Improving Indoor Air Quality and HVAC Performance Using the PDCA Methodology

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Abstract *— Improving indoor air quality (IAQ) is essential for enhancing occupant health, productivity, and building performance. This project applied the PDCA (Plan-Do-Check-Act) methodology to optimize HVAC systems and reduce harmful air pollutants. Key improvements included lowering CO_2 levels, reducing PM2.5 and VOC concentrations, optimizing relative humidity, and refining temperature control. These changes align with ASHRAE 62.1 standards and contribute to energy efficiency and sustainability. The methodology ensures continuous improvement through iterative evaluation and adjustment. The results demonstrate measurable benefits in health outcomes, cognitive performance, and operational efficiency, making this approach a practical framework for IAQ enhancement in commercial and institutional buildings.*

Key Terms *— Air Quality, HVAC Optimization, PDCA Cycle, Sustainability*

INTRODUCTION

Indoor air quality (IAQ) is a critical factor affecting occupant health, comfort, and productivity in commercial buildings. HVAC systems play a central role in controlling IAQ by regulating ventilation, humidity, and filtration. However, in many facilities, poor maintenance, outdated filtration systems, and inadequate ventilation strategies lead to the accumulation of pollutants such as carbon dioxide, volatile organic compounds (VOCs), and airborne pathogens. These issues can cause health complaints, reduce employee performance, and increase liability risks for building owners and operators.

In the specific office building selected for this project, these challenges are compounded by the absence of systematic IAQ monitoring and HVAC operational planning. This lack of structured management practices has raised concerns about indoor environmental quality and occupant well-being. Although advanced HVAC technologies are available, their potential is often undermined by inconsistent maintenance, limited data collection on IAQ, and weak communication between employees, facility managers, and technical staff. These factors contribute to a reactive approach to air quality issues, rather than a proactive, data-informed strategy.

The objective of this project is to develop a management-oriented framework aimed at improving indoor air quality in office buildings through the optimized operation of HVAC systems. This framework will provide building managers and engineering teams with structured guidance to enhance air quality, ensure compliance with relevant standards, and promote the long-term health and well-being of office occupants. It is intended to be practical, adaptable, and aligned with the operational realities of modern office environments, ultimately supporting better decision-making and more sustainable facility management practices.

METHODOLOGY

The Plan-Do-Check-Act (PDCA) methodology provided a structured approach to problem-solving and process optimization. As the name suggests, it consists of four iterative phases. It was applied to this project as follows:

- Plan: The initial phase focused on understanding the current IAQ and HVAC operations through walkthroughs, maintenance record reviews, ventilation layout assessments, and occupant surveys. This provided a baseline assessment of risk factors and operational gaps.

- Do: Real-time IAQ monitoring was conducted by deploying sensors in selected office zones to track CO_2, PM2.5, VOCs, relative humidity, and temperature. HVAC system responses to IAQ demand were evaluated against operational logs and equipment specifications.
- Check: Collected data was compared with ASHRAE 62.1 guidelines [1] and evaluated against best practices [2-4] to identify compliance gaps. Occupant feedback and benchmark analysis further supported the gap assessment.
- Act: Based on the findings, a practical IAQ management framework was developed. This framework integrated routine monitoring, preventive maintenance, and demand-controlled ventilation strategies to ensure long-term sustainability. The framework also defined KPIs and provided a roadmap for continuous improvement, aligned with updated ASHRAE 62.1 requirements.

This cyclical process ensures that IAQ improvements are not only achieved but sustained over time.

STRATEGIC PLANNING FOR IAQ AND HVAC OPTIMIZATION

A custom IAQ management framework was designed to guide the project. This framework integrates real-time monitoring, preventive maintenance and compliance with ASHRAE 62.1 standards for indoor air quality. It served as the backbone for decision making and continuous improvement. Five IAQ indicators were selected based on their relevance to health and HVAC performance. Baseline measurements were taken and optimized targets were set as follows:

- CO_2 Reduction: 950 ppm → 600 ppm Lower CO_2 levels enhance cognitive function, reduce fatigue, and improve decision-making.
- PM2.5 Reduction: 35 $\mu g/m^3$ → 12 $\mu g/m^3$ Reducing PM2.5 improves air quality and aligns with ASHRAE 62.1 guidelines.
- VOCs Reduction: 300 ppb → 100 ppb Lower Volatile Organic Compounds (VOCs) contribute to fresher air, minimize irritation and long-term health effects.
- Humidity Optimization: 65% → 45% Maintaining RH between 40–60% prevents mold growth and discomfort. The optimized range supports respiratory health and reduces microbial proliferation.
- Temperature Control: 25°C → 22°C Improved temperature regulation contributes to thermal comfort and HVAC energy efficiency.

