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INDOOR AIR QUALITY AND ITS INFLUENCE ON WORKER PRODUCTIVITY A COMPREHENSIVE REVIEW

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ABSTRACT

Indoor air quality (IAQ) has become a critical environmental and occupational health issue due to the amount of time that workers spend in indoor controlled environments where ventilation, temperature, humidity, particulate matter, carbon dioxide, VOCs and biological contaminants are known to impact health and performance. This comprehensive review provided a synthesis of the available evidence on the major pollutants in indoor environments, ventilation and environmental conditions, physical and respiratory health effects, cognitive performance, comfort and well-being, absenteeism/fatigue and workplace productivity. The reviewed literature showed that reduced work efficiency and performance, absenteeism, cognitive functioning, headaches, discomfort, reduced concentration, fatigue, and respiratory symptoms have been linked to poor IAQ. There was also evidence that thermal comfort, particulates, carbon dioxide, and overall indoor environment conditions had affected worker productivity and physiological responses. Other measures taken into account were sufficient ventilation, proper filtration, environmental monitoring, pollutant-source control, workplace IAQ policies, and sustainable practices. Overall, the evidence underscored the potential for effective IAQ management to benefit workers' health, comfort, cognitive function, well-being, and productivity, and to create a healthier, more sustainable workplace environment.

Keywords: *Indoor Air Quality, Worker Productivity, Workplace Environment, Ventilation, Cognitive Performance, Occupational Health.*

1. INTRODUCTION

IAQ stands for indoor air quality, and it is a crucial environmental and occupational health issue due to the considerable amount of time that people spend indoors in office buildings, industrial plants, and other work environments [1]. Indoor air quality is affected by many variables like ventilation, temperature, moisture content of air, particulate matter, carbon dioxide, volatile organic compounds, biological contaminants, and other pollutants. Poor IAQ may provide uncomfortable conditions that may cause harm to workers, especially in situations with poor ventilation or presence of indoor pollutants.

Apart from being physically unpleasant, poor IAQ may cause additional problems to workers. For example, the presence of pollutants and poor thermal and ventilation conditions may cause tiredness, headaches, irritation, poor concentration, and other symptoms, which may interfere with normal functioning and effective completion of work tasks [2].

Indoor air quality (IAQ) has become a significant issue related to both environmental and occupational health due to the large amount of time people spend in enclosed offices, factories, institutions, and other places of work [3]. Indoor air quality is affected by various factors, including ventilation, temperature, humidity, particulates, carbon dioxide, volatile organic compounds, biological pollutants, and other indoor pollutants. IAQ issues can make a work environment unpleasant and even dangerous for workers, especially if there is poor ventilation or indoor pollutants build up.

Effects of poor indoor air quality go beyond physical distress and respiratory symptoms associated with exposure to pollutants or poor thermal and ventilation conditions. They include fatigue, headaches, irritation, impaired concentration, and general malaise experienced by workers [4].

Table 1: Summary of Reviewed Literature on Indoor Air Quality and Worker Productivity

Author(s) & Year	Study	Methodology	Key Findings
Bueno et al. (2021) [5]	Thermal comfort and productivity	Systematic literature review	Thermal comfort had influenced worker productivity, with extreme temperatures reducing performance.
Cedeño Laurent et al. (2021) [6]	$PM_{2.5}$, CO_2 and cognitive function	Empirical study of office workers	Poor indoor air conditions had been associated with reduced cognitive performance.
Chang et al. (2019) [7]	Air pollution and worker productivity	Empirical analysis of call center workers	Increased air pollution had reduced worker productivity and task completion.
Deng et al. (2024) [8]	IAQ, productivity and physiological responses	Comprehensive literature review	Poor IAQ and uncomfortable conditions had reduced productivity and affected physiological responses.
Du et al. (2020) [9]	CO_2 and cognitive function	Critical literature review	Elevated CO_2 had been associated with reductions in some aspects of cognitive performance.

2. INDOOR AIR QUALITY IN WORKPLACE ENVIRONMENTS

Indoor Air Quality (IAQ) is defined as the physical, chemical, and biological attributes of the air within an enclosed environment, and has significant ramifications for the well-being of the occupants. IAQ in modern workplace settings can be influenced by substances from outdoor air, building components, furniture, cleaning chemicals, office machinery, industry, and people [10]. Common contaminants found in IAQ include particulates, carbon dioxide, volatile organic compounds, carbon monoxide, nitrogen dioxide, ozone, mould, bacteria, and other biological agents. The presence and extent of these contaminants will be determined by such factors as building design, occupancy levels, activities performed, ventilation, and temperature and humidity levels.

