KARESİ JOURNAL OF ARCHİTECTURE
KARESİ MİMARLIK DERGİSİ

Volume 4, Number 1 | June 2025
Cilt 4, Sayı 1 | Haziran 2025

INDOOR AIR QUALITY STUDIES IN EDUCATIONAL BUILDINGS: LITERATURE REVIEW

Mustafa Serhan ÜNLÜTÜRK[1]

[1] Balıkesir University, Ayvalik Vocational School, Department of Architecture and Urban Planning, Ayvalik, Balikesir, Turkey.
serhan.unluturk@balikesir.edu.tr, 0000-0001-8368-4169

ABSTRACT
People spend a significant amount of time in enclosed spaces, which often leads to a disconnection from nature and the creation of artificial environments. The comfort conditions of indoor spaces significantly influence users and their health. While it is essential to ensure optimal thermal, visual, and acoustic performance for users in indoor environments, prioritizing ventilation performance is crucial for maintaining indoor air quality. In buildings that accommodate a large number of users, proper ventilation is especially important to prevent the spread of epidemic diseases, reduce unpleasant odours, and expel harmful particles from the indoor air. The performance of ventilation is particularly critical in educational buildings, where many users are present simultaneously. In classrooms, for instance, epidemics can spread due to insufficient ventilation. Furthermore, it is evident that indoor air quality affects academic performance and the overall success of students. This study aims to emphasize the importance of indoor air quality and ventilation performance in educational buildings. In this context, a literature review on indoor air quality was conducted, comparing studies carried out in Turkey, particularly in primary and university-level schools. The measurements from these studies indicate that CO2 levels in classrooms are highest in February and lowest in June. As the concentration of CO2, which diminishes indoor air quality, increases, the incidence of diseases also rises. The examined studies highlight the necessity of focusing on ventilation performance in educational buildings and recommend the use of mechanical ventilation systems. Additionally, it was noted that indoor air pollutants should be minimized. Future studies should aim to enhance indoor ventilation performance in educational buildings by designing systems that optimize clean air through both natural and mechanical ventilation, even in February, when indoor air quality is at its lowest, by employing optimization techniques.
Keywords: *Indoor air quality, Ventilation, Ventilation performance, Building envelope, Educational buildings.*

EĞİTİM BİNALARINDA İÇ HAVA KALİTESİ ÇALIŞMALARI: LİTERATÜR TARAMASI

ÖZET
İnsanlar zamanlarının önemli bir kısmını kapalı alanlarda geçirmektedir. İç mekanların konfor koşulları kullanıcıları ve sağlıklarını önemli ölçüde etkilemektedir. İç mekanlarda kullanıcılar için optimum termal, görsel ve akustik performansın sağlanması esas olmakla birlikte, havalandırma performansına öncelik verilmesi iç mekan hava kalitesinin korunması için çok önemlidir. Havalandırma performansı özellikle çok sayıda kullanıcının aynı anda bulunduğu eğitim binalarında kritik öneme sahiptir. Ayrıca, iç mekan hava kalitesinin akademik performansı ve öğrencilerin genel başarısını etkilediği açıktır. Bu çalışma, eğitim binalarında iç hava kalitesi ve havalandırma performansının önemini vurgulamayı amaçlamaktadır. Bu bağlamda, Türkiye'de özellikle ilköğretim ve üniversite düzeyindeki okullarda yapılan çalışmalar karşılaştırılarak iç hava kalitesine ilişkin bir literatür taraması yapılmıştır. Bu çalışmalardan elde edilen ölçümler, sınıflardaki CO2 seviyelerinin Şubat ayında en yüksek, Haziran ayında ise en düşük olduğunu göstermektedir. İç hava kalitesini düşüren CO2 konsantrasyonu arttıkça hastalıkların görülme sıklığı da artmaktadır. İncelenen çalışmalar, eğitim binalarında havalandırma performansına odaklanmanın gerekliliğini vurgulamakta ve mekanik havalandırma sistemlerinin kullanılmasını önermektedir. Ayrıca, iç mekan hava kirleticilerinin en aza indirilmesi gerektiği belirtilmiştir. Gelecekteki

İNCELEME MAKALESİ / REVIEW ARTICLE
Geliş/Received: 02.11.2025 **Kabul/Accepted:** 21.01.2025
Ünlütürk, M.S. (2025), Indoor air quality studies in educational bıildings: Literature review. *KARESI Journal of Architecture,* 4(1), 1-29.

çalışmalar, iç hava kalitesinin en düşük olduğu Şubat ayında bile optimizasyon teknikleri kullanarak eğitim binalarında iç havalandırma performansını artırmayı hedeflemelidir.

Anahtar Kelimeler: *İç hava kalitesi, Havalandırma, Havalandırma performansı, Bina kabuğu, Eğitim binaları*

EXTENDED SUMMARY

Research Problem

Many factors affect academic achievement. The air quality of classrooms is also a factor that affects students' academic achievement. Inadequate indoor air quality (IAQ) in educational buildings negatively affects students' health and academic achievement. Studies indicate that dense student population, inadequate indoor ventilation and seasonal effects are effective on IAQ. This study investigates the level of IAQ in educational buildings in Turkey. The study compiled studies analyzing the current situation in Turkey. It also prepares the ground for future research and improvements.

Research Questions

This study focuses on the current state of indoor air quality in educational buildings and strategies for improvement. "What is the current state of indoor air quality in educational buildings, and how can these conditions be improved?" is the study's main research question. Other questions that helped to conduct the study are listed below.

1. What pollutants affect indoor air quality in educational buildings?
2. Is indoor air quality related to students' achievement and attendance?
3. What is the level of indoor CO2 concentration in different seasons?
4. Do the regions where schools are located impact indoor air quality?

Literature Review

This study continues research on IAQ in educational buildings, especially in classrooms that serve many users. In this context, the study aims to compile studies on IAQ in educational buildings in the literature and pioneer new studies. Literature studies on IAQ indicate high amounts of air pollutants such as CO_2, volatile organic compounds (VOCs), particulate matter (PM10, PM2.5) and formaldehyde in classrooms. During the winter months, when the use of classrooms increases and ventilation decreases, CO_2 levels are up to 4 times higher than acceptable limits, leading to headaches, fatigue, lack of attention and respiratory disorders in students. Studies on IAQ in the literature show that students' academic performance and absenteeism rates are negatively affected in classrooms with low IAQ. Studies on IAQ indicate the inadequacy of ventilation systems in educational buildings. Studies suggest developing hybrid systems that include natural and mechanical ventilation to overcome this problem. Studies also point out that another factor affecting IAQ is the building materials used in buildings.

Methodology

The study adopted a systematic literature review as a method. The study searched Google Scholar, Elsevier and Scopus databases in this context. The study identified the keywords “indoor air quality, ventilation, ventilation performance, building envelope, educational buildings”. Studies not related to the subject in the databases were excluded, and the studies examined focused on IAQ improvement strategies in educational buildings.

Results and Conclusions

The study aims to reveal strategies to deal with indoor air pollutants in educational buildings in the literature. Low IAQ levels in educational buildings negatively affect students' health, causing headaches, fatigue, respiratory disorders, and their success in the lessons. Inadequate classroom ventilation causes indoor CO2 levels to be much higher than they should be, especially during periods of intensive use. In addition, studies indicate that the properties of building materials used in buildings are an essential parameter affecting IAQ. Studies emphasise that natural ventilation is insufficient for indoor ventilation in educational buildings and should be supported by mechanical systems in addition to these systems. Future studies can use optimisation methods to design systems that combine natural and mechanical ventilation.

1. INTRODUCTION

People spend most of their day indoors, often due to inadequate ventilation in enclosed spaces and the high number of occupants, both of which contribute to elevated pollution levels. Enhancing ventilation and air quality in indoor environments is essential for the health of occupants (EPA, 2001). When healthy indoor air quality is not maintained, individuals may experience both physical and psychological discomfort. For indoor air quality to be considered healthy, known pollutants must not be present in harmful concentrations, and at least 80 percent of occupants should not express dissatisfaction with the air quality (EPA, 1997).

People have increasingly begun to inhabit enclosed spaces in urban areas, distancing themselves from natural environments. This shift has resulted in the emergence of various health problems over time. The concept of building biology, which aims to create healthy structures that prioritize user health and the natural environment, has gained prominence (Akman, 2005). By focusing on the mental and physical well-being of individuals, aspects such as building design, materials, interior furnishings, and the overall indoor environment are thoroughly examined. Today, users, designers, and manufacturers recognize the principles of building biology as essential criteria for design and construction. There should be harmony and interdependence among all living things in nature. When this balance is disrupted, negative consequences can arise, including decreased work efficiency due to inadequate comfort conditions and health issues that may occur directly or indirectly for the user (Jones, 1999).

The stability of our environment is compromised by various environmental conditions. The emergence of environmental issues typically results from human intervention in the natural balance. Factors such as population growth, urbanization, and the rapid development of industry and technology significantly contribute to pollution and environmental degradation (Ozer, 1995). Our environment is increasingly polluted, rendering a substantial portion of it unusable. Key environmental challenges include ozone depletion, global warming, climate change, and the depletion of natural resources. These issues can lead to health problems, including diseases such as cancer (Gokdayi, 1997). It is well-established that structures which are designed to meet the diverse needs of users are effective in addressing environmental challenges. Building materials play a crucial role in shaping the project and ensuring its longevity, reflecting their inherent characteristics. Furthermore, these materials are directly linked to building physics and user comfort (Eric, 1994). The life cycle of building materials begins with the acquisition, production, application, maintenance, repair, and recycling of the raw materials that constitute the product, concluding with the end of the product's use. Given that building products interact both directly and indirectly with humans and the environment throughout their life cycles, the selection of building materials should prioritize human health and comfort (Taygun et al., 2008).

Educational buildings include a diverse range of classrooms and offices for students, educators, and staff. The primary purpose of these institutions is to facilitate and support the learning process. In this context, the environmental conditions within classrooms should be a primary concern when designing physically comfortable teaching spaces, due to the relationship between these conditions, concentration, and ultimately, learning outcomes. With the increasing awareness of health and performance, professionals involved in the design and construction of educational facilities are striving to create better-conditioned buildings. The significance of ventilation in educational buildings cannot be overstated.

