TABLE OF CONTENTS

PURPOSE

The purpose of this document is to outline the Laboratory Ventilation Management Program (LVMP) and provide guidance to departments that have responsibility for laboratory ventilation. The main goal of the laboratory ventilation management program is to ensure the health and safety of laboratory users while optimizing ventilation serving the laboratories and reach energy savings goals of KAUST CTPS, which includes reducing campus energy consumption 10% by 2025.

SCOPE

This program applies to all research spaces on the KAUST campus. This includes specialized lab spaces such as Animal Resources Core Lab, Clean Room Facilities, CMOR Aquarium, among others. Future scope may include the KAUST Research and Technology Park and the Innovation Cluster.

OBJECTIVES

- Ensure the health and safety of laboratory users.
- Achieve energy savings.
- Proper maintenance of ventilation equipment.
- Proper installation of equipment that requires ventilation.
- Proper utilization of ventilated equipment.
- Provide specifications for the design and operation of lab ventilation systems.

DEFINITIONS

- ACH: Air changes per hour - a common means for expressing a volumetric airflow through a room. Each ACH for a room is intended to represent an amount of air equal to the gross volume of the air passing through the room each hour.
- ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- Constant air volume (CAV) ventilation system: A ventilation system designed to maintain a constant quantity of airflow within its ductwork. The airflow quantity is based upon the amount required to handle the conditions of outdoor-weather-related heat gain or loss and internal building loading. Although relatively simple, a constant volume ventilation system typically requires the maximum ongoing energy usage since the system always operates at maximum capacity.
- Control banding: A hazard identification and risk assessment system that organizes information about hazards and processes into groups based on their relevance to the health and safety scenario of concern.
- CTPS: Campus and Technology Park Services
- Dilution ventilation: Ventilation airflow that dilutes contaminant concentrations by mixing with fresh air. This is distinguished from capturing of contaminated air at the source.
- Face velocity: The air velocity at the plane of and perpendicular to the opening of a laboratory chemical hood.
- FLP: Fire Loss Prevention. A division of HSE consisting of fire engineers, fire protection engineers, fire inspectors with authority for all matters related to fire and life safety.
- HSE: Health, Safety and Environment Department
- ICAS: Integrated Campus Automation System
- LSR: Lab Safety Representative, liaison person between the lab and Research Safety Team.
- NFPA: National Fire Protection Association
- PHS: Particularly Hazardous Substance
- RST: Research Safety Team, a division of HSE responsible for safety in laboratories.
- Room air balance: A general term describing the requirement that a laboratory room has the proper relationship with respect to the total exhaust airflow from the room and the supply makeup airflow. The relationship of these airflows also establishes the pressure differential between the laboratory room and adjacent rooms and spaces.
- Variable air volume (VAV) ventilation system: A type of mechanical ventilation system specifically designed to vary the amount of conditioned air supplied and exhausted from the spaces served. The amount of air supplied is intended to meet (but not exceed) the actual need for space at keeping occupants comfortable and maintain temperature set points.

- Ventilation effectiveness: The ability to reduce the accumulation of unsafe concentrations of chemicals through the combined mechanisms of dilution and contaminant removal throughout a laboratory room by the laminar flow of air from supply and exhaust points.
- Volatile chemicals: Chemicals that can be readily vaporized at relatively low temperatures (i.e., below 38°C [100°F]). The level of volatility correlates with the vapor pressure of the chemical and thus is chemical-specific. For example, a material such as acetone has a high vapor pressure and a low boiling point, which equates to high volatility.

LABORATORY VENTILATION MANAGEMENT PROGRAM

This document identifies roles and responsibilities of stakeholders related to the use, management, and maintenance of laboratory ventilation systems. Standard procedures include chemical fume hood testing, laboratory ventilation design and fume hood commissioning, and a ventilation effectiveness test. Ventilation "control banding" assignment is utilized as a risk assessment system to group laboratories by hazards and ventilation needs.

Roles and Responsibilities

Academic Projects

- Ensure proper design, installation, and commissioning of systems.
- Provide lab users, HSE RST and CTPS an opportunity to review and comment on new or renovated laboratory ventilation systems projects.
- Efficiently propose design options following hazard assessment findings from HSE.
- Ensure system capability to provide safe, dependable and efficient operation.

