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Indoor Air Quality Standards of Performance Applications Guide

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ABSTRACT

This paper discusses the development and application of standards of performance (SOPs) for HVAC&R equipment, plumbing systems, and building envelope systems in relation to maintaining acceptable indoor air quality (IAQ) in buildings. The utilization of the SOP procedure, developed in ASHRAE Research Project 853, will aid in the proper operation of systems and verify that acceptable building IAQ levels are obtained.

INTRODUCTION

It is well known that maintenance practices and levels vary for HVAC&R systems. This variation is due to many factors, including building size, owners' preferences, equipment age, and the level of knowledge of the operation and maintenance (O&M) staff. Unfortunately, maintenance practices do not place a specific emphasis on indoor air quality (IAQ) and are typically conducted for system performance, not to meet specific requirements for IAQ. Even in cases where IAQ is a concern of the O&M staff, maintenance practices may focus on the wrong needs or resources may not be available to fix identified problems. Statistical analysis of survey data from commercial buildings in the Chicago area show trends confirming that O&M practices improve as building size increases and that IAQ levels increase with improved O&M practices.

The goal of this ASHRAE research project (RP-853) was to review available information and to develop O&M management tools. The primary tool developed was standards of performance (SOPs). The use of SOPs for HVAC&R equipment, plumbing, and envelope systems can assist O&M personnel in maintaining and increasing the overall IAQ level within their building. SOP development and implementation for a specific building allows the O&M staff to document and practice a thorough O&M plan while verifying the results through the measurement of building IAQ.

It is estimated that in the U.S., approximately $63 billion per year is lost due to decreased worker productivity in commercial buildings because of poor indoor air quality. Of this estimate, more than $24 billion is related to office buildings (Dorgan et al. 1998a). Application of the SOP procedure will enable staff to improve IAQ levels in buildings and increase the productivity of building occupants.

BASIC TERMINOLOGY

The term *standard of performance* has been used in ASHRAE literature; however, the meaning of the term has been ambiguous (ASHRAE 1991, p. 71). To clear up the meaning, a concise definition of SOP was one objective of this ASHRAE research project. This was accomplished by reviewing the definitions of *standard* and *performance*.

A *standard* defines the following items for rating purposes (ASHRAE 1991, p. 87):

- properties
- processes
- dimensions
- materials
- relationships
- concepts
- nomenclature
- test methods

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In the context of O&M, a standard defines the properties and processes of O&M practices and their relationship to the quality of building environment, including IAQ.

The *performance* of a component or system is regarded as acceptable when the design parameters are achieved under actual load conditions (ASHRAE 1991, p. 71).

Using these definitions for *standard* and *performance* and related concepts taken from *ASHRAE Guideline 4-1993, Preparation of Operating and Maintenance Documentation for Building Systems* (ASHRAE 1993), a standard of performance is defined as:

> "A standard (acceptable indoor air quality [IAQ], efficiency, or cost) that ensures a building system or component is operating properly—determined through a series of measures. The measure can be a property, process, dimension, material, relationship, concept, nomenclature, or test method. A component is any part of a system that could affect the standard (coil, fan, ductwork, thermostat, etc.)."

As *acceptable IAQ* is used in the definition of SOP, it also must be defined. ASHRAE (1989) defines *acceptable IAQ* as:

> "Air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction."

Since acceptability is subjective, many components interact to determine the IAQ level. These components include:

- Temperature
- Infiltration/exfiltration
- Outdoor air ventilation rates
- Number of occupants
- Contaminant levels
- Air movement
- Humidity
- HVAC-produced noise
- Chilled-water temperature
- Supply air temperatures
- Odors

Of the components listed, temperature, outdoor air ventilation rates, contaminant levels, humidity, and air movement have the greatest influence on occupant IAQ satisfaction.

IAQ RELATIONSHIPS TO O&M PRACTICES

Maintenance practice and frequency vary from building to building. This is related to differences in building size, owners' preferences, age of equipment, and level of knowledge of the O&M staff.

The fundamentals of building systems are typically related to building size. For example, smaller buildings usually utilize packaged unitary systems with simple single-point control, while large buildings usually utilize complex systems consisting of built-up units, central heating and cooling plants, and individual space control. Large buildings are more likely to have full-time O&M personnel or service contractors to maintain and operate the systems.

