a great extent.
These are due to short-term (hours, days) as well as long-term (months, years) exposure and include:

• respiratory and cardiovascular morbidity, such as aggravation of asthma, respiratory symptoms and increased level of admissions to hospitals,

• deaths caused by problems about cardiovascular and respiratory systems and by lung cancer. The influences of exposure to PM_{10} in the short period of time have been very well documented, but for mortality, and as a result of exposure over a long period of time, $PM_{2.5}$ poses a greater risk than the coarse part of PM_{10} (particles in the 2.5–10 μm range). It is estimated that all-cause mortality is thought to be on the rise by 0.2–0.6% per 10 $\mu g/m^3$ of PM_{10} [43]. There seems to be an association between long-term exposure to $PM_{2.5}$ and the increased risks of deaths caused by cardiopulmonary diseases in the long term by 6–13% per 10 $\mu g/m^3$ of $PM_{2.5}$ [44-45].

In this study, PM_{10} and $PM_{2.5}$ values were measured at 57 points of open office system (Figure 3).

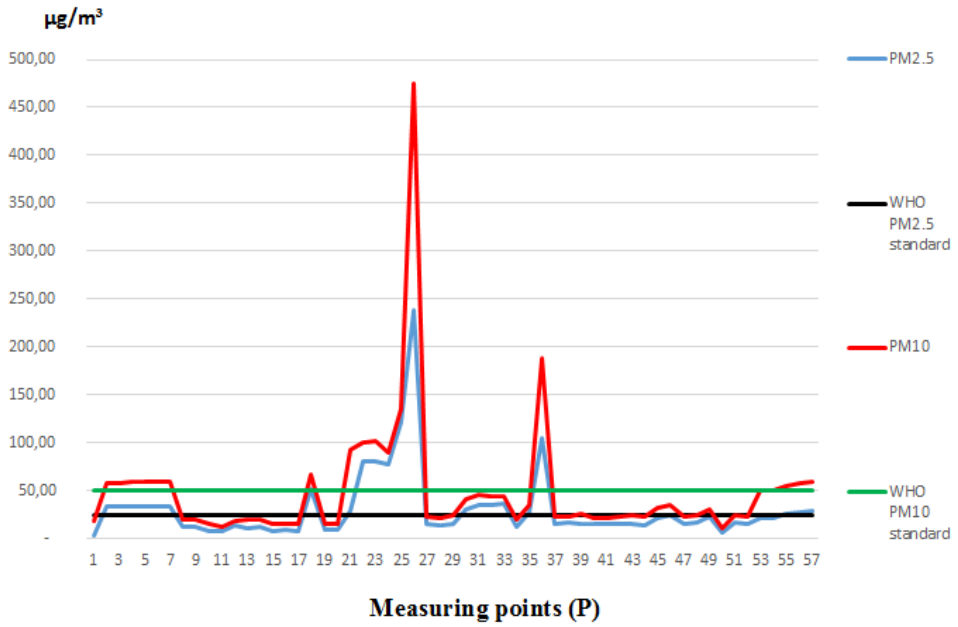

Figure 3. PM_{10} and $PM_{2.5}$ indoor measurement values

The reason for the high mean values of $PM_{2.5}$, which was 34 µg/m³, and PM_{10}, which was 58 µg/m³, at points 3, 5, 7 on the first floor and 7,8,19 on the second floor as shown in Fig 3 is that these points are close to restrooms and the measurements were made at crowded times. The very low values of $PM_{2.5}$ and PM_{10} of 11 µg/m³ and 20 µg/m³ respectively at the points of 11,12,13,14,15 and 16 on the first floor are since the number of employees on this floor is low and there are no interview rooms. The reason for the high mean values of $PM_{2.5}$ and PM_{10}, which were 230 µg/m³ and 450 µg/m³ respectively, on the second-floor measuring points of 24, 25, and 26 is because the number of people interviewed was about 200 and the ventilation was insufficient. A similar level for measuring points 35, 36, and 37 on the 3rd floor is due to a nearby tearoom and the interview room. At the measurement point 50 on the 5th floor, the reason why PM_{10} and $PM_{2.5}$ values are low is that the room is constantly closed, and no entrance is made.

Güneş et al. (2015), in their study on the indoor air quality in Marmara University Central Library, reported that the arithmetic mean of PM_{10} in 2014 winter was 23 µg/m^3 and the maximum value was 130 µg/m^3 while the arithmetic mean was 19 µg / m3 and the maximum value was 127 µg/m^3 in spring. Regarding the relationship between the dust concentration and the number of users, they found that there was an increase in dust during exam periods in both cases and that the correlation between PM_{10} concentrations and the number of people was high for both day and night [46].

