Schneider Electric

Application Note

AN-HC-002

Laboratory Control

with EcoStruxure™ for healthcare

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Schneider Electric

About this Document

This paper explores the air compensation strategy for laboratories in healthcare and the recommended solution from Schneider Electric. The objective is to provide understanding and explanations for the working of a typical HVAC control solution in a critical laboratory.

EcoStruxure for Healthcare™

EcoStruxure™ for Healthcare is Schneider Electric's IoT enabled platform for digital hospitals, designed to deliver improved safety, patients' well-being, and operational efficiency. EcoStruxure™ represents the infrastructure holistic architecture for smart, connected hospitals and it brings the digital transformation in healthcare beyond the Electronic Medical Records (EMR), by connecting smart devices with big data analytics and artificial intelligence to ensure that critical infrastructure is smart, fast, efficient and patient-focused.

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Application Notes

Application Notes describe the design considerations for engineers who are involved in the planning, design, installation, commissioning or operation of applications within healthcare facilities. The documents are intended as guidance only and will reference recognized standards and regulations and industry equipment.

The document will provide indicative illustrations for the application and its configuration.

About the Author

Chee Keong LIM is a senior Solution Architect in healthcare and responsible for the East Asia and Japan region. He brings over 28 years of experience in the controls industry and has been involved in many complex projects involving the design and operations of laboratory and clean room applications. CK has used this knowledge to develop innovative solutions and engineering standards for Schneider Electric's healthcare offer.

Disclaimer

This document does not attempt to describe the proposed solution in its entirety. Users are solely responsible for compliance with national and international safety laws and regulations. This document does not replace any specific project documentation.

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1 Laboratory Overview

A laboratory is a facility that provides controlled conditions, so that scientific and/or technological research, experiments, and measurements may be performed. Laboratory services are provided in a variety of settings: physicians' offices, clinics, hospitals, and regional and national referral centers [(1)].

1.1 Laboratory

There is a wide variety of uses for laboratories in healthcare, all of which have differing requirements and needs depending on the specialism they are designed to serve. The specialism will have a significant impact on the function of the laboratory and the equipment and services needed. For example, in a science research laboratory there may be sensitive devices such as particle accelerators or gamma emitter machines, whereas in a medical or life science laboratory, there will be devices that are used to store biological, medical or research containment. A laboratory could also be a doctor's examination room, which contains a chair and an examination table for blood extraction, heart monitoring equipment, or breathing apparatus.

There are of course applications outside of healthcare such as data centers where engineering data is stored and analysed for design, build and test equipment. Laboratories are designed, adapted and built for many industries and disciplines. They come in the form of research and study spaces in educational schools and universities, commercial buildings, industry, government, or military facilities. Laboratories are found not only in buildings but in cars, planes, ships and most famously spacecrafts.

In healthcare industries, specifically hospitals, laboratories are common and require complex and reliable infrastructure services to maintain operations to safeguard specimens and research so patients are protected. The planning, design and operations are therefore important, and this document will describe the major considerations for laboratories handling specimens to those handling potential deadly agents.

1.2 Medical Laboratory

A medical or clinical laboratory is where clinical pathology tests are carried out. Blood, tissues, bodily fluids and human waste are some of the clinical samples taken from patients. These specimens will be tested, studied and validated to obtain information about the patients' health. They will allow for forensic diagnosis of an illness to allow for treatment and prevention of diseases.

They are an applied science facility that tests and validates a wide range of specimen, as opposed to a life science or research laboratories that will focus on basic science. The laboratories are more specific in their studies, such as those in academic institutions or industrial development and manufacturing.

The size, type, complexity and the purpose of a hospital will determine the scale, complexity and grade of a medical laboratory in terms of the variety, quantity and required speed of research and testing services.

In acute-care hospitals, medical centers and university hospitals a wide variety of specialist and ambulatory services are provided which relay on the diagnosis from laboratory testing to allow treatment of patients.

1.3 Biosafety

Laboratories are also spaces where biological elements are stored, researched, studied and tested. All biological elements have an impact on humans, be it positively or negatively. It is critical we understand the impact of these biological elements and ensure the correct steps, processes and safety measures are put in place to prevent these biological elements having a negative impact. These biological elements must be properly contained and removed to prevent the spread to surrounding areas.

The World Health Organization defines biosafety as "*the containment principles, technologies and practices that are implemented to prevent the unintentional exposure to pathogens and toxins, or their accidental release*". [(2)]

Biosafety is the application of knowledge, techniques and equipment to prevent personal, laboratory and environmental exposure to potentially infectious agents or biohazards. It defines the containment conditions under which infectious agents can be safely manipulated. The objective of containment is to confine biohazards and to reduce the potential exposure of the laboratory worker, persons outside of the laboratory and the environment to potentially infectious agents.

These prevention mechanisms require regular reviews of the biosafety in laboratory settings, as well as strict guidelines to follow. Biosafety is used to protect from harmful incidents. Many laboratories handling biohazards employ an ongoing risk management assessment and enforcement process for biosafety. Failures to follow such protocols can lead to increased risk of exposure to biohazards or pathogens. Human error and non-adherence to standard operating procedures contribute to unnecessary exposure and compromise the best safeguards set into place for protection

Laboratories that are in the constant presence of biological elements are required to have biosafety. The complexity, scale and elaborateness of the biosafety protocol level depend on the severity, potency and fatality risk of the biological element within the facility.

1.3.1 Biosafety Level

Biosafety covers specifically the handling of bodily fluid, organs or tissues from biological origin, or genetic natured materials, bacteria and viruses with respect to the ecology and environment. Biosafety ensures the safety and protection of clinical personnel, medical and lab staff, research personnel, patients, and the general public.

The consideration for Biosafety level needs to be holistic to cover planning, construction, containment, security, terrorism, equipment, practices, operational procedures and most important of all, disposal. It requires the cooperation, commitment and discipline of all stakeholders in the handling of biohazard agents.

BioSafety Level is defined in 4 levels.

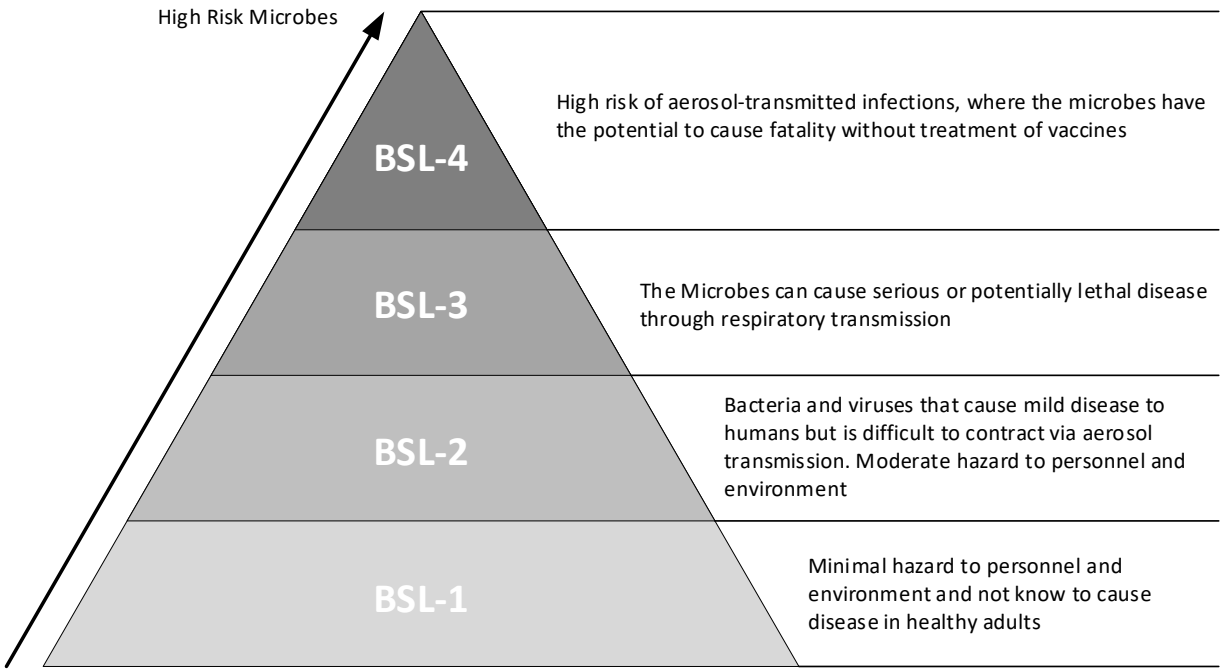


Figure 1f: Biosafety Levels, Centers for Disease Control and Prevention

1.4 Laboratory Space and Environment

A laboratory is defined as a space demarcated and dedicated to research, experiments testing analysis and manufacture or discovery products or elements. There is nothing in the understanding or definition of a laboratory that requires the environment of the laboratory to be controlled in any way. Even in Biosafety levels, the requirement is for containment and isolation from the user and environment and not controlling of the environment.

A life science pharmaceutical laboratory might have highly precision controlled laboratory environment, while a local medical school or institution might have a lab with academics and students conducting experiments under no environmental controls. There is no definitive definition within the laboratory specification to have precise environmental control.

More recent and modern medical laboratory requirements have incorporated environmental control which is a concept incorporated from cleanroom design.

