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Indoor air quality from commissioning through building operations

Commissioning and operations play major roles in the actual performance of HVAC systems

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Building commissioning and operations are both important factors in maintaining acceptable indoor air quality (IAQ) in new or existing buildings. As defined by ASHRAE *Standard 62-1989*, acceptable IAQ is indoor air: that contains no known contaminants at harmful concentrations as determined by cognizant authorities; and with which 80% or more of the people exposed do not express dissatisfaction.[2]

The commissioning process includes procedures and methods for verifying and documenting the performance of HVAC systems to ensure proper operation according to the original or reconfigured design intent. The commissioning process also includes documentation and verification that the owners' or tenants' design criteria have been adhered to, a description of installed HVAC systems and their intended operational modes, and performance goals (see *Figure 1*).

Although most buildings are generally considered by the public to be safe, healthy working environments, appearances can be deceiving. The manner in which buildings are delivered to their owners or operators often makes them prone to potential IAQ problems.

Important factors that contribute to the buildup of

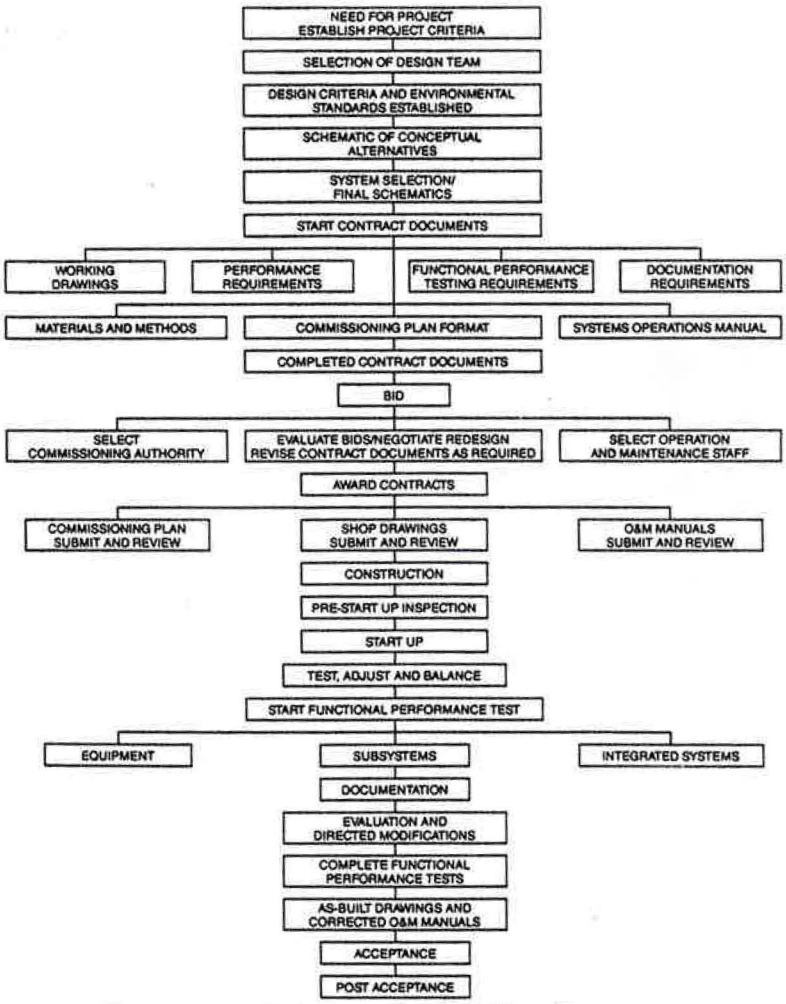

Figure 1. Sample commissioning process process (from *ASHRAE Guideline 1-1989, Guideline for Commissioning of HVAC Systems*).

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indoor air contaminants involve the placement of synthetic materials, the out-gassing of volatile pollutants, energy conservation measures that minimize the infiltration and introduction of outdoor air, tightly sealed building envelopes (now demanded by building owners, tenants and energy use/construction codes, etc.), inadequate design, unsafe operations, and poor maintenance practices. Volatile pollutants include formaldehyde, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs).

