JTC CleanTech One @ CleanTech Park

Green Tenant Fit-Out Guide

JTC Corporation

Jointly Developed By:

Supported By:

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EXECUTIVE SUMMARY

Project Overview

CleanTech Park is Singapore's first eco-business park. It is being developed on a 50-hectare site next to the Nanyang Technological University. Development will take place in three phases over the next 20 years. CleanTech One, the first building in the park, is being developed for multi-tenant use. CleanTech Park is targeting CleanTech tenants who want to show their commitment to green technologies by locating their research and development, engineering, or headquarters activities in a green building. Tenants will include both public and private entities.

CleanTech Park is being developed by JTC Corporation, an industrial infrastructure provider. One of the goals of the project is to foster the cross fertilization of ideas and alliances between tenants. Another goal is to make the development as sustainable as possible. Sustainable developments are commonly defined as developments that "meet present needs without compromising the ability of future generations to meet their needs" (World Commission on Environment and Development, 1987). Sustainability encompasses many ideas, for CleanTech Park this includes energy and water conservation, resource conservation, and indoor and outdoor environmental quality.

Sustainability is an important global issue, but there is a special emphasis in Singapore. Singapore is an island nation of about 5 million people. With a large population and a small amount of land, resource conservation is important. There are several key drivers to the sustainability movement in Singapore.

- Singapore imports a significant portion of the water used in the country from Malaysia.
- A large portion of the natural gas is imported from Malaysia and Indonesia. Energy and water conservation can reduce the reliance on these imports. Additional information on water and energy savings can be found at http://www.bgbg.org/Resources/Documents/RBB/11-06-07RBB_AlicenKandt.pdf
- Singapore is also at risk from global climate change. The melting of glaciers produced by global warming leads to higher sea levels. Rising sea levels endanger low lying coastal land and put fresh water reservoirs at risk.

CleanTech Park has many sustainable features. Storm water from the site is directed into wetlands where is can be treated and reused. The site is conserving trees and plants and protecting biodiversity. The buildings are located on the site to promote walking. The buildings themselves are designed with passive features to help reduce energy use. These features include a green trellis to provide shade between buildings and buildings oriented to reduce solar heat gain.

In addition to the sustainable features of the development, each tenant contributes to the sustainability of the project. This document provides Tenant Guidelines for CleanTech Park. It will help tenants define and achieve goals for sustainability in their fit-outs.

Tenants can employ many strategies to make their spaces green. Energy conservation is very important and it has many benefits. One benefit is that it reduces the carbon footprint of the building. Energy conservation also helps reduce operating costs and reduce the reliance on imported energy.

Water conservation is also very important. Water in Singapore comes from several sources. Some of the water is imported, but the rest of the water is produced in Singapore through several different techniques including rainwater catchment, desalination, and waste water reuse. Water conservation helps to reduce the dependence on imports and expensive production methods such as desalination.

A healthy indoor environment and minimal impact on the community are two other sustainable issues for tenants to consider. A healthy indoor environment is produced by designing spaces with ventilation, lighting, and temperature levels that contribute to the comfort of the occupants in the space. Tenants can be mindful of their impact on the community by reducing solid, airborne, and waterborne waste.

Tenant Design Strategies

This guide provides specific strategies and examples to help the tenants of CleanTech Park to design energy efficient and eco-friendly spaces. It is estimated that the use of the strategies in this guide will help reduce energy use by 50%. The figure below shows how the use of the strategies can lead to this savings.

Energy Use (Percentage of Standard Design)	Strategy
100%	Standard Building Design
	Energy Star and High Efficiency Equipment
	High Efficiency Lighting
	Occupancy Sensors for Lighting and Equipment
	Daylighting Controls
	Variable Air Volume Air Distribution
	Demand Control Ventilation
	Enthalpy Recovery Wheel
50%	Enthalpy Recovery Wheel with Passive Desiccant Dehumidification

Figure 1: Energy Efficiency Strategies

The process begins in the project planning phase. Spaces planned to take advantage of daylighting will save energy and improve occupant comfort. Efficient layouts with minimized hazardous material areas and fume hoods located away from doors and traffic allow for more efficient air distribution. Energy Star rated equipment or the most efficient equipment available saves energy and reduces cooling loads.

The air-handling systems usually account for the largest amount of the energy usage in a lab and are therefore an important component of an energy efficient design.

- The design airflows should first be reduced as much as possible. This can be done by reducing the cooling loads in the space, reducing the air exhausted by fume hoods and reducing the required air change rate of the space.
- Demand controlled ventilation can then be used to reduce airflows even further when the labs are unoccupied or when sensing technology indicates that it is safe to lower the air change rate.

A low pressure air system design can help deliver and exhaust air from spaces more efficiently reducing fan motor energy use.

- Size air-handling units for an air speed of 1.5 m/sec. to reduce the pressure drop through the unit.
- Establish a target pressure drop for the supply and exhaust ductwork and terminal devices. Optimize the components to meet this target. Once the airflows and pressure drops have been optimized as much as possible, the energy required for cooling the air can be reduced.

In Singapore's hot and humid climate there is always a need for cooling. Energy recovery systems can reclaim some of the energy used for cooling from the exhaust air.

- If the exhaust air is suitable, an enthalpy wheel can be used to reduce the temperature and moisture content of the supply air. This reduces the energy required for cooling by an estimated 35%.
- Additional strategies, such as a wraparound heat pipe, can be utilized if some of the exhaust air can't be used in an enthalpy wheel.

The humidity in the air requires that the supply air be cooled to 12.8°C (55°F) to remove moisture. Supplying air to the spaces at this temperature may lead to over-cooling, which may require reheat to maintain spaces at temperatures that are comfortable for the occupants. Further energy savings can be realized by reducing this reheat.

- Reduce or eliminate reheat by adding a passive dessicant dehumidification wheel after the cooling coil. This wheel dehumidifies and reheats the air and saves reheat energy. This wheel combined with the enthalpy wheel can reduce energy for cooling and reheating by an estimated 68%.
- Use a heat recovery chiller to pre-cool the air before the cooling coil and reheat the air after the cooling coil.

Lighting and receptacle loads are also large energy users in a lab.

- Employ daylighting controls and occupancy sensors to turn lights off when there is enough light from the exterior or if a space is unoccupied.
- Add sensors to turn equipment that is not used frequently off when not in use.
- Design lighting systems to deliver the required illumination level with the least amount of wattage possible.

Water conservation is another important part of designing an eco-friendly space.

- Conserve water with low-flow fixtures.
- Electronic faucet sensors turn faucets off to reduce water waste.
- Collect lab waste and dispose of it properly. Sinks should not be used for waste disposal.
- Many pieces of typical lab equipment use water. Alternatives that don't use water or use less water can be specified.

Controls and monitoring are used to ensure that the equipment is functioning as designed and that energy is being saved.

- Meter all energy using systems in the space.
- Sub-meter equipment to provide information for optimizing operational efficiency.

- Optimize system controls.

Following the strategies in this guide will help tenants reach their sustainability goals. This guide will help tenants save energy and reduce their carbon footprint. In addition, strategies in this document will help tenants create a safe and healthy working environment for the occupants of the space. By locating in this park tenants are demonstrating their commitment to sustainability and the successful completion of a green space using the strategies in this guide will further show this commitment.

FORWARD

Goals

This Tenant Green Fit-Out Guide provides specific strategies, suggestions, and recommendations for the topics shown below as to how to satisfy the sustainability objectives of CleanTech Park when fitting out your tenant space:

- Space programming
- Air heating, ventilating and air conditioning (HVAC) systems
- Electrical systems including lighting and lighting controls
- Water and plumbing systems
- Controls and monitoring
- Specialized rooms such as cleanrooms, cold/warm room, environment rooms, etc.

Incorporating some or all of the suggestions presented in this guide will reduce both energy and water usage as compared to a "typical" fit-out and will allow your tenant space to be a contributing part of the eco-friendly environment at the CleanTech Park.

Appendix A is the JTC Green Fit-Out Guide Checklist. This is to be used by the tenant for tracking and documenting green features incorporated into the fit-out design. The tenant shall return the completed checklist to JTC along with a set of the construction documents.

