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Theoretical and experimental analysis of indoor air quality. Case study: air quality in offices

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Abstract. The paper presents a case study on office air quality. First, it highlights the importance of selecting low-emission building materials and furniture to reduce indoor pollution. It also discusses the use of efficient energy recovery systems and adapted ventilation to ensure good air quality without increasing energy consumption. The study involved measurements of temperature, humidity and CO_2 concentration in two offices, using a Testo instrument equipped with an indoor air quality probe. The data were statistically analysed, highlighting the effect of opening windows on reducing CO_2 concentrations and moderating temperatures. In conclusion, the paper highlights the importance of air purification and efficient ventilation for maintaining a healthy and comfortable environment in offices.
Keywords (3–5): indoor air quality, humidity, CO_2 concentration.

1. Introduction

The main purpose of buildings is to create comfortable thermal conditions for occupants with low energy consumption. A large part of the population spends more than 20 hours a day in an artificial environment: at home, at work, in shops, in various places of recreation. This has led to increased interest in studying and understanding the influence of the indoor environment on humans [1]. This has led to a growing interest in studying and understanding the influence of indoor environments on humans. As more research has been conducted in this field, national and international standards have improved. These standards cover aspects such as indoor air quality, temperature, mean radiant temperature, humidity levels, air movement, and human activity, including clothing.

An environment can be characterized from a hygrothermal perspective by indoor air temperature, the temperature of boundary surfaces, humidity and air movement speed. Research based on experiments with large groups of people in environments with different characteristics has concluded that thermal comfort can be achieved with various combinations of microclimatic parameters, depending on the nature of the activity and clothing. For production rooms the notion of comfort is replaced by the notion of work efficiency, corresponding to the activity performed [2]. Working conditions must ensure the performance of work with high efficiency and the maintenance of health. There is a widespread concern that the indoor environment can affect the health of the occupants, comfort and performance [3].

Consequently, the state of comfort is a characteristic of very high technical complexity, it can be negatively influenced by a multitude of factors. Individual performance is affected by the work environment, ability and personal motivation. The working environment encompasses factors such as the indoor climate, access to specific services and infrastructure, all of which individually and collectively impact health [4]. The quality of the environment is determined by the building's exterior and interior design, the characteristics and thermal conditions of the indoor air, the noise level and lighting intensity [5]. Numerous studies have been conducted on thermal comfort conditions in office buildings and workplaces, as well as their impact on individual productivity [5], [6]. Several studies have shown that if someone lives in a comfortable environment, their performance and productivity increase [7]. According to these, the productivity of office work without physical effort is maximum at a temperature of 22°C. The efficiency of office activities has an increasing trend up to temperatures of (21 – 22)°C, and decreases with increasing temperature above (23 – 24)°C.

The sustainable building model emphasizes the importance of a healthy indoor environment for occupants [6]. A healthy indoor microclimate is characterized by factors such as thermal comfort, adequate lighting, low noise levels, and high indoor air quality. Maintaining good indoor air quality means ensuring pollutant levels and thermal conditions (such as temperature and relative humidity) are at levels that do not harm the health, comfort, or productivity of building occupants. Indoor air is complex, containing various pollutants from multiple sources, which makes it difficult to manage effectively [8].

2. Assessing air quality and thermal comfort

2.1. Physical indicators of the indoor microclimate

To achieve thermal comfort, it is essential to maintain an average operative temperature that takes into account air temperature, surface temperatures, humidity, and air velocity, while also considering the type of activity and the clothing of the occupants [4].

Atmospheric air consists of dry air and water vapor, along with small quantities of gases such as argon and carbon dioxide. Humid air can store moisture in the form of gas, liquid, or solid. When the air reaches its saturation point, it can no longer hold additional moisture, causing excess moisture to form as droplets, leading to the creation of fog.

2.2. The main parameters characterizing humid air

Moist air has several main characteristics, including pressure, temperature, humidity, specific heat, density, and enthalpy.

The pressure can be broken down into types like the partial pressure of dry air, water vapor, and total pressure.

Temperatures in moist air are described by dry bulb, wet bulb, and dew point temperatures.

Absolute humidity measures the moisture content, while relative humidity compares the current moisture level to the maximum possible at a given temperature.

Specific heat is the energy needed to raise the temperature of moist air, density refers to the mass per volume, and enthalpy is the total heat content of the air.

3. Case study: offices

Improving indoor air quality can be achieved by choosing low-emission building materials and furniture, which reduces overall pollution. High-quality air can be maintained even with low ventilation rates by using specialized ventilation, rather than traditional systems. Ensuring good air quality doesn't have to be costly or energy-intensive if ventilation systems provide clean air and are well-maintained and cleaned regularly. Proper upkeep of these systems is crucial to prevent them from becoming pollution sources.

