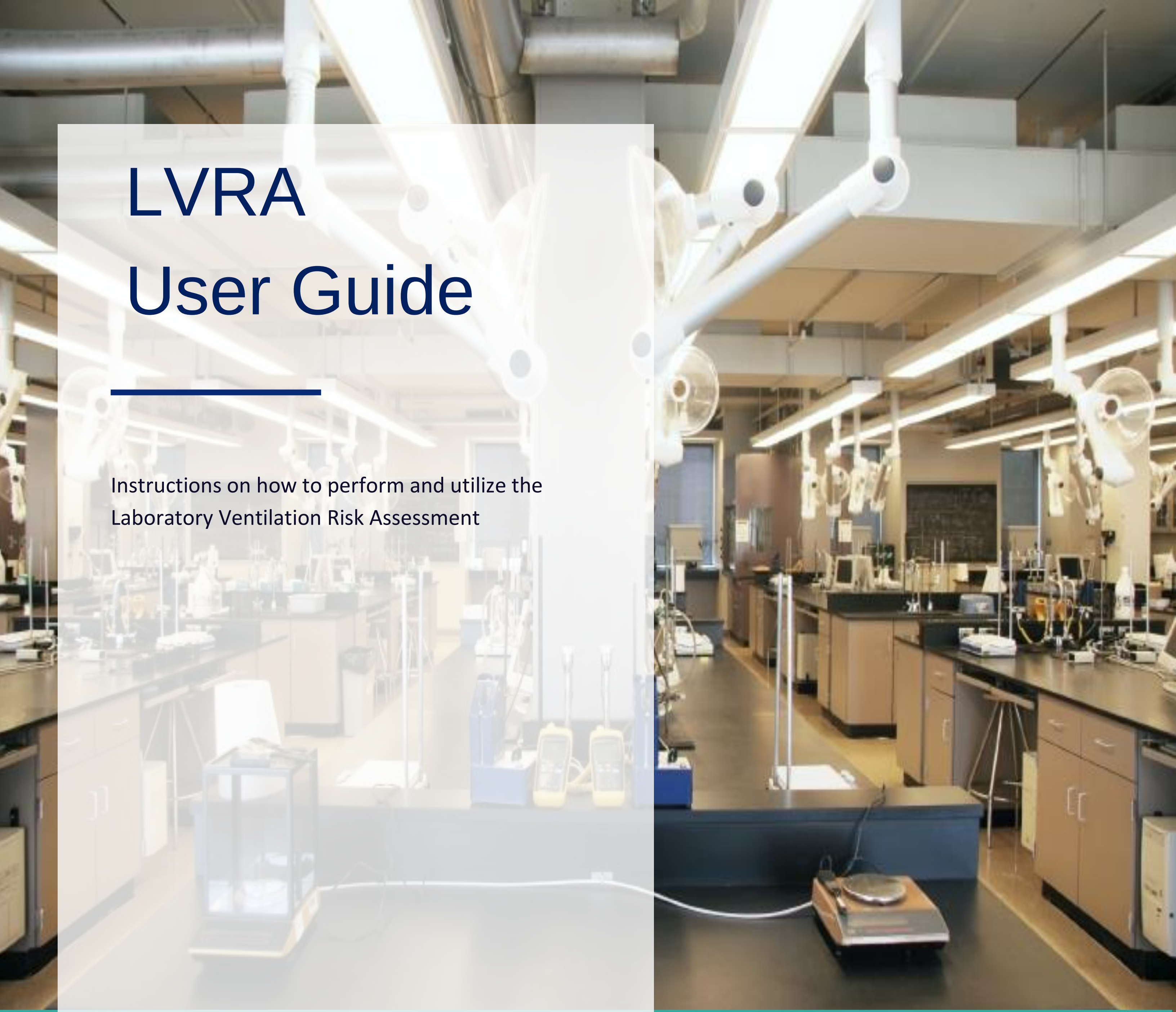


LVRA User Guide

Instructions on how to perform and utilize the Laboratory Ventilation Risk Assessment

FEBRUARY 25, 2019

VERSION 3.0

Contents

Introduction

Airborne hazards may be generated in labs that could cause harm to people, property or the environment. Lab ventilations systems serve as the primary engineering control (i.e. safety measure) applied to mitigate risk associated with generation of airborne hazards in labs. The primary mechanism of control is source capture by use of appropriate exposure control devices (ECDs) and secondarily through dilution and removal of the contaminants by the laboratory ventilation systems.

ECDs and lab ventilation systems must be properly designed and operated to help mitigate risk. This requires a method to assess risk, determine the required level of protection and establish appropriate specifications for selection, design and operation of the ECDs and the lab ventilation systems. The Lab Ventilation Risk Assessment (LVRA) described herein was based on methods developed by 3Flow and the University of California-Irvine (UCI) to evaluate risk associated with the generation of airborne hazards in labs. The risk information is used to recommend appropriate specifications for design and operation of ECDS and Lab Ventilation Systems referred to collectively herein as the Laboratory Airflow Control System (LACS).

Purpose

This User Guide outlines the processes used to conduct the Laboratory Ventilation Risk Assessment (LVRA). In this docment, you will be introduced to the LVRA process. Specifically, we will define the LVRA and its integral components including the methods to evaluate processes conducted in ECDS and the laboratory environment. We will describe the steps followed in conducting the survey, the data entry methods, and how to interpret the overall results that are derived from the data.

Scope

The LVRA helps determine the level of risk associated with airborne hazards that can be mitigated through use of ventilation. The LVRA process applies to hazards where the required level of protection is associated with maintaining airborne concentrations below specified levels of concern. The process is specifically applicable to controlling hazardous concentrations of vapors, gases and particulates. The process does not apply to control of airborne contaminants where there are no established control levels, recognized exposure limits or where ventilation is not an appropriate means of control (may include some biological contaminants, nanomaterials, etc.).

The Process

Researchers are potentially exposed to a wide variety of airborne hazards. These hazards must be uniquely characterized and evaluated to determine the demand for ventilation, ensure appropriate exposure control devices and establish appropriate operating specifications and performance criteria. The working environment of the researcher must be considered for processes involved with the ECD and on the benchtops.