2. METHODOLOGY

The study identified the keywords air quality, air quality in educational buildings as priorities. These keywords were searched using the Google Scholar, Elsevier, and Scopus databases. First, the keyword Air Quality was examined in detail, focusing on its effects on user health and work performance. The subsequent search emphasized ventilation performance in educational buildings, highlighting its effectiveness in educational settings. Additionally, studies aimed at reducing air pollutants in the indoor environments of educational institutions were explored. The research specifically investigated indoor air quality studies conducted in educational buildings at various levels in Turkey to raise awareness about the issue of indoor air quality in these facilities. During the literature review, i) studies outside the scope of the research and ii) articles not related to educational buildings were excluded. Figure 1 illustrates the workflow of the study.

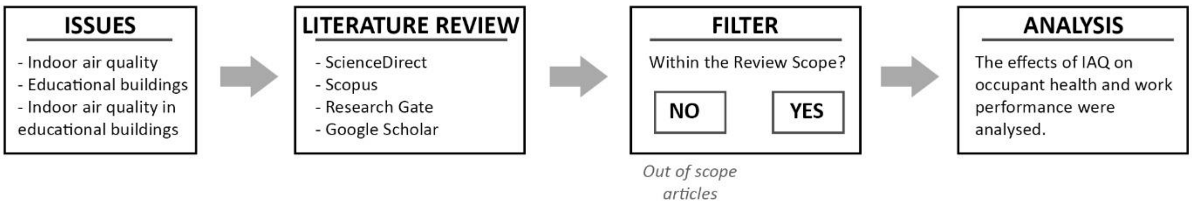

Figure 1. Workflow of the study.

3. INDOOR AIR QUALITY

3.1. Parameters Effective in Providing Comfort Conditions

In conjunction with advancing technology, modern buildings are constructed using artificial materials and equipment to meet human needs. However, this artificial environment can lead to various health issues over time. Factors such as temperature, humidity, acoustics, radioactivity, electric fields, magnetic fields, light, gases, and particulate matter contribute to these adverse effects (Balanli et al., 2006).

Providing thermal comfort is one of the primary factors in creating a conducive indoor environment. Today, the widespread use of central heating results in uniform temperature distribution across all rooms in buildings, leading to thermal monotony. Both indoor air temperature and surface temperatures play a crucial role in establishing comfortable conditions. Often, the interior air is heated excessively to achieve a perceived comfortable temperature, while the interior wall surfaces remain cold due to inadequate insulation and inefficient heating systems resulting from poor material selection. Consequently, this can lead to difficulties in breathing, decreased humidity and airflow rates, and an accumulation of dust and bacteria indoors (Balanli et al., 2006).

To ensure comfortable living conditions, indoor relative humidity should be maintained between 40% and 70%. Indoor humidity often remains low due to the use of moisture-resistant and impermeable building materials, vapor barriers, and heating systems that utilize radiators, which can absorb moisture from the air (Senkal, 2001). When humidity levels drop below 40%, dust and germs become more prevalent, leading to the proliferation of bacteria. Conversely, excessively humid environments can promote the growth of fungi and mold. Insufficient moisture in the air can result in difficulty breathing, as well as an increase in infectious diseases, stress, and fatigue. High humidity levels can also exacerbate conditions such as rheumatoid arthritis and asthma (Balanli et al., 2006). Mold spores, which thrive in humid conditions, pose significant health risks to humans. When airborne microorganisms are subjected to high humidity levels, typically between 80% and 90%, they can lead to fatigue, upper respiratory infections, and asthma. Noise pollution, defined as unpleasant and unwanted sounds from various sources, can have detrimental physiological and psychological effects on individuals (Akman, 2000). Exposure to noise pollution has been linked to various health issues, including depression, stomach and intestinal ulcers, and cardiovascular disorders. Interestingly, individuals may also experience anxiety in situations of complete silence (Eric, 1994).

Radioactivity refers to the decay of matter through the emission of various types of radiation, including alpha, beta, and gamma rays. The levels of radioactivity in buildings and construction materials should be minimized. Generally, exposure to radiation is associated with a reduction in lifespan; longer exposure durations or higher doses correlate with greater decreases in life expectancy (Yaren et al., 2005).

Today, the increasing reliance on electrical energy, combined with the interaction of telecommunication, electrical, and magnetic fields, contributes to a daily rise in these elements within our environment. This escalation disrupts the natural balance. The deterioration of the electro climate physiology in the atmosphere, along with high-voltage power lines and electrical installations, poses psychological risks to human health. Research indicates that exposure to magnetic fields may also be linked to cancer (Bold et al., 2003). Furthermore, the proliferation of artificial light sources has emerged as a significant factor contributing to adverse effects on both humans and the environment. As urban areas expand, streets and buildings illuminated by neon lights exacerbate severe light pollution. This intense light pollution has been associated with various eye-related diseases and psychological disorders in humans (Akman, 2000). The atmosphere consists of various components, including air, gases, and steam, such as nitrogen, oxygen, carbon dioxide, water vapor, ozone, and noble gases. The presence of these gases in varying concentrations can lead to a range of ailments and health issues. In addition to these gases, airborne particles also pose health risks. The small size of these particles can result in diseases affecting the lungs and respiratory tract (Balanli et al., 2006; De Nevers, 2010).

3.2. Types Affecting Indoor Air Quality and Effects on Health

The physical external environment, building materials, occupants, and specific substances generated by their activities can all contribute to indoor air pollution, disrupting the balance of indoor air quality. The effects of pollutants that compromise indoor air quality vary based on the concentration of the pollutant, the duration of exposure, and the biological characteristics of the individual (Balanli et al., 2005; Kosonen et al., 2004).

Artificial ventilation systems have increasingly supplanted natural ventilation in newly constructed buildings. As a result, the same air is continuously recirculated within these structures, leading to minimal changes in air quality. Consequently, pollutants accumulate, adversely affecting indoor air quality. Many individuals entering these buildings report a range of complaints. Exposure to these pollutants can result in various ailments and symptoms, contributing to conditions such as Sick Building Syndrome, Building-Related Diseases, Kawasaki Syndrome, and Malodorous Syndrome. These health issues can lead to decreased productivity, serious illnesses, and even fatalities (US et al., 1996; Rowley et al., 1998).

The deterioration of indoor air quality in work or living environments can lead to various disturbances that are challenging to understand and define. The conditions resulting from this phenomenon are commonly referred to as "Sick Building Syndrome" (Burge, 2004; Thörn, 1998).

In Sick Building Syndrome, individuals experience health issues while inside a building, and these symptoms typically resolve upon exiting. The primary ailments associated with Sick Building Syndrome include headaches, dizziness, nasal discharge, nausea, difficulty concentrating, respiratory disturbances, and itching or burning sensations in the eyes, face, and skin (Burge, 2004; Keskin et al., 2005; Tuncer et al., 2005).

Diseases classified as "Building-Related Diseases" have emerged due to individuals becoming ill from the effects of indoor air pollutants in environments where they have spent extended periods (Keskin et al., 2005; Quagraine et al., 2008).

The most significant distinction between building-related diseases and sick building syndrome is that the symptoms of building-related diseases can be clinically defined, and their causes are well understood. In contrast, complaints associated with sick building syndrome typically resolve once the individual leaves the building. Building-related diseases, which encompass diagnosed and identifiable disorders, pose a greater risk to human health. Major ailments classified as building-related diseases include allergies, cough, shortness of breath, high fever, chills, and muscle pain (Quagraine et al., 2008).

Kawasaki Syndrome was first described in 1967 by Tomisaku Kawasaki, a Japanese pediatrician. The exact cause of Kawasaki Disease remains unknown; however, bacteria, airborne allergens, and certain chemicals have been suggested as potential contributors. This syndrome typically presents with prolonged fever, red skin spots, eye inflammation, the formation of burrs, and redness and swelling of the mouth and neck glands in infants and children. As the disease progresses, it can affect the heart and may lead to severe outcomes (Rowley et al., 1998; Dannecker, 2006; Tezer et al., 2005). In contrast, Cacosmia syndrome, characterized by an aversion to unpleasant odors, manifests with symptoms such as headaches, migraines, nausea, vomiting, nasal and ocular discharge, skin rashes, reluctance, and persistent fatigue (Ozyaral et al., 2005).

Pollutants that contribute to these disturbances and impair indoor air quality are classified into three categories: chemical, biological, and particulate matter, which includes fibers. Table 1 illustrates various indoor air pollutants.

Table 1. Types of pollutants that affect indoor air quality (US et al. Commission, 1996; Esin, 2004).

Types of Chemical Contaminants	Types of Biological Contaminants	Particles and Fibers
Volatile Organic Compounds	Bacterias	Asbestos
Formaldehydes	Viruses	Lead
Radon	Pollens	Fiber
Carbon dioxide		Dusts and Particles
Carbon monoxide		
Nitrogen dioxide		
Sulfur dioxide		
Ozone		
Pesticides		

4. INDOOR AIR QUALITY IN EDUCATIONAL BUILDINGS

The Environmental Protection Agency (EPA) identifies indoor air pollution as a significant environmental issue that adversely affects human health (EPA, 2003). According to a report by the U.S. Government Accountability Office, one in five public schools in the United States experiences poor indoor air quality (Bayer et al., 2000). Furthermore, a study examining schools across the USA, revealed that more than 50 percent of these institutions face indoor air quality challenges. It was noted that older schools may encounter more issues due to a lack of maintenance (Buchanan, 2007).

Formaldehyde, total volatile organic compounds (VOCs), carbon dioxide (CO2), and bioaerosols are recognized as the most prevalent indoor air pollutants in educational buildings (Bayer et al., 2000). Mould, paint odour, cleaning chemicals, and pet dander from occupants contribute to the deterioration of air quality in these environments. Exposure to these pollutants can lead to symptoms such as sneezing, coughing, irritation of the eyes, nose, and throat, congestion, fatigue, shortness of breath, and headaches (Buchanan, 2007). Furthermore, air pollutants can result in more severe health issues for both students and educators, leading to increased absenteeism. For instance, asthma is the most common chronic condition associated with poor indoor air quality. According to the National Heart, Lung, and Blood Institute, asthma has adversely affected student academic performance, resulting in over 14 million lost school days, and it incurred $14 billion in health and productivity losses in 2002 (EPA, 2003; Buchanan, 2007).