The strategies and suggestions included in this document were developed based on the Labs for the 21st Century (Labs21) Tool Kit with specific attention paid to what sustainability measures are most applicable to the hot and humid climate of Singapore and the CleanTech One building configuration. The Tool Kit is divided into the following sections:

- Intro to Low-Energy Design (Appendix B)
- Case Studies
- Best Practices Guides
- Technical Bulletins
- Energy Benchmarking
- Design Guide
- Laboratory Energy Efficiency Profiler (LEEP) Tool
- Energy-Efficient Laboratory Equipment Wiki
- Environmental Performance Criteria (Appendix D)
- Design Intent Tool
- Design Process Manual (Appendix C)

Because of the extensive nature of the Labs21 Tool Kit, only print-outs of the highly relevant sections are included in the Appendices of this guide. The complete Toolkit can be found at http://www.Labs21century.gov/toolkit.

THE FIT-OUT DESIGN PROCESS

A Design Process Checklist is included in the Labs21 Took Kit. This process aims to "ensure that sustainability is integrated into each stage of the building design and delivery process." A detailed description of all checklist items can be found at http://Labs21.lbl.gov/DPM/checklist/index.htm. A short summary of the suggested Labs21 design process checklist follows.

Pre-Design

1. "Select and Energy / Sustainability Champion"
2. "Select a multi-disciplinary design team with sustainable design experience"
3. "Ensure that project budget allows for sustainable design consulting services"
4. "Establish sustainability goals (including energy use)"
    a. Suggested CleanTech Park goals are as follows:
        i. A tenant fit-out should aim for energy usage and costs that are 30% less than ASHRAE Standard 90.1 (most recent year).
        ii. Satisfy all six Labs21 Environmental Performance Criteria (EPC) Prerequisite Credits and five (of seven) additional EPC Credits (Appendix D).
5. "Conduct a pre-design charrette to identify potential strategies"
6. "Identify all governing and relevant standards and codes"
    a. The use of this guide does not relieve the design team from identifying and complying with all applicable codes and legal requirements. All tenant fit-outs must conform to the legal requirements established by the Singapore Government. These are provided in the Building Control Act (most current year). At a minimum, the following codes apply:
        i. For HVAC and energy, this regulation references the following three building standards (most current year) in the Code Interpretation document entitled "Acceptable Solutions":
            (A) SS 530 – Energy Efficiency Standard for Building Services and Equipment, SPRING Singapore
            (B) SS 553 – Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings, SPRING Singapore
            (C) SS 554 – Code of Practice for Indoor Air Quality for Air-Conditioned Buildings
        ii. For electrical systems the design shall meet the following codes and standards (most current year):
            (A) Singapore Code of Practice for Electrical Installations (CP 5)
        iii. Singapore Code of Practice for Installation and Servicing of Fire Alarm Systems (CP10)
        iv. If the fit-out requires the modification of 2000 m^2 (21,500 ft^2) or more of gross area with major retrofits to the building system, the design must additionally comply with:

(A) The Code for Environmental Sustainability of Buildings (http://www.bca.gov.sg/EnvSusLegislation/others/Env_Sus_Code2010.pdf)

(B) The Code of Practice on Buildability (http://www.bca.gov.sg/BuildableDesign/others/copbdapr2011.pdf).

Schematic Design

1. "Conduct schematic design charrette(s)"
2. "Incorporate codes and standards"
3. "Begin energy analysis of design concepts using appropriate energy design tools"
    a. Possible methods for performing an energy analysis include:
        i. Using a whole building energy analysis tool to perform an ASHRAE Standard 90.1 base building to proposed design analysis.
4. "Update energy and sustainability goals"

Design Development

1. "Conduct design development meeting(s)" to "Review and refine design and integration of sustainable design strategies."
2. "Conduct iterative detailed analysis of energy and environmental performance"
3. "Ensure that value engineering is based on life-cycle cost"
    a. First costs should not be used to make energy consuming system and equipment design decisions. Life cycle costs that, at a minimum, account for energy costs and operations and maintenance costs, shall be used for decision making.
4. "Update status of energy and sustainability goals"

Construction Documents

1. "Conduct final design review" to "Ensure that sustainable design features are incorporated as intended."
2. "Establish checkpoints for key environmental performance features and systems"
3. "Highlight energy efficiency and sustainability attributes associated with specific products and materials"
4. "Update energy and sustainability goals"

Bid and Award

1. "Include sustainability criteria in selection of contractors"
2. "Specify detailed construction commissioning activities in contracts" and "In particular, ensure that commissioning covers performance verification in addition to installation and operational verification."

3. “If cost cutting is required, consider life-cycle energy and environmental costs and benefits in keeping/deleting features.”
4. “Update energy and sustainability goals”

Construction

1. “Include sustainability criteria in selection of contractors”
2. “Update energy and sustainability goals”

Acceptance and Close-Out

1. “Verify building performance during post-construction commissioning”
2. “Develop operations and maintenance manual”
   a. The manual should include more than just the technical literature on the installed equipment. Summaries of intended operation highlighting building features that are innovative and require additional explanation should also be included.
3. “Update energy and sustainability goals”
4. Train operation and maintenance personnel on use of systems.

Occupancy & Operation

1. “Develop and implement EHS management plan” The “plan should include consideration of energy efficiency and sustainability.”
2. “Train occupants on proper use of low-energy equipment and features, especially fume hoods”
3. Benchmark lab energy performance
   a. Use the Labs21 Benchmarking Tool available at http://Labs21benchmarking.lbl.gov/
4. “Setup continuous or periodic monitoring of energy and environmental performance”
   a. Consider using the International Measurement and Verification Protocol
5. “Consider post-occupancy evaluation studies” to “ensure energy, environmental and health and safety requirements are being met.”

While not all steps of the Labs21 Design Process may be absolutely necessary to every CleanTech tenant fit-out project, it is recommended that the general approach be used. The approach ensures that the topic of sustainability and energy efficiency is introduced from the onset of the project, and then provides specific iterative goal setting, analysis, and pricing steps that produce a final installed fit-out that meets the sustainability goals of CleanTech Park.

LAB PLANNING CONSIDERATIONS

The way the lab space is arranged can have a significant effect on occupant comfort and safety, efficiency and energy consumption. A very important step in developing a space that is efficient and useful to researchers occupying it is the selection of the space planning professional responsible for the programme. This person or team shall have a demonstrated track record of successful laboratory projects where energy efficiency goals have been met. The following is a list of guidelines for a space programme that can help improve energy efficiency:

1. **Minimize and separate the area housing hazardous materials**. Labs in which hazardous chemical and material are used must be exhaust to outdoors and typically require high ventilation rates. Thus minimizing the area in which hazardous material are used and separating from other areas via wall results in:

    a. Smaller areas requiring high airflow rates.

    b. Minimizing areas requiring exhaust to outside and thus make-up air.

    c. Ability to return air from non-hazardous areas to the AHU to minimize make-up air.

    A space plan example illustrating these points is shown in Figure 2.

    Note that if the wall segregating the fume hoods from the general laboratory space is eliminated than the area requiring the minimum ventilation rate of 2 ACH is quadrupled. This results in significantly greater ventilation airflow and eliminates the opportunity to return air to the air handler.

2. **Minimize the number and size of fume hoods**: Consider sharing hoods among different staff and department. This will reduce the amount of exhaust and make-up air.

3. **Minimize the number of freezers and other large energy consuming equipment** : Consider locating in a manner that can allow the devices to be shared by the maximum number of laboratory units.

4. **Use Energy Star equipment:** Use only EnergyStar rated equipment for things such as small refrigerators and desktop electronics.

5. **Use the most energy efficient lab equipment**: Investigate all manufactures of lab equipment and select the one that meets your needs at the minimum energy consumption.

6. **Maximize the use of daylighting.** A good reference is provided in Labs21 Best Practice Guides[1] Recommendations include:

    a. Specify light-colored interior spaces, tall ceilings, and high windows to distribute natural light most effectively. If private offices must be along exterior walls with windows, specify a horizontal band of glass that is above eye level adjacent to the ceiling on the walls across from the windows.

    b. Coordinate the daylighting design with the electric lighting design so they work together as one system. This includes defining zones for electric lights, selecting proper task and ambient lights, and determining the best control strategy for the lights, including

[1] Laboratories for the 21st Century: Best Practices – Daylighting in Laboratories, October 2003.

photosensors and occupancy controls. Commissioning the lighting controls system to make sure it works as designed is an important consideration.