To help avoid subsequent and costly IAQ problems, designers must now look to the manufacturers of interior building products to furnish data on chemical composition, possible emissions and manufacturing test methods prior to their selection, specification and approval. The American Society of Testing and Materials (ASTM) recently adopted the *Standard Guide for Determination of VOC Emissions in Environmental Chambers from Materials and Products*, which may serve as the basis for more specific standards for testing emissions from various interior building materials.

Proper building commissioning[1,3] can play a major role in the actual performance of otherwise properly designed and installed HVAC systems. It is difficult to determine the full design intent. To avoid performance defects, the designer should: document the design intent clearly in a suitably written form;[3] make it available throughout the design/construction process to architects, owners, contractors and commissioning authorities; and ultimately employ it as a vehicle to assist in the training of building operations and maintenance (O&M) personnel.

Early delegation of a commissioning authority to oversee the commissioning process is often the key to achieving expected performance goals. Early involvement of the various material manufacturers, suppliers and key subcontractors in commissioning is essential for identifying potential construction or installation problems. The commissioning authority must also be directly responsible for training building operators (prior to turning over the building to its owners) by employing the above-referenced documentation as training tools and helping to familiarize building operators with overall HVAC system features and controls.

A detailed commissioning plan[1,3] should contain a complete listing of the responsibilities each team member is expected to assume in such things as the work schedule, documentation for construction, operations and training verification procedures for installed operating systems, staffing requirements for ensuring adequate commissioning, and operations and maintenance. When commissioning becomes an integral element of the design/construction/ move-in process, most potential IAQ problems are more easily identified and, therefore, more easily prevented.

Verifying ventilation for reconfigured space

Ventilation requirements originally intended for a given space use may not be adequate if, subsequently, the same building area becomes reconfigured space. Reconfiguring a space is defined as changing the purpose of an originally intended use. For example, when older office space is reconfigured, the net effect

of different interior finishes, carpets, housekeeping procedures and increased thermal load (i.e., due to computers, higher population densities, after-hours use, etc.) can result in a buildup of harmful indoor air contaminants not experienced earlier. This may call for rebalancing or adjusting the ventilation air rates.

The following steps are suggested when reconfiguring any building space:

- Develop independent design criteria that address potential IAQ concerns according to the latest applicable ASHRAE filtration, IAQ and comfort standards rather than the minimum code requirements necessary for a plan check of the building permit approval. Such standards currently include ASHRAE *Standard 62-1989, Standard 55-1981* and *Standard 52-76.*
- Determine and verify the capacity of existing HVAC systems based on the original design intent (see *Table 1* for a sample HVAC subsystem). This can be accomplished through design documentation, a clear description of O&M tasks that must be performed on a regular basis, and HVAC test and balance reports filed prior to the building owner's final acceptance of the construction. Where such documentation does not exist or where HVAC systems are determined not to have been tested and/or balanced recently, request an updated test and air balance report. Also determine if there have been any HVAC system modifications in the interim and, if so, the effect such modifications may have on current HVAC system operational capabilities.
- Reconfigure the HVAC air distribution system to accommodate the new space layouts by providing air distribution that ensures maximum ventilation efficiency. Analyze the overall new system capacity to determine its adequacy for new thermal loads associated with the new layouts.
- Thoroughly test balance the reconfigured system and document the results in suitable AABC or equivalent report format.
- Verify the HVAC system performance (under anticipated full- and part-load conditions) to comply with the new tenant plans and specifications developed by the architects or space planners and check that all applicable codes have been followed according to commissioning guidelines (ASHRAE *Guideline 1-1989*).
- Where the performance of the reconfigured HVAC system is determined to be unfavorable, repeat the above procedure.

Avoiding potential IAQ pitfalls

Unfortunately, many IAQ problems are not easily foreseen and cannot be corrected without substantial rework. Therefore, early prevention involves sensitivity to occupant complaints, avoiding construction odors on partially tenanted floors, and applying common sense in selecting the most appropriate initial corrective measures.