A cleanroom is a controlled environment, which places emphasis on the environmental controls required based on the level of contamination from particles. It also considers other factors such as temperature, humidity, static pressure, etc. Control of these variables protects the processes, specimens and products from contamination or conditions that could compromise the integrity of those elements from the external environment as well as users, occupants and public. The main purpose of the cleanroom concept is to achieve a good level of containment either to keep contaminants in or out of the confined space.

1.5 Cleanroom Classification

Cleanrooms have several classification and specifications as detailed in table 1

Standard	Reference	Link
International Standard of Organization	ISO14644-1	https://www.iso.org/standard/53394.html
International Standard of Organization	ISO14698-1	https://www.iso.org/standard/53394.html
US Standard	US FED STD 209E	Replaced by ISO14644-1, refer to ISO link
European Standard	EU GMP classification	https://www.gmp-compliance.org/guidelines/gmp-guideline/eu-gmp-annex-1-revision-manufacture-of-sterile-medicinal-products-draft
British Standard	BS 5295	https://www.mssl.ucl.ac.uk/www_cleanroom/cleanroom/cr_standards.html

Table 1: Standards and regulations relating to clean rooms

The cleanliness of the cleanroom is defined according to the number and size of particles permitted per volume of air with ISO1 as being the cleanest and ISO9 being the least clean. Once ISO7 is required it requires isolation, which means airflow direction needs to be maintained to avoid a back flow of air. The cleanliness depends on the size of the particle, the smaller it is the more difficult to block or remove, thus a borderline is set for the size of particles depending on the process or product engaged within the room.

For a room with ISO3 (Class 1 in US FED STD 209E) classification, there is a tolerance for

- 1000 particles / m3 for particle size >= 0.1micron
- 35 particles / m3 for particle size >=0.5micron.

Class	Maximum particles/m^3						FED STD 209E Equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10[b]	[d]	[d]	[d]	[d]	[e]	
ISO 2	100	24[b]	10[b]	[d]	[d]	[e]	
ISO 3	1,000	237	102	35[b]	[d]	[e]	1
ISO 4	10,000	2,370	1,020	352	83[b]	[e]	10
ISO 5	100,000	23,700	10,200	3,520	832	[d,e,f]	100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	1,000
ISO 7	[c]	[c]	[c]	352,000	83,200	2,930	10,000
ISO 8	[c]	[c]	[c]	3,520,000	832,000	29,300	100,000
ISO 9	[c]	[c]	[c]	35,200,000	8,320,000	293,000	Room air

[a] All concentrations in the table are cumulative, e.g. for ISO Class 5, the 10 200 particles shown at 0,3 µm include all particles equal to and greater than this size.
[b] These concentrations will lead to large air sample volumes for classification. Sequential sampling procedure may be applied; see Annex D of standard.
[c] Concentration limits are not applicable in this region of the table due to very high particle concentration.
[d] Sampling and statistical limitations for particles in low concentrations make classification inappropriate.
[e] Sample collection limitations for both particles in low concentrations and sizes greater than 1 µm make classification at this particle size inappropriate, due to potential particle losses in the sampling system.
[f] In order to specify this particle size in association with ISO Class 5, the macroparticle descriptor M may be adapted and used in conjunction with at least one other particle size. (See C.7. of standard)

Table 2: Cleanroom classification derived from ISO 14644-1 and ISO 14698

Although the US FED designation is more well known the standard has been replaced by ISO1644-1, The ISO standard is becoming the industry specification for cleanrooms. In cleanrooms with biocontamination risks, ISO14698-1 needs to be referenced.

The cleanliness level of a laboratory will depend on the type of filter used, high efficiency partial air (HEPA) or ultra-low particle air (ULPA) filters and the total area covered in a laboratory.

- HEPA filter have efficiency ratings of 99.995% and provides ISO class 5
- ULPA filter have efficiency ratings of 99.999% and provides ISO class 3

2 Design Considerations

When designing a normal facility, production floor, offices etc., heating and cooling is just one of the many considerations. When designing a modern medical laboratory with a cleanroom concept, HVAC is the main, major and key consideration. The requirement for HVAC is essential for pressurization, airflow, temperature and humidity control and ensures proper containment, safety, comfort, and reliable operation of the facility.

All modern medical laboratory design and specifications will have a combination of laboratory, cleanroom and biosafety requirements, where the relevant specification and standard needs to be understood, followed and implemented.

The document will focus on the Mechanical HVAC control for a typical hospital laboratory.

2.1 Mechanical HVAC Control

In a laboratory the Mechanical HVAC control will need to provide pressurization containment, air changes, airflow direction, temperature control and humidity control. The proper measuring, monitoring and controlling of these five parameters are critical to the effective, efficient and safe operation.

2.1.1 Pressure Control

Pressure control regime within a laboratory is always relative in relation to the surrounding protected space. Differential pressure is measured within the protected space with reference to the segregated area. There are two pressure control regimes, positive and negative pressure referencing to the reference point.

Positive pressure rooms maintain a higher pressure within the laboratory space than that of its surrounding environment, very often this is the corridor. The pressure within a protected area is greater than the environment that surrounds that area.

This means air will only leak or leave the room and not be allowed to re-enter the space. Vice versa, external air will not be able to flow into the protected area,

In this configuration, germs, particles, and possible potential contaminants in the external environment of the laboratory will not be able to intrude and contaminate the room, keeping the space sterile, protected and clean. A positive pressure room allows staff to keep samples, processes, and tests from being contaminated.

On the contrary, a negative pressure room maintains lower air pressure within the laboratory than the surrounding area to ensure that only outside air is allowed into the confined environment. This method helps to contain potentially harmful pathogens, agents or product within the space. The negative pressure in the space also prevents internal air from leaving the confined area.

A negative room pressure is an isolation and containment technique used in healthcare to prevent cross-contaminations from room to room and the spread of any harmful biological entity.

Efficient and effective use of positive and negative pressure rooms is an important part of the medical facility to maintain containment and prevent the spread of infectious contaminants while maintaining sterile and restricted spaces.

The ASHRAE 170 standard, table 7.1 in Appendix A, defines the laboratory type and the proposed pressure regime and should be followed for design and operation of the space

2.1.2 Laboratory Air change

A containment or confined space needs to have air change. It is important for laboratories to maintain a constant amount of air change to achieve a healthy, safe and working environment.

Air change is specified as the total volume of air within a confined space which is replaced with fresh clean new air. It is calculated based on the total volume of air being replace within an hour and is represented by ACH (Air Change per Hour)

It is imperative to maintain a good air change within the laboratory to ensure:

- A good quantity of fresh air or outdoor air is delivered in to the room to sustain life.
- Remove all possible contaminants, harmful substances and odour within the confined space.

The recommended ACH by ASHRAE is to be between 10 to 12 ACH. However, it will depend very much on the size and severity of the laboratory to work out a proper design air change. Please refer to Appendix A for table.

In the 2017 Edition of ASHRAE 170 – Addendum P, it has indicated that during unoccupied conditions the overall air change of certain laboratories can be reduced. The rate of reduction of the air change shall not impact the overall pressure regime and design setting to maintain the required containment of the laboratory.

2.1.3 Airflow

Associated with ACH is the airflow within the laboratory. Like any room, the airflow control of a room is very important. If the airflow is too low, the air within the room will feel stagnant and stale. If the flow is too strong, there will be strong draft causing discomfort and flying debris. More disturbing will be acoustic issues created by strong airflow.

Removal of harmful components or contaminants is a key control feature required in a laboratory. The proper and shortest possible travel path is needed to ensure harmful elements are removed in the shortest and safest path possible for its occupants and environment, known as dirty to clean pathway. The airflow direction becomes critical to achieve this objective. To ensure that that airflow is going in the proper vector, a pressure stratification control is required.

2.1.4 Temperature Control

In general, temperature control in most laboratories is there for the comfort of the occupants and users. Very often, laboratory personnel are quite heavily gowned with protective clothing. Thus, proper temperature control is required to ensure comfort, indirectly creating a safe working environment.

There are special circumstances within more elaborate and critical medical laboratories that will require precise temperature control to ensure that samples, tissues, processes and test are conducted under specific temperature conditions to get the best outcomes possible for products or results.

The requirements for temperature control will be between 21°C to 24°C. However, there are exceptions depending on the design and laboratory requirement that need to be coordinated during the design stage. Please refer to Appendix A for the ASHRAE 170 guidelines.

2.1.5 Humidity Control

Laboratory HVAC control will not be complete without discussing humidity control. Very often in a laboratory there will be sensitive equipment and devices used for experiments and testing. If outdoor air is not treated properly and moisture removed, there will be a potential that the expensive and sensitive devices will be damaged by unwanted condensation. There is also the potential that tissues and samples could be affected by moisture content if humidity is not addressed.

The laboratories are exposed to viruses and bacteria which can thrive in certain humidity conditions. Without proper humidity control, these biological agents could propagate on walls or spread to users or researchers.

Laboratory humidity is usually controlled between 45%RH to 60%RH, although ASHRAE 170 does not specify or recommend the humidity level to be controlled. The humidity requirement for a laboratory will vary based on the sample or the test subject. Considering the risk of static charges and condensation on medical instruments, good engineering practices will normally define humidity to be controlled between 45%RH to 60%RH.

2.2 Redundancy and Power Backup

The laboratory systems should be part of the essential power systems to ensure fans, alarms and monitoring systems do not fail if there is a loss of power to the building. For laboratories, a duty/standby, fan arrangements will be needed on the exhaust system to provide safety and reliability. It will also allow maintenance to be carried out without impacting the room pressure.