The **Laboratory Ventilation Risk Assessment (LVRA™)** is an assessment tool developed by 3Flow and UCI to provide ventilation design and laboratory safety personnel with an effective tool to assess risk, help optimize ventilation controls and enhance worker safety. Laboratory settings are assessed across a wide array of categories that utilize control banding techniques to provide a hazard assessment rating for which ventilation can be properly customized. As part of an overall facilities management program, the LVRA helps optimize the operational effectiveness of labs, minimizes maintenance and control problems, and enhances occupant safety and comfort.

The LVRA can be applied to existing ECDs or a space where potential exists for exposure to hazardous airborne contaminants. Additionally, Risk Control Bands (RCBs) can be forecast to lab areas under design through application of pre-defined risk design levels or through analysis of what is known or can be predicted about anticipated use or future scientific activities. In this way, the LVRA helps determine the demand for ventilation, assess risk and recommend lab ventilation design and operating specifications for new or existing spaces.

Assessment Categories

Working closely together with facility and safety staff, principal investigators and research lab staff allows for the determination of lab ventilation requirements by evaluating:

- The types of hazards and procedures including use of highly toxic chemicals
- Hazard generation characteristics (i.e. gases, vapors, mists, dusts)
- Quantity of materials used or generated during lab procedures
- Frequency and duration of hazard generation
- Exposure control devices (ECDs) in the lab, their use and appropriateness

> “We will describe the steps to conduct the survey, the data entry methods, and how to interpret the overall results to be derived from the data.”

Preparing for the Survey

Prior to performing the field survey, it is often helpful to acquire and review historical information. Some of these items may include:

- As-built mechanical drawings
- Space and Floor Plans
- Fume hood inventories

- Chemical inventories and Safety Data Sheets
- Hazardous waste disposal records

Laboratories are inherently busy environments that are highly sensitive to surrounding physical conditions. Making appointments with researchers for lab visits is highly recommended to set boundaries for defining the "do's and don'ts" while visiting the laboratory – identifying requisite PPE, areas that may be "off-limits" to access and/or photography. Advance appointments with researchers can also provide direct and current information on laboratory function and processes.

For instances where lab managers are unavailable, a pre-survey questionnaire may be utilized to gather and exchange advance information. Post survey interviews may also be necessary to further understand lab activities and determine the demand for ventilation as a function of safety, space conditioning, occupancy and utilization.

Performing the Survey

The LVRA survey should be performed by a qualified individual – such as facilities or environmental health & safety professionals - with knowledge of mechanical ventilation, core sciences, and occupational safety and health. We recommend that LVRA findings and conclusions be reviewed by a licensed Professional Engineer and/or Certified Industrial Hygienist prior to any implementation of recommendations.

The definition of a laboratory is varied. For the purpose of the LVRA, a laboratory is defined as "a room or functional space where laboratory activities and/or processes are typically conducted that may present a ventilation hazard to occupants". They may include both wet and dry labs along with associated support areas. We recommend LVRA survey activities encompass areas that may present potential exposure to airborne hazards that can be controlled with ventilation.

We recommend allowing between 15 and 30 minutes for the completion of field survey activities for small to medium size laboratories less than 1000 ft^2. Larger labs with multiple user groups and activities may require more time and development of a strategy to segment spaces not separated by defined physical boundaries.

Data Collection

The LVRA is initially performed in large part by compiling information on a survey form, and a LVRA survey form is referenced within this User Guide. If formatted properly, the LVRA could be documented electronically. Regardless of the collection method, the physical survey and data collection is to be completed on site.

The protective capabilities of the fume hood and other exposure control devices exceed those provided by dilution of activities performed on the open benchtop. As such, the LVRA survey addresses the laboratory from two distinct perspectives: (1) the use of exposure control devices, and (2) from the laboratory as a whole that reflects the contents, operations, and associated risk with work performed within the ECDs as well as on the benchtop within the space. These two environments are addressed independently by the survey (See Figure 1). In both instances, however, the survey consists of three basic steps:

- **Step 1: Description** of the ECD or laboratory (i.e. type, size, access, monitoring)
- **Step 2: Evaluation** of the device or room purposing and condition, and processes
- **Step 3: Assessment** of the risk using predetermined criteria and ratings.