Güllü et al. (2009), in their research on fine particulate matter concentrations, size distributions and seasonal changes observed in different types of indoor environments, measured the indoor and outdoor levels and average particle sizes of $PM_{2.5}$ at home, workplace, school and kindergarten, in seasons of summer and winter, at different times of the day and on different days of the week. The average $PM_{2.5}$ concentrations measured during the winter period were found to be higher in almost all environments compared to the summer period. They measured the highest $PM_{2.5}$ indoor concentration during the winter period in a meeting room of a workplace, which was 53.82 µg/m^3 and the lowest in a sleeping room of a nursery, which was found to be 25.92 µg/m^3. In both seasons, dust emitting activities in indoor environments such as smoking and students who run, and inversion in the outdoor environments were found to cause increase in dust concentrations while they found that there was a significant decrease in dust concentrations when it rained or snowed in the outdoor environment. [47].

3.2. Temperature and Relative Humidity

In many countries around the world, there some standards set maximum permissible limits of indoor air quality. For example, the relative humidity level is 30 - 60% and the temperature value is 20 - 25.5 °C according to ASHRAE standards. Figure 4 shows the winter-summer temperature and relative humidity values measured indoors as a, b, c, and d. In Fig 4.b, the reason why the temperature is higher than the ASHRAE limit in the summer period is since the temperature is around 38-45 °C in the outdoor environment in Sanlıurfa and that the isolation and ventilation is not good.

3.3. Noise

Too much exposure to noise in work areas like workplaces, building sites, bars, and even in our homes can affect psychological health. Noise and vibration, which have a negative effect on people and living things, is a natural phenomenon. Since noise is one of the most important environmental factors, noise pollution is equally important to air pollution [48-49]. It has been shown in several studies that excessive noise levels can be associated with cases of aggressive behavior, problems with sleeping order, permanent stress, tiredness, and hypertension. These can lead to more serious and chronic health problems afterward. Levels of blood pressure, cardiovascular disease, and heart problems associated with stress are increasing.

It has been suggested in several studies that noise with high intensity leads to increased blood pressure and heartbeat rate as it causes problems in normal blood flow. How to manage these issues depends on our understanding of noise pollution and how we deal with it. Stansfeld and Matheson, who study on the physiological effects of noise on humans, state that when exposed to noise, there may be disorders such as an increase in heart rate, increase in blood pressure, contraction / shortening of the vessels and consequently an increase in peripheral vascular pressure [50].