Fortunately, the major causes of sick-building syndrome (SBS) or building-related illness (BRI) are known and, therefore,

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Table 1. Input/Output Summary for Chiller System*

BUILDING: SAMPLE / SYSTEM: CHILLER	INPUTS: ANALOG								INPUTS: BINARY								OUTPUTS: ANALOG								OUTPUTS: BINARY								OUTPUTS: 3-POINT FLOATING								ALARMS				FEATURES															
DESCRIPTION	Room Temperature	Duct Temperature	Water Temperature	O.A. Temperature	Static Pressure	K.W.	Flow (Totalization)	BTU	Flow Switch	Switch Closure (Status)	Static Pressure						Modulating Actuator	E/P Transducer							Control Relay	Solenoid	Start/Stop	2-Position Damper Mod.					Actuator	Mercury Relay	Feed/Bleed Sav						High Limit	Low Limit	Run Time	Maintenance Message					Scheduled Start/Stop	Temperature Setback/Setup	Optimized Start (Adapt.)	Demand Limiting	Duty Cycle	Ventilation Delay	Economizer Cycle (D.B.)	H.W. Reset w/O.A. Temperature	VAV Control	Remote Read/Reset	Tenant Override	Color Graphics	Point Lockout	Trend Log				
Chiller																										X														X	X																
Chiller Output							X	X																																		X																
Chiller Input					X																																			X																		
CW Supply			X																																					X	X																	
CW Return			X																																					X	X																	
Condenser Supply			X																																				X	X																	
Condenser Supply			X																																					X	X																	
Tower Fan										X																	X																X	X														
Chiller Pump									X																		X																X	X														
Cond. Water Pump									X																		X																X	X														
Make-Up Water							X																		X																		X														

*From *ASHRAE Guideline 1-1989, Guideline for Commissioning of HVAC Systems.*

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prolonged unacceptable IAQ can be avoided. Preventive measures may, in some cases, increase construction and occupancy costs. However, failure to maintain adequate IAQ can ultimately be more costly because of loss of productive time, subsequent modification or replacement of troublesome HVAC components, and interior finishes and materials (i.e., carpet, paneling, etc.) that may be needed to correct the problems.

The following procedures are recommended during applicable phases:

Design phase. Choose building materials, finishes and equipment carefully and review those selections made by an outside interior decorator.

Design an energy-efficient HVAC system that provides a reasonably contaminant-free interior environment. HVAC systems (otherwise adequately designed for peak thermal loads) may not be suitable for meeting ventilation needs at all part-load conditions. Additionally, questionable energy conservation measures affecting air supply rates should not be allowed to jeopardize IAQ or occupant health concerns without a thorough review of all foreseeable operating modes and related consequences.

Allow proper access to all HVAC systems for ease of maintenance or replacement of potential microbial contaminant sources.

Construction phase. Do not substitute materials or modify the design where such changes are known to result in increased indoor air contamination.

Check carefully to ensure that the entire HVAC system is installed according to the design. It is not uncommon for entire ductwork runs to be omitted or dead-ended; for all moving parts not to be operating; for fans and motors to be omitted or in reverse relation; or for supply and return ducts to be omitted, interchanged or interconnected. The owner's O&M staff should be in attendance during the construction phase.

Close-out phase. Thoroughly clean the HVAC system and especially remove all dust and debris from all interior equipment surfaces prior to start-up.

Allow emissions from new interior construction materials to vent to the atmosphere before gasses permeate other building materials, thus lengthening the off-gassing period. This can be done by ordering the materials and receiving them at the construction site early enough to allow unpacking and venting potential odors outdoors long before actual installation is completed.

Thoroughly test balance the HVAC system according to applicable industry practices. For example, the ratio of outdoor make-up air to clean recirculated air, particularly in VAV systems, cannot be allowed to change during part-load (i.e., variable supply-air rate) conditions. One way to accomplish this is to supply outdoor air by a separate supply fan that can maintain a predetermined flow rate. Another way is to utilize an automatic return-air damper that is controlled by return airflow and is therefore capable of adjusting to a lower system pressure loss at part-loads.

Be sure to take appropriate airflow measurements as part of the HVAC system balancing process. Also, consider increasing the make-up air substantially for the first few weeks or even months of building operations. Advise occupants as to potential causes of stress related to moving, odors due to new construction, and individuals to contact in case of complaints.