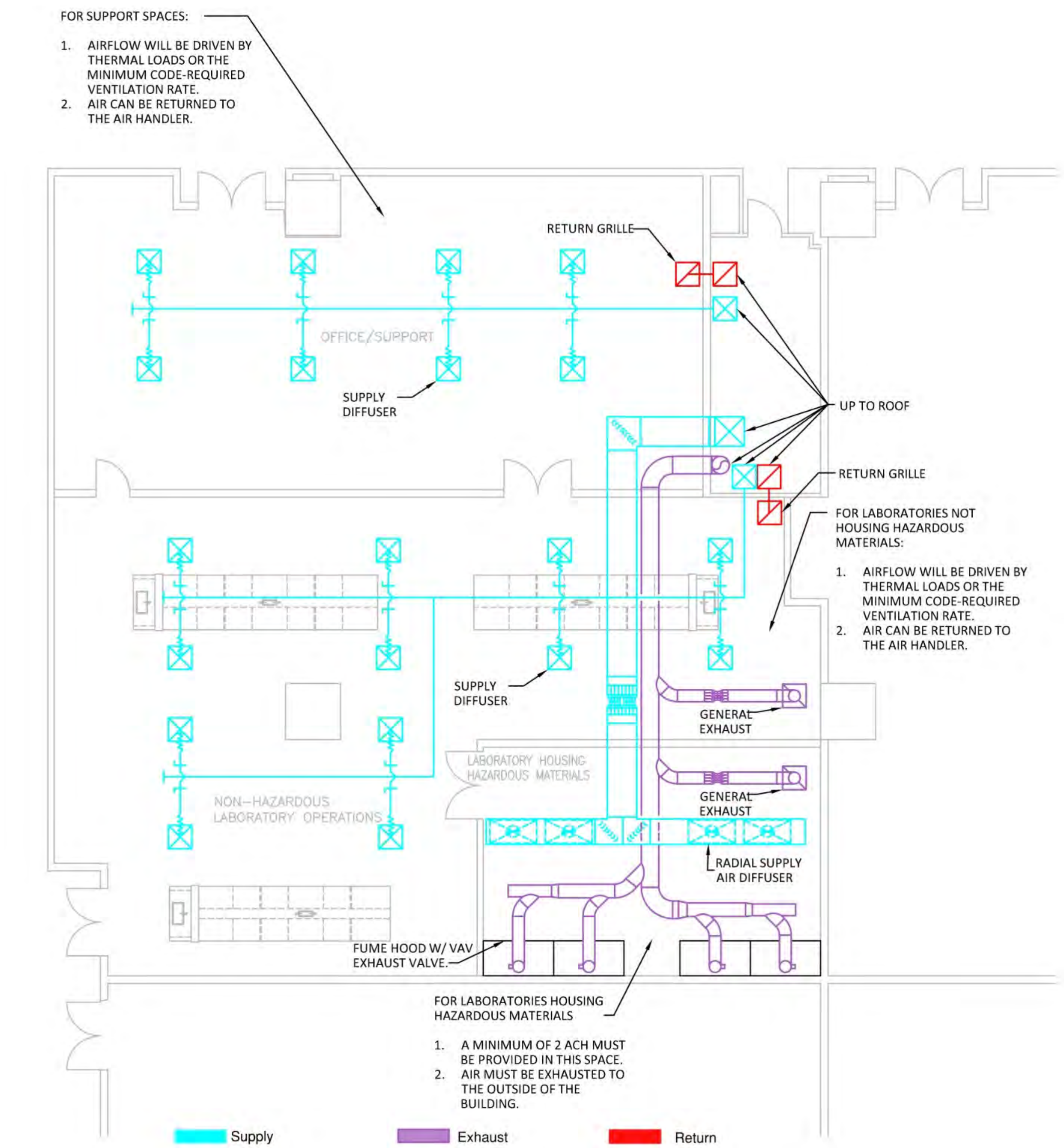

Figure 2: Minimize area of space housing hazardous materials.

Other good-practice lab space planning recommendations that will improve fume hood performance and thus occupant safety are given below:

1. **Carefully consider the placement of fume hoods**. Guidance is provided in Figure 3.

   a. Fume hoods shall be located away from walkways within the lab. People commonly walk at a speed of 0.9-1.3 m/s (2–3 miles per hour), creating a "wake" that can draw air out of a hood.

   b. Fume hoods shall be located away from doors.

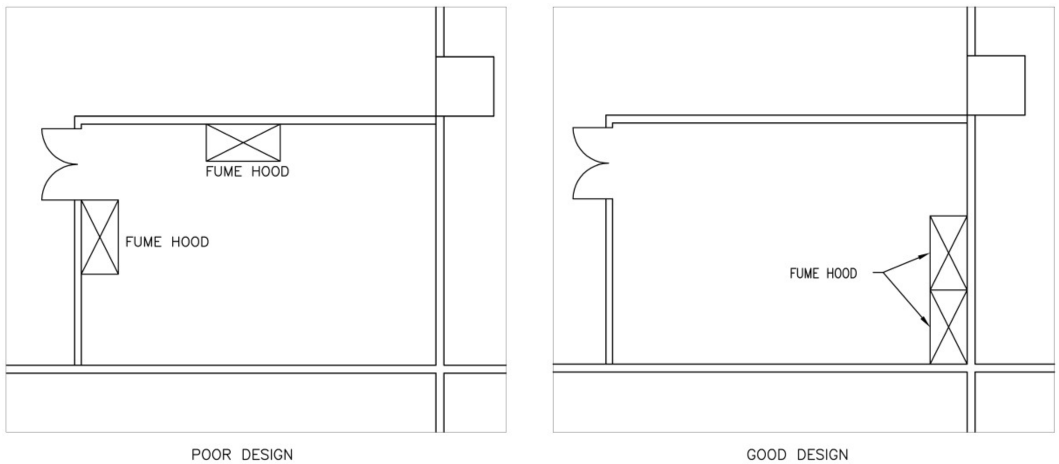

Figure 3: Proper location of fume hoods

AIR HVAC SYSTEMS

HVAC Systems Design Overview

Because the majority of the energy consumed in laboratories is associated with the HVAC system, significant attention must be paid to their design. This section describes, first from a high level and then from a detailed level, the prioritized steps to take to attain an energy efficient HVAC system that will meet the sustainability requirements of CleanTech Park.

The Labs21 Tool Kit includes a Sustainable Strategies Checklist as part of the Labs21 Design Process Manual Version 1.2, which can be found at http://Labs21.lbl.gov/DPM/bestpractices/index.htm. Three of the sustainable strategy topics are applicable to the design of the CleanTech air HVAC systems; 1) Energy & Atmosphere, Loads, Minimize Loads; 2) Energy & Atmosphere, HVAC, Maximize Ventilation Efficiency; 3) Energy & Atmosphere, HVAC, Maximize Cooling Efficiency. The Energy & Atmosphere, HVAC, Maximize Heating Efficiency strategies, which addresses space heating and humidification are not be applicable in Singapore's climate.