A survey of commercial buildings in the Chicago area, performed as part of this ASHRAE research project, documented the relationship between building size and the O&M procedures performed in the building. While it is true that there were both good and poor practices in both small and large buildings, a trend showed that the average level of maintenance increased as the building size increased (Dorgan et al. 1997). The building size categories were broken down by height and floor area. The categories used were:

- High rise (ten or more stories)
- Low rise
- Large (over 50,000 ft^2)
- Medium (20,000 ft^2 to 50,000 ft^2)
- Small (less than 20,000 ft^2)

The trend is illustrated in Figure 1.

The follow-up evaluations done on site documented a trend between the O&M practices performed in buildings and the IAQ within the building (Dorgan et al. 1997). The data, while limited in sample size, are statistically significant. The IAQ/O&M trend is illustrated in Figure 2. The perceived IAQ is evaluated as a degradation value. The lower the IAQ degradation number, the better the building IAQ perception.

The building IAQ O&M rating was obtained by awarding points for specific O&M practices and the frequency with which they were performed. The maximum score possible was 4000. The IAQ degradation was determined by assigning point values when characteristics that determine acceptable IAQ level, as discussed previously, did not meet occupant satisfaction. Specific information on the survey forms and scoring can be found in the ASHRAE Research 853-TRP Final Report (Dorgan et al. 1997).

All data were analyzed for statistical significance using an ana ysis of variance (ANOVA), residuals, and frequency plots. This analysis indicates that both the relationships between O&M level and building size and between O&M

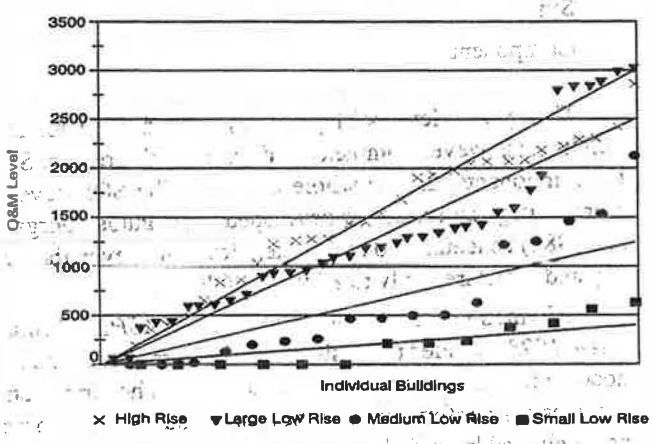

Figure 1 *O&M trends by building size.*

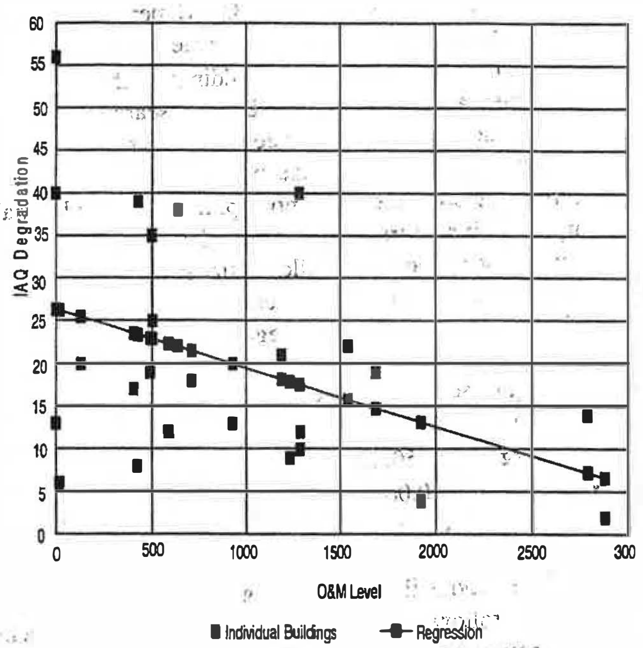

Figure 2 IAQ/O&M trend.

level and IAQ are statistically significant (p-values <0.05). These trends were obtained through analysis of a sample of office buildings in the Chicago metropolitan area. However, the trends indicate similarities throughout the United States and Canada. The statistical analysis also recognized the fact that larger buildings typically have more components and would have higher O&M levels. This was accomplished through a statistical comparison of IAQ information from small and large buildings, which was independent of size, outdoor ventilation rates, and space temperature.