The following test procedure is recommended as a minimum and should be modified, where required, based on the complexity of each building to obtain the best possible test results:

- Inspect the HVAC and electrical systems to verify proper installation/interconnection and to ensure that all corrective measures have been finalized according to construction contract requirements.
- Clean the building interior to ensure that it is free of standing water prior to testing.
- Install movable screens, furniture and other fixtures prior to testing.
- Set the HVAC system to operate at a maximum heating mode for at least 24 hours with full lighting on. The bake-out time required to heat some heavy structural masses may require more than 24 hours, so consider the effect of construction mass in setting this appropriate timeframe. (Bake-out is when the air temperature and ventilation in a building are increased for a certain time period to promote off-gassing.)
- Set the HVAC system to operate at a normal operation mode for 12 to 24 hours after a predetermined temperature has been reached.
- Set the HVAC system to operate at a maximum heating mode for 12 to 24 hours with all lighting on after a predetermined temperature has been reached.
- Set the HVAC system to operate at a normal mode for a minimum of 24 hours after a predetermined temperature has been reached.
- In buildings with repetitive, typical floors and separate HVAC systems, it may be economically advisable to measure the concentrations of indoor air contaminants on the first floor for a week or two to determine if it is effective or if additional bake-out time is necessary. This will be invaluable in case of subsequent litigation.

Occupancy phase. Provide heating or cooling capability early in the morning (before normal office hours) on a daily basis with 100% outdoor air only for the first few weeks (or longer if necessary), followed by normal heating or cooling operations with maximum ventilation provided (for purging). During occupancy hours in the first few months, operate the HVAC system below normal thermostat settings to reduce adverse off-gassing effects.

To evaluate IAQ conditions (temperature, humidity, stuffiness, etc.), designate one employee on each floor to record these conditions a few times each day.

While monitoring employee comments very closely, decrease the cooling/heating/ventilation requirements prescribed above gradually over three to six months until normal design cooling/heating/ventilation levels are established.

Operations and maintenance. Avoid outside sources that will contaminate air intakes such as bird nests or feathers, standing water, and exhaust air from adjacent buildings, parking garages or streets. Replace outside air filters regularly.

Use adequate ventilation air to avoid the buildup of indoor air contaminants. A decrease in lighting load to conserve energy may result in a decreased heating load and air change requirement. Using inadequate outdoor make-up air can cause excessive recirculation of indoor air contaminants and should be avoided at all costs. Also, inadequate recirculation can create stagnant air.

Maintain the HVAC system to be operational at all times. Train O&M personnel thoroughly on complete system operation and acceptable tolerances for system adjustments, emergency procedures, use of O&M manuals, and other factors. Maintain a standard method of recording HVAC operation complaints.

Investigating IAQ problems

Investigating IAQ problems poses a great challenge even to the most experienced health professionals because the complaints in buildings can be rather diverse and non-specific. For example, SBS has been known to cause non-specific symptoms such as headache, dizziness, nausea and eye irritation.

Table 2 shows some probable causes of SBS resulting from 346 indoor air investigations conducted by the National Institute of Occupational Safety and Health (NIOSH). Of the 346 investigations conducted, 179 (or 51.7%) were attributed to inadequate ventilation.

If building owners, managers, operators or others wish to investigate IAQ problems, they may gather the necessary information by using questionnaires that also promote the efficient use of investigative time during subsequent site inspections. These questionnaires should include inquiries about occupants, building and building environments, and HVAC systems.

Table 2. Probable Causes of Sick Building Syndrome

Probable Causes	Cases Investigated (%)	No. of Cases
Fabric Contamination	4.0	14
Microbiological Contamination	5.5	19
Outside Contamination	11.0	38
Inside Contamination	16.5	57
Inadequate Ventilation	51.7	179
Unknown Sources	11.3	39

VOC levels in new and existing buildings may be measured by using screening devices such as a survey meter. Levels in excess of 1 ppm may call for an in-depth investigation. However, increased ventilation rates may not always reduce the VOC concentrations.

Other control techniques such as a bake-out may be used. As mentioned, high temperatures maintained for a sufficiently long time increase the VOC emissions and eventually drive them off from furnishings and building materials.

Necessary precautions must be taken to avoid material damages due to low relative humidity and high temperature. The high costs of conducting a bake-out and delayed occupancy may limit the use of this process in all buildings.

Failure to identify the cause of an IAQ problem following the above-referenced inspections may warrant a more extensive investigation. If that occurs, the actual airflow rates of outdoor and recirculated air should be measured and compared to the design and recommended *Standard 62-1989* airflow rates.

Other measurements that should be taken are the indoor air temperature, relative humidity, and outdoor wind velocity and direction. These measurements will help ascertain whether symptoms coincide with specific outdoor weather conditions consistent with transmission of seasonal pollens and dust. Low relative humidity (less than 30%) can also cause dryness of the eyes, nose and throat, while high humidity (greater than 70%) can cause proliferation of micro-organisms.