The IEC standards specify the following

"IEC-710.313.1.102 Power supply for medical locations of group 2

In case of a single fault in the power supply, a total loss of power shall be prevented. This may be achieved by:

- *Provision of two independent supply lines, and/or*
- *A UPS system within the same fire section for supplying the medical IT system, or*
- *A UPS system which supplies a number of group 2 locations"*

3 Application

There are many different types and configurations of medical laboratories depending on their use, class, biosafe classification and complexity. A biology test lab in a university hospital used by students will require no more than an opened air room with simple test benches and test instrument compared to a hospital or commercial testing laboratory, which may be bio level classified with full HVAC control.

This document will describe the basic mechanical HVAC control requirements of a BSL-3 lab, with a complete HVAC ventilation system supplying the laboratory. As we are exploring a BSL-3 laboratory, it will be mandatory to have an Autoclave inside the laboratory. The document will briefly discuss critical equipment such as BioSafe Cabinets, (BSC) and Fumehoods, (FH) as they will have an impact on the laboratory pressure, air change and airflow of the room.

3.1 Equipment influencing the control parameters of a laboratory.

Within a laboratory there are three major pieces of equipment that will influence the pressure, air change, airflow and, to a certain extent, the temperature and humidity.

- Autoclave
- FumeHood (FH)
- BioSafety Cabinet (BSC)

3.1.1 Autoclave

Technically an autoclave is a device designed to have elevated pressure with reference to its surrounding, with pressure and humidity moderation. Autoclaves are used to create a specific condition for medical purposes in the case of sterilization or incubation.

Autoclaves are built purposely for containment and confinement and their design has morphed into a full room which provides a transitional passageway. This is used as a change from un-sanitized to fully sanitized and sterile conditions, through proper pressure and airflow control.

In complex, mission critical medical laboratories, the passage from the external environment could progress through several autoclaves, depending on the class, severity, bio level and containment tightness of the laboratory.

3.1.2 Fume Hood, (FH)

Fumehoods, FH or sometimes referred to as Fume Cupboard, are commonly found in a laboratory. Tests or research procedures are carried out in a FH which provides an isolated and protected work area within the larger laboratory environment.

FH is a ventilated furniture or enclosure which will contain by-products of processes or test results like gases, vapours and fumes, through directional airflow. This keeps the lab technicians, researchers and users free and safe from the harmful gaseous substances resulting from the experiments that are being carried out.

There are different operating conditions or modes in a FH, where different strengths of airflow are required from the suction side of the laboratory HVAC exhaust, depending on the different operating

conditions. When activated, the different airflow requirements will affect the total room pressure, air change and airflow direction within the laboratory.

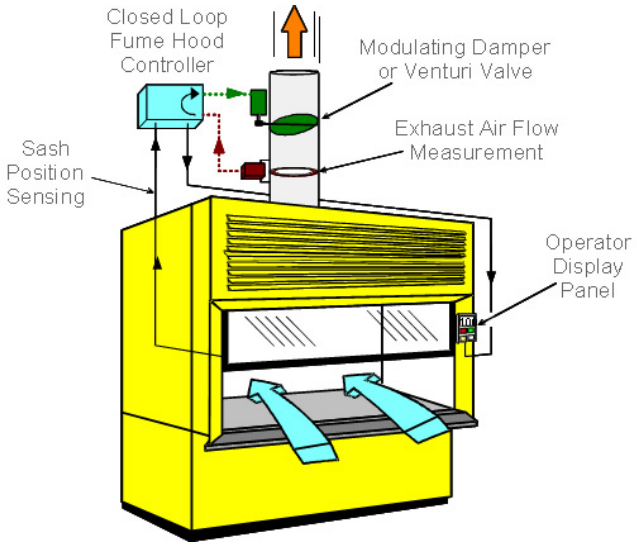


Figure 2: Fume Hood Unit

3.1.3 BioSafety Cabinet, (BSC)

Biosafety Cabinets, (BSC), are commonly found in a laboratory that is in contact with bio agents or contaminant. In principal, the BSC works like a FH, however a BCS protects not only the user but also the test results and the laboratory environment.

The BSC cabinet has built-in HEPA filters and all extracted air is passed through the HEPA filters and then recirculated back within the cabinet. The vertical and unidirectional airflow flowing within the cabinet shields the researchers from exposure to airborne biohazards and potential viruses and bacteria. HEPA filters will trap and remove this agent thus allowing the cleaned air to be removed.

While BSCs are meant to trap particulates and bio agents, they cannot be used for trapping chemical and gaseous substances.

The different airflow strengths and air removal within the BSC will impact the total room pressure, air change and airflow direction within the laboratory.

3.2 Laboratory Mechanical Air Control

Having understood some of the basics of laboratory control and equipment needs, it is time to have a look at a typical laboratory mechanical control. Refer to the figure 3, which depicts a typical single room, single pass, BSL-3, negatively pressurized laboratory.

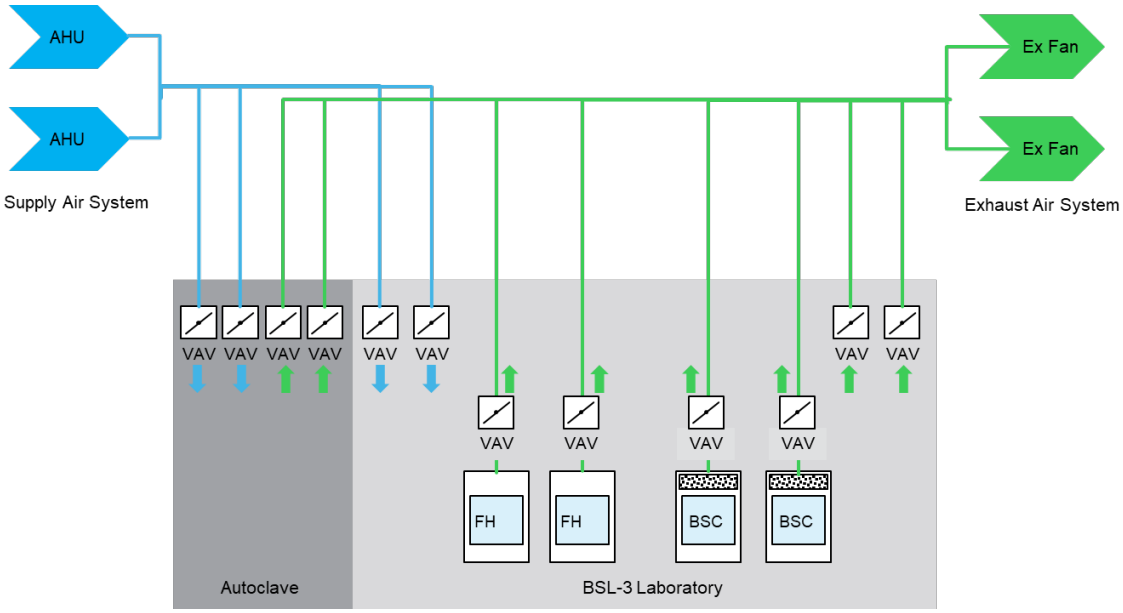


Figure 3 – Single pass, negative pressured, airflow compensation laboratory

The BSL-3 laboratory will have four segments of control: Supply Air, Autoclave, Laboratory and Exhaust Air.

Figure 3 depicts a single pass configuration. There will be no return air being piped back to the supply air stream, thus removing a little of the control complexity. In a more critical or hazardous laboratory, it is recommended to have a single pass configuration laboratory to prevent or reduce the risk of contamination and spread of infections.

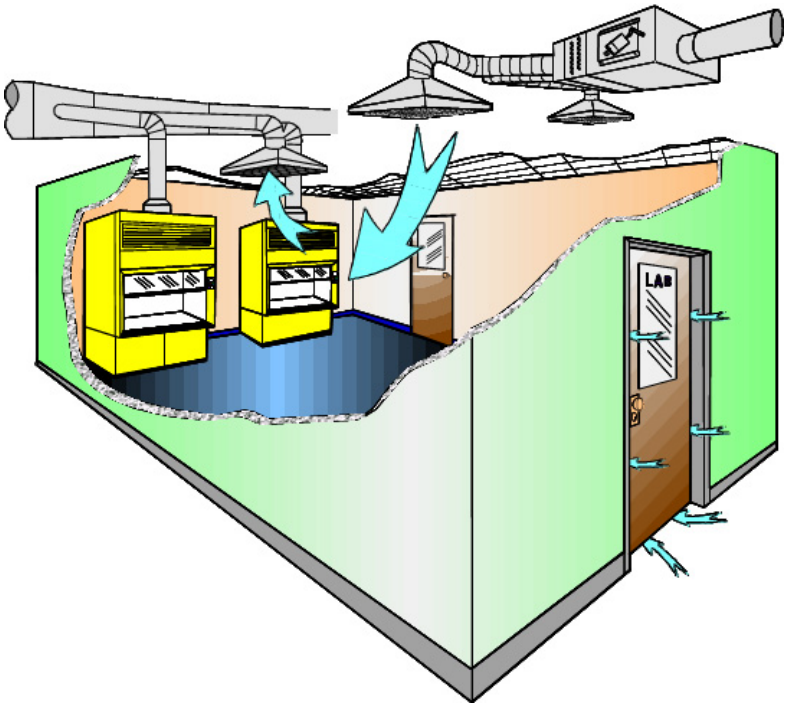


Figure 4: Typical airflow arrangement for a laboratory

3.2.1 Supply Air System Mechanical Control

The laboratory requires air to be ducted in from the atmosphere. Natural air is not suitable for the laboratory and will need to be treated before being supplied into the space. The supply air control will provide this centrally as shown on figure 5.