To eliminate or reduce health problems caused by indoor air pollution, it is essential to address indoor air quality issues in educational buildings. Improving air quality can enhance the academic performance and productivity of both students and educators. According to the EPA, diseases and the associated costs of managing indoor conditions can be reduced by 10 to 30 percent. Additionally, a study indicates that eliminating the sources of indoor air pollution led to a 39 percent reduction in asthma cases and saved $402 million in the United States (Cummins et al., 2001). Adequate indoor ventilation, control of relative humidity, and effective particulate filtration are crucial for preventing indoor air quality problems (Bayer, 2000). Beyond maintenance and repairs in educational buildings, addressing this issue can be further improved by developing standards related to indoor air quality (Buchanan, 2007).

4.1. The Impact of Indoor Air Quality in Classrooms on Success

Measurements taken between September and June, during the educational and training period from 2016 to 2017, indicated a decline in indoor air quality, particularly in winter. The levels of carbon dioxide in poorly ventilated classrooms were found to be significantly elevated. These levels fluctuated monthly, peaking at four times the acceptable limit when outdoor temperatures were low. The highest in-class carbon dioxide concentrations were recorded during the coldest months, specifically January and February. Interviews with students, alongside the measurements, revealed that as carbon dioxide levels exceeded 1000 ppm—considered the threshold—students' interest in lessons diminished. A study conducted in the classroom increased, and the adverse effects of declining indoor air quality on students' health and academic performance.

It has been found that when the CO_2 level exceeds 1,000 ppm, it can cause headaches, dizziness, fatigue, concentration difficulties, and olfactory disorders. When the level surpasses 1,500 ppm, it can lead to nasal irritation, coughing, and eye drainage. Such conditions can have detrimental effects on learning.

This study determined that students experienced discomfort that coincided with the aforementioned symptoms during periods when carbon dioxide levels were within acceptable limits throughout the lesson (Ercan, 2012).

When students are exposed to elevated levels of carbon dioxide (CO_2) in poorly ventilated classrooms, their learning abilities and perception can significantly decline. High concentrations of CO_2 not only adversely affect individual health but also lead to negative outcomes for all students in the same environment. Furthermore, the number of students experiencing acute issues is rising in classrooms with high levels of gases like carbon dioxide. This presents a serious challenge that diminishes classroom performance and disrupts the educational experience for both students and teachers (Hwang et al., 2000).

It has been observed that the conditions leading to health deterioration and loss of concentration in environments with poor indoor air quality, commonly referred to as "Sick Building Syndrome, when the area is properly ventilated or when individuals are removed from the building (WHO, 1983).

The symptoms observed in individuals living in environments with poor indoor air quality in Denmark included 24.6% reporting spring fever, 15.3% experiencing tonsillitis, 13.7% suffering from asthma, and 2.7% affected by sinusitis (Meyer et al., 2004). In Sweden, it was found that 32.4% of children studying in locations exceeding the acceptable air quality limits reported issues such as eczema, 20% spring fever, and 14.4% had asthma (Åhman et al., 2000). Additionally, children residing in areas with low air quality in Mexico have been found to exhibit a higher prevalence of hyperintense white matter lesions in brain magnetic resonance imaging compared to their peers (Calderón-Garcidueñas et al., 2008).

While designing new school buildings, education administrators should take into account various physical conditions, particularly ventilation systems. They should collaborate with architects and engineers who specialize in educational environments to create optimal learning spaces. Additionally, improvements should be made to existing school buildings in this regard. However, if financial constraints prevent such upgrades, administrators, teachers, and other staff should receive training to understand the significance of air quality and implement the recommended practices.

4.2. Indoor Air Quality in Primary Schools

Working in a comfortable environment enhances well-being, productivity, and learning. A study conducted in seven primary schools in Venice, Italy, surveyed 614 students to examine how indoor air quality was influenced by students' psychology and behavior. The research also explored the impact of indoor air pollutants based on gender. The findings revealed elevated levels of carbon dioxide and insufficient lighting in classrooms, which contribute to various health issues (De Giuli et al., 2012).

The study conducted in South America examined indoor environmental quality (IEQ) in educational facilities. It collected health data from students at 70 schools in the southwestern United States over two academic years. In addition to this data, measurements of temperature, relative humidity, carbon dioxide levels, and settled dust—factors that contribute to indoor air quality—were included. The study also investigated the socioeconomic conditions of the students. Significant correlations were found between the percentage of students achieving satisfactory scores in mathematics and reading tests and the indoor temperature and ventilation rates (Haverinen-Shaughnessy et al., 2015).

Primary Schools in Izmir

In the study conducted, the concentrations of volatile organic compounds (VOCs), including formaldehyde, were measured in the classrooms, kindergartens, and outdoor playgrounds of three primary schools in Izmir, Turkey's third most populous city, during the spring, winter, and autumn seasons. The three state schools selected for measurement were chosen based on their characteristics, including the structure and geographical features of School-1, School-2, and School-3. Schools 1 and 2 are located in the city center, while School 3 is situated in a district farther from the city centre. Measurements were taken in a classroom, a kindergarten, and a school playground during the winter, spring, and autumn months when students were actively using the facilities, specifically between 11:00 AM and 4:00 PM on weekdays (Sofuoglu et al., 2011).

VOC concentrations in three primary schools were measured across three seasons (winter, spring, and autumn) in Izmir, Turkey. Formaldehyde was detected in the samples. Excluding formaldehyde, the measured VOC count ranged from 25 (School 2, autumn) to 37 (School 3, spring) in at least one sample, while the overall count was between 12 and 19 (mean = 16) across all samples. The concentrations measured in classrooms are presented as a season-school matrix. Compounds such as benzene, chloroform, 1,3-dichlorobenzene, 1,4-dichlorobenzene, naphthalene, toluene, trichloroethene, and xylenes were found at relatively higher concentrations. Toluene and benzene were among the three most abundant compounds, with overall average concentrations of 18.7 and 10.4 g / m3, respectively and were significantly higher than the remaining six components (Sofuoglu et al., 2011). Figure 2 illustrates the amount of VOCs present in kindergartens.

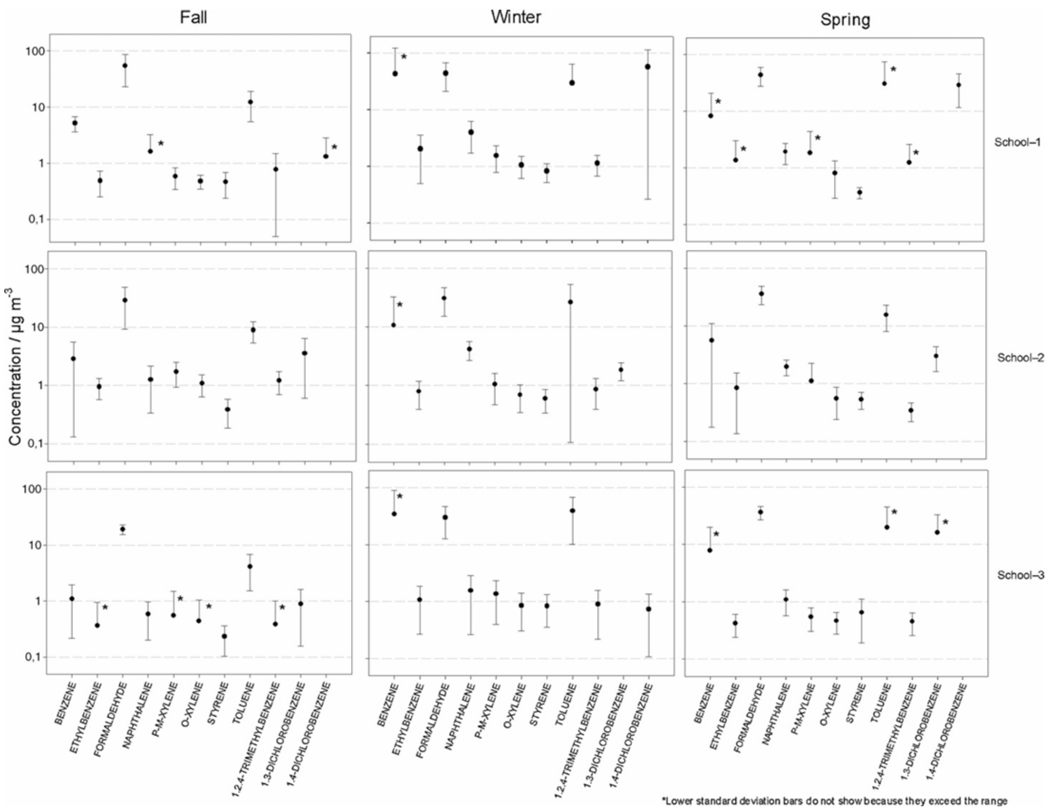

Figure 2. Concentrations of VOCs in the Indoor Environment (Sofuoglu et al., 2011).

Average concentrations measured in the two city schools differ significantly. Toluene levels are low in winter and spring but increase in the fall, while benzene concentrations are higher in winter. On average, toluene concentrations in the fall are 2.6 times higher in city schools compared to the suburban school, and benzene concentrations are 4.4 times higher. However, this trend reverses in winter and spring, when the suburban school exhibits higher average concentrations—1.4 times higher for toluene and 2.0 times higher for benzene (Sofuoglu et al., 2011).

All three schools studied had a kindergarten, and samples were collected from these kindergartens for analysis. The measurements indicated that toluene and benzene were the compounds with the highest concentrations, as shown in Figure 3.