The use of air sampling to confirm prevailing IAQ levels can be expensive, and the results may not always reliably indicate

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abnormal operating conditions. Permissible exposure limits (PEL) and threshold value limits (TVL) — developed by the Occupational Safety and Health Administration and the American Conference of Governmental Industrial Hygienists, respectively—are based primarily on *industrial* environments.

These procedures are used for sampling an 8-hour time-weighted average (TWA) and a 15-minute short-term exposure limit (STEL). However, the sampling procedures may not be capable of measuring contaminant concentrations much lower than those normally found in industrial environments. Therefore, they may not be applicable to all indoor environments.

Some commonly collected samples and instrumentation (detector tubes or direct-reading devices) include carbon monoxide (2-200 ppm), carbon dioxide (0-2,000 ppm), nitrogen oxides, ozone, radon and particulates (as low as 2,000 particles/cubic centimeter of air).[4]

To determine the nature of a specific IAQ problem, additional information not available through questionnaires may be necessary. This information should be collected by a walk-through inspection of a building to look for possible indoor air contaminants in materials, finishes, furnishings, equipment and supplies. Insome cases, the walk-through may require several site inspections and a more intensive IAQ investigation, including environmental monitoring. Prior to a walk-through, it is recommended the building and HVAC system blueprints, the HVAC modification and O&M records, and the current employee list be thoroughly reviewed. ■

References

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3. Meckler, M. 1990a. "Role of commissioning and building operations in maintaining acceptable indoor air quality." *Proceedings of the 5th International Conference on Indoor Air Quality and Climate.* Indoor Air '90, Toronto, Canada.

4. Meckler, M. 1990b. "Investigation of indoor air quality in buildings." *Indoor Air Quality Design Guidebook.* Chapter 15. Lilburn, Georgia: The Fairmont Press.

PUMPS

An overview of pumps and equipment available in the HVAC&R marketplace

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Bronze pump

Grundfos Pump Corporation, Clovis, California, has added a new model to the Series 7000 centrifugal pump line. The Bronze pump features bronze housing and stainless steel fittings. It can be used in hot or cold water applications (5° to 250°F or −15° to 121°C) as well as potable systems and other open loop applications using clean, non-explosive thin liquids. It is capable of flows up to 230 gpm (14.5 L/s).

Circle Item No. 151

Pump controller

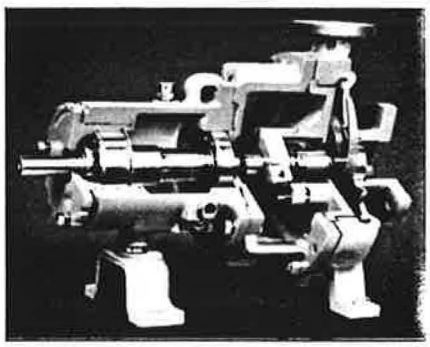
The Series 7592 microprocessor-based pump controller provides flow rate, speed, rpm, torque and repeat dispensing. Available from *Barnant Company,* Barrington, Illinois, the controller is programmable through the membrane keypad or external controller. It comes in wall-mountable NEMA enclosures and slope-front benchtop housing. A hand-held remote feature is optional.

Circle Item No. 152

Sequencing device

Alyan Pump Company, Upper Darby, Pennsylvania, is introducing a pump sequencing device for domestic water pressure systems. The module sequences the pumps through a flow sensor in the suction line. The system's gpm is displayed through an analog or liquid crystal display. A transmitter and dual alarm modules transmit signals to the control panel and display.

Circle Item No. 153



Chemical service pump

The Duriron Company Inc., Pump Division, Dayton, Ohio, has refined its Mark III line of chemical service process pumps to simplify service and prolong equipment life. The pumps feature an oversized stuffing box that allows larger, more rugged mechanical seals; provides more area for liquid circulation and heat transfer; and more room for corrosive particles to centrifuge out and away from the seal. Other features include heavy-duty power end design with several lubrication and bearing options, improved oil seals and preventive maintenance features; improved hydraulics; a micrometer-type impeller adjustment; oil level sightglass; double lipped oil seals; and permanently lubricated double sealed bearings.

Circle Item No. 154