Campus & Technology Park Services (CTPS)

- Performs maintenance, inspection and repairs as required to ventilation systems.
- In consultation with Research Safety Team, place vacant labs into unoccupied mode.
- Conducts ventilation effectiveness test in collaboration with Research Safety Team.
- Implement changes as applicable to ventilation settings after reviewing with Research Safety Team.
- Keep a record of projection table changes.
- Update lab schedule and ventilation projection tables and submit documentation to the technical library.
- Secure funding for project requests related to ventilation systems.
- Provide resources to make control set point changes.
- Monitor ventilation performance and energy savings.

Engineering Department

- Ensure ventilation systems design criteria is aligned with the objectives of the LVMP.
  Update the design standard for ventilation systems in collaboration with HSE.

HSE Research Safety Team

- Has overall responsibilities of the Laboratory Ventilation Management Program including an annual program review.
- Assist laboratory users with recognition and evaluation of hazards.
- Conduct routine safety inspections of laboratories.
- Provide training to laboratory users related to laboratory ventilation.
- Conduct testing for fume hood and other ventilation equipment (snorkels, ventilated enclosures, gas cabinets, canopy hoods, etc.).
- Provides input and comments to Academic Projects regarding plans for new labs and laboratory ventilation systems modifications.
- Conducts ventilation effectiveness test and analyze results in collaboration with CTPS staff.
- Conduct annual lab review of the established control bands.
- Propose ACH recommendations for laboratories based on control bands, m^ hCD- tGt ‹ +«•L•.
- Maintain management of change documents related to ventilation changes.

Laboratory Users

- Utilize laboratory hoods and other ventilation devices in accordance with operating requirements and safety guidelines.
- Indicate and report ventilation performance problems to 959 or fchelpdesk@kaust.edu.sa.
- Contact researchsafety@kaust.edu.sa with concerns about safe use of laboratory ventilation system components, including chemical fume hoods, snorkels, gas cabinets, ventilated cabinets, etc.
- Provide information on potentially hazardous materials to be used or changes in hazardous operations to the Research Safety Team.
- Maintain good chemical housekeeping practices in the laboratory.
- Properly use containment devices and understand the impact of laboratory ventilation in their work.
- Conduct chemical hazard assessments of laboratory work; identify and implement less hazardous chemical operations when possible.
- Seek assistance and training from their Supervisor or the Research Safety Team in relation to the correct use of ventilated equipment.

Stakeholder Communications

Other departments impacted by the Laboratory Ventilation Management Plan will be informed of the changes in ventilation systems. A list of stakeholders is described below with a communication method.

Stakeholder group	**Communication**
Building Management Team	Group informed through the MOC process.
Building Operations	Group informed through the MOC process after building management team review.
FC Helpdesk	Main system to record issues, complaints and service requests.
Lab Managers / LSRs	Group informed by RST.

Maintenance Department	Group responsible for implementing ventilation changes. This group is informed by Building Operations Team.
Technical Library	CTPS will submit projection tables to Technical Library for record keeping.

Standard Procedures

The following section lists the operational procedures and documentation that organize the Laboratory Ventilation Management Program.

- *Design and Construction Ventilation Standards* - Research and Academic Design Criteria document from Engineering Department, Section 11 covers Heating, ventilation and air conditioning.
- *Fume Hood and Lab Ventilation Systems Commissioning* - Completed as part of commissioning process and with inspection test plans referring to NFPA 45 Chapter 7 Laboratory Ventilating Systems and Hood Requirements and ASHRAE Handbook for HVAC systems, Chapter 16 for detailed requirements on Ventilation and Commissioning.
- 1o6orotory *space occupancy shut down procedure* - Conducted by CTPS and includes mechanical reduction of ventilation systems, shut down of other utilities supply.
- ***RST Fume Hood* testing *Procedure*** - HSE-RST procedure for testing fume hoods.
- *Ventilation Effectiveness Test* - This procedure describes the process for assessing laboratory ventilation effectiveness in specific laboratories rooms using CO2 tracer gas.