The following table shows each detailed item included under the three main applicable Sustainable Strategies Checklist topics and a recommendation as to if the item should be considered for use in the CleanTech Park tenant fit-outs:

Table 1: Sustainable Strategies Checklist

Sustainable Strategies Checklist Topic	**Specific Labs21 Sustainable Strategies Item**	**Recommendation for Incorporation into Tenant Fit-Outs**
Energy & Atmosphere – Loads: Minimize Loads	Optimize ventilation requirements	Highly recommended
	Minimize simultaneous heating and cooling loads	Highly recommended
	Right-size laboratory equipment	Highly recommended
	Daylighting in laboratory spaces	Limited opportunity due to overhangs and planting shading windows.
	High performance facades	Not applicable – façade part of base building design.
	Optimize temperature and humidity setpoints	Highly recommended
Energy & Atmosphere HVAC: Maximize ventilation efficiency	Efficient fumehoods	Highly recommended
	Low pressure-drop design	Highly recommended
	Manifolded exhaust system	Limited opportunity due to distributed nature of exhaust shafts
	Specifying efficient fans and motors	Highly recommended
	Ventilation system control strategies for efficiency	Highly recommended
Energy & Atmosphere	Energy Recovery	Recommended

Sustainable Strategies Checklist Topic	Specific Labs21 Sustainable Strategies Item	Recommendation for Incorporation into Tenant Fit-Outs
HVAC: Maximize cooling efficiency	Efficient chiller systems for labs	Base building is providing cooling chilled water. Only applicable to tenant process chilled water.
	Thermal energy storage	Not recommended
	Evaporative cooling	Not recommended
	Desiccant dehumidification	Recommended

Based on an analysis of the highly recommended and recommended items above, five specific strategies have been identified and prioritized as the most effective ways to reduce the energy consumption of the lab air HVAC systems at the CleanTech Park. These strategies are, in recommended order of incorporation, as follows:

1. **Step 1**: **Minimize both the minimum and maximum lab airflow requirements.**
2. **Step 2: Control airflow in response to varying conditions:** The cooling load, fume hood usage, and lab occupancy are constantly changing in the laboratory: Continuously adjusting the airflow to just satisfy the needs of the lab at any particular time reduces the fan energy used to deliver the air to the space.
3. **Step 3: Minimize the pressure drop of the supply and exhaust systems**: Minimizing the pressure drop of all of the various components in the air side HVAC system will reduce the fan energy for the air system.
4. **Step 4: Recovery energy from the exhaust airstream**: Recovering both latent and sensible energy from the exhaust airstream to pre-condition the outside air, cooling and dehumidification energy is reduced.
5. **Step 5: Minimize the energy used to provide acceptable humidity conditions in the lab**. Traditional methods call for cooling the outside air via cooling coils to a temperature below 55F and then reheating the air with reheat coil. Use an alternate, more energy efficient method.

The rest of the Air HVAC Systems section discussion describes in detail the specific methods for achieving these four big-picture strategies. An illustration of the priorities of the recommendations made in the rest of this section is illustrated in Figure 4.

Minimizing Lab Airflow

Lab Air Change Rates

Labs and vivarium facilities use large amounts of energy and have high carbon emissions because of the large volumes of outside air that are conditioned, supplied to, and exhausted from these facilities. For example, laboratories typically consume 5 to 10 times more energy per square meter than do office buildings. And some specialty laboratories, such as clean rooms and labs with large process loads, can consume as much as 100 times the energy of a similarly sized institutional or commercial structure. With many modern laboratories operating with fewer fume hoods and more energy-efficient equipment and lighting the labs’ minimum air exchange rate requirement is often the dominant energy use driver.

Achieving the safe reduction or variation of air change rates in labs and vivariums can represent the greatest single approach for reducing their energy consumption and carbon footprint.

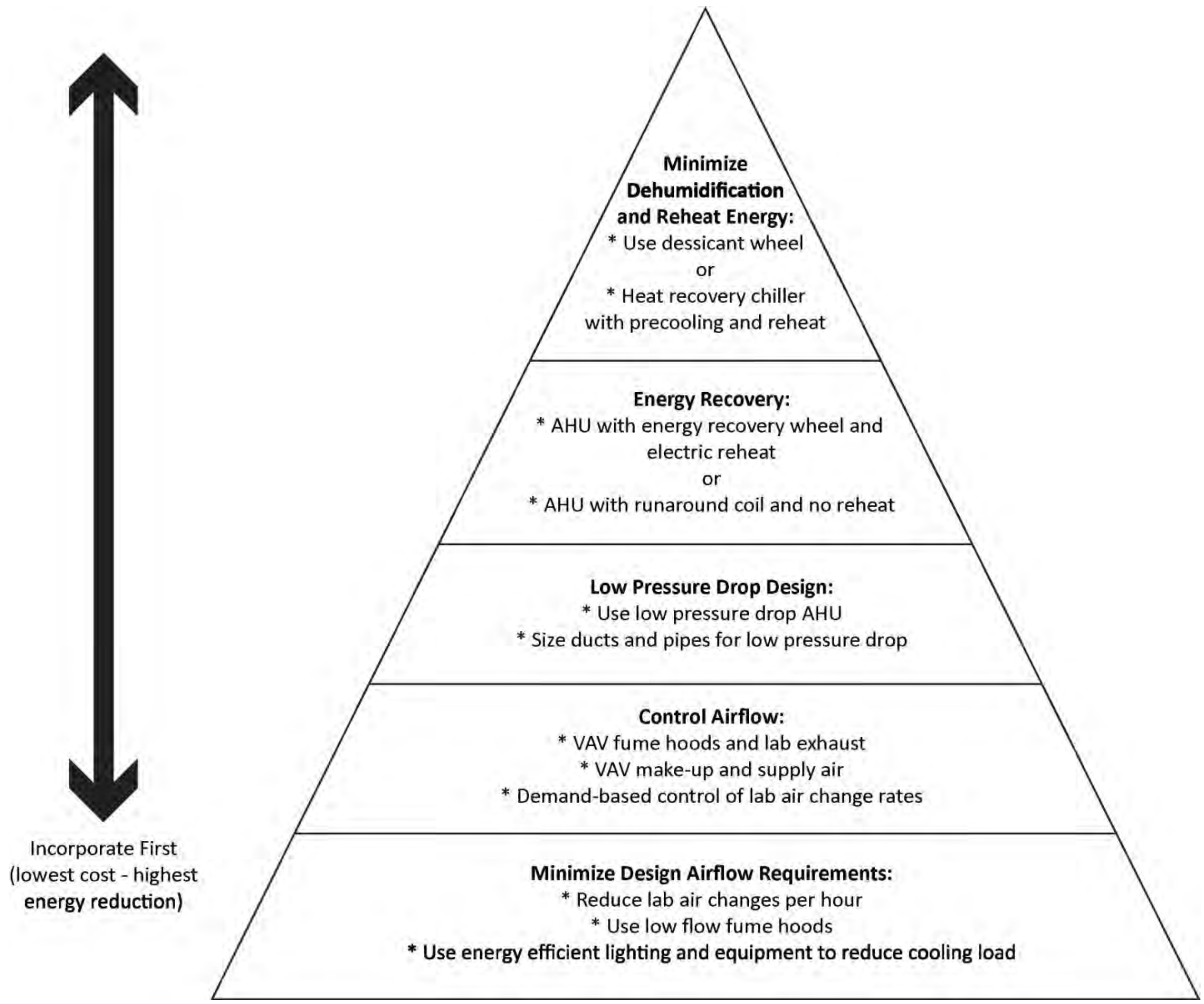

Figure 4: Hierarchy of Sustainable Options

Generally speaking, minimum ventilation rates should be established that provide a safe and healthy environment under normal and expected operating conditions. The dilution ventilation provided by this airflow is no substitute for the containment performance of a laboratory fume hood or other primary containment device regardless of the room ventilation rate. The appropriate ventilation rate for clearing a room of fugitive emissions or spills varies significantly based on the amount of release, the chemical's evaporation rate and hazard level, and ventilation system effectiveness.

Fixed minimum airflow rates in the range of 6 to 12 air changes per hour (ach) when the space is occupied have been used in the past. However, recent university research (Klein et al. 2009)[2] showed a significant increase in dilution and clearing performance by increasing the air change rate from 6 to 8 ach with diminishing returns above 12 ach. Similarly, CFD research (Schuyler 2009)[3] showed that increasing the lab's dilution ventilation rate from 4 to 8 ach reduced the background contaminant level by greater than a factor of 10. This indicates that minimum ventilation rates at the lower end of the 6 to 12 ach range may not be appropriate for all laboratories. Minimum ventilation rates should be established on a room-by-room basis considering the hazard level of materials expected to be used in the room and the operation and procedures to be performed. As the operation, materials, and hazard level of a room change, an increase or decrease in the minimum ventilation rate should be evaluated. [4]

Active sensing of air quality in individual laboratories (Sharp 2010)[5], also known as Demand Based Control, is an alternative approach for dealing with the variability of appropriate ventilation rates, particularly when energy efficiency is important or when less may be known about the hazard level. With this approach, the minimum airflow rate is varied based on sensing the laboratory's actual air quality level or "air cleanliness." When air contaminants are sensed in the laboratory above a given threshold, the minimum air change rate is increased proportionally to an appropriate level to purge the room. When the air is "clean" and contaminants are below the previously mentioned threshold, lower minimum airflow rates may be appropriate. Extensive studies of lab room environmental conditions (Sharp 2010)[6] have shown that the air in labs is typically "clean" over 98% of the time.