2.1. Major Indoor Air Pollutants and Sources

Indoor workplaces expose workers to different types of pollution, which could be caused by indoor and outdoor factors. The major sources of pollutants in indoor places are particulate matter ($PM_{2.5}$ and PM_{10}), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone, volatile organic compounds (VOCs), and biological pollutants, which include bacteria, fungi, Mold, and allergens. The main source of particulate matter includes dust, combustion, printing, industrial activities, and resuspension of particles from the surfaces [11]. VOCs are emitted from paints, adhesives, furniture, cleaners, solvents, and building materials. Carbon dioxide is produced by respiration and could indicate poor ventilation when it is present in high amounts.

Sources and levels of pollutants inside workplaces could be different depending on the type of workplace, design, occupancy, maintenance, and work activities. Industries may have their pollutants from manufacturing processes, machines, chemicals, and combustion; whereas offices may suffer more from pollutants from furniture, electronics, and poor ventilation [12]. Damp environments and maintenance issues of ventilation could cause high levels of biological pollutants. Long-time exposure to these pollutants could lead to irritations of eyes and respiratory system, headaches, fatigue, discomfort, and cognitive problems, and therefore should be identified and controlled.

2.2. Ventilation and Indoor Environmental Conditions

Ventilation is one of the key elements affecting the indoor air quality as it ensures the influx of fresh outdoor air and elimination of indoor contaminants [13]. Ventilation will ensure that the levels of CO_2, particulates, and VOCs remain low, while inadequate ventilation will allow the buildup of contaminants. Ventilation can either be natural, mechanical or a combination of both methods. The efficiency of ventilation depends on a number of things like air exchange rates, filtration efficiency, occupancy of the building, the design of the ventilation system, and its maintenance. Thus, proper maintenance of HVAC systems is crucial for maintaining good indoor air quality conditions.

Temperature, relative humidity, air flow rate, and thermal comfort are the additional indoor environmental parameters that might affect employees' physical comfort and concentration. Too high or too low temperature levels may be discomforting and tiring, while improper humidity level may provide an opportunity for the development of microbes or lead to the irritation of the eye area or airways [14]. Inadequate air flow will additionally result in stagnation and accumulation of pollutants in such areas. Maintaining a proper temperature and humidity balance, providing adequate air distribution, timely replacement/cleaning of filters, and ventilation efficiency can thus contribute to a healthier work environment.

3. EFFECTS OF POOR INDOOR AIR QUALITY ON WORKERS

Indoor air quality can greatly influence the health, well-being, and capability of employees to conduct their jobs adequately. Prolonged exposure to pollutants in the indoor environment, including particulates, volatile organic chemicals, carbon monoxide, biological agents, and poor ventilation settings, can lead to acute and chronic impacts. Employees who are working in polluted indoor settings can experience adverse reactions like headaches, dizziness, irritations in eyes and throat, coughing, difficulty breathing, fatigue, and general malaise [15]. The extent of impact will vary based on the levels of pollutants, time of exposure, nature of the work environment, susceptibility of individuals, and quality of ventilation and pollution control strategies.

3.1. Physical and Respiratory Health Effects

Poor air quality can affect the physical well-being of employees significantly, especially if constant exposure to pollutants is experienced during long working hours. Such pollutants include particulate matter, volatile organic compounds, carbon monoxide, nitrogen dioxide, ozone and biological pollutants that cause irritation of the eyes, nose, throat and respiratory tract [16]. Health effects include symptoms like coughing, sneezing, nasal and throat irritation, sinus congestion, headaches, dizziness, and breathing difficulty. Ineffective ventilation can result in higher levels of pollutants and increased severity of symptoms. Severity of the effects will depend on the level of pollutants, duration of exposure, workplace environment and individual sensitivity.

Exposure to poor indoor air quality on a regular basis can lead to persistent respiratory problems and deteriorated state of occupational health. Moisture and microbial pollution can lead to greater exposure to Mold, fungi, bacteria, and allergens causing aggravation of allergic and respiratory symptoms. Employees with persistent health problems can be affected by taking more sick leave, decreased productivity and inability to perform consistently [17]. Therefore, effective control of pollutants, adequate ventilation, regular maintenance of buildings and proper environmental monitoring are essential for protection from physical and respiratory effects.