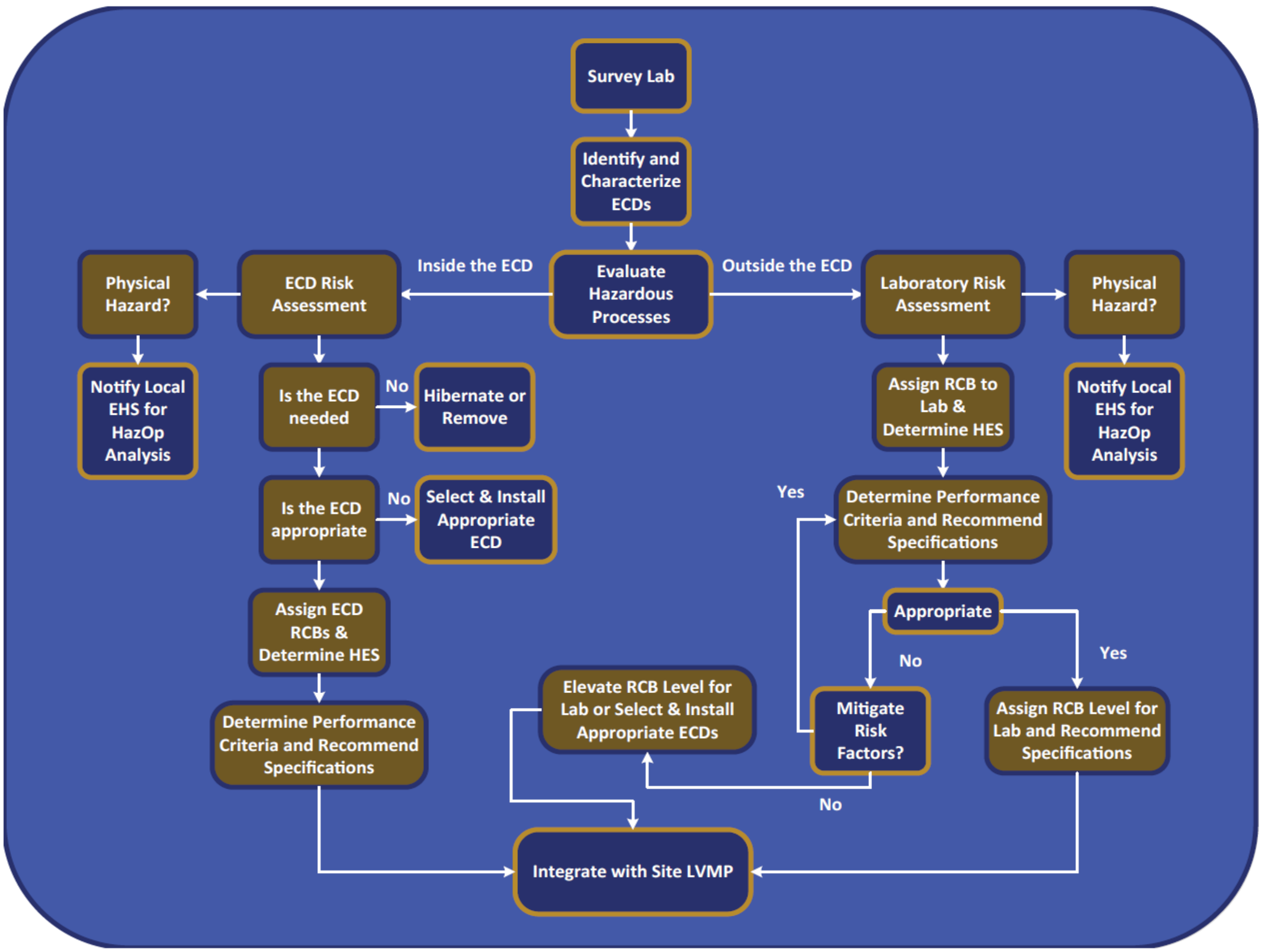


Figure 1 LVRA Flow Chart showing evaluation of ECDs first and then the Laboratory Environment second.

Scoring Parameters

For both the device and laboratory surveys, scoring systems are employed to categorize conditions for various parameters outlined in the following tables and sections. Categorical scoring performed in Step 3 of each relative process plays an essential role in laying the groundwork for establishing risk control band values and the subsequent development of airflow specifications. For perspective, the scoring values and risk control band values are based upon a zero-to-four scale as shown if the Table below.

Table 1 Risk Control Bands and Description of Associated Risk Level

Risk Control Band (RCB)	Risk Level Description
0	**Negligible**
1	**Low**
2	**Moderate**
3	**High**
4	**Special - "Extreme"**

The level 4 risk control band (RCB-4) denotes a special situation where there may not be a representative hazard emission scenario from which to evaluate and derive airflow specifications. The RCB-4 area may also designate extreme risk resulting from use of extraordinarily hazardous materials, quantities or generation. The ventilation solutions may need to be custom engineered and uniquely handled for these applications.

The ECD Survey

For laboratories with exposure control devices, we begin by compiling information describing the ECD (Step 1) - the type, manufacturer, quantity, opening type, and approximate size. A unique number (or inventory number, serial number, or another identifier) should first be assigned to each device. Gathering this information in such manner allows the end user to establish or supplement a device inventory.

Many types of exposure control devices are used in the laboratory setting. Important identifiers include how the device is ducted and/or filtered, mounting type, and various other identifiers.

Some examples for these categories include:

Figure 1 ECD Information by Category

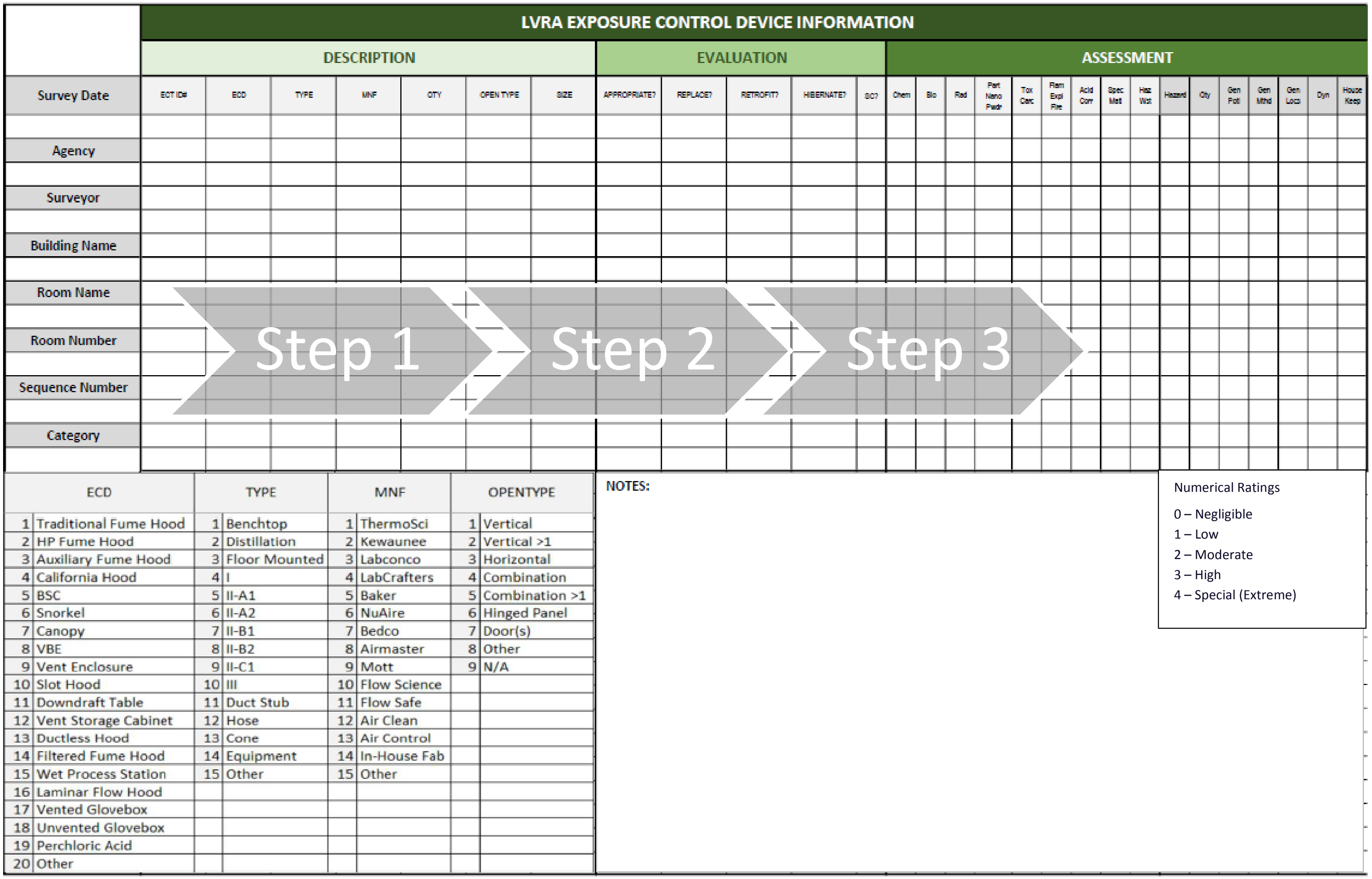
ECD		TYPE		MNF		OPENTYPE	
1	Traditional Fume Hood	1	Benchtop	1	ThermoSci	1	Vertical
2	HP Fume Hood	2	Distillation	2	Kewaunee	2	Vertical >1
3	Auxiliary Fume Hood	3	Floor Mounted	3	Labconco	3	Horizontal
4	California Hood	4	I	4	LabCrafters	4	Combination
5	BSC	5	II-A1	5	Baker	5	Combination >1
6	Snorkel	6	II-A2	6	NuAire	6	Hinged Panel
7	Canopy	7	II-B1	7	Bedco	7	Door(s)
8	VBE	8	II-B2	8	Airmaster	8	Other
9	Vent Enclosure	9	II-C1	9	Mott	9	N/A
10	Slot Hood	10	III	10	Flow Science		
11	Downdraft Table	11	Duct Stub	11	Flow Safe		
12	Vent Storage Cabinet	12	Hose	12	Air Clean		
13	Ductless Hood	13	Cone	13	Air Control		
14	Filtered Fume Hood	14	Equipment	14	In-House Fab		
15	Wet Process Station	15	Other	15	Other		
16	Laminar Flow Hood						
17	Vented Glovebox						
18	Unvented Glovebox						
19	Perchloric Acid						
20	Other						