<u>Demand Based Control of Air Change Rates in Labs and Vivariums:</u>

A demand-based approach to dilution ventilation typically operates with a variable air volume lab airflow control system set to a low minimum airflow of between 2 to 4 ACH. The control system typically overrides this low minimum flow based on fume hood makeup air requirements, cooling load requirements, or an IEQ-based minimum ventilation override signal from the demand based control system. This IEQ based override signal is based on sensing organic and inorganic chemical vapor contaminants as well as particulates, and even carbon dioxide in case there are high levels of occupancy in the lab areas. When contaminants are sensed at sufficient levels the lab airflow will be overridden to a higher level that should typically be at least 8 ACH but no more than 16 ACH based on the air volume capabilities of the lab VAV terminal devices.

One approach to economically and reliably sense environmental conditions in many labs and vivarium rooms of a facility is to use a sensing architecture known as multiplexed sensing. With this approach, one central set of sensors is used in a multiplexed fashion to sense not one but many different rooms or areas. Instead of placing multiple sensors in each room, this networked system routes packets, or samples of air, sequentially in a multiplexed fashion to a shared set of sensors. Typically, 15 to 20 areas can be sampled

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[2] Klein, R.C., C. King, A. Kosior. 2009. "Laboratory air quality and room ventilation rates." Journal of Chemical Health & Safety (9/10).

[3] Schuyler, G. 2009. "The effect of air change rate on recovery from a spill." Presented in Seminar 26 at the ASHRAE Winter Conference.

[4] ASHRAE, Applications Handbook, 2011, Chapter 16 Laboratories, pg. 16-8.

[5] Sharp, G.P. 2010. Demand-based control of lab air change rates. ASHRAE Journal 52(2):30-41.

[6] Sharp, G.P. 2010. Demand-based control of lab air change rates. ASHRAE Journal 52(2):30-41.

with one set of sensors approximately every 15 minutes, which theoretical and empirical spill testing[7] has shown meets the time requirements for safe, demand-based control of lab and vivarium spaces.

This multiplexed sensing approach can measure many different air parameters cost effectively. For laboratories, the use of a Photo-Ionization Detector or PID type of TVOC sensor is beneficial for accurately detecting hundreds of commonly used laboratory chemicals that can volatize and become a safety concern. Additionally, other nonorganic compounds (such as ammonia, which is of interest in vivarium rooms) can be detected with a PID sensor. Other TVOC sensors such as metal oxide (MOS) sensors should be used in addition to the PID sensor for broader detection of chemical contaminants. Combining these sensors with a laser-based particle counter allows the identification of particles, which can be used as a proxy for animal allergens in a vivarium, as well as for detecting aerosol vapors and smoke particles in a lab room. Carbon dioxide sensors and accurate dew-point or humidity sensors also can be used to sense the lab and vivarium rooms for other control and monitoring purposes.

By varying lab air change rates down to at least 2 ACH at night and perhaps 3 to 4 ACH during the day, the average airflow of labs that don't have high hood densities (greater than four 1.8 meter fume hoods per dual lab module of about 60 sq. meters) can typically be cut at least in half generating significant energy savings. Often times the HVAC energy of the lab can be cut in half and create paybacks of less than 1 or 2 years. Additionally, the indoor environment information that becomes available from this approach can also be used to understand and improve equipment operation and lab practices to eliminate contaminants through better source control. Finally, if there is occasionally an undetectable contaminant in the lab room air, since the far majority of commonly present contaminants are sensed, this concept will still deliver, on average, greater dilution air to the lab when contaminants are present to create a safer lab environment.

Occupied/Unoccupied Control of Lab Air Change Rates

The reduction of lab air change rates during unoccupied periods without active sensing of the lab environment might save some energy but can jeopardize the safety of the researchers when they renter the space even if the airflow is increased as soon as they enter the space. This is because it can take over an hour to clear a lab space of raised contaminant levels once air change rates are increased. For example, the 2011 ASHRAE Applications Handbook[8] states that:

> *"There should be no entry into the laboratory during unoccupied setback times and occupied ventilation rates should be engaged possibly 1 h or more in advance of occupancy to properly dilute any contaminants."*

CO_2 based Demand Control Ventilation

For non-lab areas, outside air ventilation can be controlled and optimized to realize significant energy savings. Paybacks in the range of 1 to 4 years can be achieved by the use of carbon dioxide based demand control ventilation. This can be used advantageously where there can be a high density of people such as in conference rooms, auditoriums, class rooms, libraries, lunch rooms, etc. Additionally, demand control ventilation can often be used beneficially in large cubicle areas where many people may be working.

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[7] Abbamonto, C., G. Bell. 2009. "Does Centralized Demand-Controlled Ventilation (CDCV) 52Allow Ventilation Rate Reductions and Save Energy Without Compromising Safety?" Presented in Session E2 at the 2009 Labs21 Conference

[8] ASHRAE, Applications Handbook, 2011, Chapter 16 Laboratories, pg. 16-19.

However, one significant problem with the use of carbon dioxide based demand control ventilation is that commercial and even industrial grade carbon dioxide sensors are subject to significant drift and inaccurate performance[9],[10]. One way to solve these drift and accuracy problems is with the use of multiplexed sensing systems as mentioned above with respect to Demand Based Control. With this approach the drift of the sensors can be canceled by subtracting a measurement of outside air from the measurement of the inside air locations using the same central CO_2 sensors. Another more recent study by LBNL (Lawrence Berkeley National Laboratory in the US) tested a couple of these multiplexed sensing systems and verified that this approach can be much more accurate than the use of individual CO_2 sensors for demand based control and stated that[11]:

> *"The study results illustrate the advantage of incorporating a measurement of outdoor air CO_2 concentration with each sensor – offset errors cancel out in the indoor minus outdoor CO_2 concentration difference. "*

<u>Methodology for Determining Lab Airflow Rates</u>

The total airflow to any lab is the greatest of the following airflows:

- **Lab make-up air requirement**: Supply air required to offset the total exhaust from the space including that from fume hoods and other exhaust devices.
- **The minimum required laboratory airflow rate**: Typically specified in air changes per hour (ACH).
- **The airflow required to adequately cool the room.**

The following is a more detailed description of determining the three airflows and thus the required airflow for any given lab.

1. Step 1: Determine the Make-Up Air Based on Exhaust Devices
   a. The total exhaust make-up air to a lab space in the sum of the airflow devices used to exhaust hazardous fumes and vapors including fume hoods, snorkel exhausts some type of bio-safety cabinets, etc. The balance between the supply and exhaust airflows is critical in maintaining space pressurization as discussed in subsequent sections of this guide.
   b. Maximum fume hood airflow should be used for this calculation, which is the airflow required when the face velocity is at its maximum and the sash is fully open. Because make-up airflow required for fume hoods can be a significant, close attention should be paid to selecting a fume hood.
   c. Fume hood use diversity may be considered in fume hood-dominated laboratories to size the supply air systems.

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[9] Accuracy of CO2 Sensors in Commercial Buildings: A Pilot Study, (LBNL- 61862, October 2006)
[10] Product Testing Report: Wall Mounted Carbon Dioxide (CO2) Transmitters, national building Controls Information Program, Iowa Energy Center, June 2009.
[11] CO_2 Monitoring for Demand Controlled Ventilation in Commercial Buildings – (LBNL-3279E, March 2010)

d. Refer to the Fume Hood discussion later in this guide to assist in selecting fume hood types that minimize airflow requirements.