IMPLEMENTATION OF IAQ MONITORING AND SYSTEM ENHANCEMENTS

The implementation phase focused on deploying the planned IAQ framework in real office environment as follows:

- Sensor Deployment: High precision IAQ sensors were installed in strategic office zones to monitor the five target parameters continuously.
- Operational Adjustments: HVAC systems were reconfigured to support demand-controlled ventilation, ensuring the airflow responded dynamically to occupancy and pollutant levels.
- Preventive Maintenance: Maintenance schedules were revised to proactively address filter changes, duct cleaning and thermostat calibration.
- Stakeholder Engagement: Facility managers, maintenance teams and occupants were involved throughout the process to ensure accurate feedback. Training sessions were conducted to familiarize staff with the monitoring tools and maintenance protocols.

PERFORMANCE EVALUATION AND COMPLIANCE REVIEW

The evaluation phase focused on analyzing the data collected during the implementation phase in order to assess the effectiveness of the interventions.

Figure 1 illustrates the baseline and optimized values for five IAQ parameters. Each bar represents the measured concentration or level before and after the implementation of HVAC improvements. The visual comparison highlights the effectiveness of the IAQ management framework in achieving significant reductions in pollutants and optimizing environment.

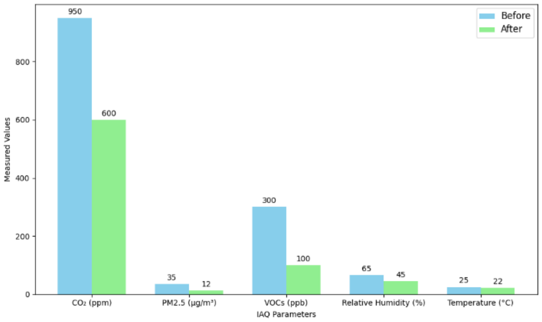

Figure 1

IAQ Improvements Before and After HVAC Optimization

The results revealed significant opportunities for improving indoor air quality and HVAC performance through structured management practices. Real-time monitoring across selected office zones identified elevated levels of CO_2, VOCs, and PM2.5, confirming the presence of IAQ risks. These findings, combined with occupant feedback and maintenance record analysis, highlighted gaps in ventilation efficiency and system responsiveness. By comparing collected data with ASHRAE 62.1 standards, the project pinpointed areas of non-compliance and operational inefficiencies. The implementation of a tailored IAQ framework featuring demand-controlled ventilation, preventive maintenance, and continuous monitoring demonstrated measurable improvements in air quality and system reliability. This outcome validates the effectiveness of the PDCA methodology in guiding sustainable, data-informed decisions for healthier indoor environments.

CONTINUOUS IMPROVEMENT AND FRAMEWORK REFINEMENTS

The project transitioned from reactive to proactive IAQ management, supporting healthier indoor environments and more efficient HVAC operations. It also laid the foundation for future innovations in smart building technologies.:

- Framework Refinement: The IAQ framework was updated to include automated alerts, performance dashboards and integration with building management systems (BMS).
- Policy Updates: Maintenance protocols were revised to include IAQ metrics as part of routine inspections.
- Scalability Planning: The framework was documented and adapted to replication in other office buildings, ensuring adaptability and long-term impact.

CONCLUSION

This project successfully demonstrated how the PDCA methodology can be applied to improve indoor air quality (IAQ) and HVAC performance in office buildings. By systematically assessing current conditions, implementing real-time monitoring, and aligning operations with ASHRAE 62.1 standards, the project addressed key gaps in ventilation, maintenance, and stakeholder communication. The integration of demand-controlled ventilation and preventive maintenance strategies provided a practical roadmap for transitioning from reactive to proactive IAQ management. This approach not only enhances occupant health and comfort but also supports energy efficiency and regulatory compliance.

The developed framework offers a scalable and adaptable solution for facility managers and engineering teams seeking to improve IAQ in diverse office environments. Its emphasis on continuous improvement, data-driven decision-making, and stakeholder engagement ensures long-term sustainability and operational resilience. By aligning technical solutions with management practices, the project bridges the gap between engineering design and real-world implementation. Ultimately, this work contributes to healthier indoor environments, more efficient HVAC operations, and a stronger foundation for future innovations in building management.

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