3.1. Study method

The measurements were conducted in June in two offices: one located on the building's ground floor, with a single occupant facing east, and another on the top floor, where two individuals work, also facing east. The employees in these offices perform research and office tasks, they work with students and staff. Their work requires increased attention, high concentration, good communication, logical reasoning under time pressure, frequent use of advanced software. These tasks are typical in most office environments, so if the performance in these offices was affected by changes in the indoor environment, it would imply that similar office tasks elsewhere might also be impacted. The windows are [4]made of PVC with a thermal transfer coefficient of 0.8 $W/m^2{\cdot}K$, are airtight and were replaced in 2017. The outdoor air supply rate per person varied consistently throughout the day.

To gather data, measurements were taken in the offices using a Testo instrument equipped with an indoor air quality probe placed approximately 1 meter above the floor, across five measurement points, to determine the average air temperature and relative humidity. Testo specifications include temperature measurement between 0 and +50°C with an accuracy of ±0.5°C, humidity measurement between 5% and 95% relative humidity with varying accuracy based on the range, and CO_2 levels measured up to 10000 ppm with accuracy varying according to concentration.

3.2. Results

Next, the results and analysis of the temperature and relative humidity measurements taken inside the two offices will be presented.

3.2.1. Interpretation of the measured data in the top floor office

The data were statistically analysed, so for CO_2 concentration, the mean is 396.02 ppm, the median is 421.5 ppm, the standard deviation is 124.24 ppm, and the values vary between 239 ppm and 553 ppm. For humidity, the mean is 67.35 percent, the median is 67 percent, the standard deviation is 3.73 percent. For temperature, the mean is 25.15 degrees Celsius, the median is 25.3 degrees Celsius, the standard deviation is 1.24 degrees Celsius.

The figure 3.1 graphically illustrates the measurement results.

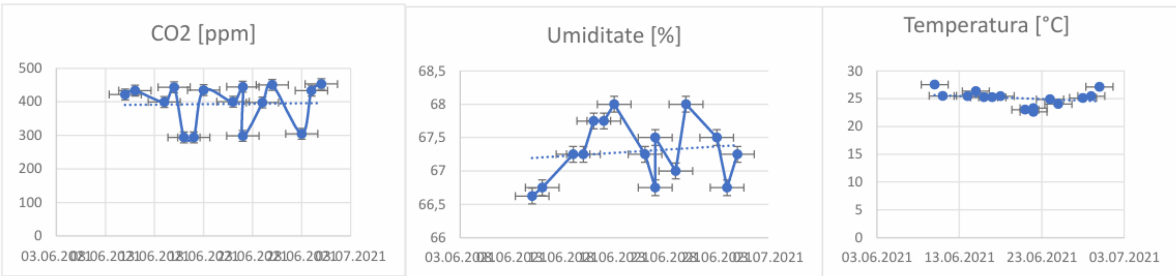

Figure 3.1 Air parameters measured in the top floor office

CO_2 concentration values range between 239 ppm and 553 ppm. Typically, concentrations are higher when the window is closed, reaching peaks of over 500 ppm, which suggests the accumulation of CO_2 in the closed space. When the window is open, CO_2 values are lower, for example: 357 ppm (10.06.21), 311 ppm (15.06.21), and 264 ppm (16.06.21), indicating better ventilation. Opening the window has a visible impact in reducing CO_2 values, ensuring better ventilation.

Humidity ranges between 65% and 77%. Higher values occur in most cases regardless of whether the window is open or closed, but we note that some days have maximum humidity (e.g. 77% on 17.06.21 and 24.06.21) without having contradictory observations. Humidity remains relatively constant regardless of the opening of the windows, which may indicate that the source of humidity is independent of ventilation.

Temperatures vary between 22°C and 28.8°C. The highest values are usually recorded when the windows are closed, suggesting an accumulation of heat (e.g. 28.8°C on 10.06.21, 28.7°C on 16.06.21). When the window is open, temperatures are more moderate, e.g. 28.8°C (10.06.21), 26.7°C (15.06.21) and 23.4°C (16.06.21). Temperatures are more moderate with the windows open, suggesting effective ventilation for temperature control.