2. Step 2: Determine Total Exhaust Based on Lab Air Change Rate

a. This is the maximum airflow at which the lab will ever operate.

b. It is recommended that all of the air supplied to labs in which hazardous material are used be exhausted directly to outside. Historically, labs have been designed to have a minimum number of air changes per hour. If the volume of the lab is known, the airflow can be determined.

c. Recently there has been much debate over acceptable air change rates in laboratories using hazardous materials. The Labs21 Design Guide section on room air change rates states that: "The conventional, "national consensus standard" has been four to six outside air changes per hour recommended for a "safe" B-occupancy laboratory; in laboratories that routinely use more hazardous material, such as known carcinogens, 10 to 12 outside air changes per hour have been recommended."

d. Refer to the Laboratory Air Change Rate discussion later in this guide to assist in determining a lab air change rate.

3. Step 3: Determine Airflow Required to Cool the Lab

a. Thermal load calculations shall be performed for all tenant space fit-outs using the methodology prescribed in the latest version of the ASHRAE Fundamentals Handbook. Typically, the air volume for laboratories with a high density of ventilated devices, such as fume hoods, will be driven by the ventilation loads. On the other hand, thermal loads in highly instrumented laboratories, such as analytical laboratories, will establish the airflow requirement for those spaces. The following design conditions shall be used to perform the load calculations:

i. Outside design conditions[12]: 29.4°C (85 °F) dry bulb, 27.8 °C (80.6 °F) wet bulb

ii. Indoor design conditions: 22.2 °C (72 °F) dry bulb, maximum 60% relative humidity (rh).

4. Step 4: Determining the Controlling Airflow

a. Compare all three airflow requirements from Steps 1, 2, and 3. The largest airflow will determine the lab airflow requirements.

b. The following table gives three examples of the same lab with different airflow results:

[12] ASHRAE, Fundamentals Handbook, 2009, weather table for Singapore (.4% dehumidification day).

Table 2: Factors for Determining Design Airflows

	Fume Hoods			Lab Air Changes			Thermal Load	Final Requirements	
	# of Hoods	Exhaust Airflow per Hood	Min Hood Make-Up Airflow	Room Dimensions (WxLxH)	Min ACH	Min Lab Airflow	Min Cooling Load Airflow	Max Airflow driven by	Min Lab Airflow
Fume Hood Dominated	4	1,020 cmh (600 cfm)	4,080 cmh (2,400 cfm)	12.2m x 6.1m x 3.1m (40'x20'x10')	6	1,360 cmh (800 cfm)	(680 cmh) 400 cfm	hoods	(4,080 cmh) 2,400 cfm
Air Change Dominated	1	1,020 cmh (600 cfm)	1,020 cmh (600 cfm)	12.2m x 6.1m x 3.1m (40'x20'x10')	6	1,360 cmh (800 cfm)	(680 cmh) 400 cfm	min air change	800 cfm
Thermal Load Dominated	1	1,020 cmh (600 cfm)	1,020 cmh (600 cfm)	12.2m x 6.1m x 3.1m (40'x20'x10')	6	1,360 cmh (800 cfm)	2,040 cmh 1,200 cfm	thermal load	1,200 cfm

Minimizing airflows related to all three factors including exhaust devices (particularly fume hoods), room air change rates, and thermal load will minimize the total airflow to the room. Suggestion as to how to minimize these are described below with references to where they are discussed in more detail within this guide.

1. Minimizing fume hood airflow (see Exhaust Devices, Fume Hoods)
   a. Use high performance/low flow fume hoods: minimize maximum airflow of hood
   b. Use variable air volume (VAV) fume hoods: allows for reduction of flow when hood is not in use.
2. Minimize lab air changes (see Lab Air Change Rates section)
   a. Carefully consider the minimum air change requirements; don't set higher than necessary.
   b. Use demand-based controls: Allows reduction of lab air change rates when not necessary to control air quality in lab based on "active sensing of air quality in individual laboratories"[13] . This approach can reduce the minimum airflow in a research lab to as low as 2ACH when the lab air is clean which is typically over 98% of the time.
3. Minimize terminal loads by minimizing lighting and equipment loads (see Electrical)
   a. Use energy efficient lighting: (reduces load and load determined airflow)
   b. Specify energy efficient computers, printers, copiers, refrigerators and vending machines. Many of these will be available with ENERGY STAR labels which assure than certain energy efficiency requirements are met. The U.S Department of Energy, Federal Energy Management Program provides guidelines for purchasing efficient equipment at http://www1.eere.energy.gov/femp/technologies/eep_purchasingspecs.html.

[13] ASHRAE, Applications Handbook, 2011, Chapter 16 Laboratories, pp. 16-9 & 16- 19.

c. Specify energy efficient lab equipment; compare different manufacturers/options and select the most efficient.

d. Use equipment with remote heat rejection whenever possible. For example, purchase refrigerant-cooled freezers with remote condensing units that can be located outdoors instead of air-cooled freezers that reject heat to the space.

e. Do not overestimate the equipment load in the labs from which the thermal loads are calculated. See Appendix E for "Labs21 Best Practice Guide for Right Sizing Laboratory Equipment Loads".

f. If the thermal loads are high and driving the total airflow up consider decoupling the thermal load from driving the room airflow volumes by using a hydronic cooling solution such as either chilled beams or fan coil units. This can save considerable energy particularly where ventilation airflow rates are low such as where there are lower densities of fume hoods and demand based control is being used. This energy savings is achieved by reducing the use of outside air by directly cooling and recirculating the room air within the room versus having to exhaust the room air and replace it with conditioned outside air just for cooling purposes

Space Pressurization

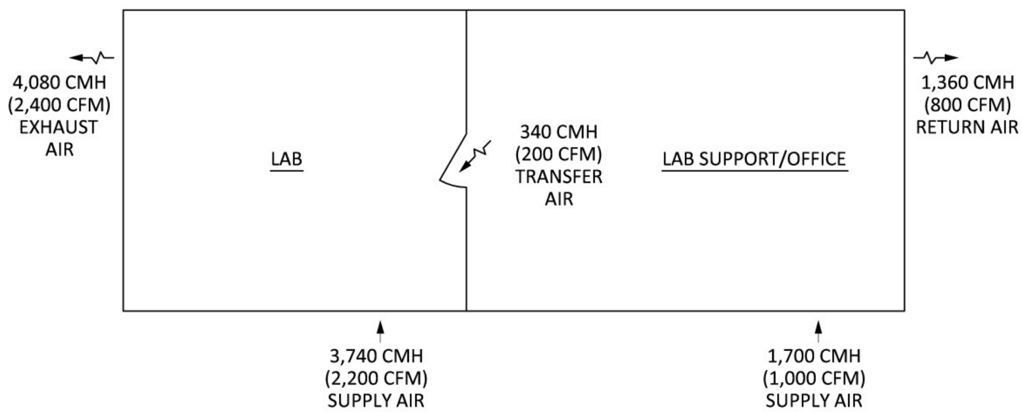
This Space Pressurization Section incorporates the following Labs21 Sustainable Strategy Checklist items:

- Optimize ventilation requirements

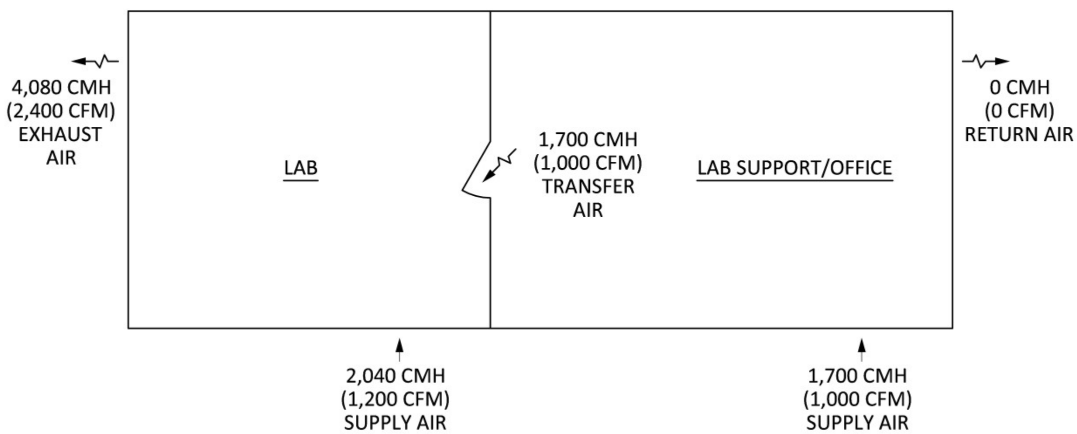
Once the airflow requirements for each room in a tenant fit-out is determined, space pressurization requirements will affect how and where the supply and exhaust air is delivered to the entire fit-out area, "As a general rule, airflow shall be from areas of low hazard to higher hazard unless the laboratory is used as a Clean Room… or an isolation or sterile laboratory…."[14]

