Laboratories for the 21st Century: Best Practice Guide

Cover photos: courtesy of Laconic Corporation, Kansas City, MO

Commissioning Ventilated Containment Systems in the Laboratory

Introduction

Ventilated containment equipment has commonly been delivered and installed as off-the-shelf selections, considered state of the art by default if not by superior design. However, with advancing technology of ventilated containment systems (VCS) and with heightened concern over material hazards, environmental protection, and energy conservation, equipment efficacy must be assured. Consequently, commissioning has become an essential discipline for the effective construction and operation of laboratory facilities. Additionally, a well-implemented commissioning plan can help pave the way to Leadership in Energy and Environmental Design (LEED) certification, as established by the U.S. Green Building Council.

The concept of *commissioning* has been shaped over time by design teams to fit their particular time, place, and set of needs. It has been viewed as any set of inspection and testing activities somewhere between planning and end-use

EPA United States Environmental Protection Agency

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Federal Energy Management Program

operations. To provide an operational definition: "Commissioning is everything you do to make certain that you get the performance you asked for in a given facility design."

This *Best Practice Guide* does not cover comprehensive building commissioning, but focuses on the specialized approaches required for VCS, understood to be all components that drive and control ventilated enclosures and local exhaust systems within the laboratory. The system typically begins with the dampers that modulate air supplied to the laboratory and ends at the top of the exhaust stack. Everything in between is considered part of this system: supply-air diffusers, ventilated enclosures, exhaust valves, fans, controls and algorithms, and related items integral to this equipment.

Many resources exist for understanding and implementing commissioning activities (see References and Resources). This guide is one in a series of best practices for laboratories produced by *Laboratories for the 21st Century* ("Labs 21"), a joint program of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE). Geared toward architects, engineers, and facility managers, these guides provide information about technologies and practices to use in designing, constructing, and operating safe, sustainable, high-performance laboratories.

A Spectrum of Ventilated Containment Equipment

The contemporary laboratory may be a simple installation of one ventilated enclosure or may contain multiples of the entire range of containment devices in use today:

- Fume hoods
- Custom ventilated enclosures
- Articulated arm exhausts
- Balance enclosures
- Downdraft tables
- Slotted backdraft hoods
- Biological safety cabinets
- Gloveboxes and glovebags
- Canopy hoods

Each device has multiple types designed for a specific purpose with specific performance criteria that can only be determined by those familiar with the characteristics of the materials and the operation. Ideally, each device type will be tested individually and as it interacts with other equipment in the system. This customized complexity is the primary reason that VCS commissioning must begin with the design process.

Bringing Together Essential Personnel

It is unlikely to find a single commissioning company that has all the expertise necessary for coordinating comprehensive building commissioning and that is also skilled with the intricacies of VCS commissioning. Creating a multidisciplinary team with experience in engineering design, construction, and facility operations is essential. The initial commissioning team should combine the architectural and enginering (A&E) firm with in-house staff, forming a group that embraces all the needed talents. This core team can put together the initial plan, turning to a larger group for review and feedback. Consider including these resources:

Internal staff:

- End users
- Engineering
- Health, safety, and environmental
- Project management
- Maintenance

External Staff

- A&E firm
- Commissioning agent
- Testing consultants

Several key parties can be identified later: the equipment manufacturers and vendors, general contractors and their subcontractors, and the testing, adjusting and balancing (TAB) contractors; however, based on past experience the commissioning agent and testing agents should be hired early on. The commissioning firm should be experienced in laboratory building startup, and the testing consultants must have documented experience with the specialized equipment and knowledge required to be proficient with VCS. Interviews help to evaluate verbal and people skills, but should be backed up by references and work samples. Commissioning and/or testing agents may be from internal staff, but it is rare to have staff with broad experience in VCS commissioning.

The prospective testing consultant should fully comprehend equipment design: the aerodynamics of ventilated enclosures, including airfoils and baffles, the subtle effects of shape on airflow patterns, and air-supply modifications such as auxiliary air, bypass grilles, and supply diffusers. The consultant must understand safety, quality, and environmental equipment options and how they affect the commissioning protocol, including the benefits and disadvantages of variable air volume (VAV) compared to constant air volume (CAV) air supply and exhaust. Another option is with exhaust systems, where manifold systems can reduce costs, conserve energy, and increase safety. The

consultant should be conversant with testing standards: face velocity range, criteria for flow visualization, and tracer gas or particle-counting challenges. Particularly, the consultant should be able to discuss the variables of static vs. dynamic conditions, sash positions, and test duration. The consultant should be able to extrapolate from these standard fume hood tests to recommend procedures for other ventilated enclosures.