Control Banding Assignment

Control Banding is a system for assigning generic protection strategies to similar hazards based on a risk assessment of specific instances of those hazards; the hazards are grouped into “bands” that can be managed by the same suite of controls. Factors to consider in making this assignment in the context of laboratory ventilation include chemical hazard, quantity, and the potential for airborne emissions in the laboratories and building. It is important to note that some processes may fall outside a specific control banding system due to unusual hazards or application. Determination as to whether a specific area, device, or process is appropriate for control banding is the first step in making a control banding assignment.

In the chemical laboratory, general dilution ventilation is a core engineering control of occupant chemical exposures during normal operations. Specification of general ventilation rates should be based on a risk assessment of the hazards associated with the use of volatile chemicals in the laboratory, as outlined in ASHRAE - Classification of Laboratory Ventilation Design Levels (2018). Over-ventilation of laboratory spaces can interfere with the use of the laboratory for specific operations and can make the detection and diagnosis of operational and ventilation problems in the laboratory more difficult.

In this program, ventilation rates are optimized to utilize energy appropriately and contain costs to the university. This optimization is made when four operating conditions are met:

1. A review of laboratory chemical uses to determine whether the labs require high, medium, low or specialized general ventilation and volatile chemical sources are controlled.
2. The ventilation effectiveness within the lab prevents the accumulation of significant concentrations of chemical vapors.
3. The laboratory housekeeping is adequate to avoid ongoing sources of fugitive emissions of the laboratory.
4. Changes capable of keeping ventilation and temperature control set points.

Chemical Assessment

High ventilation: Laboratories in which there are significant volatile chemicals or specific process hazards for which employee exposures are expected to be controlled by the general ventilation system. These labs are designated for ventilation at 10 air changes per hour (ACH) when the laboratories are occupied and 8ACH when the labs are unoccupied. This recommendation relies on the expectation that significant point sources of volatile chemicals are contained by effective local exhaust, in the form of a fume hood, local point exhaust, or an appropriate chemical storage cabinet. For this reason, in these control bands laboratory workers will be trained in best practices for using ventilation systems in the laboratory, specifically in the proper use of the specific fume hood models and control systems provided in their laboratory and the process of deciding which processes should be located in a fume hood based on risk criteria.

Moderate ventilation: In many cases, where use of volatile chemicals are more limited, the specified ventilation rates can be lowered to 6 ACH occupied / 4 ACH unoccupied. Specific chemical classes that require this level of ventilation are those that are used in concentrations and quantities that can create odors and nuisances.

Low ventilation: In the lowest hazard control band are laboratories where the chemicals used are minimal and ventilation requirements can be lowered to those required to support air exhaust from the space, temperature and human occupancy needs for the room to 4 ACH occupied and 2 ACH unoccupied. It should be noted that such rooms may have other hazards, such as lasers, welding fumes or significant heat sources which may drive risk-based ventilation needs. One potential strategy is to manage these occasional or discrete chemical risks with local exhaust ventilation rather than general ventilation.

KAUST Ventilation Control Banding		
Control Banding Assignment	Explanation	Types of Laboratories or Applications
HIGH 10-8 ACH	• Heavy chemical use of chemicals with inhalation hazards, especially used on the benchtop without point exhaust: & Dry nanomaterials	• Inorganic/Organic Synthesis in which exhaust requirements for ventilated enclosure does not drive dilution ACH rates.

	& Toxic and health hazards with inhalation hazards (PHS >500 grams) & Flammable liquids used readily on the bench (>20 liters) & Corrosive chemical vapors (>1 liter) & Cryogens and inert compressed gases • Any flammable, oxidizing, corrosive or toxic compressed gas usage and storage without other performance based measures to control of exposure for operational use. • Nature of work being performed needs higher ventilation, i.e., high temperature experiments, combustion experiments, etc.	• Typical research labs in all disciplines that require dilution to remove emissions of hazardous chemicals used on the bench.
MODERATE 6-4 ACH	• Moderate chemical usage: & Toxic and health hazards (PHS < 500 grams) & Flammable liquids < 20 liters) & Corrosives (<1 liter). • Inert compressed gas usage and storage. • Nature of work only needs moderate ventilation, i.e., use of general non-volatile	• Biological labs focused on aqueous solutions. • Low use chemical labs. • Shop areas with point sources of hazardous chemicals.