The outdoor air is filtered before being cooled to remove the moisture content. The off-coil temperature sensor (ref: T1) is used to measure the dryness of the air and, at the same time, controls the chilled water control valve. As a result of removing moisture from the air, the off-coil temperature sensor (ref: T1), can be very low (cold) and is not suitable to be ducted directly into the laboratory for comfort reasons. Therefore, some form of reheat is required to provide more sensible load to the air prior to distributing into the laboratory. For this example, electric heaters will be the source of heat. The duct temperature sensor (ref: T2) is used to measure the air temperature while controlling the electric heater to provide the required heating of the cool supply air to achieve the desired supply air temperature.

The supply air system provides the necessary supply air quantity to the laboratory to affect the required air change needed for the space. As the laboratory is a negative pressured laboratory, the total air quantity supply into the confined space will be lower than the total amount of air being exhausted from the space. A duct static pressure, sensor (ref: P1) will be mounted in the main duct work of the supply air system to measure the duct static pressure for the supply air. The measured value will be used to control and modulate the supply air fan to ensure the proper quantity of supply air is delivered to the laboratory.

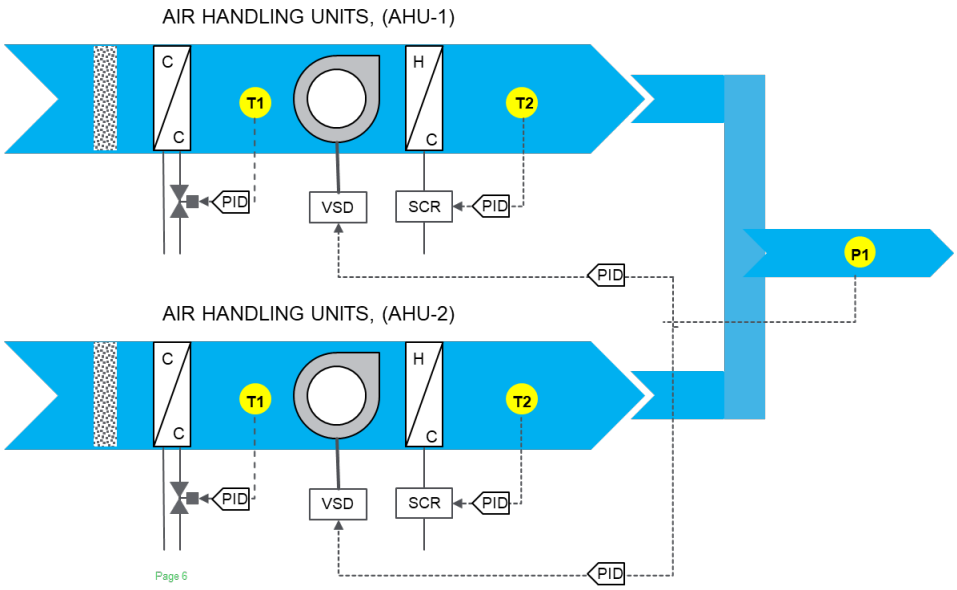


Figure 5 – Laboratory Air Handling Unit, (AHU) – Supply Air Control

3.2.2 Autoclave Air Control

The autoclave provides the barrier between the external environment and the laboratory. It is the transition between the dirty space and the sterile confined space. The pressure in the Autoclave will have to be higher than the external environment and the laboratory to ensure the sterile environment within the laboratory is maintained and the external environment is not contaminated.

The pressure requirement is achieved by controlling the quantity of supply air and adjusting the exhaust air into and out of the autoclave. This will ensure a positive pressure is achieved. Control of the VAV boxes in the supply duct and exhaust duct are used to achieve this.

As humans, biological elements and equipment will be moving through the space, temperature control is required to provide a comfortable environment and safe operating conditions for the equipment. A space temperature sensor is installed to monitor the space temperature. An electrical heater (for this example we reference electric heater, but other sources of heat could be provided) is installed in the VAV box supply stream to provide temperature adjustment to the space to achieve the desired temperature.

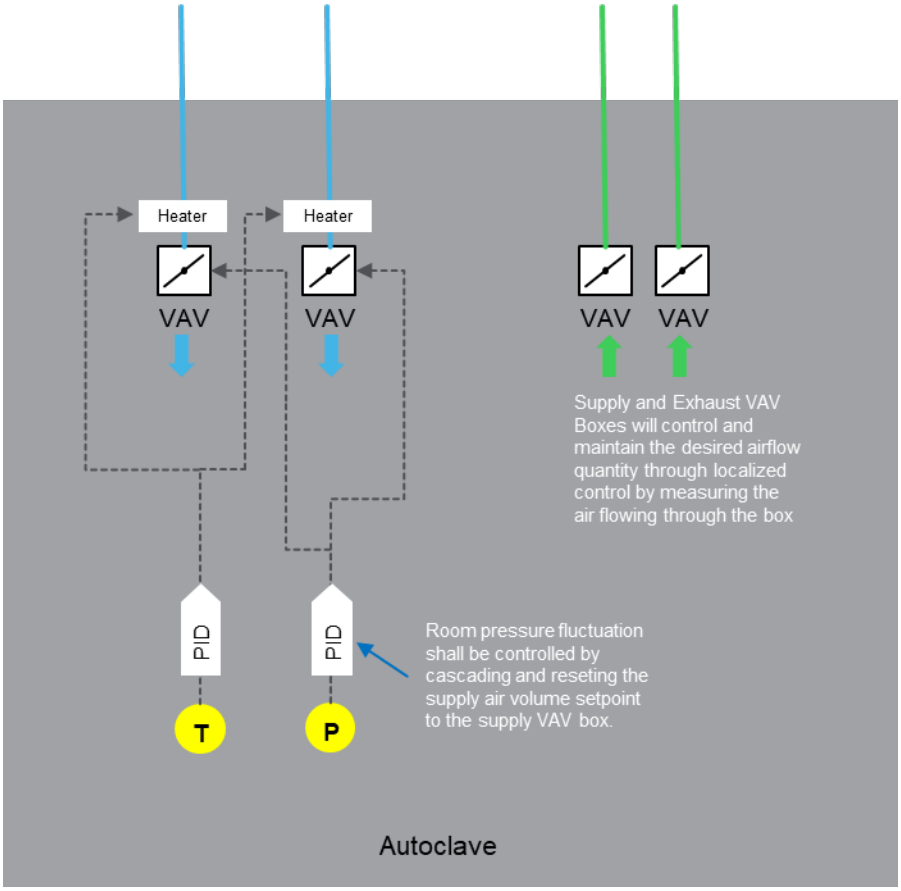


Figure 6 – Typical Autoclave Room Control

3.2.3 Laboratory Environment Air Control

In the laboratory as described, there will be FHs and BSCs installed. In many instances, there will be several FH and BSC installed within the laboratory. As described earlier, their function will require exhaust air. Each of the FHs and BSCs will be connected to the laboratory exhaust duct system. The airflow requirement of the FHs and BSCs will vary based on the different operational requirements and modes. Depending on this, a VAV box installed on each FH and BSC will be used to regulate the air flow. When different operating modes are activated, the VAV boxes will regulate to the required airflow extraction value to ensure the proper operation of the FH and BSC.

The operation of FHs and BSCs are not consistent and will be fluctuating constantly. A compensating exhaust box is recommended to compensate for any increase or decrease in the exhaust requirement of the FHs and BSCs. This will ensure a constant total exhaust from the laboratory to maintain the air change and stability of the laboratory. This is a form of volumetric control with compensation.

However, sometimes by maintaining a constant exhaust, the pressure regime of the laboratory may be compromised. It is therefore necessary for a pressure sensor be mounted within the laboratory to constantly monitor the pressure within the laboratory. This is used to ensure that the integrity of the laboratory is not compromised. The pressure sensor will modulate the main supply air VAV box to ensure that enough fresh, treated air is being ducted into the laboratory. At the same time, it ensures the integrity of the laboratory is not breached.

With humans, equipment, bio samples, tissues and test products located within the laboratory, temperature and humidity become important for comfort, life supporting and safety needs of the laboratory. Temperature sensors and humidity sensors are recommended for the monitoring of the laboratory. The temperature reading from the sensor will be used to control the electric heater mounted on the main supply air box of the laboratory, while the humidity sensor will provide reading for cascade control to the off-coil temperature control to affect humidity control for the laboratory.

Humidity control can be challenging for a laboratory. Often, liquid and vaporizers are used within the laboratory which will have direct effect on the humidity of the space. In such situations, separate mechanical or chemical dehumidifiers will need to be deployed to achieve better humidity control within the laboratory. The solution will have to be explored on a case by case basis, depending on the operations of the respective laboratory.