The next step is to evaluate the appropriateness of the ECD (Step 2) for its observed use, general condition, and potential likelihood for replacement or viability as a candidate for retrofitting (a physical performance upgrade). Devices that exhibit evidence of physical damage, obstruction, dysfunction, or other significant contributing factors should be considered for correction. Inappropriate ECDs, such as those that are inadequate for the current process, should be brought to the immediate attention of facilities and EHS personnel.

We also note the deployment location relative to other ventilation components within the lab and note misdirected airflow and/or "short-circuiting." This information is used for determining general short-term needs for existing ventilation components.

Step 3 assesses the relative ventilation risk to the exposure control device. Here the hazard categories are documented that apply for each ECD. Some examples include chemical, biological, radiological, particulate, nanoparticle, powder, toxic, carcinogenic, fire, explosion, flammable, acid, corrosive, special material, and hazardous waste. Figure 2 depicts the ECD survey form and illustrates the three-step process:

Figure 2 ECD Survey Form



LVRA EXPOSURE CONTROL DEVICE INFORMATION

	DESCRIPTION							EVALUATION					ASSESSMENT															
Survey Date	ECT ID#	ECD	TYPE	MNF	QTY	OPEN TYPE	SIZE	APPROPRIATE?	REPLACE?	RETROFIT?	HIBERNATE?	SC?	Chem	Bio	Rad	Part Nano Pwdr	Tox Carc	Flam Expl Fire	Acid Corr	Spec Matl	Haz Wst	Hazard	Qty	Gen Potl	Gen Mthd	Gen Locs	Dyn	House Keep
Agency																												
Surveyor																												
Building Name																												
Room Name																												
Room Number																												
Sequence Number																												
Category																												

ECD		TYPE		MNF		OPENTYPE	
1	Traditional Fume Hood	1	Benchtop	1	ThermoSci	1	Vertical
2	HP Fume Hood	2	Distillation	2	Kewaunee	2	Vertical >1
3	Auxiliary Fume Hood	3	Floor Mounted	3	Labconco	3	Horizontal
4	California Hood	4	I	4	LabCrafters	4	Combination
5	BSC	5	II-A1	5	Baker	5	Combination >1
6	Snorkel	6	II-A2	6	NuAire	6	Hinged Panel
7	Canopy	7	II-B1	7	Bedco	7	Door(s)
8	VBE	8	II-B2	8	Airmaster	8	Other
9	Vent Enclosure	9	II-C1	9	Mott	9	N/A
10	Slot Hood	10	III	10	Flow Science		
11	Downdraft Table	11	Duct Stub	11	Flow Safe		
12	Vent Storage Cabinet	12	Hose	12	Air Clean		
13	Ductless Hood	13	Cone	13	Air Control		
14	Filtered Fume Hood	14	Equipment	14	In-House Fab		
15	Wet Process Station	15	Other	15	Other		
16	Laminar Flow Hood						
17	Vented Glovebox						
18	Unvented Glovebox						
19	Perchloric Acid						
20	Other						

NOTES:

Numerical Ratings

0 – Negligible
1 – Low
2 – Moderate
3 – High
4 – Special (Extreme)

The assessment step also differs from the first two steps in that it uses a scoring system to assign a unique risk control band (RCB) value to the ECD. After documenting the general hazard types observed for the device, each of the following seven categories are scored on a numeric scale of 0 to 4.

ECD Hazard Rating

The first of the seven categories considered in the ECD risk assessment is the ***hazard*** presented within the device. Hazard is rated by a comparison of the device contents and the lowest determined exposure limits. Exposure limit ranges are noted in the following table along with some examples for each respective control band:

Table 2 ECD Chemical Hazard Parameters

Hazard Rating	Exposure Limit	Hazard Examples
0	>500 ppm >2000 mg/m^3	Water, calcium chloride
1	50 – 500 ppm 250 – 2000 mg/m^3	Acetone, diethyl ether, hexane, methanol, xylene, toluene, pentane
2	5 – 50 ppm 20 – 250 mg/m^3	Ammonia, aniline, chloroform, dimethyl sulfide, acetonitrile
3	0.5 – 5 ppm 1 – 20 mg/m^3	Formaldehyde, nitric acid, hydrogen peroxide, phenol
4	<0.5 ppm <1 mg/m^3	Acrylamide, methyl isocyanate, nickel carbonyl, sulfur pentafluoride, Osmium Tetroxide, Dimethylmercury, Nanomaterials Unknowns

ECD Quantity Rating

The ***quantity*** of hazardous material contained within the device is also an obviously important factor in assessing relative risk. Quantities and associated ratings are determined by comparing device contents to quantity ranges:

Table 3 ECD Quantity Parameters

Quantity Rating	Amounts	Description
0	Negligible	None used
1	Small	< 1 ml < 1 g
2	Moderate	1 ml to 500 ml 1 g to 100 g
3	Large	500 ml to 5 L 100 g to 1 kg
4	Very Large	> 5 L > 1 kg

ECD Generation Rating

In addition to hazard type and quantity, factors associated with hazard generation are also significant in the assessment. The ***potential for generation*** is considered by determining the relative amount of generation based on the generation rate of the materials contained by the device:

Table 4 ECD Generation Potential Parameters

Generation Rating	Amounts	Description
0	Negligible	None
1	Small	< 0.1 lpm Evaporation
2	Moderate	< 0.5 lpm High, Vapor Pressure, Stirring
3	Large	< 4 lpm Application of Heat, Mixing
4	Very Large	> 4 lpm Large Generation, Boiling

The **method of generation** and generation location within the ECD also present important risk considerations. Generation methods - via manual or mechanical ("equipment") means - are noted, as well as process frequency (intermittent versus constant). ***Generation location*** parameters are identified by their general vertical location within the device – low, middle, or high. Note that more than one parameter method may apply for both of these scoring categories and should be considered when determining an appropriate rating:

Table 5 ECD Generation Method Parameters

Rating	Method
0	None
1	Manual
2	Manual, Intermittent Equipment, Intermittent
3	Equipment, Constant Manual, Equipment, Intermittent Manual, Equipment, Constant
4	Manual, Equipment, Intermittent, Constant

Table 6 ECD Generation Location Parameters

Rating	Method
0	None
1	Low (very close to capture device)
2	Middle (close to capture device)
3	Low, Middle or Middle, High (not close)
4	Low, Middle, High

A scaled numeric rating is also assigned for two other categories. The overall ***dynamic*** – that is, the propensity for change in the activities performed within the device – is considered, with “0” representing negligible change to contents and processes and “4” representing constant change to contents and processes. ***Housekeeping*** - the last of the seven risk categories in the ECD assessment – is not an indication of cleanliness or sterility, but rather a reflection of organization and the presence or absence of clutter – issues that can contribute to risk. In this category, “0” is indicative of no clutter or obstruction of work activity and “4” is indicative of excessive clutter and/or obstruction. This rating is also representative of the need for training.

The Laboratory Survey

Upon completing the ECD documentation tasks, the laboratory environment can be assessed. The laboratory is surveyed in a three-step process similar to the ECD methodology, and with some categorical overlap. However, there are some important differences of note. While the ECD focuses on hazard containment, the lab space must focus on the directional sweeping of air to properly remove a contaminant. Thus, there are some important categorical differences between assessing the ECDs versus the total laboratory environment. One particular distinction is lab hazards can be considered in aggregate as a combined source of airborne hazards and rated based on the worst-case activities.

Step 1 of the laboratory assessment includes describing the room purposing by general hazard (chemical, biological, radiological) and function (teaching, physics, chemical storage, fridge farm). Labs purposed as biological safety laboratory (BSL) are noted by category. Method of access and room monitoring (if applicable) are also noted.

Step 2 involves a deeper dive into an evaluation of the hazard characteristics. This step includes a categorization of elements that are also scored in Step 3 - hazard, quantity, generation potential, production methods, and generation methods – but only the descriptive components of these classifications are noted in Step 2.

This second step also notes the presence of airflow variables, such as short-circuiting and misdirected airflow, that may adversely affect ventilation sweep within the laboratory space. The concept of ventilation sweep - better described as “ventilation effectiveness” – is subsequently scored in Step 3 (“Assessment”).

Where the ECD assessment featured a total of seven rated categories, Step 3 of the laboratory environment assessment establishes risk control band values for a total of 11 parameters. These parameters and their respective criteria and associated control band values are described in the following section. The figure below shows the laboratory field survey form and illustrates the three-step process.

Figure 3 Laboratory Survey Form

LVRA LAB SURVEY INFORMATION									
LAB DESCRIPTION	LAB EVALUATION			LAB ASSESSMENT					
Lab Type	**Hazard**	**Quantity**	**Production Methods**	**Risk Ratings**	**0**	**1**	**2**	**3**	**4**
Chemistry	Chemical	Chemical Storage	Shift	Hazard					
Biology	Biological	Hazardous Waste	Continuous	Quantity					
BSL-1	Nano	Extreme	Intermittent	Generation Potential					
BSL-2	Radioactive	Large	Light Equipment Use	Method of Production					
BSL-3	Gas/Vapor	Medium	Heavy Equipment Use	Generation Locations					
BSL-4	Particulate	Small	No Equipment Use	**Lab Design/Layout Ratings**	**0**	**1**	**2**	**3**	**4**
Vivarium	Other Aerosol	Negligible	Unattended/Overnight	ECDs Available					
Animal Storage	Powder		**Generation Methods**	ECDs Appropriate					
Radiological	Gels	**Generation Potential**	Manual	Dynamic					
Teaching	Reactive	Pipetting	Equipment	Housekeeping					
Instrument	Sensitizer	Extraction	Intermittent	Ventilation Effectiveness					
Physics	Explosive	Titration	Constant	Max ECD Rating					
Chemical Storage	Corrosive	Weighing	**Airflow Variables**	NOTES:					
Necroscopy/GA	Carcinogen	Acid Baths	Short Circuiting						
Cleanroom	Flammable	Centrifuging	Misdirected						
Tissue Culture	Class I Flammables	Chromatography	Other						
Histology	Flammable Gases	Mixing/Agitating	Potential for Setback						
Fridge Farm	Flammable Solids	Recrystallization	Addl Risk Assessment						
Mechanical	**Flammable Quantity**	Rotary Evaporation	**Special Use/Features**						
Other	High Hazards	Synthesis	Anteroom						
Access	Acute Toxins	Heating	Animal Housing						
Doors Open	Toxic/Corrosive Gases	Distillation	Animal Procedures						
Doors Closed	Respiratory Sensitizers	Digestion	Controlled Environment						
Restricted	Aqua Regia/Piranna	Dehydration	Laser						
Vestibule	Pyrophoric	High Pressure Systems	Filtration						
No Doors	Water Reactive	Ultra-High Vacuums	Emergency Purge						
Monitoring	Energetic Materials	Magnetic	Mech Redundancy						
Security	HF or Generator	Furnaces/Ovens	Backup Power						
Occupancy	Acute Hazard	Temp & Humid Sensitive							
Chemical Sensors	Reproductive Toxin	**Catastrophic Risk?**							
Pressure	Irrevocable Harm	Yes							
Other	Other Aerosol	No							