If a laboratory space is deemed to be a higher hazard than adjoining spaces, the room shall be negatively pressurized relative to the adjoining spaces. This is accomplished by providing greater exhaust air volume than supply air volume to the space. The differential between exhaust and supply will be made up by transfer air from the adjoining less-hazardous space. The following diagram illustrates this concept:

[14] AIHA/ANSI, Z9.5-2003, Laboratory Ventilation, p. 27



Transferring more air from less hazardous to more hazardous spaces in order to decrease the amount of supply air to be supplied to the more hazardous space is a viable method for reducing the total airflow ducted to and from space as by the following diagram:



Finally, the space pressurization of the spaces must be maintained at all airflows as the system airflow varies. Because there are many ways to achieve the required space pressurization, it is recommended that the engineer-of-record describe the pressurization strategy at both full flow and reduced flow on the design documents.

Air Handling Units

This Minimizing Lab Airflow Section incorporates the following Labs21 Sustainable Strategy Checklist items:

- Minimize simultaneous heating and cooling loads
- Optimize temperature and humidity setpoints
- Low pressure-drop design
- Specifying efficient fans and motors
- Ventilation system control strategies for efficiency
- Energy recovery
- Desiccant dehumidification

Air handling units (AHUs) dedicated to tenant space shall use the space on the roof assigned or be located in the tenant space. This AHUs discussion is organized in the order components are configured (in the direction of airflow). The reasoning behind each recommendation is described in bold text.

All AHU discussion and analysis assume example variable air volume systems use demand-controlled ventilation.

Base Air Handling Unit (AHU)

At an absolute minimum, the AHU shall consist of an outside air intake section, filters, a chilled water coil and a supply fan(s). The supply air will need to be cooled to at least 12.8°C (55°F) in order to provide adequate dehumidification. Because delivering 12.8°C (55°F) air to the space will result in uncomfortably cold space condition, some form or reheat is required. For this basic AHU, electric reheat is assumed. The electric coil will heat the 12.8°C (55°F) supply air coming off the cooling coil to the temperature required to provide comfortable space condition. Figure 5 is a diagram of this basic system.

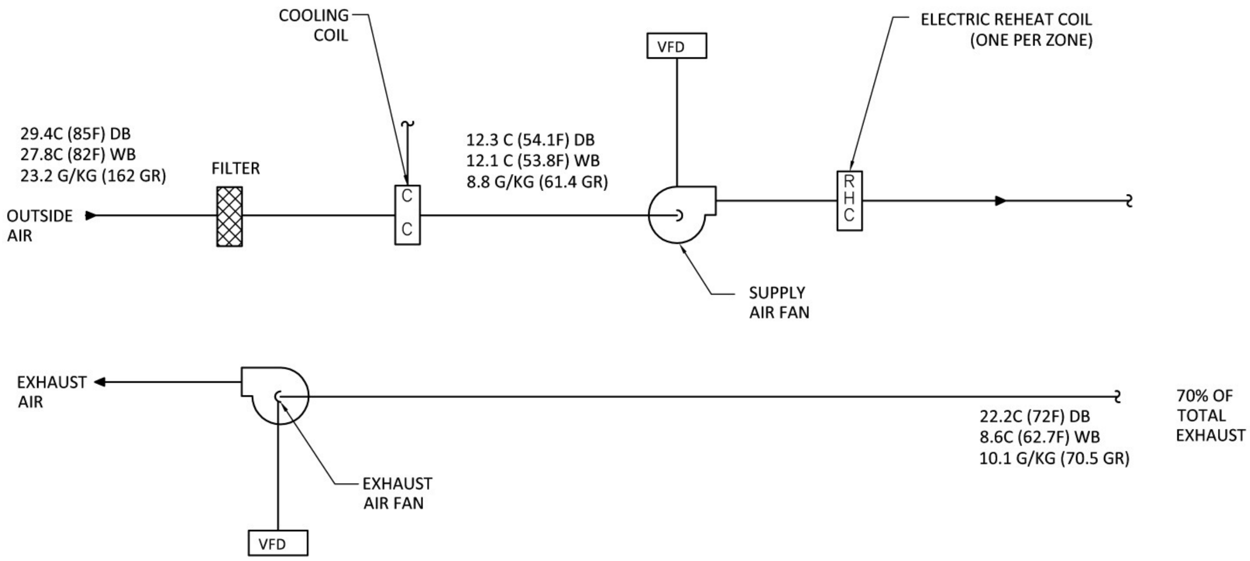


Figure 5: Basic air handling unit diagram

1. Outside Air Intake

    a. **Code and good lab design practice** stipulate that the outside air intake shall be located minimally 5 m (16.6 ft) from "exhaust discharges from any buildings, kitchens, toilets, car parks, cooling towers, laundries, rubbish dumps or plant rooms. The distance from an air intake to a cooling tower is measured from the base of the cooling tower."[15]

    b. To minimize the potential for entraining rain in the louver and to minimize the pressure drop across the outside air intake louver, a maximum velocity of 3.6 m/s (700 ft/min) through the free area of the louver is recommended.

[15] SS 553: 2009, Code of Practice for Air-conditioning and mechanical ventilation in buildings, p.14

2. Filters

a. **Filters make up a large portion of the pressure drop in an AHU. The following three recommendations aim to minimize the pressure drop across the filter bank.**

i. Traditionally, prefilters are used prior to a secondary filter located upstream of the coils and fans. With new developments in filters, there is a move away from this practice. Providing a single filter with the efficiencies (based on Minimum Efficiency Reporting Value as defined by ASHRAE 52.2: Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size, 2007) defined below is recommended:

(A) Office and other non-laboratory space: MERV 11
(B) General laboratory: MERV 13
(C) Biological and clinical laboratory MERV 15
(D) Animal, biomedical and cleanrooms: MERV 15
(E) In addition to the above, cleanrooms shall have final HEPA/ULPA filters.

ii. There have been recent developments in filters that have significantly reduced the pressure drop through filters. Filters should be compared and those that meet the MERV efficiency requirements with the least pressure should be utilized.

iii. It is recommended that the velocity through the filter section not exceed 1.5 m/s (300 ft/min).

3. Main Chilled Water Coil

a. Central chilled water is available from the base building central chilled water plant. Because the base building central chilled water plant is more efficient than a stand-alone air cooled chiller, the tenants shall use the base building chilled water as the source of cooling for the AHU chilled water coils.

b. **In order provide a low-pressure drop system**, minimizing the pressure drop of the air across the chilled water coil is recommended. A maximum face velocity of 1.5m/s (300 ft/min) across a coil with a maximum of 0.43 fins per mm (11 fins per inch) is recommended.

i. In addition to minimizing pressure loss across the coil, low velocity will reduce the risk of moisture carryover off the chilled water coils. If cooling coil condensate is not a risk, the need for moisture eliminators is unnecessary. Therefore, it is recommended that the potential for cooling coil moisture carry-over be analyzed and the velocities be limited such that a moisture eliminator is not required.

ii. If, however, the analysis shows a possibility of carryover, low-pressure drop moisture eliminators may be installed on the downstream side of the cooling coil. The eliminator shall be a stainless steel mesh-type eliminator capable of removing up to 99% of all water droplets at 2.5 m/s (500 fpm) with a rated maximum air pressure drop 250 Pa (0.1" w.g.) at 2.5 m/s (500 fpm).

c. **In order to provide adequate drainage of the cooling coil condensate and to provide reuse of the water:**

   i. A stainless steel condensate drain pan with a width of the drain pan shall be equal to or greater than 305 mm (12") minimum slope of 10 mm per m (1/8" per foot) from the horizontal toward the drain outlet is recommended.
   ii. The cooling coil condensate collected from the drain pan shall be piped to the cistern located on Level 1.

d. Two-way control valves shall be used at the chilled water cooling coils.