3.2.2. Interpretation of the measurement results in the east-facing office on the ground floor

CO_2 concentrations range between 239 ppm and 553 ppm, indicating significant variation but concentrated around the median of 421.5 ppm, with a mean of 396.02 ppm and a standard deviation of 124.24 ppm. Higher CO_2 concentrations, such as 553 ppm and 548 ppm, could be the result of accumulation in a closed space without adequate ventilation. Opening the window significantly reduces CO_2 concentrations, e.g. 264 ppm and 239 ppm.

The figure 3.2 shows the measurement results.

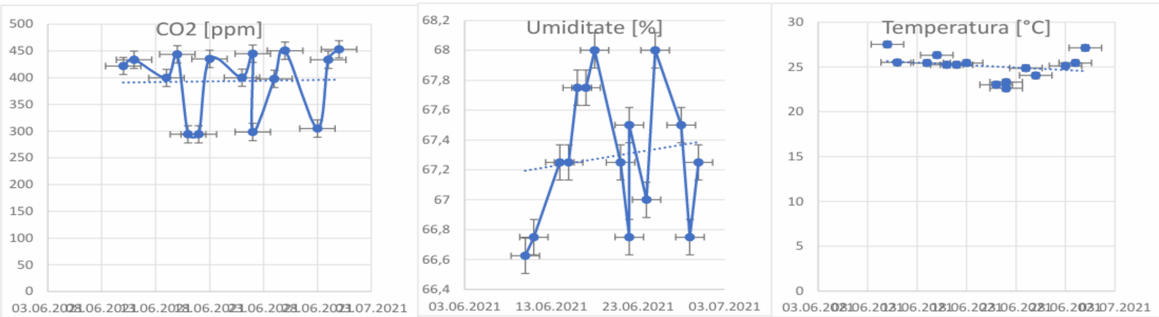

Figure 3.3 Air parameters measured in the ground floor office

Humidity ranges between 65% and 77%, with a mean of 67.35% and a standard deviation of 3.73%. High humidity can be influenced by the lack of adequate ventilation and the orientation of the room, which does not allow the air to dry quickly in the absence of sunlight.

The average temperature is 25.15°C, with a similar median of 25.3°C, suggesting stability. The standard deviation of 1.24°C reflects moderate variations between a minimum of 22.0°C and a maximum of 28.8°C. Lower temperatures, such as 22.0°C and 22.5°C, could indicate faster cooling in the absence of direct sunlight. However, higher values, such as 28.8°C and 28.7°C, suggest heat accumulation on warmer days, even without direct sunlight.

The orientation of the room to the east, which receives less direct sunlight, may influence the moderate temperatures and humidity stability. Significant variations in CO_2 values suggest accumulation in the enclosed space, especially when the windows are closed. Opening the window can help maintain a healthier and more comfortable environment by reducing CO_2 concentrations and, potentially, humidity.

4. Conclusions

To enhance indoor air quality, air purifiers are an excellent solution. These devices incorporate various purification technologies, selected based on the geographical area and the type of enclosed space. Air purifiers can either be part of an integrated system that covers several rooms or can be used as portable or fixed devices for a specific space. Their effectiveness relies on the airflow through the device, the filter load, and the maintenance method.

One common technology is mechanical filtration. This simple and widely used technique captures and significantly retains airborne particles. The efficiency of mechanical filtration is influenced by the type of filter employed. HEPA filters are especially effective, achieving over 95% efficiency in removing particles of various sizes. Factors such as the airflow within the system, the size of the contaminant particles, and the filter's age also significantly impact its performance. Another effective method is adsorption. This high-performance technique removes gaseous pollutants such as volatile organic compounds, ozone, nitrogen dioxide, sulphur dioxide, and hydrogen sulphide. Adsorption uses suitable adsorbents like activated carbon or hydrophobic zeolites, achieving over 90% removal efficiency. However, this method has some disadvantages, including reduced efficiency at high humidity, the need for regular replacement of adsorbents to prevent pollutants from re-entering the atmosphere, and the potential proliferation of airborne bacteria on carbon adsorbents.

Ultraviolet Germicidal Irradiation utilizes UV radiation from photoreactor lamps to destroy airborne bioaerosols, such as viruses, bacteria, mites, through photochemical decomposition. Although effective, this method produces ozone and free radicals, which are harmful to human health, necessitating room ventilation after lamp use.

Cold plasma or plasma treatment technology uses electrical pulses to excite air particles, creating a molecular maelstrom capable of destroying chemical contaminants and bacteria. Known as non-thermal or cold plasma, this method does not generate heat, making it safe and easier to handle. It can be implemented in domestic and industrial Heating, Ventilation, and Air Conditioning units. The process involves forcing air through a network of wires that generate the necessary electrical pulses to produce a plasma screen, theoretically deactivating viral particles.

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