Step 1

Step 2

Step 3

Lab Hazard Rating

Although the criteria differ, the parameters used in the ECD assessment are also assessed as part of the laboratory environment assessment. Again, the ventilation ***hazard*** presented by materials used within the laboratory are strongly considered. Substances that are actively used on the laboratory benchtop are compared, and the most conservative exposure limits are considered for determining a corresponding control band value:

Table 7 Laboratory Hazard Parameters

Hazard Rating	Exposure Limit	Hazard Examples
0	>500 ppm >2000 mg/m^3	Water, sodium chloride, calcium chloride
1	300 – 500 ppm 1000 – 2000 mg/m^3	Hexane, ethyl ether, ethyl acetate, isopropyl ether
2	150 - 300 ppm 500 - 1000 mg/m^3	Toluene, methanol, isopropyl alcohol, methyl acetate
3	50 - 150 ppm 300 - 500 mg/m^3	Tetrahydrofuran, ethyl bromide, acetaldehyde, dichloroethylene
4	<50 ppm <300 mg/m^3	Xylene, trichloroethylene, naphthalene, formaldehyde

Lab Quantity Rating

Excluding those contained within exposure control devices, the ***quantity*** of materials stored or used within the laboratory are also considered and rated in accordance with the following criteria:

Table 8 Laboratory Quantity Parameters

Lab Quantity Rating	Amount	Description
0	Negligible	None
1	Small	< 1 L < 10 g
2	Moderate	1 L to 10 L 10 g to 100 g
3	Large	10 L – 20 L 100 g- 1000 g
4	Very Large	> 20 L > 1000 g

Lab Generation Rating

Determining the ***generation potential*** rating is accomplished by determining and comparing relative generation rates for the material hazards within the laboratory environment:

Table 9 Laboratory Generation Parameters

Lab Generation Rating	Rate	Description
0	Negligible	None
1	Small	< 0.1 lpm Small Number of Small Containers, Low Vapor Pressure
2	Moderate	< 0.3 lpm Large Number of Small Containers, Small number of Large Containers, Low Vapor Pressure
3	Large	< 0.5 lpm Large Number of Small Containers, Small number of Large Containers, High Vapor Pressure
4	Very Large	> 0.5 lpm Large Number of Small Containers, Large number of Large Containers, High Vapor Pressure, Active Generation

Similarly outlined in the ECD assessment section, ***generation methods*** are noted – by means and by process frequency. ***Generation location*** parameters are also considered for the laboratory environment. However, for the laboratory assessment, generation methods and locations are subjectively considered as a function of quantity (as opposed to location for the ECD assessment). Both parameters are rated between 0 and 4.

In addition to the first five laboratory categories, there are five additional categories that address lab application and lab design are also considered in Step 3:

Table 10 Lab Application and Laboratory Design Parameters

Category	Description
Dynamic	How often do activities change for the laboratory, either through changes in personnel, equipment, material quantities, and/or processes? The higher the score, the greater the dynamic.
Housekeeping	The organization of materials and processes, and the ability to work without obstruction or disturbance by room elements. A lower score reflects better housekeeping and less obstruction or disturbance.
ECD Availability	Is there an exposure control device available in the laboratory? Enter “0” if there is (or if none is required), and “4” if there is not.
ECD Appropriateness	If present within the lab, is the ECD appropriate for the observed conditions? Enter “0” if appropriate (or if none is required) and enter “4” if inappropriate
Ventilation Effectiveness	Ventilation effectiveness (“V^{EFF}”) rates the directional sweep of conditioned air from entry to exit. Good V^{EFF} supplies air to the room in a manner that minimizes potential exposures to room occupants before being removed by local or general exhaust ventilation. A lower score reflects better room V^{EFF}.

The exposure control device is an element of the laboratory environment, and thus the risk presented by an ECD is included as an element of the risk for the laboratory environment. This eleventh parameter of the lab assessment is not a field judgement; rather, it is included after field data is entered in the risk assessment matrices.