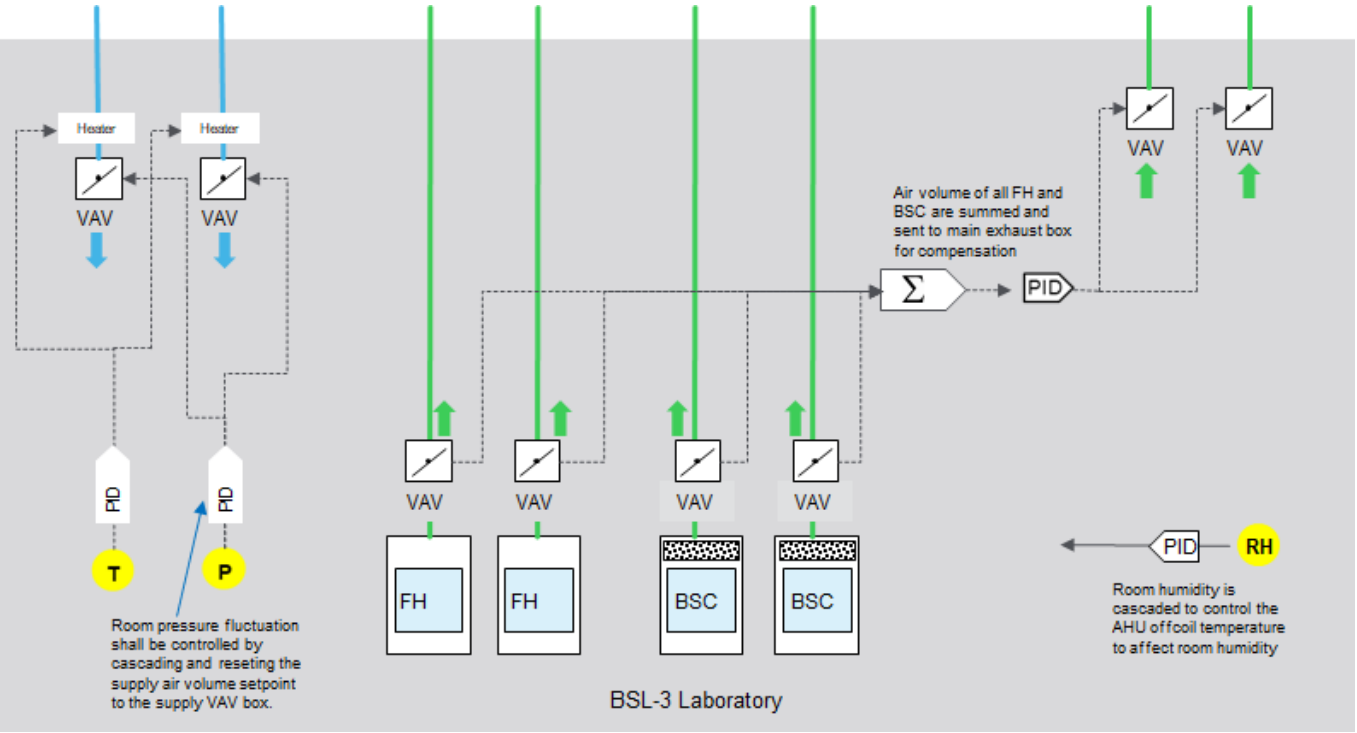


Figure 7 – Typical Laboratory Room Control

3.2.4 Laboratory Exhaust System

The exhaust system is the most critical part of a laboratory HVAC system, as the proper functioning and operation of FHs and BSCs are highly dependent on a well-controlled exhaust system. The exhaust system is also the simplest part of the control as the main and only control parameter of the system is to provide enough air extraction from the laboratory.

A duct static pressure senor (ref: P) will be installed in the main exhaust duct of the system. The sensor will monitor the static pressure of the exhaust duct and control the exhaust fan speed to achieve the required air extraction from the laboratory.

The exhaust fan system will be operating on a backup formation. When the running fan fails, the rotational back up fan will be operated automatically to replace the failed fan.

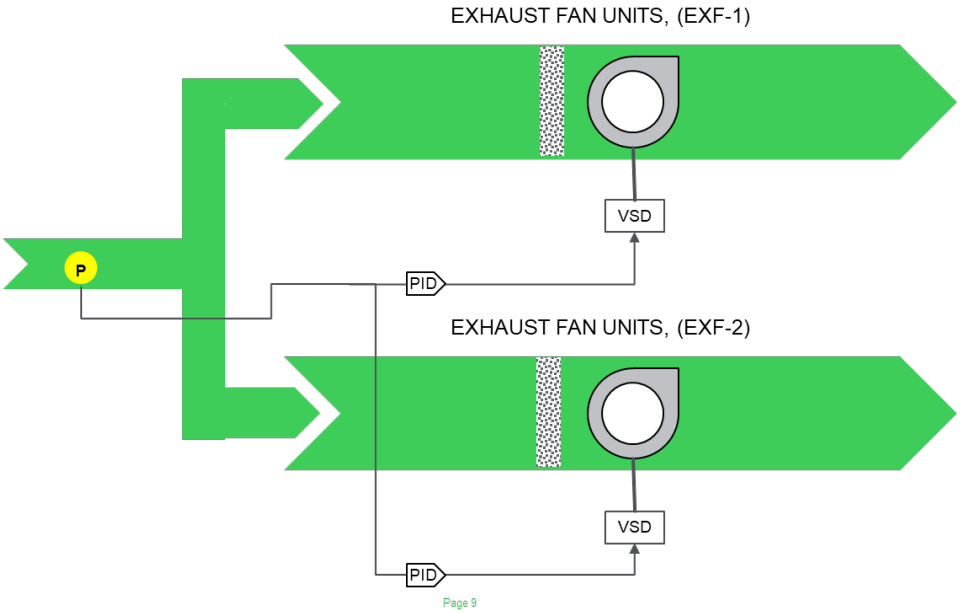


Figure 8 – Typical Exhaust System Control

All four sections of the laboratory control will have to work in tandem and be synchronized to achieve the required laboratory mechanical control for a negative pressured laboratory.

4 Proposed Reference Architecture

Schneider Electric solutions offer a complete laboratory mechanical control independent of the HVAC equipment or boxes supplied by the mechanical contractor. Schneider Electric offers a dedicated digital controller to be coupled to the mechanical HVAC equipment to monitor, supervise and control the laboratory automatically to achieve containment, segregation and isolation of a laboratory from its surrounding environment and users.

4.1 Overall System Architecture

A proposed system architecture based on the discussed laboratory configuration is depicted in figure 9.

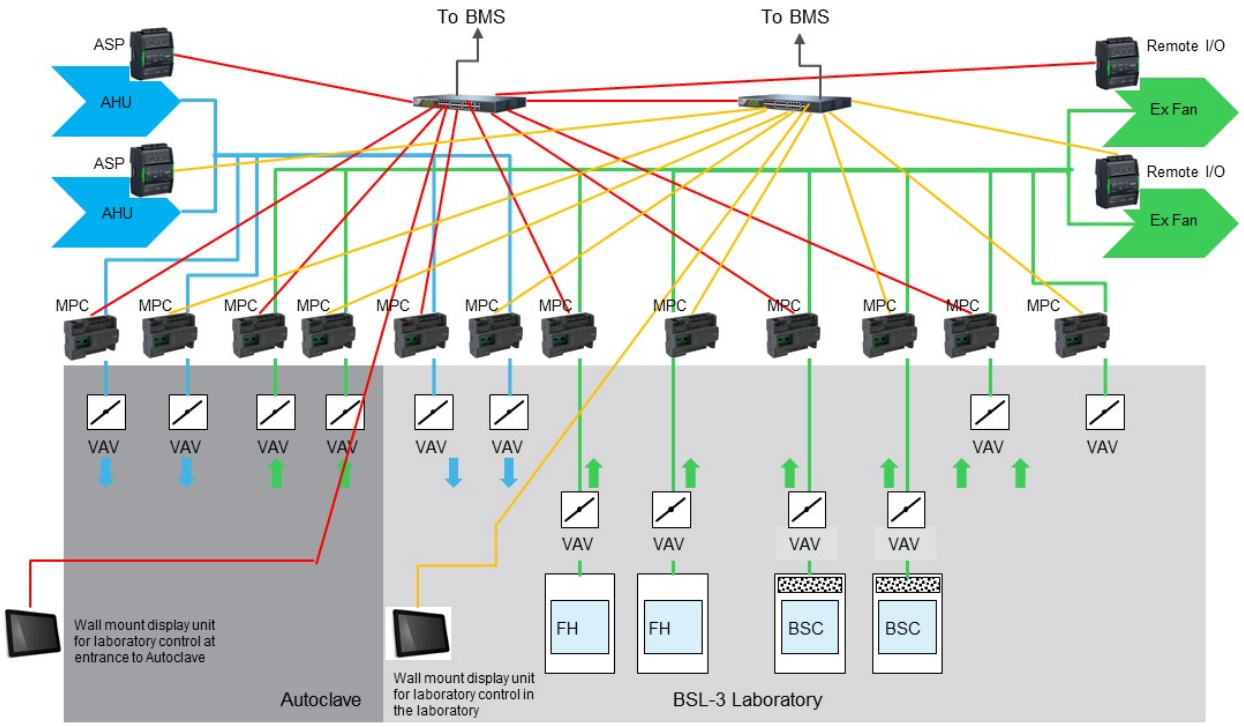


Figure 9 – Proposed Reference Control System Architecture

Using IP based controllers configuring the system architecture becomes flexible and open. The IP technology allows for more data sharing and higher transmission speed. However, with higher flexibility and higher bandwidth, networking and domain setting becomes more crucial. Proper network topology and configuration is required to ensure that there will be no data traffic congestion or worse still downed. The network should also take note of the high volume of traffic during abnormal condition or emergency.