Key Elements of the Commissioning Plan

A commissioning plan that begins in the earliest stages of a project leads to an orderly and effective succession of events. A complete plan identifies all equipment and systems requiring commissioning, with performance testing methods to be used for each component, along with parameters for acceptable performance. The documentation will include these items:

- All equipment submittals required to support the commissioning process
- Requirements for training of the operations and maintenance personnel
- Expected owner/user manuals
- Requirements for process sequence and system operation manuals
- Sample formats for reports and other documentation
- A detailed schedule for when various commissioning operations will occur

Commissioning within the Phases of a Project

In the broadest strokes we can discuss the progress of a sound commissioning plan during a three-stage timeline: ***Design, Deliver***, and ***Sustain***.

Design. End-users, A&E firms, industrial hygiene and safety personnel, engineers, and management should all be included in the design stage. This first phase will result in a formalized expression of a facility concept, which should be manifested in a *design profile* or a *design intent* document. A detailed design document reflects agreements among all parties as to the valid requirements of the project that will shape later commissioning: equipment choices, such as the design opening of hoods, and performance criteria, such as average face velocity, speed of response, stability, and containment. User needs, safety/risk assessments, and environmental and energy performance requirements all fit into the mix, expressed in a set of construction drawings, a bidding package, and a well-defined commissioning plan.

1) User needs. Many laboratory applications can appear to require highly customized ventilated enclosures and systems. These drive up facility costs and should be justified by a safety/risk analysis. Most laboratory containment requirements are accommodated by standard manufacturers' models with an array of options. If a custom design is genuinely required, detailed commissioning requirements for the item must be part of the design process. Other user requirements affecting commissioning include air cleanliness and temperature and humidity limits. Where exhaust filtration is required, criteria must be established early for appropriate filter specification and commissioning requirements.

2) Safety/risk. First, determine the nature of the risks to be managed, whether chemical, biological, or physical. Some hazards require specialized rooms, ventilation systems, or life-safety systems; and commissioning for exceptionally hazardous materials may need substance-specific monitoring during equipment operation. If exposure limits do not exist to determine pass/fail criteria, reasonable criteria must be established so that the manufacturer has a target to aim for. This type of testing may be expensive and should be prescribed judiciously. Testing with

Photo courtesy of Tintschl Engineering, Erlangen, Germany

Figure 1. A large custom enclosure requires specialized commissioning criteria.

Commissioning for LEED

The commissioning plan can also facilitate LEED certification. The LEED prerequisite *fundamental building systems commissioning* mandates specific steps that exemplify a good commissioning plan even when certification is not planned. The LEED program offers additional credit for "Enhanced Commissioning" for in-depth oversight during the design and submittal process to catch potential problems. Check www.usgbc.org for details.

surrogates (such as sulfur hexafluoride) should be done whenever possible, but safety-critical operations may require actual operational data collected by a continuous monitoring system.

The best designed ventilated enclosures are still dependent for their effectiveness on the environment in which they are installed. A containment and ventilation system is designed based on a projected interaction of a number of personnel using specific equipment and operating in concert with a correctly designed air-handling system. The number of people in a room often determines the number of ventilated enclosures per room, which in turn determines the total airflow required. Depending on the extent of containment required and the types of ventilated enclosures used, excessive air changes can make attaining the containment criteria impossible, calling for a change in basic assumptions of building size or population. Reliance on incorrect containment criteria leaves the project susceptible to extensive failures and cost overruns.

A corollary of the airflow volume is velocity, a surprisingly overlooked design factor. Even if the air-change rate is not excessive, too great an air-supply velocity has deleterious effects on containment. Commissioning criteria will guide the designers in distributing air at the proper location and velocity. A higher velocity can be tolerated if air-supply diffusers are positioned away from the enclosure. A rule of thumb is no closer than five linear feet (1.5 m) from the face of the enclosure. It is preferable, however, that air-supply velocities be kept as low as possible. The European recommendation, for reasons of comfort, is a velocity not to exceed 40 fpm (0.2 mps) at 2 m above the floor (see ANSI Z9.5-2003: supply air velocity should not exceed 50% of face velocity at head height; or NFPA 45-2004: ideally less than 30% of face velocity). Another air-delivery precaution is to avoid windows and doors that open to natural air currents that wreak havoc with containment. The amount of return air, if any is permitted, is crucial. Most laboratories should be 100% once-through air, but if a risk assessment allows it, a heavy energy burden can be reduced by prudent recirculation or transferring supply air from office areas to adjacent labs.