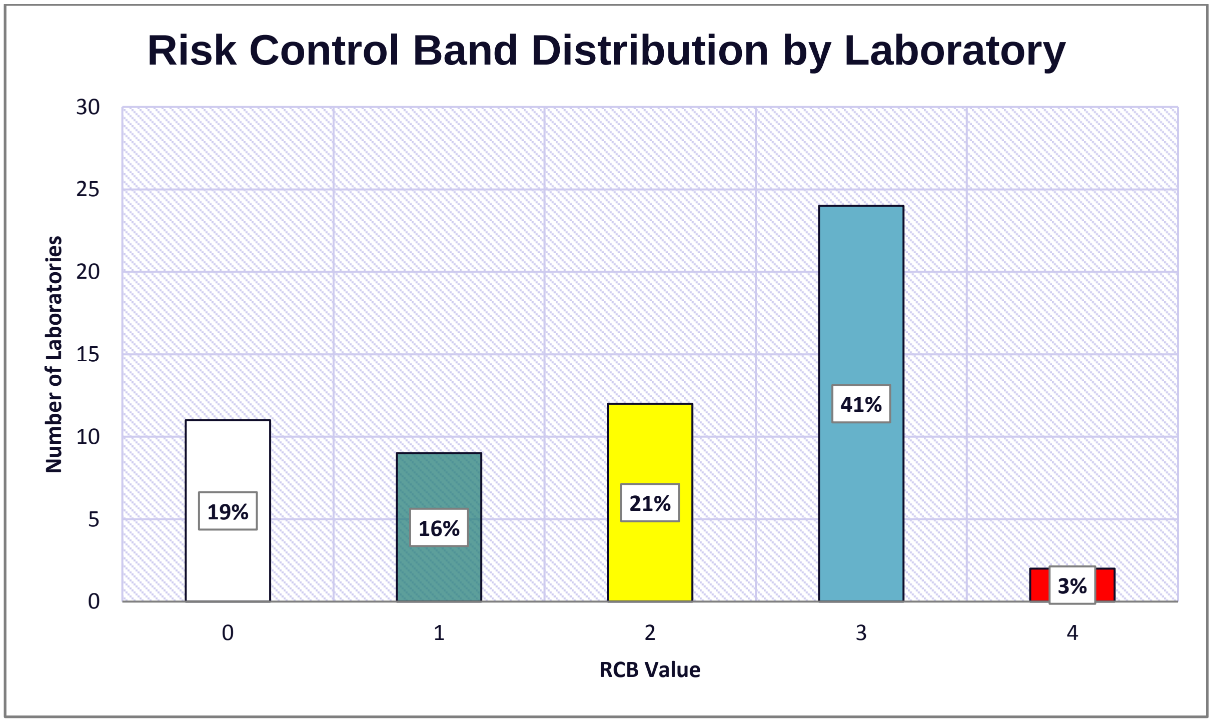
Data Entry

Matrices

Compiling field data electronically is beneficial for several reasons. Datalogging via spreadsheets or other database formats allows the user to centrally store and sort valuable information that can be used as part of an overall lab ventilation management program. Data must also be subjected to a weighting algorithm for calculation of risk control band values, which are essential for management applications.

Field data forms illustrated earlier in this User Guide are generated from electronic spreadsheets and may also be used as data collection/data entry resources. By using such a method, we can graphically visualize the distribution of ventilation risk within a laboratory. Reports can also be generated for ECD candidates for replacement, upgrade/retrofit, and hibernation. Locations of short-circuiting/misdirected air can also be easily identified.

Figure 4 Sample Risk Distribution "Riskagram"



Algorithms

The LVRA matrix contains a mixture of algorithms that calculate data and automate reports. The control banding algorithm relies on different weighting factors to determine a control band value for each ECD and lab space. Weighting and scoring information employed by the algorithms is presented in the following tables where Table 11 provides the risk factors, ratings and weightings for ECDs and Table 12 provides risk factors, ratings and weightings for lab environments. The algorithm used to determine the risk score includes the aggregate sum of the ratings multiplied by the weight multiples for each risk factor. The hazard uses in incremental weight multiple to reflect the wide range of hazard control levels. The other factors are applied linearly where the risk multiplied by the weighting factor divided by the total score reflects the sensitivity of the factor to the overall score. The hazard is attributed to the greatest importance followed by the rate of generation.

Table 11 ECD Scoring & Weighting

ECD Control Parameter	Rating	Weight Multiple	Total Max Score	Sensitivity or Importance
Hazard	4	10	40	43%
Quantity	4	3	12	13%
Potential or Rate of Generation	4	5	20	22%
Method of Generation	4	1	4	4%
Generation Location	4	1	4	4%
Dynamic or Potential for Change	4	2	8	9%
Housekeeping	4	1	4	4%
Total Max Score	28	ECD Weighted Score	92	100%

Risk Score = Sum (ratings x weight multiples)

Table 12 Laboratory Scoring & Weighting

Control Parameter	Rating	Weight Multiple	Total Max Score	Sensitivity or Importance
Hazard	4	14	56	35%
Quantity	4	2	8	5%
Potential Rate of Generation	4	12	48	30%
Method of Generation	4	1	4	3%
Generation Locations	4	2	8	5%
ECD Availability	4	1	4	3%
Appropriate ECDs	4	1	4	3%
Ventilation Effectiveness	4	3	12	8%
Dynamic or Potential for Change	4	2	8	5%
Housekeeping	4	1	4	3%
Maximum ECD	4	1	4	3%
Total Max Score	44	Weighted Score	160	100%

Risk Score = Sum (ratings x weight multiples)

Risk Spectrum and Distribution by RCB

The total max score from the risk algorithm establishes the numerical range of risk (See Figure 5). The categorization and distribution of each RCB can be adjusted based on the tolerance for risk. Each range is associated with a range of risk scores and that can be distributed with larger or smaller ranges depending on the risk tolerance. A low tolerance for risk would skew the weighted score to the higher RCBs, whereas a high tolerance for risk would skew the score range to achieve lower RCBs with an equivalent score (See Figure 6).

Range of Risk (Spectrum)				
0	1	2	3	4
Negligible	Low	Moderate	High	Special

Figure 5 Spectrum of risk divided into risk control bands. Each RCB reflects a range of risk scores.

The Risk Score will fall within one of the RCB segments in the distribution of risk for assignment to the RCB. The range of scores for each RCB can be adjusted based on the tolerance for risk. Figure 7 shows the distribution recommended for a moderate tolerance for risk with RCB-4 used to capture extreme risk activities or activities requiring special attention rather than prescriptive specifications

Tolerance For Risk	Negligible		Distribution of Risk		Extreme
Even	0	1	2	3	4
High	0	1	2	3	4
Moderate	0	1	2	3	4
Low	0	1	2	3	4

Figure 6 Distribution of RCBs by the different tolerances for risk. A high tolerance for risk enables higher risk scores to be assigned to a lower risk control band. A low tolerance for risk allows for scores to be assigned to a higher risk control band.

ECD	Negligible		Risk Control Bands		Special (Extreme)
Moderate Tolerance	0	1	2	3	4
Range of Risk Score	< 9	10 - 23	24 - 37	38 - 69	> 69

Figure 7 Range of scores for each ECD RCBs using a moderate tolerance for risk.

LAB Environment	Negligible		Risk Control Bands		Special (Extreme)
Moderate Tolerance	0	1	2	3	4
Range of Risk Score	< 24	25 - 52	52 - 80	81 - 108	> 108

Figure 8 Range of scores for each Lab Environment RCBs using a moderate tolerance for risk.

LVRA Applications and Ventilation Specifications

As noted earlier in Figure 7, the distribution of risk throughout a group of ECDs and laboratories can be illustrated graphically by rank order. Furthermore, color-coded RCB drawings can be developed to indicate the physical distribution of ventilation risk within a building. These combine well with auto-generated reports to obtain perspective on an overall building system and to develop optimal airflow specifications. Properly configured operating specifications that implement the LVRA findings optimize ventilation systems, reducing waste in overventilated areas and customizing ventilation needs throughout a facility.