4.1.1 Laboratory HVAC Control Architecture

For the laboratory, AHU control Automation Servers (AS) are recommended. It is also recommended to have one controller for each AHU. However, this will depend on the quantity of AHUs in the design, along with consideration for budget. The controls should be as depicted in the figure 10. Safety protection and other control logics should be based project by project, including the monitoring points.

The proposed temperature sensor should be an averaging, active sensor to ensure signal accuracy. Recommended sensors are listed in Appendix B.

The exhaust fans are part of the overall HVAC control for the laboratory. The AHU and EXF are interlinked and interlocked in operation. Operation or failure of either an AHU or EXF should trigger an immediate reaction. It is therefore required to have both corresponding AHU and EXF controlled by the same AS controller. This will ensure better communication and control response.

Usually the EXF is located far from the laboratory, so a remote IO module should be used to connect the fan and link to the AS controller.

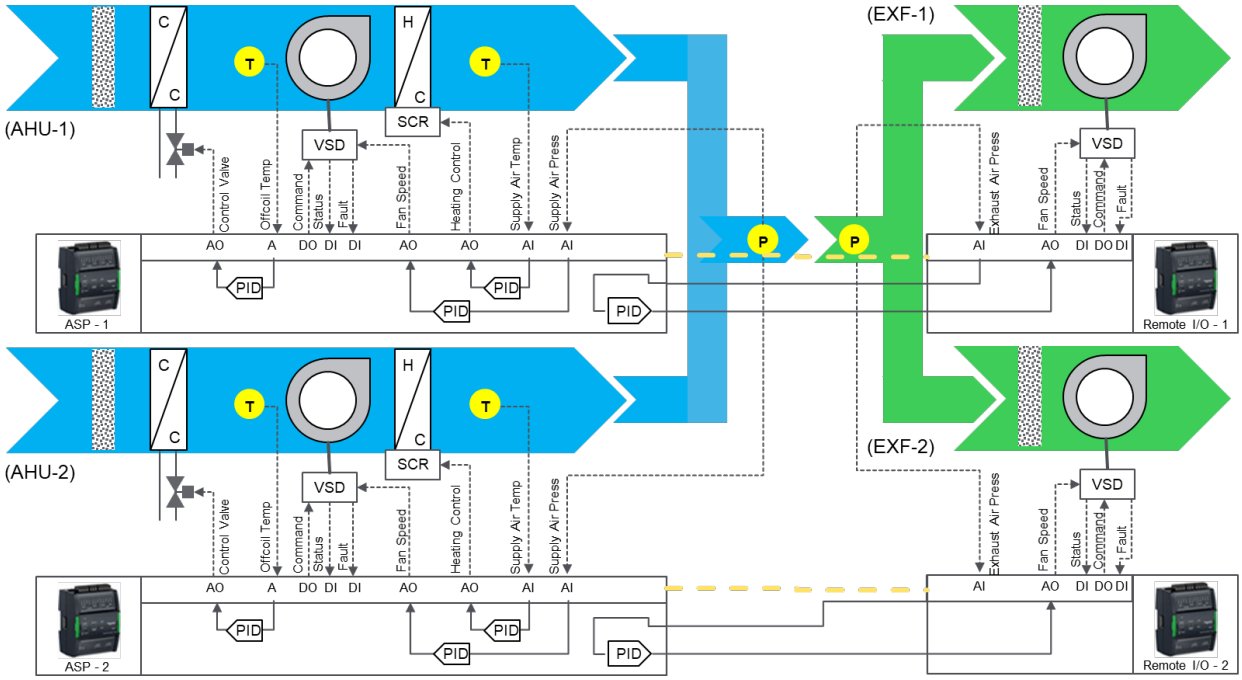


Figure 10 – Typical Laboratory Supply & Exhaust Fan Controller Configuration

4.1.2 Autoclave Architecture

In the autoclave, it is often only VAV boxes that are used for the operation, there will be more than one VAV box deployed in the room. It is then recommended to deploy an MPC controller to manage the VAV flow control as well as the room temperature control.

The connection and workings of the controller are depicted in the figure 11.

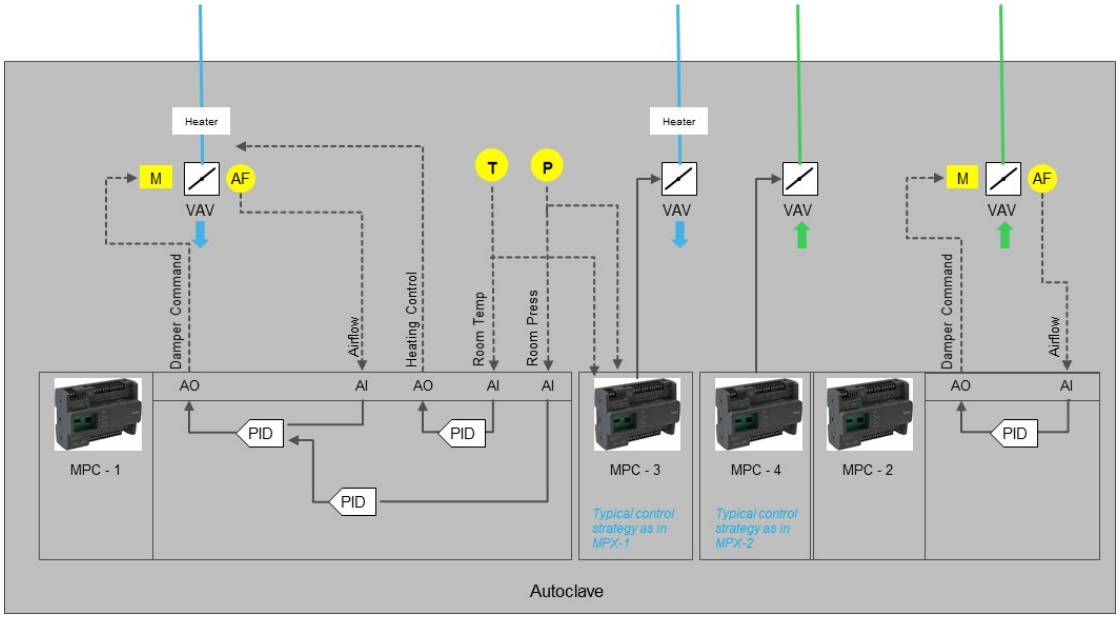


Figure 11 – Proposed Autoclave Controller Configuration

4.1.3 Fumehood and Biosafety Cabinet Control Solution

The principal and control strategy of fumehoods and biosafety cabinets have been discussed in earlier sections. Figure 12 depicts the application recommended for the implementation of a FH and BSC control.

A VAV box should be connected to the furniture to provide the air extraction requirement of the furniture based on the modes of operation. An MPC controller should be deployed for each furniture VAV box to control the airflow required to suit the operation.

Normally, the response for a FC and BSC is critical, thus the accurate and quick monitoring of airflow through the box is critical. The MPV is not recommended in this case since most FC and BSC will require accurate airflow monitoring and fast damper activation. Deploying an MPC controller allows it to be connected to high accuracy flow sensors and, at the same time, activate or drive a fast-acting damper actuator.

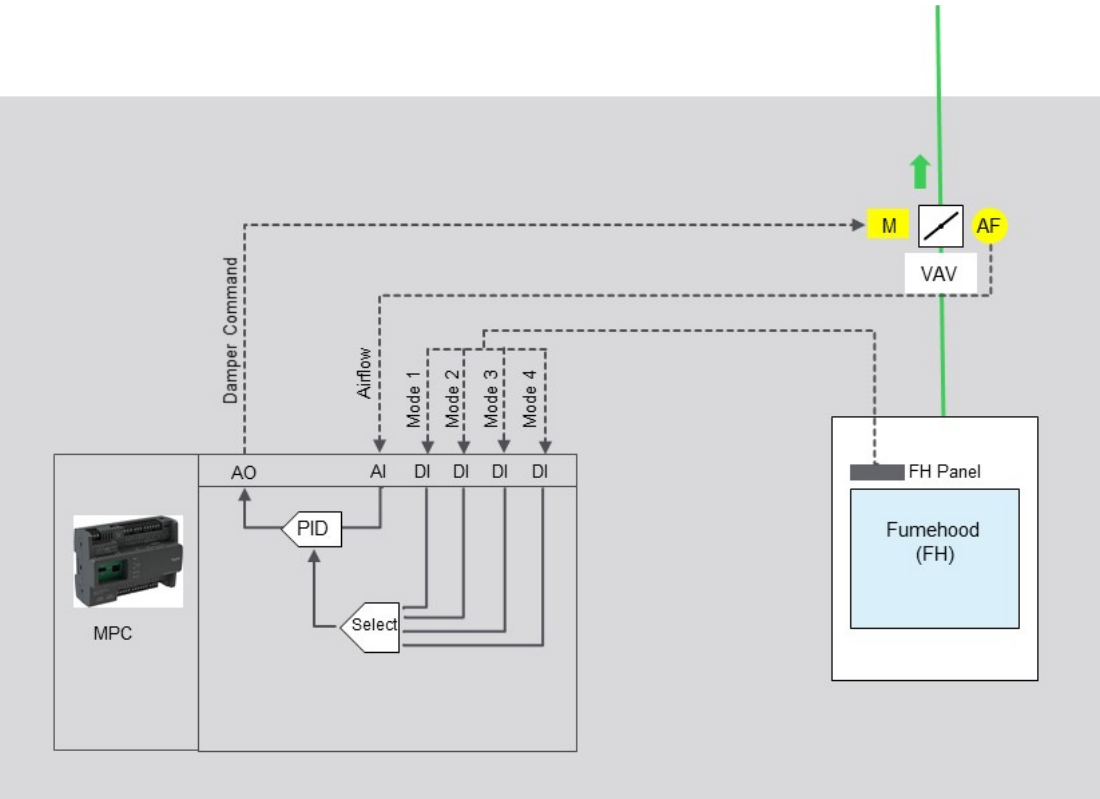


Figure 12 – Proposed Fumehood & BioSafety Cabinet Controller Configuration

FH and BSC are normally provided by clinical furniture manufacture. Operational information from the furniture are passed to the control system via hardwired points. It is more common and widespread for high level interfaces to be provided for this furniture.