3.2. Cognitive Performance, Comfort and Well-Being

The research emphasizes the relationship between the quality of the indoor air environment and its impact on workers' mental processes, physical comfort, and overall well-being at work. The lack of proper ventilation, indoor pollution, improper temperature and humidity levels, bad smells, and stagnation of the indoor air might cause tiredness, headaches, problems with focusing, discomfort, and decreased motivation [18]. Proper ventilation and good indoor environment will enhance workers' attentiveness, concentration, comfort, and psychological state.

- **Cognitive Performance**

Cognitive skills of the workers such as attention, concentration, mental alertness, decision-making, and memory skills may be influenced by the indoor air quality. Inadequate ventilation and increased pollution in the indoor environment may cause headaches, drowsiness, fatigue, and low mental alertness, thereby affecting the worker’s ability to carry out activities which need mental attention. Adequate ventilation and regulation of indoor pollutants will ensure the creation of a conducive environment for cognitive performance. A clean and properly ventilated work environment will minimize environmental distractions and hence enable the worker to concentrate and accomplish mental activities.

- **Comfort**

Comfort of employees is heavily dependent on the environmental conditions indoors, including temperature, humidity, air flow, odor, and ventilation. Overheating, cooling, high humidity, lack of air movement or bad smell indoors could cause the feeling of physical discomfort that might negatively affect the efficiency of work and

concentration of the employees [19]. Maintaining comfortable temperature, humidity and air flow could lead to creation of comfortable conditions indoors. Comfortable indoor environment would help to keep the environment less stressful and enable employees to stay concentrated during the whole working day.

❖ **Well-Being**

Indoor air quality is one of the factors that make up the physical and psychological well-being of workers. Constant exposure to bad air quality conditions can cause tiredness, headaches, problems with breathing, irritation, and general dissatisfaction with the place of work. Such factors can affect the emotional state, motivation, and overall experience of workers. Good indoor environment for workers may help by ensuring the absence of contaminants in the air and proper ventilation and thermal conditions. Therefore, efficient indoor air quality management can ensure the creation of a better working environment for workers.

Table 3: Effects of Poor Indoor Air Quality on Workers

Area of Effect	Major IAQ Factors	Possible Effects on Workers
Physical Health	$PM_{2.5}$, PM_{10}, VOCs, CO, ozone	Headache, dizziness, irritation and discomfort
Respiratory Health	Particulate matter, mould, allergens, biological contaminants	Coughing, breathing difficulty and respiratory irritation
Cognitive Performance	CO_2, poor ventilation, indoor pollutants	Reduced concentration, alertness, memory and decision-making
Comfort	Temperature, humidity, odours, air movement	Physical discomfort, dissatisfaction and fatigue
Well-Being	Poor ventilation, pollutants and thermal discomfort	Reduced motivation, mood and overall workplace satisfaction
Work Capacity	Combined IAQ problems	Reduced efficiency, increased fatigue and lower productivity

4. INFLUENCE OF INDOOR AIR QUALITY ON WORKER PRODUCTIVITY

Indoor air quality plays an essential role in determining worker productivity due to the fact that working conditions are able to influence physical well-being, thinking processes, level of concentration, and behavior at work. Workers tend to spend considerable amounts of time in closed spaces, which can result in tiredness, discomfort, headaches, inability to focus, and decreased levels of concentration caused by lack of ventilation and indoor pollution [20]. The mentioned factors are able to influence speed, accuracy, and efficiency of work and become especially relevant for workers who need to pay attention to their work or make decisions constantly.

4.1. Concentration, Work Efficiency and Performance

The emphasizes the significant connection between indoor air quality and the effectiveness of employees in concentrating on work and completing tasks efficiently. Unhealthy air with poor ventilation, excessive levels of pollutants, and fatigue can lead to a decrease in concentration, alertness, and work efficiency, thus influencing the quality of performed tasks [21]. On the other hand, proper ventilation, filtration, pollutant control, and overall good indoor environment can ensure employee comfort and concentration and minimize work distractions.

❖ **Concentration**

Indoor air quality could significantly impact the ability of employees to concentrate and pay attention while performing their duties. Excessive pollutants in the air, lack of ventilation, and poor air flow could lead to headaches, drowsiness, fatigue, and other problems that make it hard to concentrate on the job [22]. Better ventilation and cleaner indoor air could help people stay more alert and pay attention thanks to improved comfort in the environment. Proper IAQ is especially vital for jobs that require constant attention.