A risk assessment will match the appropriate biosafety cabinet (BSC) class and type to the actual hazard. Contributing factors are localized particle cleanliness, cleanability, and recirculation vs. external exhaust. BSCs fall under the jurisdiction of the National Sanitation Foundation (NSF) (see NSF Standard 49, Class II (Laminar Flow) Biosafety Cabinetry). The commissioning protocol should apply criteria from this standard, but exceptional situations, such as BSCs in aseptic environments, may call for added testing.

3) Environmental and energy performance. Establish these criteria for the proper level of emissions control. Vapor control systems to consider are the condensers, scrubbers, and adsorbers. For particulate control, consider cyclones, frame or cartridge filters, bag houses, or electrostatic filtration.

High efficiency particulate air (HEPA) filters, developed for nuclear and biological applications, are often the default choice for exhaust filters, but many particulates are not in the low micron size categories necessitating HEPA filtration. Adequate filtration can often be achieved with filters in the 65% to 85% efficiency range (ASHRAE 52.1/MERV 11-13), thus reducing both equipment and energy costs. Filtration will increase the system static pressure and therefore significantly increase the horsepower necessary to drive the system. Conduct a risk and engineering assessment to match the filtration level to the hazard level. Without this evaluation, the sizing of the system, the pressure rating of system components, and even airflow volumes can be incorrectly specified. The type of filter will drive commissioning requirements, so early filter determination is essential (see: *Low-Pressure-Drop HVAC Design for Laboratories*).

High velocity discharge and/or manifold exhaust systems may also be needed to prevent reentrainment of lab exhaust into the building or into the air intakes of neighboring buildings. You may want to enlist the aid of a firm that can conduct air emission modeling or wind tunnel testing as a precommissioning screening process. When the site is complicated by numerous buildings or complex topography, wind tunnel testing will provide the most accurate and usable data. Depending on the criticality of the application, on-site tracer gas testing may be needed at the time of commissioning to verify that the wind-tunnel design has met actual emissions criteria. On-site testing as part of the commissioning process can be heavily impacted by weather conditions. Keep in mind the possible timing of the commissioning so that if weather could be a significant factor, provisions are made in the project schedule to accommodate delays and cost overruns that could occur (see: *Modeling Exhaust Dispersion for Specifying Acceptable Exhaust/Intake Design*).

A *sequence of operations* document, prepared during the detailed design phase, sets forth an agreement on how even the most complex containment system will operate under varying conditions, from normal operation to automatic and manual flow setbacks such as alarms, spills, and power loss. Beyond the proper documents, such as the *design intent* and listing of systems to be commissioned, design-phase commissioning should include planning for quality assurance. Development of a *basis of design* document will serve to codify the criteria that have been dis-

cussed. Take sufficient time to review the ventilation system design with involved staff or consultants, and ensure that the A&E firm has fully and accurately included the commissioning criteria in the bidding and construction documents.

Deliver. During the delivery stage, verification and testing take place. *Factory Acceptance Testing* (FAT) to evaluate the equipment performance is conducted at the manufacturer's or a third-party's site. Some protocols may include *challenge tests*: the walk-by, which simulates worker movement, the fan-forced draft, which reflects room air influences, and thermal loading, which tests the enclosure's capability to overcome convective currents.

Receipt verification ensures that the specified design intent has been fulfilled, and *installation verification* makes certain that equipment and systems are physically installed in the correct manner, which may be a quick check against blueprints or require scrutiny where correct installation is exacting.

A checklist is an effective tool for ensuring quality installations. This list itemizes all piping, conduits, ductwork, and accessory fittings needed for full design functioning of the ventilated enclosure. The list first communicates the expectations of the installation, and, second, helps to evaluate the installation. Where an intricate collection of piping, conduit, ductwork, and other utilities must be coordinated, an on-site mockup can serve as a model for correct and consistent installation. The mockup should be identified in the commissioning plan, specifications, and drawing notes, and then constructed as soon as possible. Typically it can be retained for use in the final construction.

As the facility progresses to more advanced stages of construction completion, both operational testing and startup begin. Some consider these separate operations, but they are tasks that are best combined. The commissioning firm should facilitate startup and testing. The ventilated enclosure and controls manufacturers will verify that fans, dampers, and other components are functioning properly. Components not functioning correctly will be referred back to the electrical and mechanical contractors for corrections. The TAB contractor must be part of these startup operations, making certain that adequate air is provided for startup operations even though heating ventilation and air-conditioning (HVAC) system balancing is just beginning.