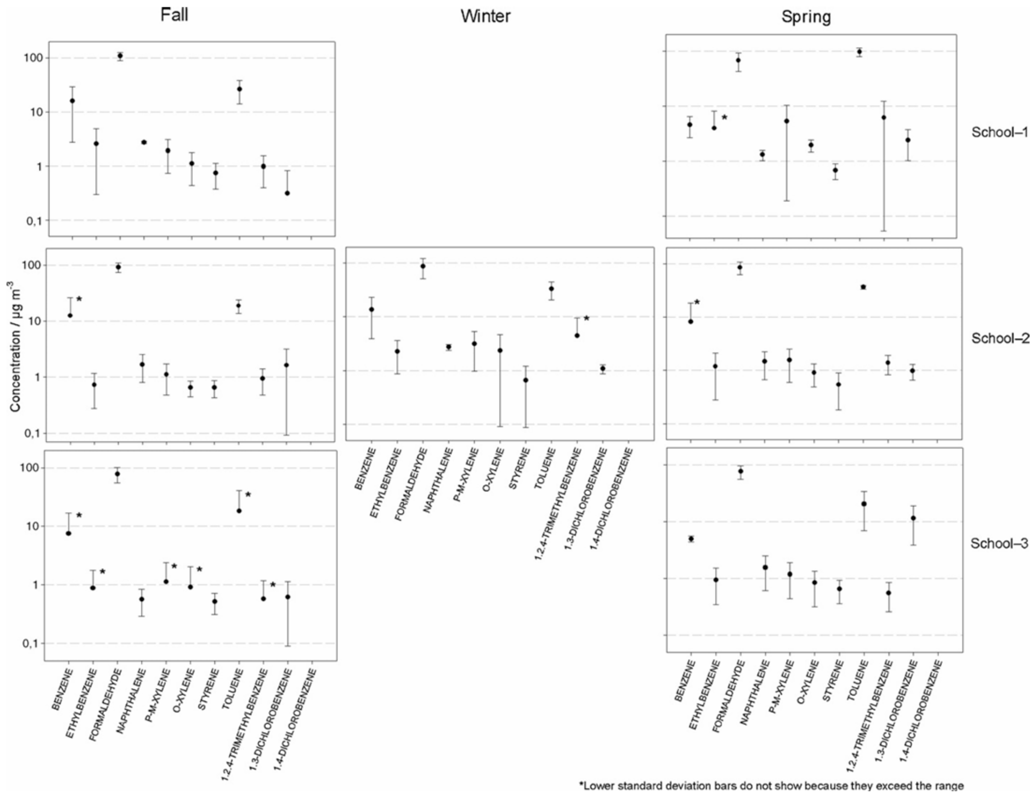

Figure 3. Concentration of indoor air pollutants (Sofuoglu et al., 2011).

Kindergarten in the Sarıyer District

Temperature grades should be set at 20 °C. An evaluation of the graph above indicates that the average temperature, which begins at 18 degrees, rises to approximately 22 degrees during the day. A more stable temperature of 20 degrees is desired. On the measurement dates, the average outdoor temperature is around 13 degrees. If natural ventilation is utilized in classrooms, the relative humidity should be maintained at 65%. The graph shows that relative humidity starts at 50%, initially increases to an average of 55%, and then decreases to 45%. On these measurement dates, the average outdoor relative humidity is 69%. The ideal indoor CO_2 concentration should range between 800 ppm and 1200 ppm. It is noted that CO_2 levels remain high until 10:00 AM, after which they begin to decline due to natural ventilation. The concentration then rises again until 14:00, followed by another decrease due to ventilation (Figure 4) (Altaca, 2015).

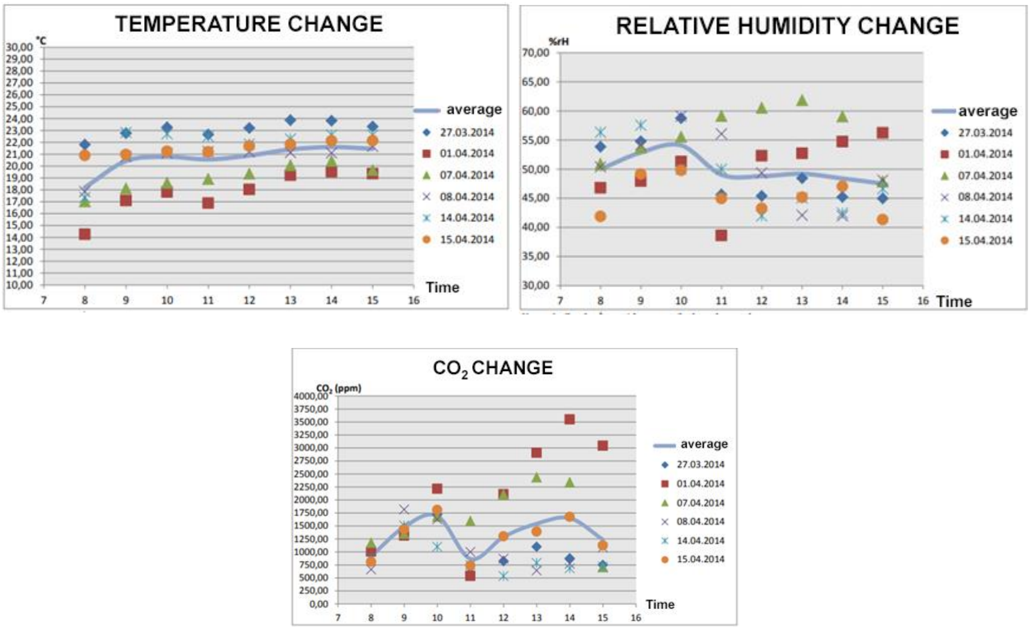

Figure 4. Changes in Temperature, Relative Humidity and CO_2 levels (Altaca, 2015).

Kindergarten in the Bakırköy District

In the morning, the temperature is stable as students enter the classroom, reaching a peak of 24 degrees Celsius. The average outdoor temperature on the measurement dates is 15 degrees Celsius. Relative humidity fluctuates significantly from day to day, ranging from 45% to 55% on average. During these measurement dates, the average outdoor relative humidity is 66%. The concentration of CO_2 is at an acceptable level before students arrive at school; however, it increases afterward. In the afternoon, CO_2 levels decrease again following additional ventilation, but they remain above the recommended level (Figure 5) (Altaca, 2015).

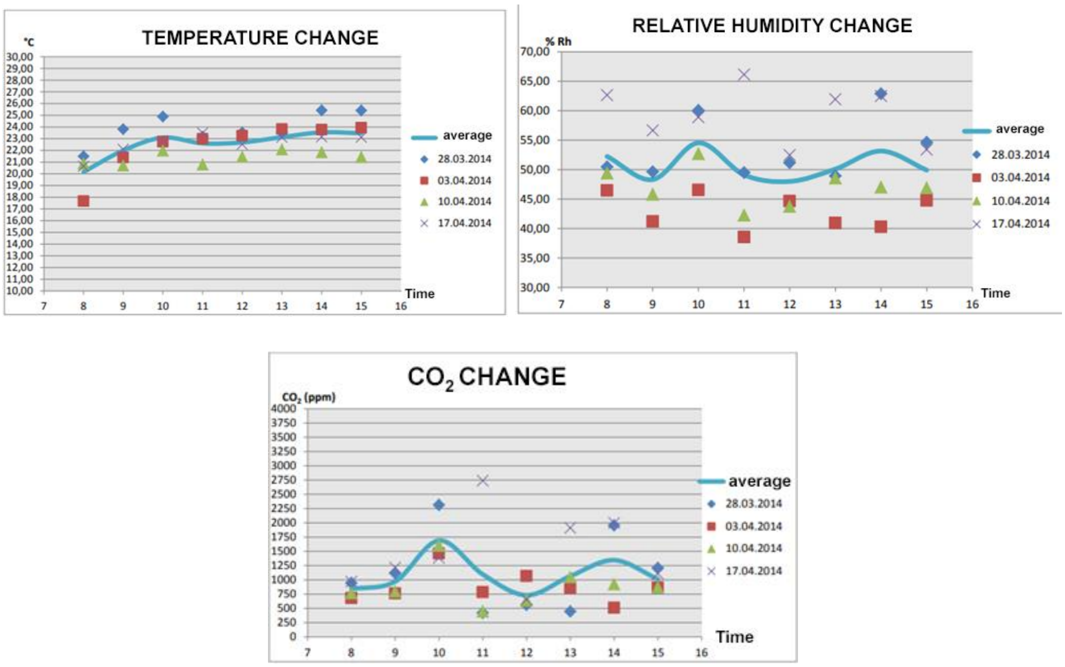

Figure 5. Changes in Temperature, Relative Humidity, and CO_2 levels (Altaca, 2015).

Primary School in Sariyer

It has been observed that there is a trend of increasing temperatures throughout the day. The average outdoor temperature is approximately 14 degrees Celsius. Additionally, relative humidity levels can drop to as low as 30 percent. During this period, the average relative humidity in the workplace is around 66 percent. The initial levels of CO_2 are significantly higher compared to the other two kindergartens. CO_2 levels decrease before noon due to subsequent ventilation, then rise again before decreasing once more with the afternoon ventilation (Figure 6) (Altaca, 2015).

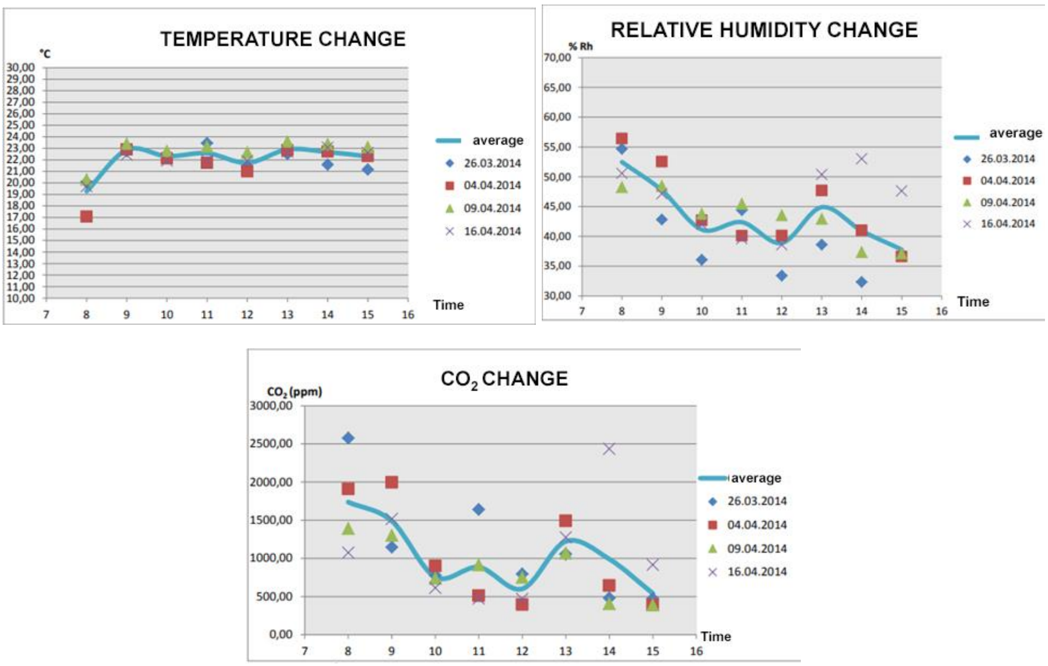

Figure 6. Changes in Temperature, Relative Humidity, and CO_2 levels (Altaca, 2015).