> *"…the LVRA helps optimize the operational effectiveness of labs, minimizes maintenance and control problems, and enhances occupant safety and comfort."*

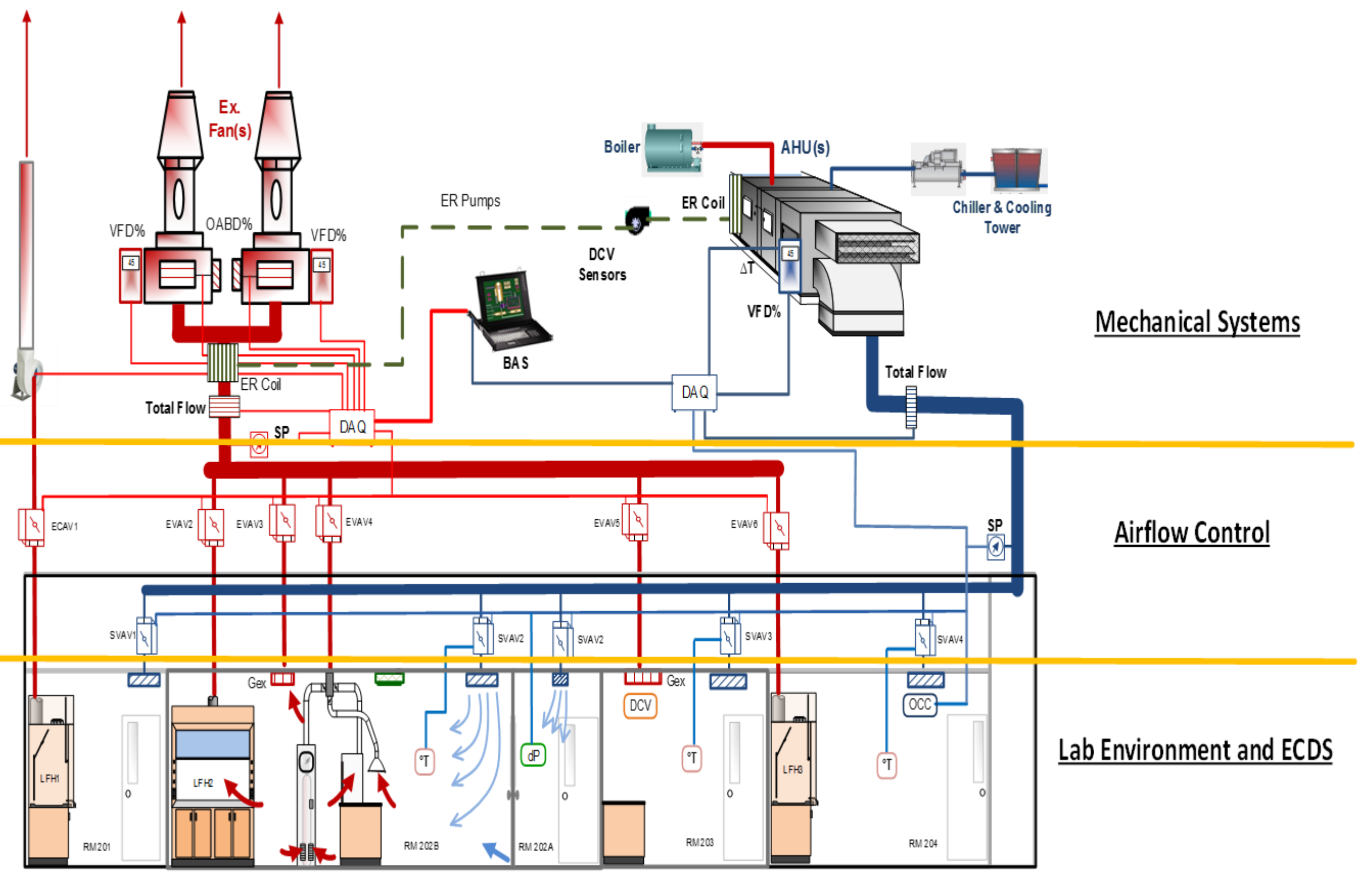


Figure 9 Diagram of example system showing segments for design and operating specifications

Recommended Design and Operating Specifications by RCB

System Feature	Parameter	Risk Control Band				
		0	1	2	3	4
Fume Hood	**ASHRAE 110 Tracer Gas Control Level**	n/a	4 lpm AU < 0.1 ppm	4 lpm AU < 0.1 ppm	4 lpm AU < 0.05 ppm	<8 lpm AU < 0.01 ppm
	Fume Hood Face Velocity	n/a	60 fpm[1]	60 fpm[1]	60 fpm[1]	>80 fpm
	Cross Draft Velocity	n/a	< 30 fpm	< 30 fpm	< 30 fpm	<30 fpm
	Minimum Fume Hood Exhaust Flow w/Sash Closed	Turn off or Hibernate	> 150 ACH_{FH}[2]	> 250 ACH_{FH}[2]	> 375 ACH_{FH}[2]	CAV
	VAV Response Time	n/a	< 5 sec	< 5 sec	< 5 sec	< 5 sec
	VAV Stability (% Variation)	n/a	< 20%	< 20%	< 20%	< 20%
	Monitor	n/a	Yes	Yes	Yes	Yes
Lab Environment	**Minimum Effective ACH**	n/a	4	6	8	10+
	Minimum Effective UnOccupied ACH	n/a	2	3	4	Review
	Recirculation of Lab Air	Yes	Filtered	Internal	Internal	No
	Lab Pressurization	Neutral	< -0.005 iwg	< -0.01 iwg	< -0.05 iwg	≥ -0.05 iwg
	Room Monitor	n/a	n/a	Review	Yes	Yes

System Feature	Parameter	Risk Control Band				
		0	1	2	3	4
	Airlock/Vestibule	n/a	n/a	n/a	n/a	Yes
	Flow Setback (DCV)	Yes	Yes	Yes	Review	No
	Energy Purge Mode	No	No	No	Review	Yes
	Future Capacity for ECD	n/a	4-ft LFH	6-ft LFH	8-ft LFH	6-ft LFH 2x
	Additional Flow Capacity	n/a	480 cfm	780 cfm	1080 cfm	1560 cfm
	Ventilation Effectiveness (VEFF) (3)	<= 2	< =1.5	<= 1	< 1	<< 1
System	**Duct Velocity**	< 200 fpm	200 fpm	300 fpm	500 fpm	>500 fpm
	VAV Controls Accuracy/Precision	+/- 10%	+/- 10%	+/- 5%	+/- 5%	+/- 5%
	Enthalpy Wheels	Yes	Review	No	No	No
	Stack Discharge	N/A	Review	Review Min. 10 ft, 3000 fpm	Wind Wake Model	Wind Wake Model