Some commissioning procedures may need adjustment for setup conditions. Deviations from design, such as duct routing, equipment substitutions, or control limitations, may require testing adaptations. Architectural, engineering, safety, and commissioning personnel should work as a team when specialized validation methodologies are needed to accommodate irregularities in installation.

Once the building is balanced, the stability of the supply and exhaust systems must be assessed. The best method for collecting this data is through the Building Management (or Automation) System (BMS). Static pressure data from the supply and exhaust manifolds should be logged once per minute for at least 72 hours to discover any problems (see ASHRAE 110-2006 for procedures or confer with the testing consultant, BMS contractor, or controls manufacturer). If an HVAC system is found to be unstable, e.g., exhibiting large swings in pressure, oscillation, or hunting, the cause must be corrected before performance testing begins.

Next, the supply and exhaust flow control system is tested for functionality and stability. This involves real-time monitoring of room pressure for a specified time while VAV components (e.g., fume hoods, temperature-controlled general exhaust) are operating. Now that the system has been checked for adequate control, the performance testing of the ventilated enclosures can commence.

The most common ventilated enclosure in the lab is the chemical fume hood, which relies on directional airflow at a specified velocity to capture contaminants. A face velocity of 80 ft/min to 120 ft/min was long accepted as assurance of containment for the fume hood, but this is now looked on as only a first check, to be followed by an array of tests. The procedure that has guided fume hood testing in the U.S. since 1985 is the ASHRAE 110 *Method of Testing Performance of Laboratory Fume Hoods* (see ASHRAE 110-2006). This document recommends a testing regimen, without setting absolute pass/fail levels, recognizing that testing criteria must be appropriate to the intended usage. Another standard, ANSI Z9.5 (see ANSI Z9.5-2003), provides useful guidance on establishing performance criteria for VCS.

Fume hood testing is currently based on any of four procedures, the American ASHRAE 110, the EN14175 for European use, the Australian AS/NZS22438 (2001), and the Canadian Standards Association (CSA) Standard Z316-04. These documents provide a foundation both for factory acceptance testing and for as-installed performance testing. Requirements vary among these standards, but all fairly agree on a basic course of testing, except for the Australian standard, which omits tracer gas testing.

A testing sequence is recommended that immediately reveals any major problems and proceeds through a range of increasingly precise analyses: beginning with face velocity, next low and then high volume flow visualization, and finally tracer gas testing. Any serious failure in this sequence according to established project criteria would call for remediation and retest before continuing.

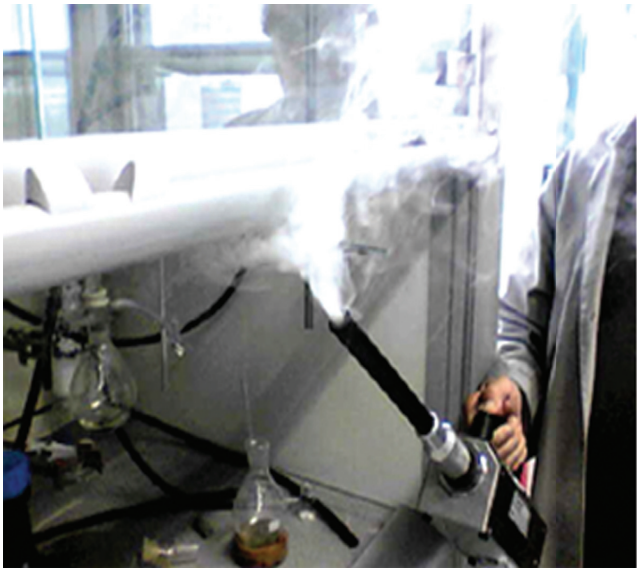

Photo courtesy of Tintschl Engineering, Erlangen, Germany

Figure 2. Flow visualization during a standard performance test.

Table 1. indicates appropriate tests for each of the ventilated enclosures listed.

Diagnostic tests may assign cause when the standard tests reveal a containment failure, possibly attributable to room air currents or the interplay of the enclosure with the building mechanical system.

Performance testing provides, first, a go-ahead for safe operations, and, second, a baseline set of data that will be used as a reference for annual preventive maintenance testing or for comparison following laboratory modifications. Random testing of multiple, similar installations is a tempting money and time saver, but a baseline of performance data should be established for each piece of equipment. However, random testing of VAV systems for speed-of-response can be a reliable indicator across systems.