Sanliurfa Fatih Sultan Mehmet Primary School

According to the measurements conducted at Fatih Sultan Mehmet Primary School, the CO_2 levels in March, April, May, and June ranged from a minimum of 498.2 ppm to a maximum of 1496.16 ppm in April. During the period from September to February, CO_2 levels fluctuated between a high of 3238.83 ppm and a low of 1279.2 ppm. Lee and Chang (2000) found that indoor CO_2 concentrations in five different classrooms in Hong Kong exceeded ASHRAE standards due to overcrowding and inadequate ventilation. Their research indicated that CO_2 accumulation began to rise at the start of lessons, decreased during breathing periods, and increased again at the beginning of the lesson. PM10 value reached the level of 228 µg/m3 especially in December. This level is the highest PM10 level measured over the entire measurement. The reason for this situation is thought to be due to the use of stoves for heating purposes, since the economic level of the measurement area is lower than other regions. Outdoor PM_{10} is above the level of 97.4 µg/m3. Indoor $PM_{2.5}$ value was also high, in December, it was measured in parallel with the PM10 value of 190.6 µg/m3. Between March and June, the lowest PM_{10} 15.2 µm/m3, the highest PM10 58.66 µg/m3 in June, the highest $PM_{2.5}$ value in March 28.3 µg/m3 and the lowest value in June was 4.6 µg/m3. Measured with an average of m3 (Figure 8) (Yildiz, 2020). Figure 7 show the classroom.

Figure 7. Classroom at Fatih Sultan Mehmet Primary School (Yildiz, 2020).

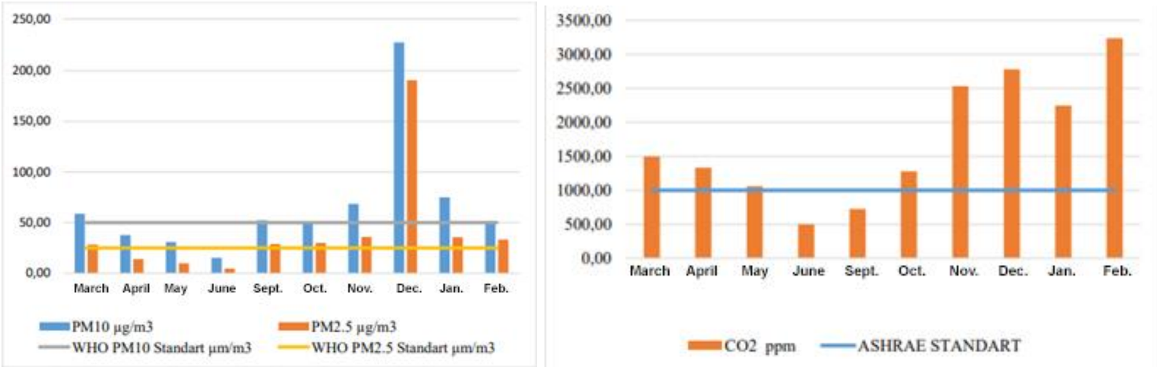

Figure 8. Results of PM_{10} and $PM_{2.5}$ and CO_2 values measured in Fatih Sultan Mehmet Primary School (Yildiz, 2020).

Sanliurfa Karaköprü Primary School

According to the measurements conducted at Karaköprü Primary School, the CO_2 levels recorded in March, April, May, and June ranged from a minimum of 460.2 ppm to a maximum of 1266.875 ppm in June. During the period from September to February, the highest CO2 level was 2311.14 ppm in January, while the lowest was 746.71 ppm in September. The lowest PM_{10} value was measured at 20.57 µg/m³ in June, and the highest was 81.28 µg/m³ in November. The lowest $PM_{2.5}$ value recorded was 8.42 µg/m³ in June, with a maximum of 47.14 µg/m³ in November (Figure 10) (Yildiz, 2020). Figure 9 shows the classroom.

Figure 9. Classroom at Karaköprü Primary School (Yildiz, 2020).

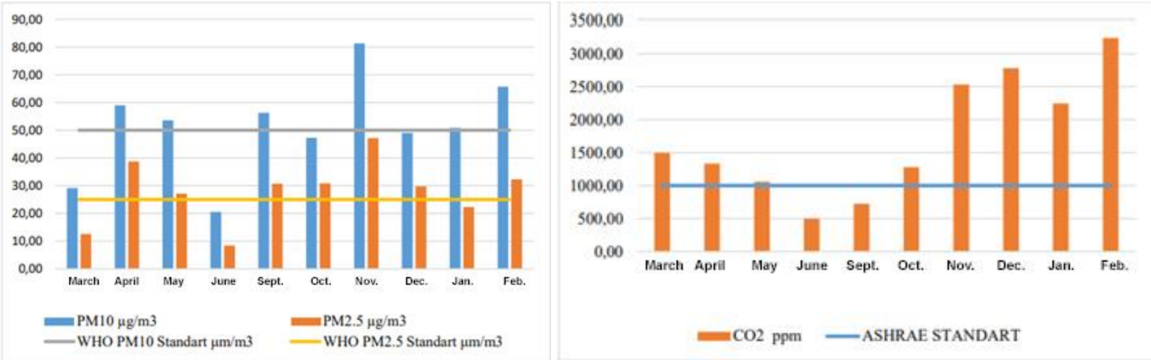

Figure 10. Results of PM_{10}, $PM_{2.5}$ and CO_2 values measured at Karaköprü Primary School (Yildiz, 2020).

Sanliurfa Cengiz Topel Primary School

According to the measurement results obtained at Cengiz Topel Primary School, the highest PM10 value recorded in March was 59.85 µg/m³, while the highest PM2.5 value for the same month was determined to be 23 µg/m³. In contrast, the highest PM_{10} value in December reached 85.28 µg/m³, and the PM2.5 value was measured at 48.14 µg/m³. Notably, the CO_2 concentration was recorded at 1031.83 ppm even in June, which is significantly higher than the values observed in other schools during the same month. This discrepancy can be attributed to the fact that while other schools had only 5 to 6 students attending in June, Cengiz Topel Primary School had between 25 and 30 students present. The lowest CO_2 value recorded was 701 ppm in September, while the highest was 2973 ppm in January (Figure 11) (Yildiz, 2020).

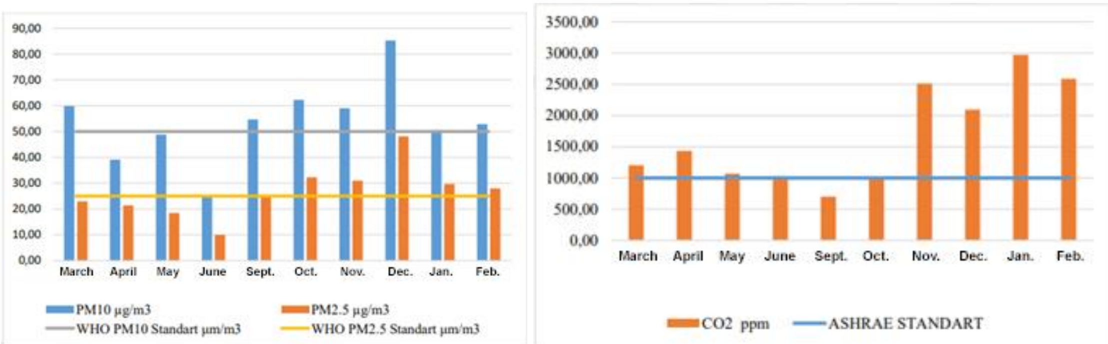

Figure 11. Results of PM_{10}, $PM_{2.5}$ and CO_2 values measured at Cengiz Topel Primary School (Yildiz, 2020).

4.3. Indoor Air Quality in Universities

Higher Education Institution, Campus 1, in Sanliurfa Province

In this study, temperature, relative humidity, carbon dioxide levels, and particulate matter of various diameters were measured simultaneously in three different classrooms at the university in Şanlıurfa (Kus, 2007).

- Measurement in the AD-1 Classroom: Figure 12 is a photograph taken during the indoor air measurements in the AD-1 classroom. The variations in indoor temperature, relative humidity, and CO_2 levels are presented in Figure 9. These figures also compare the measurements with the limit values established in the ASHRAE 62-1989 and 2001 standards for indoor air quality. Figure 13 indicates that the internal relative humidity values fall within the limits specified by the standard. However, it is evident from Figure 13 that the carbon dioxide levels exceed the 1000 ppm threshold recommended by ASHRAE. Additionally, Figure 13 shows that the changes in PM_1 and $PM_{2.5}$, which are the smallest particulate matter, are minimal, while the variations in larger particulate matter are significant (Kus, 2007).

Figure 12. Photograph taken during indoor air measurements in the AD-1 classroom.