❖ **Work Efficiency**

Work efficiency is the capacity of workers to perform assigned tasks effectively and within the stipulated time frame. Poor IAQ can cause tiredness, discomfort, and health problems, which could interfere with work activities, causing inefficiency in work efficiency [23]. Good IAQ can assist in better task execution without any distractions from the surroundings and health problems. Proper ventilation, filtration, pollutants removal, and monitoring are some ways that can lead to improved work efficiency.

❖ **Performance**

Performance of workers depends on their physical health, level of alertness, comfort and concentration on the assigned tasks. Poor indoor environmental conditions could impair the concentration levels and lead to increased fatigue and, thus, adversely affect performance in terms of accuracy, quality and reliability [24]. A healthy indoor environment provides a good working environment for the workers. Good ventilation, filtration and management of indoor pollution can help workers stay comfortable and alert and, hence, perform better occupationally.

4.2. Absenteeism, Fatigue and Workplace Productivity

The above section provides information on how poor indoor air quality affects organisational productivity due to worker absenteeism, fatigue, and reduced work capability. Indoor air pollution, poor ventilation, and unpleasant environmental factors could result in health problems, fatigue, sleepiness, and lack of awareness resulting in absenteeism or poor performance of workers working in the organisation [25]. In contrast, proper ventilation, air filtering, pollution control, and environmental management can ensure worker wellbeing and enhance productivity.

❖ **Absenteeism**

Poor IAQ can be a cause of absenteeism among workers due to the development of symptoms like headaches, irritations of the respiratory tract, allergic reactions, fatigue and many others due to being exposed to pollutants. The employees suffering from such symptoms might need sick leave or simply cannot attend work on a regular basis causing a loss of productive working time for the organization [26]. Better IAQ thanks to proper ventilation, filtering and maintenance is going to be helpful in reducing such interruptions at the workplace.

❖ **Fatigue**

Inadequate ventilation and unpleasant conditions inside the building may make people tired, sleepy, and less aware when they are at work, especially when working for a long time. Air pollution, high temperature, insufficient air flow or unsuitable thermal conditions may make it harder for people to stay active and concentrated [27]. Cleaning the air indoors and maintaining proper ventilation, temperature and humidity may create a more pleasant workplace. Less environmental discomfort may contribute to keeping alertness and ability of people to do their job during working hours.

❖ **Workplace Productivity**

Poor IAQ can cause absenteeism, fatigue, decrease in concentration and work capacity, which can impair workplace productivity. Employees that report health symptoms or discomfort may work slower, at a lower level or with more errors than they would normally do, even if they continue to work [28]. Proper IAQ management can positively impact worker health, comfort and performance. This means that if a workplace has adequate ventilation, filtration, environmental monitoring and pollutant source control, it can help to minimise productivity losses and make workplaces more productive.

5. STRATEGIES FOR IMPROVING INDOOR AIR QUALITY AND PRODUCTIVITY

Improvement in the IAQ should be achieved through an integrated system which involves efficient ventilation, control of pollutants, air filtration, environmental monitoring, building maintenance, and proper workplace management [29]. Given the impact of poor IAQ on worker health, comfort, ability to focus, and worker productivity, organisations should see IEQ as an important factor of workplace health and productivity. Assessment of indoor air quality can aid in identifying the sources of pollution as well as poor ventilation systems, and preventive actions can help to minimize the exposure of workers to hazardous contaminants.

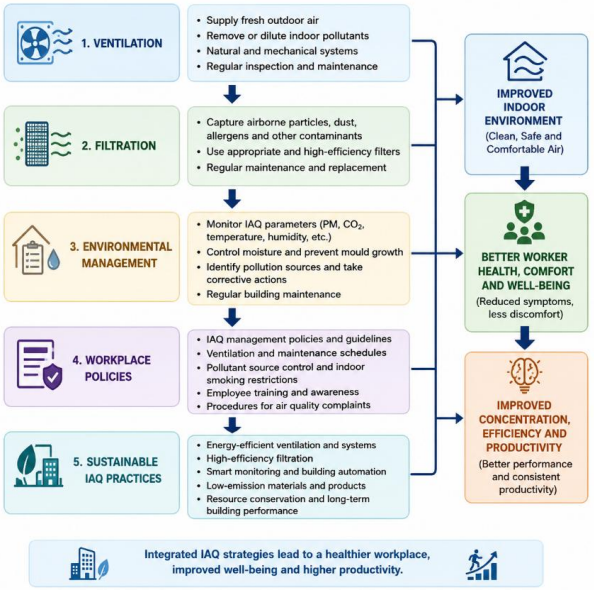

Figure 1: Framework Linking Indoor Air Quality Management with Worker Health and Productivity.