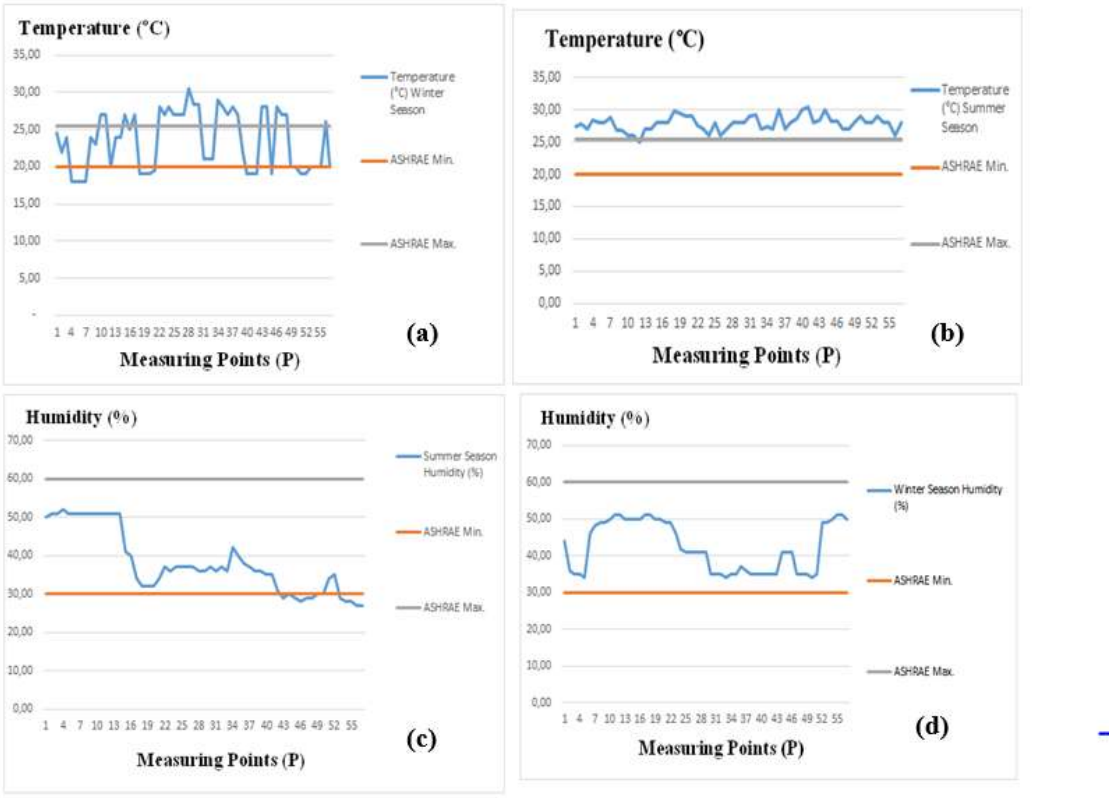

Figure 4. Office environment a. Winter period temperature, b. Summer period temperature, c. Summer period humidity, d. Winter period humidity

There have also been studies reporting that noise affects people's performance. In this sense, the experimental study conducted by Errett et al. is very important. In the study, a total of 10-person experimental group, consisting of five men and five women, was asked to work at six different noise levels in periods of 20, 40, 80 and 240 minutes and they were observed during this process. It was concluded in the study that the time of exposure to noise does not directly affect the performance and the noise level affects the performance [51].

Noises at high decibels can cause problems and can prevent people from communicating freely [52]. As a result of the measurements made at 17 points, it was determined that the noise in the interview room was approximately 70 dB and exceeded the ASHRAE standard of 55 dB. In our study, 3 different types of halls in the building (a. outdoor hall, b. indoor hall, and c. interview rooms) were measured in terms of noise level (Figure 5). The reason for the high value in the office environment is due to the high number of people in the interview rooms, the people talking among themselves, and the lack of a sound-absorbing design. Noise has been found to cause three types of damage to the human body. These are auditory, physiological, and psychological damages. This level of sound may cause health problems. To prevent this, notices about being silent in the interview rooms should be available. In the open offices, the noise was 69 dB, which is due to the absence of sound absorbers between employees' desks. While several studies have been carried out on the quality of the interior in developed countries, there are also many legal regulations regarding the interior parameters of the offices.