STANDARD SOP STRUCTURE

A standard SOP structure was developed to ensure consistency. Three levels of SOPs were developed:

- Building
- System
- Component

The system level will generally be sufficient for most buildings; however, complex buildings may also require SOPs for components and the whole building. The SOP development strategy and structure developed in the guide (Dorgan et al. 1998b) concentrate on the system level; however, the strategy and structure apply to all three SOP levels.

Information from O&M personnel and *ASHRAE Guideline 4-1993* provided the basis for the SOP structure. The SOP documentation consists of seven sections. The first section includes basic information on the system, building, or component being addressed. The other sections provide information on how to evaluate and the correct action to take if required.

Section 1: General Information

This section provides a short description of the building, system, or component to be addressed in the SOP. Documenting the Design Intent provides an important resource for understanding system operation and limitations. System SOP information contained in this section includes:

- System type
- Area served
- Control description
- Associated systems or components

Section 2: Standards of Performance

The criteria used to evaluate the SOPs are developed in Section 2. The evaluation process meets the SOP requirement of ensuring that "a building, system, or component is operating properly —determined through a series of measurements." The criteria may be taken from existing standards (ASHRAE for example), local codes/guidelines, or manufacturer's information. The criteria may be measured or subjective. The criteria used for evaluation vary by season (summer/winter) or by occupancy mode (unoccupied/occupied). Examples of SOP criteria are:

- The energy efficiency for a chiller is less than 0.6 kW/ton (0.017 kW/kW_T) full load and 0.7 kW/ton (0.020 kW/kW_T) at 50% load.
- The IAQ in a conference room meets the requirements of *ANSI/ASHRAE Standard 62-1989* for CO_2 levels.

Section 3: Information to be Recorded

Measurements must be taken to determine if SOPs are met. The validity and usefulness of the measurements require that the frequency, accuracy, number, references, and other details be determined.

An example of the measurements required for the chiller EER SOP discussed in Section 3 are:

- Entering and leaving chilled-water temperatures
- Chilled-water flow rate
- Energy input

The same measurements can be used in more than one SOP, which allows for the actual list of required measurements to be reduced.

Section 4: Calculations

The measurements are used to ascertain that the SOPs are being met. This is accomplished through calculations involving the information recorded in Section 3. Calculations may be easily automated through computerized scheduling and tracking systems.

Equation 1 is an example of a calculation for determining the chiller EER.

$$Efficiency = \frac{Energy\ Input}{C_1 \cdot flowrate \cdot \Delta T}, \quad (1)$$

where

Efficiency = energy efficiency of the chiller, kW/ton (kW/kW_T);

Energy Input = chiller energy demand, kW;

C_1 = constant, 0.04167 (ton/gpm)/°F (4.18 [kW_T·s/L]/°C);

Flowrate = chilled-water flow rate, gpm (L/s);

ΔT = chilled-water temperature differential, °F (°C).

Section 5: Interpretation

The SOPs are evaluated through their comparison to the measurements taken and the calculations completed. The evaluation often involves the interpretation of the results to decide whether SOPs are met. For example, the inherent efficiency of a chiller varies with issues such as outdoor air temperature, age of equipment, and system load. Guidance for the interpretation can reference manufacturer's information or data developed in Section 6.

Section 6: Other Information

Special measurement techniques, information forms/surveys, and information from analysis are documented to provide a resource for the SOP user. This information can be used for SOP application or understanding.

Section 7: Corrective Action

Information is presented on the recommended action when the SOP is not met. This information must be developed for each SOP.

A complete IAQ SOP for an air-handling unit (AHU) is presented in Figures 3 and 4 to provide an example of the structure and documentation.