Typical information passed from the FH and BSC to the control system are as follows:

Fumehood Parameters	Points	BioSafety Cabinet Parameters	Points
Power	DI	Power	DI
Fault	DI	Fault	DI
Operational Mode		Operational Mode	
• Shutdown	DI	• Shutdown	DI
• Standby	DI	• Standby	DI
• Operation	DI	• Operation	DI
• Emergency	DI	• Emergency	DI
Face Velocity	AI	Face Velocity	AI
		Fan Status	DI
		Fan Trip	DI
		BSC Filter Alarm	Di

Table 3: Analogue Inputs (AI) and Digital Inputs (DI) typically monitored.

4.2 Laboratory Space Control Solution

The independent section and equipment control strategy and integrated control mechanism for the laboratory has been discussed in previous section. In this section, we will look at the deployed for the control. VAV Boxes are used to control, makeup and compensate for all the containment and confinement requirement of the laboratory. Secondary heating elements are installed on the makeup air boxes for temperature control while humidity control is monitored and cascaded back to AHU for fine adjustments.

The control of each component within the laboratory are interrelated but they are controlled independently via individual VAV boxes. Therefore, a controller is recommended for each VAV box. Due to the need for an accurate airflow sensor for box monitoring and fast acting damper actuators are used for the response and control, an MPX controller is better suited for the deployment.

The most important control logic to be addressed in this configuration is the summation of all the FH and BSC exhaust consumption and the compensation needed from the compensation box. The whole connection configuration and working of this important element is detailed in figure 13.

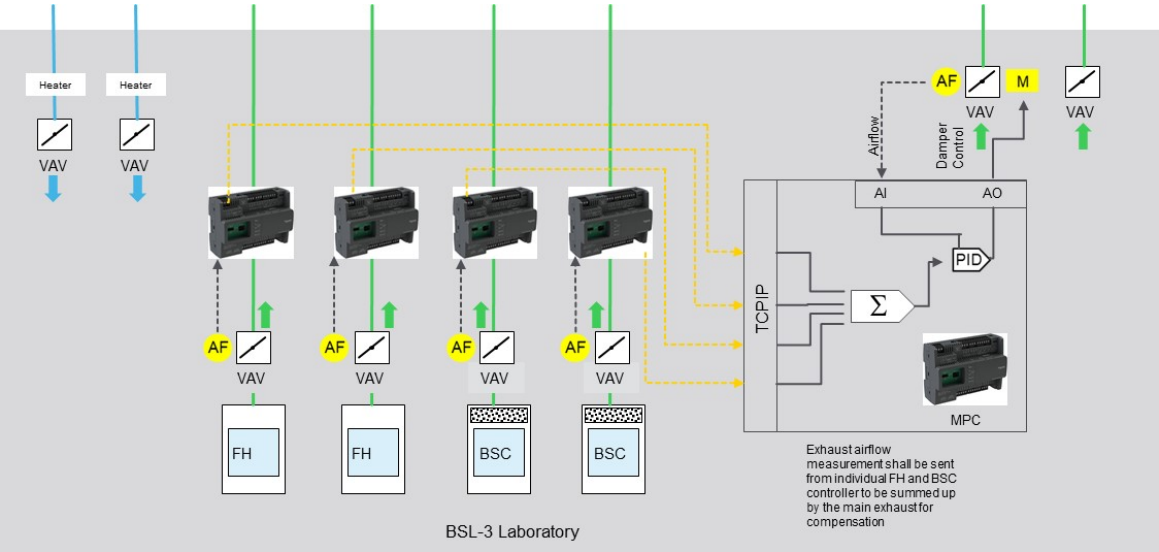


Figure 13 – Flow Compensation Control Model and Configuration

4.3 Safety and Redundant System Architecture Design

In a BSL-3 laboratory, failure of any system is not an option. A breach in laboratory integrity could lead to contamination and, more dangerous, a bio outbreak. It is defined in all Biosafe Levels that any implementation of a BSL-3 laboratory must be design with N+1 backup in mind and address all possible system failure risks with the proper risk assessment. Safety and redundancy are a must in design.

It is imperative that the mechanical equipment designed to serve the laboratory comes with a backup or standby option; i.e. two units as a minimum. The control application will then be configured to match the physical mechanical equipment. The system will be designed to provide the required N+1 backup control in the form of the following:

- Duty Standby

- Duty Cycling
- Failure Backup
- Synchronous Operation

As demonstrated in the reference architecture, all mechanical equipment will have two units minimum, with dedicated controllers. The network will be configured into two networks with a linked path between the two networks. This is to ensure that failure of one device will not affect the whole system.

In the reference architecture, it is recommended to have a visual user interface, both at the entrance to the autoclave and inside the laboratory. Operational rights and security will be managed by password and access rights.

The purpose of the control panel is to act as and N+1 to allow for operation of the laboratory in the event of a BMS system failure. The lowest level of password will allow viewing only to allow operators to see the room parameters and alarm points or condition.

Higher level password will allow laboratory supervisors to control the system in terms of changing of control parameters or setpoints.

The highest-level password will allow the activation of system shutdown or lock down, overriding and directly controlling the equipment, issue fumigation process and procedure. The most important of all is to be able to control the laboratory remotely in the event of a BMS system failure.

The proposed system is capable of interfacing to any BMS system via standard industry open protocol. The proposed laboratory system is designed with an Open Concept in mind allowing the critical facility to be interfaced to new or existing infrastructure.

Note: when designing safety and redundancy it is often requested at the controller level without much thought to the physical mechanical equipment. A safe and redundant system must include the physical mechanical equipment of the laboratory. Redundancy means redundant system and not just redundant controllers.

5 Laboratory Control with Venturi Valve System

Traditionally, the more precise laboratory, air change, pressure, temperature and humidity, HVAC control is achieved through VAV box systems. A damper is built into the box, coupled to an actuator. Operation of the damper within the box controls and limits that amount of air into the space. VAV boxes modulate and control the volume of the conditioned air into a space, maintaining the temperature and humidity of the area. Combinations of operational VAV boxes in proper sequences will determine and control the pressure, airflow and air changes of the controlled, confined space.

This document has explored and discussed VAV box controls. However, there is another device that is used to provide HVAC control to a laboratory space - the Venturi Valve. This document will attempt to discuss and provide some detail to the concept and working of a Venturi Valve in laboratory HVAC control.

5.1 What is a Venturi Valve and its application?

When fluid moves or is forced through a constriction, there will be a reduction in the fluid pressure. This natural phenomenon is known as the Venturi effect. The Venturi Valve control methodology and mechanism is based on this principal.

The Venturi Valve is an hourglass shaped device. It is comprised of a tube with a constricted neck. A cone is built into the tube at the constriction. The movement of the cone forward and backward along the constriction determines and controls the amount of air being supplied into a controlled space.

Venturi Valves pressure independent mechanical devices specially designed to control and maintain space pressure and airflow. They are also designed to maintain air volumetric control for fume hood controls and sometime biosafety cabinets.

Figure 14: Typical Venturi Valve Device

5.2 Venturi Valve Laboratory Mechanical Control

A laboratory is classified as a critical room in a hospital environment. These areas are often designed separately by teams of specialist designers. The proposed control system can be a separate, independent system remotely connected to the main hospital BMS system. This may or may not be from the same BMS manufacturer of the main hospital system. A Venturi Valve system, instead of the traditional VAV box system, is possible for a laboratory.

Venturi Valve system is designed for space pressure and airflow control. In a laboratory, the Venturi system is only being deployed within the autoclave and laboratory space to control the containment, air change and airflow. It will also be used to control the operation airflow of FH and BSC units based on the mode of operation of the furniture.

In a Venturi Valve system, the preconditioning of outdoor air being supplied to the space (Venturi system) and the extraction of the air within the containment space is still being affected by the BMS HVAC system. Often in a laboratory control system which employs a Venturi Valve system, there will be a need for the BMS HVAC control on the supply and exhaust air mechanical system to work in tandem with the Venturi Valve system.

The same four segments of control of a laboratory - Supply Air, Autoclave, Laboratory and Exhaust Air - are needed. The control scheme and logic of the four segments remain the same as discussed in the earlier sections of this document. The difference for the Venturi Valve system and VAV box system is in the laboratory. VAV boxes are replaced by the Venturi Valve. Figure 15 shows the location of the Venturi Valves.

5.3 Venturi Valve System Reference System Architecture

Most Venturi Valve manufacturers only manufacture the physical Venturi Valves. The manufacturers will work or collaborate with BMS control manufacturers to utilize the digital control system to control the physical Venturi Valves in the autoclave and the laboratory. The BMS system manufacturer will provide the control system for the Venturi system, complete with graphics, headend and possibly gateways for integration.