	chemicals, non-hazardous aqueous solutions, microscopy work, etc.	
LOW 4-2ACH	• Minimal chemical usage: & No cryogens & No compressed gases & Flammable liquids (squirt bottles) • Nature of work does not require any special ventilation needs, i.e., storage room, unused laboratory's without hazards, etc.	• Biology laboratories with no volatile hazards beyond disinfectants. • Computer and instrumentation laboratories. • Electronic, robotics laboratories.

Specific ventilation design required: Some specific laboratory uses of chemicals may require higher or lower ventilation rates than those generically described above due to specific hazards or requirements that arise from the processes conducted in the laboratory. Assignment of ventilation requirements for these situations lies outside the scope of the generic control banding process and requires specific analysis to determine ventilation needs. Examples of such situations include animal use areas, semi-conductor processing facilities, and glass-cleaning rooms without local exhaust ventilation, or areas where non-chemical hazards are present.

Ventilation rates potentially higher than 10 ACH (occupied):

- Ventilation systems that require higher rates due to environmental condition needs, such as clean rooms;
- Labs, where the stability of temperatures or humidity are important for the processes occurring in the space and, will be negatively impacted by the ventilation rate reduction;
- Small labs with a fume hood in which the general airflow rates are driven higher to meet the exhaust requirements of the hood (fume hood driven rooms);
- Labs with high human or animal occupancy;
- Labs whose chemical operations change so often that effective oversight of their ventilation requirements is not possible.

Ventilation rates lower than 4 ACH (occupied):

- Low hazard/low volumes of chemicals in use;
- Human occupancy and personal odor control is the main driver for ventilating the space;
- Intermittent chemical sources that require single-pass air but do not constitute a "significant chemical source;

- Lab support spaces that meet the definition of a lab but where there is little or no lab work occurring;
- Labs where the maintenance of temperature is the main driver.

Ventilation Effectiveness

Ventilation effectiveness (VE) represents the airflow pattern and the ability of ventilation to remove contaminants within a room. In a room with single-pass airflow, it enters the space through the supply diffusers and exits through the exhaust points, such as exhaust diffusers, point exhausts, and fume hoods. If there is poor effectiveness of the ventilation, reducing the volume of air supplied and exhausted may exacerbate conditions present with chemical emissions or heat generation. Optimizing the volume of ventilation in a laboratory depends on the types and quantities of chemicals used that have inhalation hazards, where they are used in the room and whether the emissions are captured at the source, and that heat generation is maintained within control set points.

The tracer gas field test used at KAUST, described in accompanying documents, provides descriptions of room VE observations based on field testing conducted by RST and CTPS staff members. Re-testing of spaces following ventilation rate reductions will be based on the following conditions:

Criteria effecting the decision to re-test or re-evaluate:

- Poor location of supply and exhaust diffusers that do not create laminar flow through space. Poor mixing and dilution of chemical emissions may be exacerbated with ventilation turndown;
- Short-circuiting (supply diffuser too close to exhaust point - within 2 meters);
- Furniture blocking airflows in areas of the room, which can create dead zones (no air movement) with reduction of ACH rates;
- Stagnation at the floor if there are emissions of chemicals with high vapor densities (this could create fire concerns due to accumulation of flammable vapors near refrigerator or freezer compressors);
- Heat generating equipment (refrigerators, freezers, incubators, ovens, etc.) that will cause room temperature issues (accumulation that ICAS will not adjust airflows in order to keep up with temperature changes);
- Differential pressure between rooms that are changed and will require rebalancing between occupied labs and non-occupied spaces;
- Open-labs where one ventilation zone is reduced and the adjacent is not reduced;
- Spaces with curtains or partial walls that block airflow within a zone (i.e., lasers and compressed gas usage where there could be an accumulation of asphyxiating gases);
- Accumulation of odors (chemical, human, animal);
- Static pressure in ductwork not maintained or reaching Phoenix valve limitations that cause system instability.