ECONOMICS

The purpose of the SOP is to provide building owners and personnel with a procedure to ensure proper system operation and maintenance of good IAQ. One concern of owners is that O&M programs be economical as well as useful. Economics must not focus solely on the direct cost of the O&M program but rather on the whole interaction of the program and the associated benefits:

- Health
- Productivity
- Maintenance costs

Health

The World Health Organization (WHO) defines health as

Indoor Air Quality Standard of Performance

Central Air-Handling Unit (AHU-1)

GENERAL INFORMATION

System Type: Variable-air-volume (VAV) built-up air-handling unit with chilled water cooling, hot water heating, and an economizer cycle. Conditioned and ventilation air is supplied to the space through VAV terminal diffusers. Supplemental heat is provided by a perimeter baseboard hot water radiation system.

Area Served: This two-story building is served by AHU-1, 2, and 3 (all identical). Each room has individual control, and each floor is divided into two primary suites for the purpose of minimum air control.

Description: AHU-1, 2, and 3 are equipped with a chilled water coil (440 Mbh, 88 gpm, 45°F entering, 55°F leaving), a hot water coil (500 Mbh, 33 gpm, 120°F entering, 90°F leaving), an economizer section, filters, and a supply fan (20,000 cfm) and return (18,000 cfm) fan. Each air handler provides a variable volume of air to maintain a constant static pressure (0.4 in. w.g.) in the ductwork, based on a static pressure sensor located in the supply ductwork above room 125, 225, or 280. Individual zone VAV terminal units vary the air to maintain the space set point based on integral thermostats.

The supply air temperature is reset based on the return air temperature. At a return air temperature of 76°F, 50°F supply air is provided, and at a return air temperature of 72°F, 58°F supply air is provided. A central direct digital control (DDC) system maintains the discharge air temperature by varying the position of the chilled and hot water coil valves. The controls also operate the economizer when the outdoor air temperature is below 63°F. When the outdoor air is above 63°F, the outdoor air dampers go to their minimum position. The minimum position is reset based on the total supply airflow to maintain 4,000 cfm of outdoor air. At full system flow, the outside air dampers are set to 20% flow, and at minimum system flow (5,000 cfm), the dampers are set to 80% of flow (4000 cfm).

Cooling is disabled below an outdoor air temperature of 55°F, and heating is disabled above an outdoor air temperature of 53°F.

***Figure 3** Section 1 example of SOP for an air-handling unit.*

2. STANDARDS OF PERFORMANCE

	Performance Item	Time of Year			Operating Condition		
Indoor Air Quality		**Summer**	**Winter**	**Switchover**	**Occupied**	**Unoccupied**	**Start-Up**
1	Supply air temperature/humidity adequate to dehumidify the space	52°F/51°F	N/A	52°F/51°F	52°F/51°F	52°F/51°F, when operating	52°F/51°F
2	Proper outdoor air mixing	MA variance ±2°F	Same	Same	Same	N/A	N/A
3	Outdoor airflow correct	N/A	N/A	N/A	4,000 cfm	600 cfm, leakage	600 cfm

3. INFORMATION TO BE RECORDED

Measurement	P.I. #	Frequency	Accuracy	# Recorded	Other	Ref.
Discharge air dry/wet-bulb temperature	1, 9	Monthly	±1°F	3		27a
Return air dry/wet-bulb temperature	3	Monthly	±1°F	3		27b
Outdoor air dry/wet-bulb temperature	3	Monthly	±1°F	3		27d
Mixed air dry/wet-bulb temperature	2, 3	Monthly	±1°F	3		27c
CO_2 (return air minus outdoor air)	3	Monthly	50 ppm	2 each		29d
Discharge airflow	3, 5	Monthly	100 cfm	3		28b
Outdoor airflow	3, 5	Monthly	ASHRAE Std. 62	3		28b

* P.I. # = Performance Item Number from Standards of Performance Table
Ref. = item number from O&M questionnaire