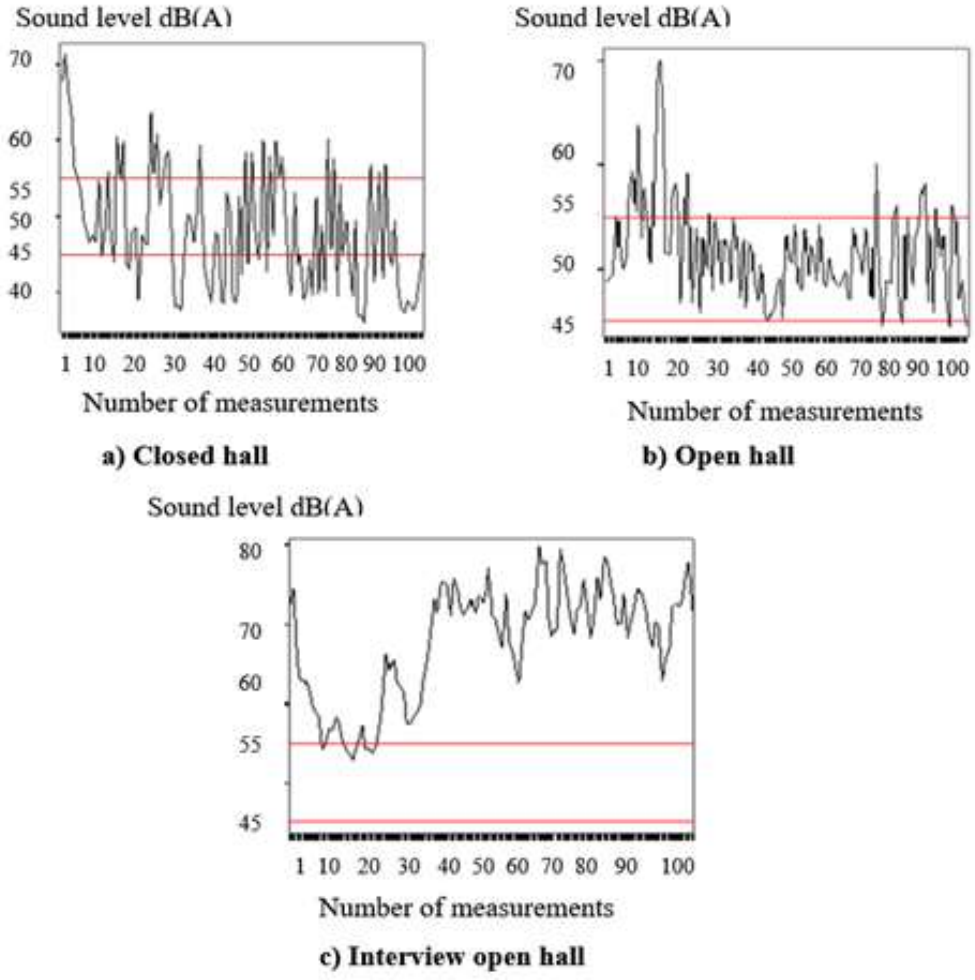

Figure 5. Noise measurement values in a. Open hall, b. Closed hall, c. Interview time the open hall

3.4. Questionnaires Administered to the Employees

As a result of a survey study on 469 office workers in Hong Kong and Shenzhen regions, more than half of the participants provided responded which indicated the presence of RLS symptoms [53]. In this study, face-to-face surveys were conducted with 40 staff (male and female) who work continuously in the building. In Table 1, the questions prepared by Özyaral 2007 about the indoor air quality, noise, and the physical structure of the organization were asked to the staff to measure the exposure on them [54]. When the results obtained are evaluated in terms of personal exposure, it has been indicated by the participants that ventilation is usually inadequate (42%), the office environment is always noisy (57%), there is always a disturbing smell in the office building (32%), the environment is extremely hot for most of the time (58%) and the building is usually crowded (58%).

To measure the effects of factors such as indoor air, noise, and temperature on the health of the same 40 employees, questions prepared by Özyaral 2007 were asked to health effects due to the exposure (Table 2) [54]. In the studies conducted by Abdul Wahab et al. (2015) in the main library of Sultan Qaboos University in Oman, people and students working there were found to have sinusitis, dry throat and, eye inflammation. Studies conducted in schools in Malaysia revealed that students complain of dizziness and nausea as well as problems such as runny nose, sore throat, cough, and wheezing [55]. It can be seen in the results of survey 2 that 42% of employees complained of frequent dry and sore throat, 40% complained of headache, 60% often experienced irritation and redness in eyes and 45% reported frequent fatigue (Figure 7). Acute symptoms can be easily diagnosed, but the root cause of the disease can be difficult to determine. Research shows that there is a connection between low air quality and acute or chronic health problems that some people face. More than half of the problems are caused by insufficient or improper ventilation and deficiencies in air conditioning systems for heating and cooling.

Table 1. Survey to determine the impact of indoor air quality exposure on office workers

Questions	Always	Often	Some times	Never
The air in taking too little	10	12	17	1
Excessive ventilation	0	2	15	20
Excess dry	7	15	11	6
Excessive humidity	2	4	15	19
So hot	7	8	22	1
Very cold	9	9	19	3
Very bright	5	10	13	12
Too dim	1	3	17	18
Surfaces are very bright/eye-catching	1	1	15	22
Very noisy	23	10	6	1
Very calm	2	1	12	22
More than enough stuff	3	7	18	11
Too much cigarette smoke	1	2	14	21
Airless / off	12	9	13	6
Unpleasant smell	13	10	17	0
Crowded	21	14	17	0

Table 2. Survey questions prepared to find out the health effects of indoor air quality on office workers

Questions	Always and Often	Sometimes	Never	More afternoons
Dry and sore throat	17	20	3	0
Skin drying	13	19	8	0
Skin rashes-redness	3	17	20	0
Eye irritation-redness	8	23	6	1
Nasal flow	6	26	8	0
Nasal congestion	6	24	9	0
Problem with contact lens use	1	10	23	2
Difficulty in breathing	5	20	12	2
Constriction of the rib cage	5	23	10	2
Fluid type symptoms	7	22	7	2
Headache	16	21	3	0
Dizziness	9	21	7	1
Nausea	5	18	14	3
Numbness	6	24	5	3
Fatigue	18	17	3	2
Itching on the arm	6	11	11	5
Pain in the chest	5	15	17	0

4. Conclusion

As a result, indoor air quality directly affects the quality of life of people as well as their work efficiency, concentration, and work performance. It is necessary to transform old, unventilated, uninsulated office environments by the indoor air standards specified by WHO.
Therefore, for effective and efficient use of interior spaces, it is highly important for public institution offices in our country to;

- work on improving the quality of the interior,
- specify principles for design,
- make the necessary improvements in the existing buildings regarding the current situation,
- design buildings to be constructed in the future by considering these principles [56].

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