5.1. Ventilation, Filtration and Environmental Management

The concentrates on the main methods that have been applied to ensure and improve indoor air quality in office settings. Ventilation is necessary for providing fresh air and cleaning of contaminants, and the process of filtration will decrease airborne contaminants, dust, allergens, etc. [30]. Environmental management includes regular monitoring of the air quality, temperature, humidity, moisture, sources of pollution, and building maintenance. These steps may help decrease employees' exposure to indoor contaminants and create a clean working environment.

❖ **Ventilation**

Ventilation is necessary for ensuring clean air inside buildings through supply of outdoor air and removal of indoor contaminants. Proper design of natural and artificial ventilation systems depends on occupancy in workplaces, building construction and work processes. Ventilation systems require regular checking and servicing to provide proper airflow and avoid contamination [31]. Better ventilation decreases levels of CO2, particulates, odors and other contaminants in indoor environments. Proper airflow promotes comfort at work and avoids discomfort caused by bad ventilation conditions, providing healthier surroundings conducive to work and productivity.

❖ **Filtration**

Filtration serves as a significant approach to minimize contaminants, including particulates, dust, and other suspended particles. Proper filtration systems are useful in improving indoor air quality through the capture of such pollutants before their dispersion across the working place. Filtration system needs to be chosen in accordance with the workplace demands and needs to be maintained properly [32]. It is especially important to use filtration in places of work that face high exposure to outdoor pollutants or indoor processes that cause generation of airborne particles. With good ventilation and source control, filtration may prove helpful in minimizing workers' exposure to pollutants.

❖ **Environmental Management**

This includes the monitoring and regulation of the elements affecting air quality inside buildings such as particulates, CO2, temperature, humidity, moisture and pollutant sources. Regular monitoring may assist in identifying the parts where air quality is inadequate and allows organisations to implement proper measures. Adequate moisture management is also necessary since increased levels of moisture may stimulate the development of mold and microorganisms [33]. A good environmental management strategy consists of ventilation, air filtering, pollutant source control, moisture management and regular building maintenance. These practices may help in keeping a stable and healthy environment inside the building while limiting the workers' exposure to pollution.

5.2. Workplace Policies and Sustainable IAQ Practices

Indoor air quality can be further improved by the implementation of effective workplace policies which clearly identify the responsibilities, monitoring, maintenance, and employee awareness programmes. Organisations may establish guidelines for IAQ management regarding maintenance of the ventilation system, cleaning, control of pollution sources, restrictions on indoor smoking, moisture management and procedures for responding to complaints about air quality [34]. Education for employees about the importance of indoor air quality and the need to reduce the amount of pollutants in the air, for example by using and storing chemicals appropriately and by reporting ventilation or moisture related issues can also help workers to understand the issue. Frequent assessment of the workplace can help to ensure IAQ measures continue to be effective over time.

Any action taken to achieve sustainable IAQ should strive to reduce air quality issues and to enhance energy efficiency, resource conservation and building performance over time. Organisations are able to achieve a balance between healthy air conditions and energy consumption with the energy-efficient ventilation systems, high-efficiency filters, smart indoor environmental monitoring and building automation technologies. Pollutants can also be minimized when constructing sustainable buildings with sustainable materials and products with low emissions [35]. Therefore, incorporating IAQ into the occupational health, facility management, and sustainability policies can have long-lasting impacts by safeguarding the health of workers, creating a comfortable workplace, and promoting productivity, as well as in managing the workplace in an environmentally responsible way.

6. CONCLUSION

The review found that IAQ was a key parameter related to worker health, comfort, cognition and productivity. Respiratory symptoms, fatigue, decreased concentration, discomfort, absenteeism and decreased work efficiency and performance have been correlated with poor IAQ or poor ventilation, indoor pollutants, and uncomfortable thermal conditions. The evidence reviewed showed that: Effective ventilation, filtration, environmental monitoring, pollutant-source control, regular maintenance, workplace policies, and sustainable IAQ practices could help to achieve healthier and more comfortable working environments. In conclusion, integrated IAQ management was critical to the well-being of the workers and to maintaining continuous productivity, and to creating healthier and more sustainable workplaces.

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