4. CALCULATIONS

3) Outdoor airflow using temperature readings and total system airflow:

$$Outdoor\ Airflow = \%OA \cdot System\ Airflow = \frac{T_{ma} - T_{ra}}{T_{oa} - T_{ra}} \cdot System\ Airflow$$

where

$\%OA$ = percent outdoor air

T_{ma} = temperature of mixed air

T_{ra} = temperature of return air

T_{oa} = temperature of outdoor air

5. INTERPRETATION

	Performance Item	Time of Year		Operating Condition	
		Summer*	**Measured**	**Occupied***	**Measured**
Indoor Air Quality					
1	Supply air temperature/humidity adequate to dehumidify the space	52°F/51°F	50.5°F/50°F		
2	Proper outdoor air mixing	MA variance ±2°F	±1.8°F		
3	Outdoor airflow correct			4,000 cfm	3,000 cfm
	Date: July 15, 1998		Recorder Name: Sam D. Whorwell		

*Fill in the time of year and operating condition being evaluated.

GUIDANCE ON INTERPRETATION

3) CO_2 difference between outdoor and indoor air should be < 700 ppm.

6. OTHER INFORMATION

3) Proper outdoor airflow is required to ensure occupant-generated odors are properly diluted in order to maintain good indoor air quality (occupant satisfaction).

7. CORRECTIVE ACTION

3) Verify outdoor air damper is open, supply fan is operational, and the control loop for mixed air control is within proper parameters.

***Figure 4** Example of SOP for air-handling unit continued.*

"the overall level of physical, mental and social well being, not the absence of disease" (WHO 1946). This implies that building-related illness (BRI), sick building syndrome (SBS), and mental health are all important items in health considerations. These considerations demonstrate the benefits of proper IAQ. Table 1 includes estimates of medical and physical costs associated with common IAQ problems in commercial buildings in the United States (NEMI 1995).

TABLE 1
Medical and Physical Costs

Item	Cost per year, $
Acute Respiratory Disease	1.2 billion
Legionnaire, Humidifier Fever, Occupational Asthma	0.8 billion
Mild IAQ and SBS Symptom-Related Illnesses	6.0 billion
Total	8.0 billion

Productivity

Productivity is the measure of an employee's actual work output to the employee's predicted work output under ideal conditions. While productivity related to the environment is difficult to measure, it is generally agreed that factors such as comfort, IAQ, lighting, furniture, office layout, management, salary, work load, and personnel characteristics (education, training, experience) have an impact on productivity. The IAQ factor can be linked to the employee's health, both mental and physical, which can, in turn, be translated to productivity. Table 2 details an estimate of lost employee productivity in commercial buildings in the United States due to poor IAQ conditions (NEMI 1995).

Maintenance Costs

Maintenance programs are, in general, relatively inexpensive to maintain. Total maintenance costs typically vary from 1% to 5% of the first cost of the system (EPRI 1993). The additional cost of adding a comprehensive SOP program is estimated to be less than 0.5% of the system first cost. The low cost is due to the need to only add an extra layer of documentation and analysis to an already existing O&M program.

SUMMARY

The importance of proper IAQ has come to light in recent years. Poor IAQ has been linked to numerous adverse mental and physical health effects that decrease worker productivity and can lead to sick buildings. Survey data from this ASHRAE research project show the link between O&M programs and acceptable building IAQ. Trends demonstrate that as O&M procedures increase in quality, a building's IAQ increases in perceived quality.

The SOP structure developed through this ASHRAE research project provides guidelines regarding which measurements are needed to ensure proper operation of HVAC&R systems. The guidelines allow the O&M personnel to develop their own SOPs to evaluate their own system's operation and building IAQ levels. Through the evaluation process, O&M personnel can identify problem areas and derive solutions. The implementation of the SOP procedures ensures proper building IAQ with a minimal cost addition to the O&M budget. The benefits are significantly higher than the O&M costs.

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TABLE 2
Worker Lost Productivity Costs

Building Category	Commercial Building Lost Cost Per Year, $(billion)	Cost Per Worker, $	Office Building Lost Cost Per Year, $(billion)	Cost Per Worker, $	Productivity Decrease, %
Healthy	0.0	0	0.0	0	0.0
Generally Healthy	12.5	520	6.1	610	1.5
Unhealthy, Problem Unknown	18.8	1,270	7.6	1,440	3.5
Unhealthy, Problem Known	10.7	1,270	4.8	1,440	3.5
SBS/BRI	12.8	2,200	4.8	2,465	6.0
Total	54.8		23.3		

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