Housekeeping

Fugitive emissions in laboratories are not limited to instrumentation and bench top processes, but can also result from long-term storage of containers of volatile chemicals or the off gassing of residues of chemical spills and other long-term releases that have not been well managed by lab occupants. The high general ventilation rates associated with laboratories can often obscure these fugitive releases, which can become more evident when the ventilation rate is reduced.

Management of Change Process

Initial Review

- Initial laboratory visit to determine and confirm ventilation rates. See section on Control Banding Assignment in this document.
- Recommendation letter with findings, proposal changes, recommendations and estimated savings from RST.

Approval Process

- Management of Change (MOC) process initiated by RST.
- CTPS Operations & Maintenance to review projection tables for applicability.
- Final approval from CTPS Operations & Maintenance for implementation.

Implementation Process

- RST to work with Lab Managers and LSRs to inform them about changes to ventilation.
- Operations to gather initial trends to evaluate savings.
- Maintenance Department to change ACH value.
- Maintenance Department to generate new projection tables and submit changes to the technical library.
- Operations Department to monitor the system behavior for a week after implementation (offset, temperature, ACH, air flow).
- Conduct a lab ventilation effectiveness test as needed.
  - In the event of ventilation concerns by lab users.
  - After a 50% ACH reduction.
  - In the event of alarm notifications from ICAS.
- Operations to quantify energy savings.

See Flowchart in Appendix 1.

Key Performance Indicators

Indicator	Oversight Department	Type of Indicator
Number of changes **initiated to modify ACH in** labs	RST	Leading indicator
Number of labs with approved ACH reduction	RST	Leading indicator

Amount of energy saved	CTPS	Lagging indicator
Improvement in laboratory safety observations, based on inspections.	RST	Lagging indicator
Number of tickets **from FC** Helpdesk related to ventilation	**CTPS**	Lagging indicator

Training

Elements of the laboratory ventilation program are included in the RST Safety Training programs. General Lab Safety is a required course for everyone using a laboratory. Other courses include proper use of fume hoods, biosafety cabinets, ventilated enclosures, compressed gas safety, flammable liquid safety and pressurized vessels among other courses. This also includes awareness materials, safety bulletins, Lab Safety Forum Presentations, LSR emails, RST webpage. Supervisors of lab users also provide job specific training.

References:

- ANSI/ASSP Z9.5 Laboratory Ventilation
- ASHRAE handbook, HVAC applications, Chapter 16
- Classification of Laboratory Ventilation Design Levels, ASHRAE
- Design Criteria from Academic Projects Section 11 Heating, Ventilation, and Air Conditioning
- International Code Council
- KAUST Lab Safety Manual
- NFPA 45 Chapter 7 Laboratory Ventilating Systems and Hood Requirements

Document reviewed by the following stakeholders:

- Research Operations
- Academic Projects
- Engineering Department
- Selected Lab Safety Representatives

Rec [redacted]

Appendix 1 Management of change process flow chart

MOC

- RST to generate MOC
- Attach pre-evaluation for suggested ACH change

'Values Review "

- CTPS 0&M to review projection tables for applicability

MOC Approvals

- Route MOC for signature
- CTPS 0&M get a copy of the approved MOC

Projection Tables

- CTPS 0&M to generate new projection tables

Saving Baseline

CTPS Operations to gather initial trends before implementing the changes to evaluate savings

Communication

- RST to inform the new changes to lab users, LEM, research operations

Implementation

- CTPS Maintenance to apply the new suggested airflow values in LCS servers
- CTPS Maintenance to submit the new projection tables to technical library

Behavior Monitor

- CTPS Operation to monitor the system behavior for a week after implementation (offset, temperature, ACH, air flow)

***Ventilaion Effectiveness**

- RST to conduct a lab ventilation effectiveness test as needed:
  - In the event of ventilation concerns by lab users.
  - After a 50% ACH reduction and
  - In the event of alarm notifications

Energy Quantification" " " "

- CTPS Operations quantifies energy savings for the ACH reduction