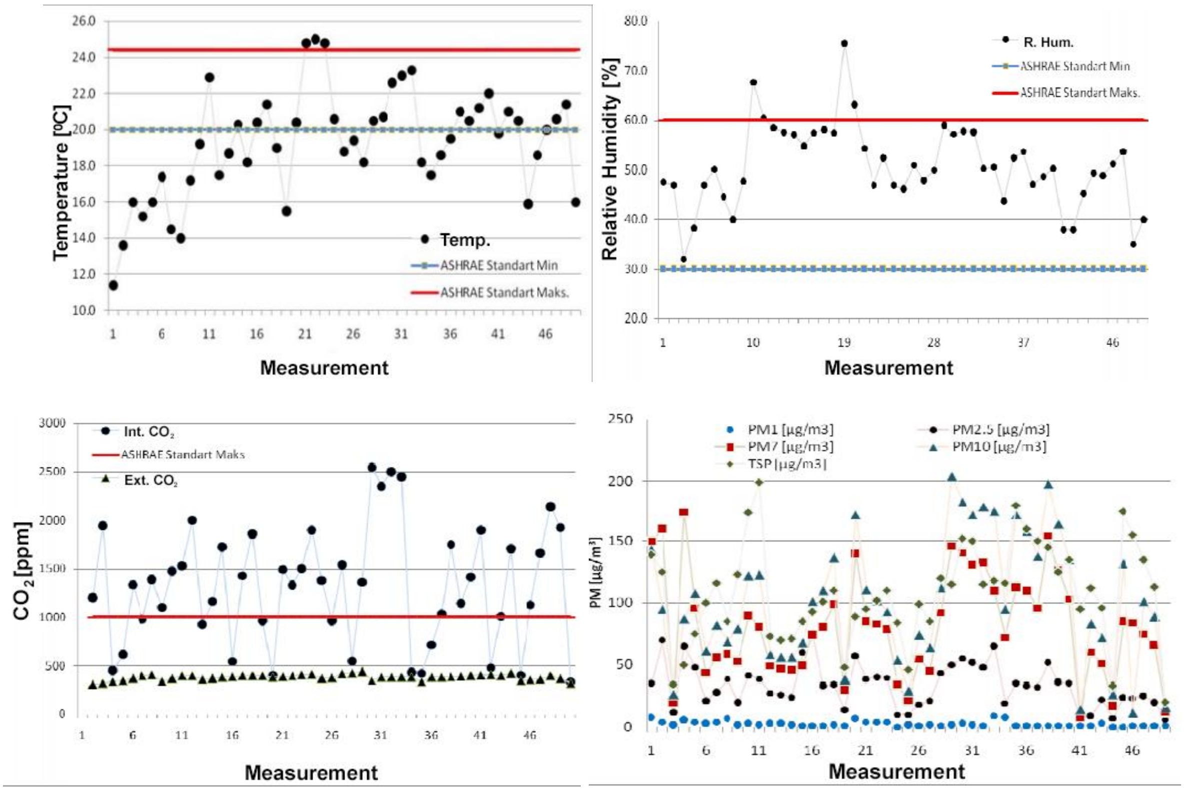

Figure 13. Changes in Temperature, relative humidity, CO_2, and PM in the AD-1 classroom (Kus, 2007).

Measurements in the AD-2 Classroom: The measurements in the AD-2 classroom (see Figure 14) align with those taken in the AD-1 classroom. It was noted that the indoor relative humidity remained within the limits specified by ASHRAE standards, while other parameters deviated from the established values. Additionally, the ratio of internal to external particulate matter (PM) consistently exceeded 1. Figure 15 illustrates the variations in temperature, relative humidity, CO_2 levels, and PM concentrations in the AD-2 classroom (Kus, 2007).

Figure 14. Photograph of the AD-2 classroom (Kus, 2007).

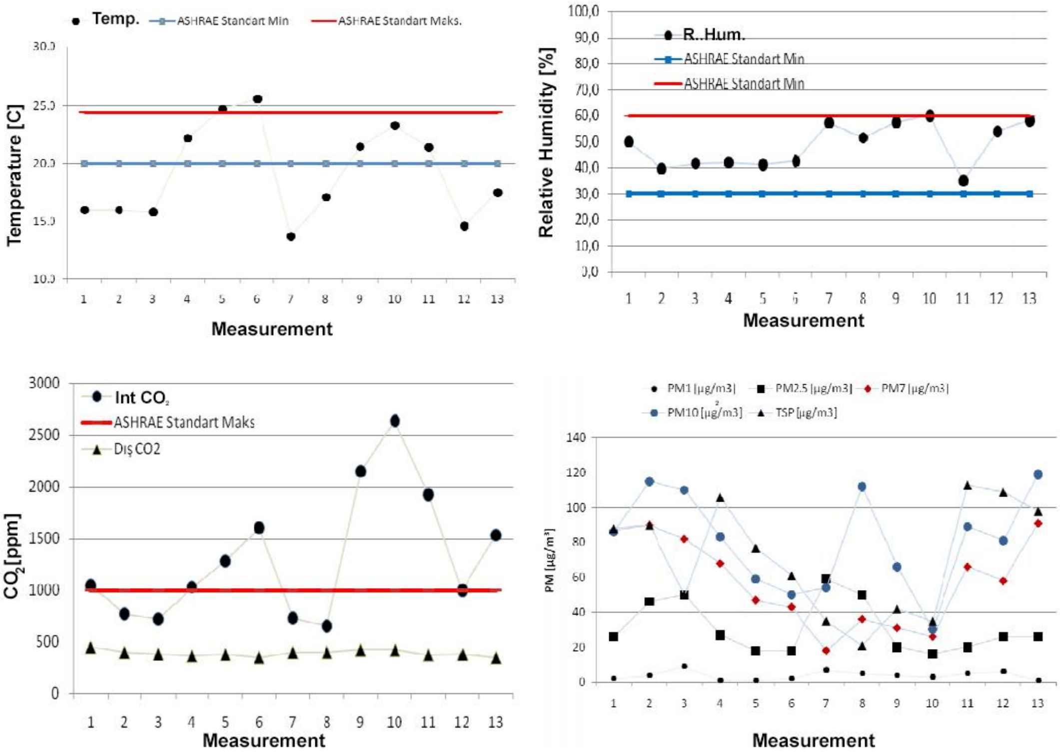

Figure 15. Changes in Temperature, relative humidity, CO_2, and PM in the AD-2 classroom (Kus, 2007).

Measurement in the AD-3 Classroom: The changes in indoor air quality measurement parameters for the winter term in the AD-3 classroom (Figure 16) at Campus I are illustrated in Figure 17. As shown in the figures, the variations in these parameters exhibit a similar trend to the results observed in the AD-1 and AD-2 classrooms (Kus, 2007).

Figure 16. Photograph of the AD-3 classroom (Kus, 2007).

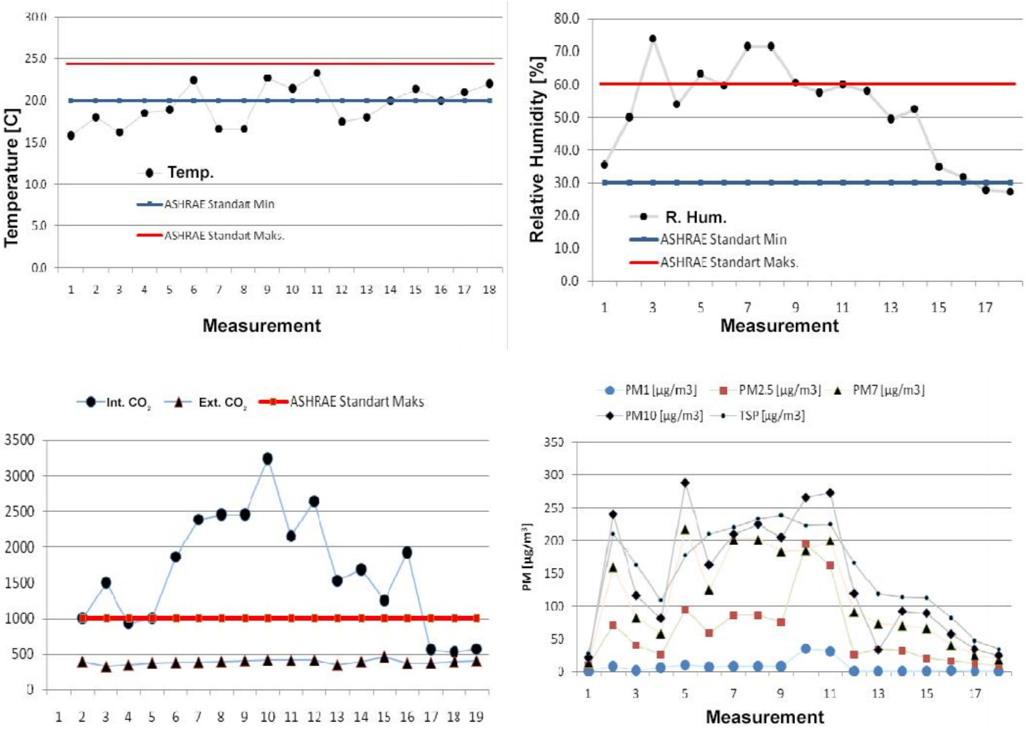

Figure 17. Changes in Temperature, relative humidity, CO_2, and PM in the AD-3 classroom (Kus, 2007).

Higher Education Institution Campus 2 in Sanliurfa Province

At the other campus in Şanlıurfa, measurements were taken in two different classrooms. Figure 19 displays the results of the measurements conducted in the BD-2 classroom (Figure 18).

Figure 18. Photograph of BD-2 class (Kus, 2007).

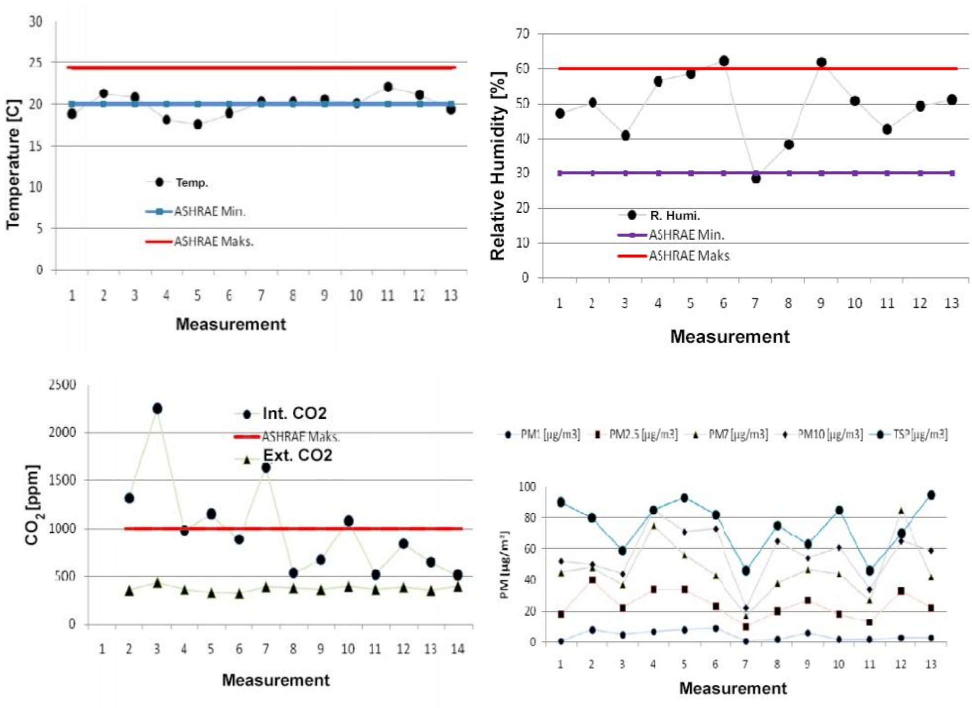

Figure 19. Changes inTemperature, relative humidity, CO_2, and PM in the BD-2 classroom (Kus, 2007).