Widely recognized procedures do not exist for ventilated enclosures other than benchtop fume hoods or BSCs, but testing for other enclosures should be similar. Appropriate test protocols can be developed by adapting procedures for the standard fume hood and/or BSC. Because of their unique customization, downdraft tables, gloveboxes, and glovebags should be tested according to specifications developed in conjunction with the manufacturer, the testing consultant, and the in-house engineering and industrial hygiene staff.

A performance testing protocol should include all details to preclude later disagreements regarding 1) who will do the testing, when and where, 2) a list of each item and all tests to be conducted for each, 3) pass/fail criteria, 4) test results reporting, and 5) responsibility for remediation and retesting.

The final step in delivery is documentation. Testing guidelines can suggest a report format or the project team can establish its own.

Table 1. Recommended Tests

Tests		Laboratory Fume Hood (LFH)	Ventilated Balance Enclosure (VBE)	Custom Ventilated Enclosure (CVE)	Biological Safety Cabinet (BSC)	Local Exhaust Ventilation (LEV)
Installation inspection		standard	standard	standard	standard	standard
Velocity at face (plus downflow for BSC)		standard	standard	standard	standard*	good
Low-volume flow visualization (smoke/fog)		standard	good	good	standard	good
High-volume flow visualization (smoke/fog)		good	N/A	better	N/A	N/A
Tracer gas	Static test	standard	good**	standard	good**	good
	Dynamic test	good	N/A	better	N/A	N/A
	Challenge test	good	better	better	better	better
Face velocity alarm or flow alarm		standard	standard	good	standard	better
Exhaust filter integrity		N/A	standard***	N/A	standard	N/A
Supply filter integrity		N/A	N/A	N/A	standard	N/A
Duct air flow volume		good	good	good	good	standard
Sound level		good	better	good	standard	better
Lighting level		better	better	better	standard	N/A

* Indirect measurement (see NSF 49 or EN12469 for specifics)

** Tracer gas testing on these devices only if they are exhausted externally.

***This is mandatory if the ventilated balance enclosure is recirculated.

N/A = Not Applicable

Photo courtesy of Tintschl Engineering, Erlangen, Germany

Figure 3. Mannequin simulates worker exposure during a tracer gas test .

Sustain. After performance testing, training programs and maintenance procedures pave the way for an operationally and economically sustainable facility. Training is the responsibility of the facility owner, but the owner can negotiate with equipment vendors for training assistance. The lab users and maintainers must understand the design intent of the system and how to respond to prompts and alarms. Failure to train these personnel can result in wasted energy, loss of productivity, broken equipment, and even illness or injury. Responsible and proactive vendors will insist on leading an in-depth training program, which typically reduces warranty claims.

Maintenance and repair training should be part of the vendor contract documents. Staff must be trained in preventive maintenance, making clear what should be attempted only by trained manufacturer's representatives and what can be done in-house. Vendors should provide a list of critical spare parts to keep on hand and information on lubrication, cleaning, calibration and preventive maintenance intervals. Performance testing data should be retained as a baseline reference for preventive maintenance procedures. The commissioning agent can help create a long-term auditing program. The in-depth system audit should evaluate preventive maintenance in regard to both safety and energy efficiency. Ongoing preventive maintenance and auditing programs should be documented in the commissioning manual.

A laboratory of any age that has not been commissioned or has undergone modifications should be scheduled for retrocommissioning with a professional that has expertise in testing containment systems (see *Retro-Commissioning Laboratories for Energy Efficiency*).

Moving through the 21st Century: Issues & Innovation

As the art of commissioning continues to evolve, changes will result from technological advances, particularly in the area of ventilated enclosure testing. New and better analytical equipment will make testing faster, and it's even possible that self-diagnostic systems could eventually replace some baseline testing. It is unlikely though, that the fundamental commissioning tasks (e.g., verification tasks) would ever be automated. Nonetheless, as human interfacing decreases, commissioning costs should also shrink (the major cost now attributable to hourly compensation). While commissioning must encompass an array of factors, economics will always play a role. Managing costs is essential, because the more affordable commissioning can be made, the more likely a thorough commissioning will be conducted. Ultimately, it is the safety of the user that is at stake.

In terms of economics and the environment, it is also essential to minimize energy use and maximize energy efficiency. When developed and implemented in parallel with design and construction, a comprehensive commissioning plan will serve this purpose well. The Labs21 program provides many ideas, references, and tools for improving energy performance (see Labs for the 21st Century). Environmental Performance Criteria (EPC) specifically address ventilation-related energy principles to consider in the commissioning plan.

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