It may be the same BMS manufacturer for the Venturi Valve system that is engaged by the specialist contractor for the laboratory system or another independent BMS. Regardless, the whole system needs to be interfaced or integrated to work seamlessly to ensure the operation and safety of the laboratory.

Schneider Electric can provide control only to the Venturi system or provide a complete laboratory system. In this example, the Venturi system and the supply and exhaust air control system are of different manufactures. The different system will be connected through workstations or gateways via standard industry protocol.

Control logic, schemes and algorithm, methodology and principal shall be the same as the VAV box solution.

Figure 15 illustrates the possible reference system architecture principle for a Venturi Valve system.

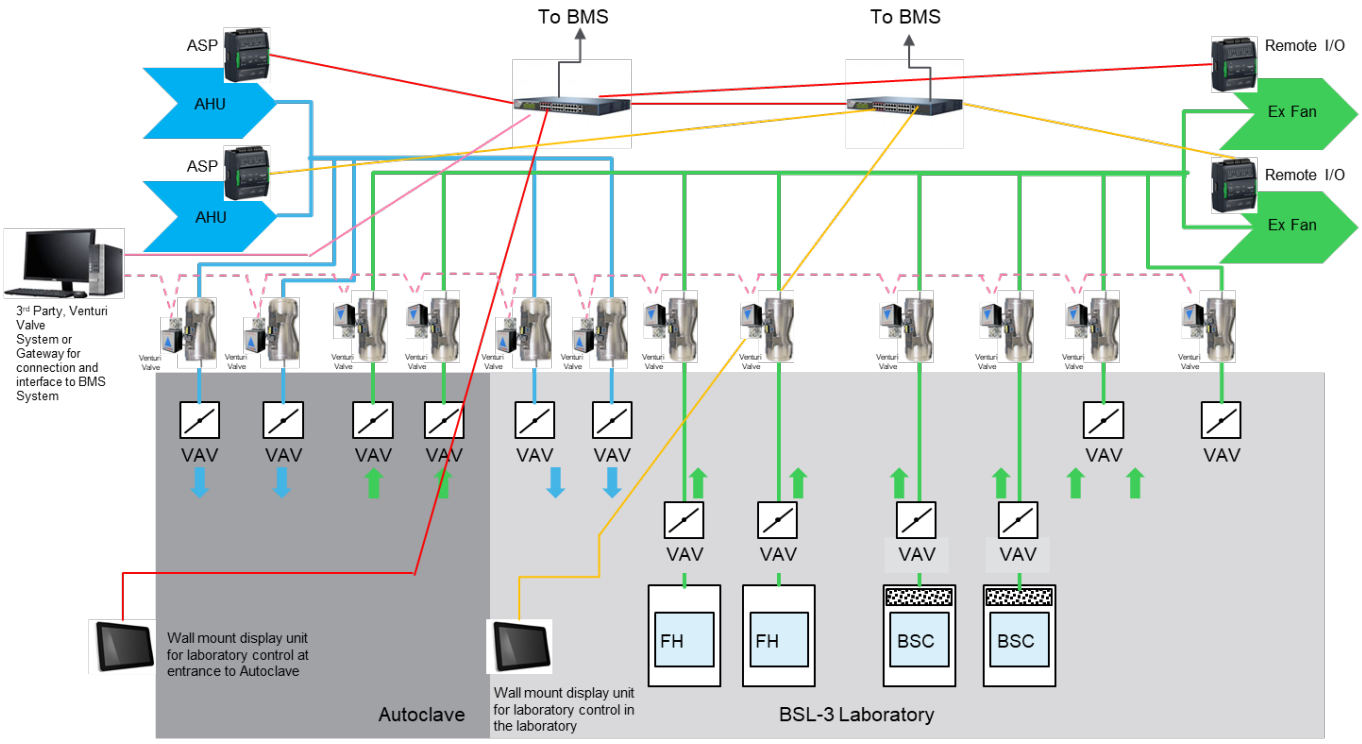


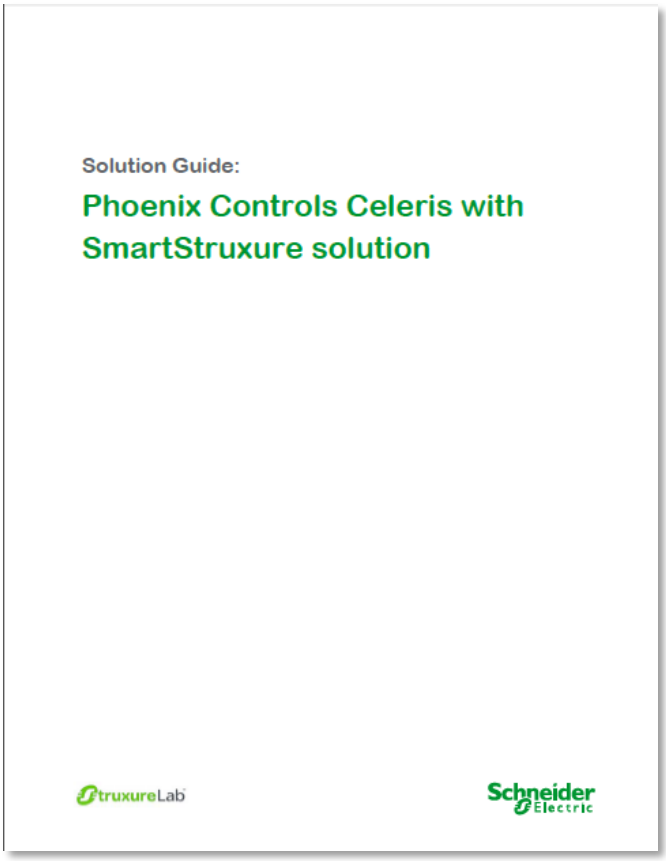
Figure 15 – Proposed Reference Venturi Valve Control System Architecture

5.4 Tested Validated Documented Application, TVDA

The BMS system engaged by the Venturi Valve manufacturer to provide control for the Venturi system will go through a rigorous control and testing regime which will be certified and verified with, and by, the Venturi Valve manufacturer.

It is common that independent BMS systems are deployed to control the laboratory supply and exhaust air system only and to provide monitor only the laboratory room control. In these instances and applications, please take note that the BMS system should act as a secondary monitoring system for the room pressure only. It should not be mixed or interfered with the primary laboratory room control system provided by the Venturi system provider.

Schneider Electric has made such integration and interface with Phoenix Controls Venturi Valve system. A TVDA can be found on the Schneider Exchange for the integration and interface to Phoenix Controls system for reference and information.



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7 Appendices

7.1 Appendix A – ASHRAE 170 – Table 7.1

TABLE 7.1 Design Parameters (*Continued*)

Function of Space	Pressure Relationship to Adjacent Areas (n)	Minimum Outdoor ach	Minimum Total ach	All Room Air Exhausted Directly to Outdoors (j)	Air Recirculated by Means of Room Units (a)	Design Relative Humidity (k), %	Design Temperature (l), °F/°C
Laboratory, general (v)	Negative	2	6	NR	NR	NR	70–75/21–24
Laboratory, bacteriology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, biochemistry (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, cytology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, glasswashing	Negative	2	10	Yes	NR	NR	NR
Laboratory, histology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, microbiology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, nuclear medicine (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, pathology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, serology (v)	Negative	2	6	Yes	NR	NR	70–75/21–24
Laboratory, sterilizing	Negative	2	10	Yes	NR	NR	70–75/21–24
Laboratory, media transfer (v)	Positive	2	4	NR	NR	NR	70–75/21–24

Source: Laboratory types and pressure regime proposed by ASHRAE, information extracted from, Table 7.1 - ASHRAE 170 (2013)

7.2 Appendix B - Proposed Sensor Specification

As this is a critical room, accurate measuring equipment is needed, and the requirements and proposed sensor are proposed:

Room Pressure Sensor	• Should be ultra low pressure monitoring sensors • Active Sensors, 4 to 20mA recommended • Comes with Digital or Analog Display, Digital recommended • Range : -50Pa to +50Pa • Accuracy : +/- 2% of the sensor range • Stainless steel 316 diaphragm
Room Humidity Sensor	• Active Sensors, 4 to 20mA recommended • Comes with Digital or Analog Display, Digital recommended • Range : 5% to 95% • Accuracy : 1% RH • Solid state, chemical free agent. • Non-condensing type.
Room Temperature Sensor	• Active Sensors, 4 to 20mA recommended • Comes with Digital or Analog Display, Digital recommended • Range : 0degC to 50degC • Accuracy : +/- 0.2degC at atmospheric, low flow • Temperature Element : PT1000, Ni1000 • Wall Mounted
Airflow Sensor	• It is recommended where possible and commercially viable to install airflow stations for monitoring and control • Another option of to recommend accurate flow sensor however it must be tested, calibrated and bench tested with the linked VAV Box. It is important to test and work out the coefficient of measurement for the VAV Box accurately.
Air Handling Unit Temperature Senor	• Active Sensors, 4 to 20mA recommended • Range : 0degC to 50degC • Accuracy : +/- 0.2degC at atmospheric, low flow • Temperature Element : PT1000, Ni1000 • Duct Type • Averaging Sensor element • Element Length, min 1 m • Flexible element and not rigid