Measurement in the BD-3 Classroom: Figure 20 illustrates the variation in measurement results taken indoors and outdoors during winter for the BD-3 class. As shown in Figure 16, the indoor temperature averaged around 20 °C, with only a few measurements indicating lower values. The indoor relative humidity was found to be within the limits specified by ASHRAE standards, ranging from 40% to 60%. It was observed that CO_2 levels changed significantly at concentrations exceeding 1000 ppm.

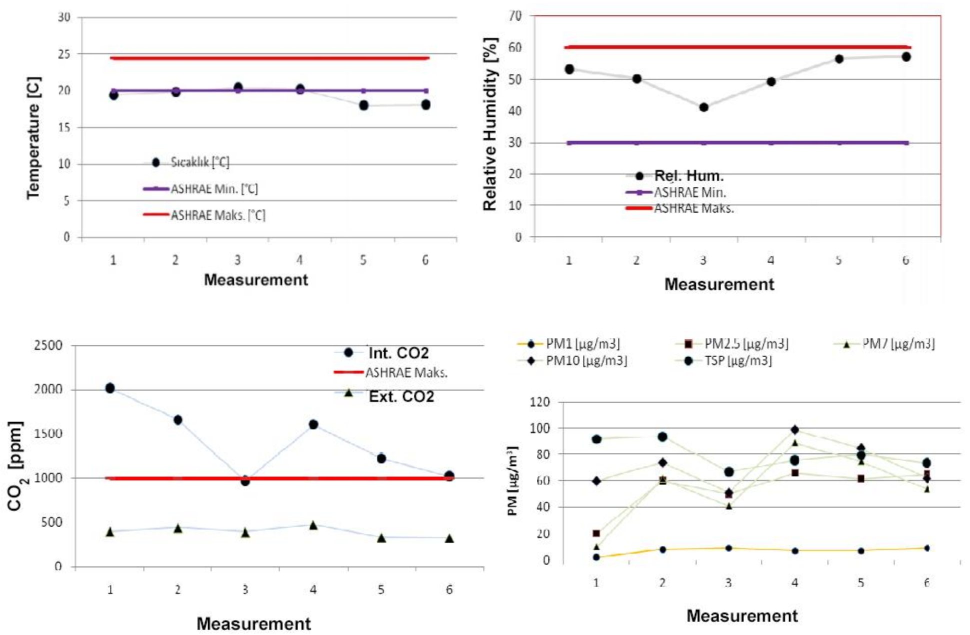

Figure 20. Changes in Temperature, relative humidity, CO_2, and PM in the BD-3 classroom (Kus, 2007).

METU Faculty of Architecture

One classroom and one design studio within the Faculty of Architecture were analysed in this study. To assess the current indoor air conditions in these spaces, measurements of temperature, relative humidity, and carbon dioxide levels were taken at two points in each location between September 13, 2011, and February 24, 2012. Additionally, air velocity measurements were conducted at ten-day intervals from November 26, 2011, to January 5, 2012. Figure 21 illustrates the temperature and CO_2 measurements recorded in the classroom (Betuz, 2012).

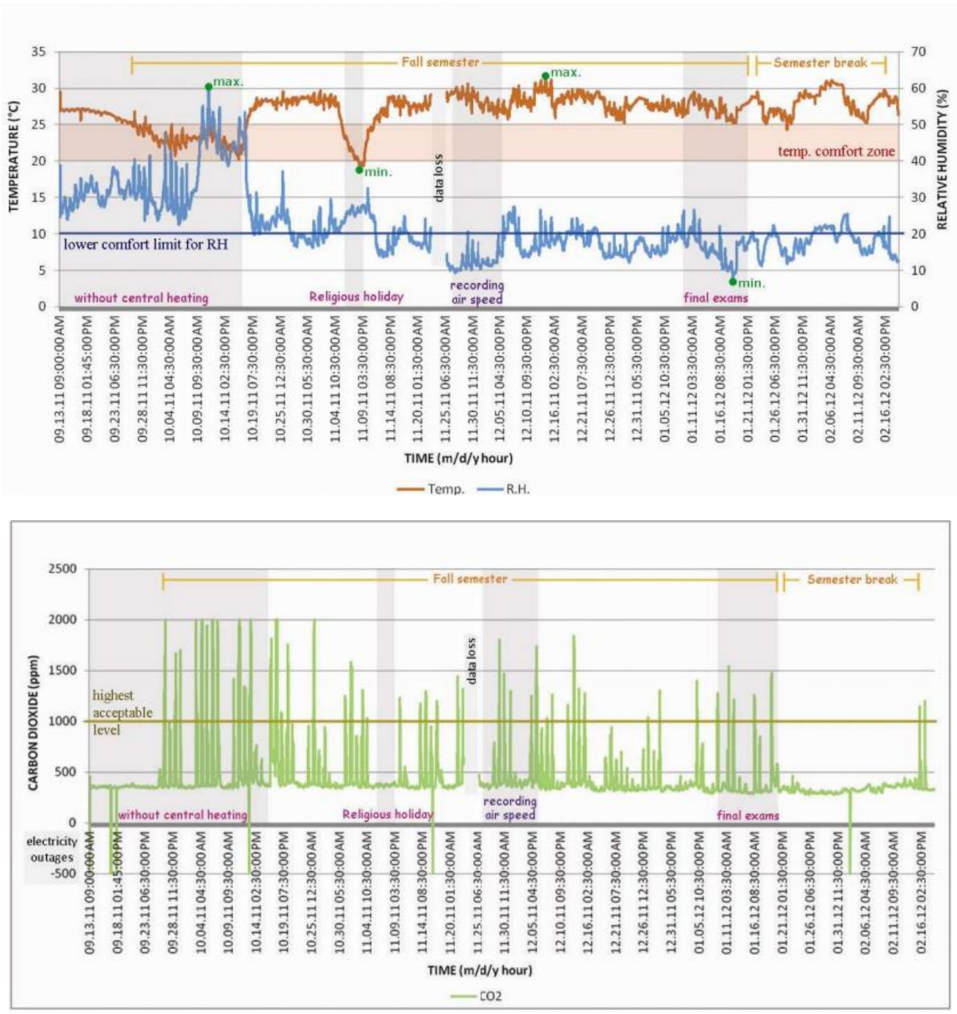

Figure 21. Temperature and CO_2 Levels in the Classroom (Betuz, 2012).

Figure 22 presents the temperature and CO_2 measurement results obtained at the architectural studio.

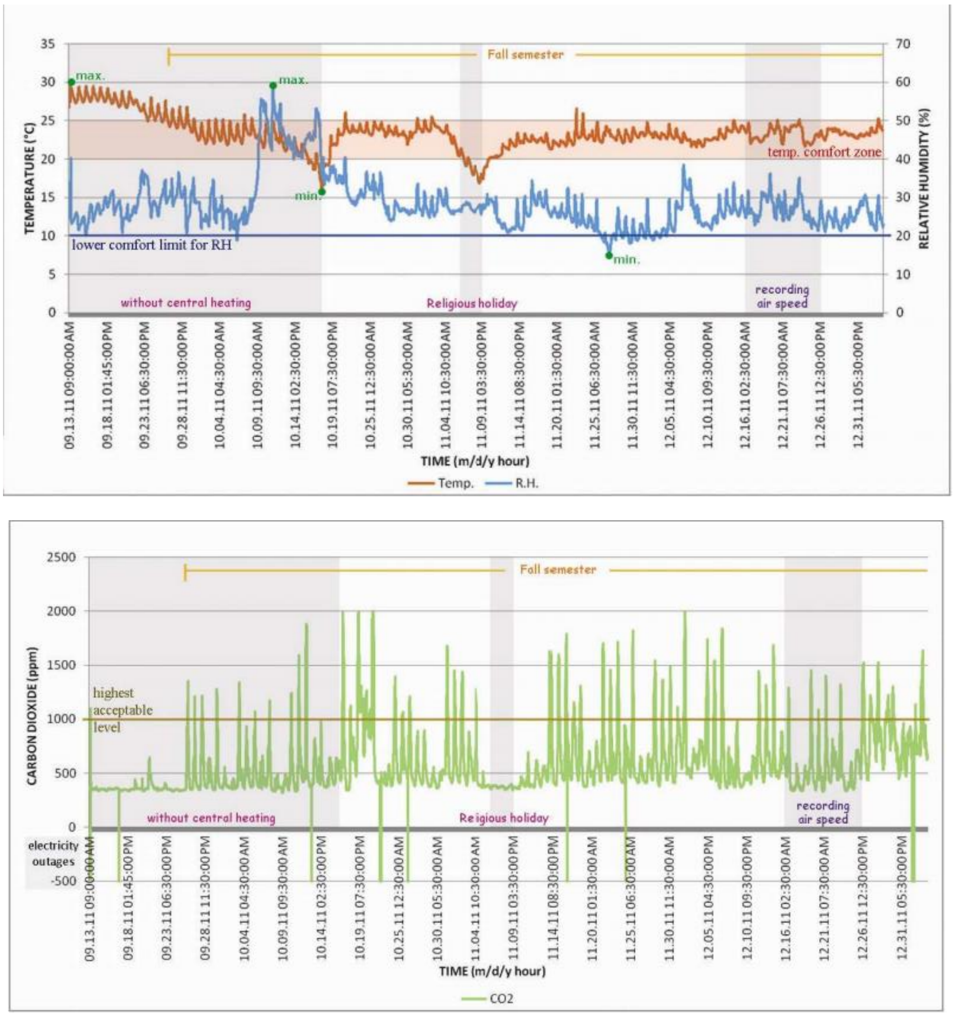

Figure 22. Temperature and CO_2 Levels in the Studio (Betuz, 2012).

5. DISCUSSION AND FUTURE WORK

The study focused on the indoor air quality of educational buildings, particularly those in Turkey where field studies are available. The analysed studies indicate that carbon dioxide levels in classrooms exceed acceptable limits, especially during the winter months. This situation negatively impacts the performance and health of students attending classes in these environments. Additionally, research shows that factors such as relative humidity and temperature also significantly affect indoor air quality. The literature underscores the necessity of implementing both natural and mechanical ventilation systems to enhance indoor air quality for the reasons mentioned.

When examining the studies in the literature, it is evident that future research should focus on developing new strategies to enhance indoor air quality. To create these strategies, optimization techniques can be employed to design hybrid ventilation models that integrate both natural and mechanical ventilation systems. Furthermore, real-time measurements should be conducted to inform improvement recommendations for existing buildings, and measures should be implemented to enhance indoor air quality once the current conditions are assessed. Additionally, future studies should evaluate the impact of materials used in educational buildings on indoor air quality.

6. CONCLUSION

The importance of indoor air quality in educational buildings is undeniable. In addition to significantly impacting the health of users, it also plays a crucial role in students' academic performance. This study compiles research on indoor air quality conducted in educational buildings across Turkey and analyses the results in a comparative manner. A common finding from the analysed studies is that inadequate ventilation and elevated carbon dioxide levels adversely affect student health.

According to the measurement results, the CO_2 levels in the classrooms peaked in February and reached their lowest point in June. This variation is influenced by factors such as the number of students, the building's location, the frequency of cleaning, and environmental conditions like temperature and relative humidity. Furthermore, a decline in indoor air quality can lead to health issues and increased absenteeism among students. The observation that CO_2 levels can rise up to four times during periods of intensive use of educational buildings highlights the inadequacy of the ventilation systems in these facilities.

In these studies, it was observed that the relative humidity and CO_2 concentration fluctuated throughout the year in the classrooms where measurements were taken. The levels of these parameters can be regulated through various measures. These measures include:

- It is advisable to prefer mechanical ventilation systems in both existing schools and those that are yet to be constructed.
- Reducing or preventing the factors that contribute to the increase of pollutant levels.
- Hours of repair and renovation work that generate pollution should be scheduled when children are not in school to prevent their exposure to harmful pollutants.
- Classes should be ventilated during recess in schools. Windows that are not fully opened should remain open during lessons if necessary.
- Information about indoor air quality should be provided to school personnel, teachers, students, and administrative units.
- It is recommended that classrooms be cleaned regularly to reduce the elevated levels of particulate matter (PM) observed.

REFERENCES

ÅHman1*, M., L Undin, A., M Usabašić, V., & S¨ Derman, E. (2000). Improved health after intervention in a school with moisture problems. Indoor air, 10(1), 57-62.

Akman, Y., Ketenoğlu, O., Evren, H., Kurt, L., & Düzenli, S. (2000). Environmental pollution (environmental biology)(in Turkish). Palme Publishing, Ankara, 189.

Akman, A. (2005). Human health, healthy building and building biology (in Turkish). Construction Journal, 279, 89-92.

Altaca, S. İ. (2015). Indoor air quality management application in primary schools (in Turkish) (Doctoral dissertation, Bahçeşehir University Institute of Science).

Balanli, A., & Tuna Taygun, G. (2005). Building biology and asbestos. Architect (in Turkish). ist, 16, 107-110.

Balanli, A., Ozturk, A., Karabiber, Z., Unver, R., Gedik, G., Yavuz, G., & Vural, M. (2006). An examination and evaluation of YTU library and documentation building in terms of building biology. Building and environment, 41(8), 1079-1098.

Bayer, C. W., Crow, S. A., & Fischer, J. (2000). Causes of indoor air quality problems in schools: Summary of scientific research (Revised ed.) (Report No. ORNL/M-6633/R1). U.S. Department of Energy, Oak Ridge National Laboratory.

Betuz, N. E. (2012). Assessment of indoor air quality in crowded educational spaces [Master's thesis]. Middle East Technical University.

Bold, A., Toros, H., & Şen, O. (2003). Effects of Magnetic Field on Human Health (in Turkish). III. Atmospheric Sciences Symposium, Istanbul, 62 – 68.

Buchanan, B. (2007). Sick Buildings, Sick Students: Poor air quality and other environmental irritants can lead to health concerns for your students and staff. American School Board Journal, 194(6), 48.

Burge, P. S. (2004). Sick building syndrome. Occupational and environmental medicine, 61(2), 185-190.

Calderón-Garcidueñas, L., Mora-Tiscareño, A., Ontiveros, E., Gómez-Garza, G., Barragán-Mejía, G., Broadway, J., ... & Engle, R. W. (2008). Air pollution, cognitive deficits and brain abnormalities: a pilot study with children and dogs. Brain and cognition, 68(2), 117-127.

Cummins, S. K., & Jackson, R. J. (2001). The built environment and children's health. Pediatric Clinics of North America, 48(5), 1241-1252.

Dannecker, G. (2006). Kawasaki syndrome. Monatsschrift Kinderheilkunde, 154, 872-879.

De Nevers, N. (2010). Air pollution control engineering. Waveland press.

De Giuli, V., Da Pos, O., & De Carli, M. (2012). Indoor environmental quality and pupil perception in Italian primary schools. Building and Environment, 56, 335-345.

EPA, H. B. (2001). Healthy People, a Vision for the 21st Century. US Environmental Protection Agency: Washington, DC, USA.

EPA, H. B. (1997). An Office Building Occupant's Guide to Indoor Air Quality. US Environmental Protection Agency: Washington, DC, USA.

EPA (2003b). Indoor Air Quality Tools for Schools: Communications Guide, Retrieved June 3, 2012 from the World Wide Web: http://www.epa.gov/iaq/schools/pdfs/publications/communicationsguide.pdf

Ercan, M. S. (2012). Green is your compass "environmental indicator" (in Turkish). X. International Symposium on Installation Technology in Construction, Proceedings Book, 30, 169-175.

Eric, M. (1994). Building Physics and Materials (in Turkish). Literatür Publishing, Istanbul, 173.

Esin, T. (2004). The role of building materials in the formation of indoor air quality affecting human health (in Turkish). Construction Journal, 275, 99-103.

Gokdayi, İ. (1997). The future of the environment: Approaches and policies (in Turkish). Turkish Environment Foundation.

Haverinen-Shaughnessy, U., Shaughnessy, R. J., Cole, E. C., Toyinbo, O., & Moschandreas, D. J. (2015). An assessment of indoor environmental quality in schools and its association with health and performance. Building and Environment, 93, 35-40.

Hwang, J. S., Chen, Y. J., Wang, J. D., Lai, Y. M., Yang, C. Y., & Chan, C. C. (2000). Subject-domain approach to the study of air pollution effects on schoolchildren's illness absence. American Journal of Epidemiology, 152(1), 67-74.

Jones, A. P. (1999). Indoor air quality and health. Atmospheric environment, 33(28), 4535-4564.

Keskin Y., Özyaral O.,Başkaya R.,Lüleci N.E.,Avcı S.,Susur M. (2005). ''Investigation of the Microbiological Quality of the Indoor Atmosphere of a Public Building and the Perception of the Work Environment in Terms of Sick Building Syndrome'' (in Turkish). Asthma Allergy Immunology, 3: 56 – 67.

Kosonen, R., & Tan, F. (2004). The effect of perceived indoor air quality on productivity loss. Energy and Buildings, 36(10), 981-986.

Kuş, M. (2007*). Investigation and modelling of indoor air quality in classrooms of higher education institutions in Şanlıurfa province (in Turkish)* [Doctoral thesis]. Balıkesir University Institute of Science.

Meyer, H. W., Würtz, H., Suadicani, P., Valbjørn, O., Sigsgaard, T., & Gyntelberg, F. (2004). Molds in floor dust and building-related symptoms in adolescent school children. Indoor air, 14(1).

Ozer, U. (1995). Introduction to Environmental Sciences (in Turkish). Uludağ University Publications, Bursa.

Ozyaral, O., & Keskin, Y. (2005). Health effects of indoor atmosphere: cacosmia (bad odour) syndrome (in Turkish). Asthma Allergy Immunology, 3(2), 86-96.

Peters, A., Dockery, D. W., Heinrich, J., & Wichmann, H. E. (1997). Short-term effects of particulate air pollution on respiratory morbidity in asthmatic children. European Respiratory Journal, 10(4), 872-879.

Quagraine, V., & Boschi, N. (2008). Behavioral changes can help prevent indoor air-related illnesses in Ghana. Building and environment, 43(3), 355-361.

Rowley, A. H., & Shulman, S. T. (1998). Kawasaki syndrome. Clinical microbiology reviews, 11(3), 405-414.

Senkal, F. (2001). The effects of moisture and mould on human health (in Turkish). Building Journal, 233, 89-90.

Sofuoglu, S. C., Aslan, G., Inal, F., & Sofuoglu, A. (2011). An assessment of indoor air concentrations and health risks of volatile organic compounds in three primary schools. International journal of hygiene and environmental health, 214(1), 36-46.

Taygun, G. T., & Balanlı, A. (2008). Building Product-Environment Interaction in Life Cycle Processes (in Turkish). Megaron, 3(1).

Tezer, H., & Seçmeer, G. (2005). Innovations in Kawasaki disease (in Turkish). Hacettepe Medical Journal, 36, 105-110.

Thörn, Å. (1998). The sick building syndrome: a diagnostic dilemma. Social science & medicine, 47(9), 1307-1312.

Tuncer, A., & Soyer, Ö. U. (2005). Sick building syndrome. Asthma Allergy Immunology (in Turkish). 3(2), 97-102.

US Consumer Product Safety Commission. (1996). Indoor Air Pollution: An Introduction for Health Professionals. DIANE Publishing.

World Health Organization. (1983). Indoor air pollutants: exposure and health effects EURO Reports and Studies No 78. WHO Regional Office for Europe: Copenhagen.

Yaren, H., & Karayilanoğlu, T. (2005). Radiation and its effects on human health (in Turkish). TAF Preventive Medicine Bulletin, 4(4), 199-208.

Yildiz, M. (2020*). Investigation of Indoor Air Quality in Primary Schools (in Turkish)* [Doctoral thesis] Harran University.