4. Supply and Return or Exhaust Fans

a. The supply fans shall be positioned in a draw-through arrangement.

b. **Utilize efficient fans and motors:** Fans shall be direct drive equipped with motors that meet or exceed the requirements for level IE3 (premium efficiency) as defined by IEC 60034-2 and connected to variable frequency drives (VFDs).

c. Multiple fans in parallel, also known as a fan array, are **an efficient way** to provide more airflow for larger AHUs while minimizing the length of the AHUs. Fan array design can be optimized with the following strategy:

   i. Optimize the fan, motor, and drive efficiency.
   ii. Smaller motors are less efficient than larger motors; in a fan array reduce the number of fans to increase the motor efficiency.
   iii. Use direct drive fans.
   iv. Fan arrays can reduce fan noise reducing the need for sound attenuation and eliminating the pressure drop through sound attenuators. Account for this reduction in required pressure drop when selecting the fans.
   v. Compare the total kW input of the fan array options to a dual fan arrangement. Revise design to a dual fan arrangement if the total kW input is less for that arrangement.

d. **Minimize pressure drop** at the outlet of the AHU by arranging the discharge duct from the unit to minimize system effect creating a pressure loss.

e. **The success of the low pressure drop** goal for this Base Case system should be compared to the following table from Labs21 Best Practices Low-Pressure Drop Design for Laboratories. It is recommended that the Base Case system fall into the "Better" category. Limiting the basic AHU pressure drop to 250 Pa (1.0" w.g.) will allow additional energy saving features defined later in this section to be incorporated into the AHU while still maintaining a "Good" pressure drop rating.

<u>Table 3: Air-Handling Unit Criteria for Low-Pressure Drop Design</u>

Component	Standard	Good	Better
Air handler face velocity	2.5 m/s (500 fpm)	2.0m/s (400 fpm)	1.5 m/s (300 fpm)

Component	Standard	Good	Better
Air handler pressure drop	670 Pa (2.7″ w.g.)	425 Pa (1.7″ w.g.)	250 Pa (1.0″ w.g.)

Enhanced Air Handling Units Energy Analysis

Eight options reducing the energy consumption of the air handling system as compared to the Base AHU were analyzed. Below is a table summarizing the results based on a 100% outside air AHU.

Table 4: Analysis of Air-Handling Energy Recovery Options

Option	Total Electric Energy Savings (kWh)	Percent Energy Reduction (as compare to base case)	Energy Savings Ranking	First Cost Ranking	Recommendation
Base case (cooling coil with electric reheat)	0			1Ana	not recommended
Enthalpy wheel energy recovery with electric reheat (100% exhaust through wheel)	74,250	35%	4	2	recommended
Heat pipe heat recovery with electric reheat	10,930	2%	6	2	not recommended
Heat pipe heat recovery with evaporative pre-cool and electric reheat	10,930	5%	5	3	not recommended
Wrap around heat pipe (no reheat)	72,500	34%	5	2	recommended
Enthalpy wheel energy recovery with passive desiccant wheel and no reheat (100% exhaust through wheel)	144,213	68%	1	4	highly recommended
Enthalpy wheel energy recovery with passive desiccant wheel and no reheat (70% exhaust through wheel)	104,350	49%	3	4	highly recommended
Enthalpy wheel energy recovery with passive desiccant wheel and no reheat (45% exhaust through wheel)	75,250	35%	4	4	not recommended(1)
Enthalpy wheel with heat recover chiller for pre-cool and reheat	129,390	61%	2	5	highly recommended

(1) This option is not recommended because the energy savings are comparable to other options with lower first costs.

The following discussion addresses the two highly recommended options, the enthalpy wheel energy recovery with passive desiccant wheel and the enthalpy wheel with a heat recovery chiller to pre-cool and reheat.

For the options involving wheels, exhaust air from fume hoods and bio-safety cabinets were not included in the exhaust air stream through the wheel. Only general laboratory exhaust air can be included on the exhaust air stream. For this reason the energy savings for the wheel options were run with different amounts of the total exhaust air being put though the wheel.

Enhanced AHU 1 - Dual Wheel (Enthalpy Wheel Energy Recovery with Passive Desiccant Wheel)

In this option, two wheels will be placed in the airstream. The system diagram is shown below, and more description of each wheel is given after the diagram.

1. Enthalpy Wheel

   a. **An energy recovery enthalpy wheel** is placed in the exhaust airstream and the supply airstream upstream of the cooling coil as shown in the figure above.

      i. Energy recovery is achieved by drawing outside air across half of the enthalpy wheel and drawing exhaust air across the other half. Latent and sensible heat is transferred from the hotter moister outside air and to the cooler dryer exhaust air, thus reducing both the temperature and humidity of the air entering the chilled water cooling coil.

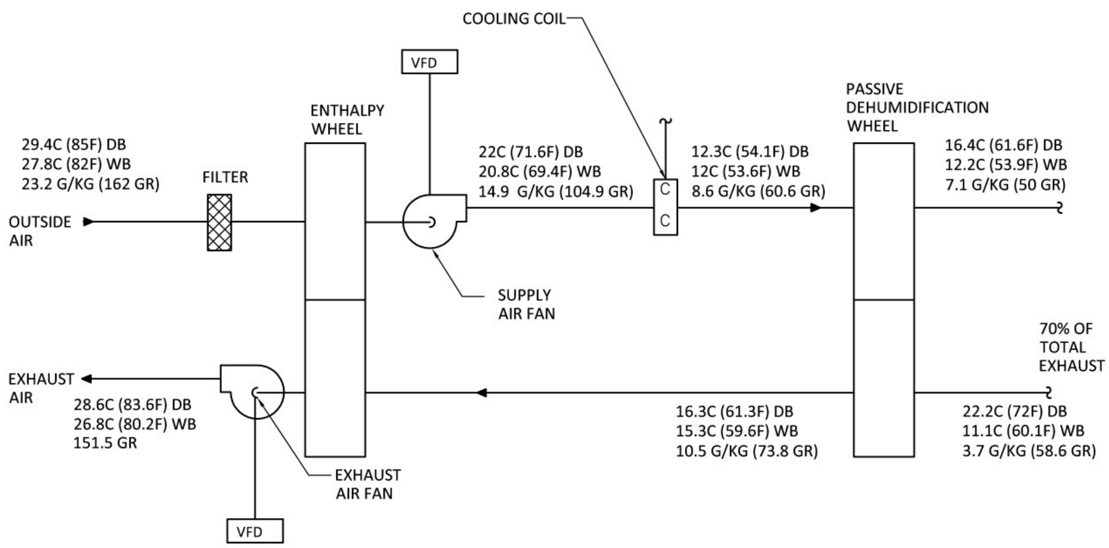


Figure 6: Dual wheel air handling unit diagram

      ii. A wheel with a sensible and latent effectiveness of no less than 70% is recommended.

      iii. The airside pressure drop created by the energy recovery wheel shall be less than 75 Pa (0.3 in w.g.) per side.

2. Passive Desiccant Wheel

a. A passive desiccant wheel, a wheel which requires no regeneration heat to remove the moisture from the wheel, is placed in the exhaust airstream and in the supply airstream downstream of the cooling coil.

   i. This wheel both dehumidifies and heats the supply air via a desiccant. The exhaust airstream provides the desiccant regeneration.
   ii. No reheat is required in this option because the supply air is dehumidified and reheated with the desiccant wheel such that it will not overcool the space.
   iii. If additional space cooling is required, either fan coils or chilled beams may be installed in the spaces requiring the additional cooling.
   iv. The airside pressure drop created by the desiccant wheel shall be less than 75 Pa (0.3 in w.g.) per side.

3. Confirmation of Successful Low Pressure System

   a. Ideally, the addition of these two wheels should not increase the AHU pressure drop to more than 425 Pa (1.7" w.g.), so the AHU can still fall within the Labs21 "Good" range.

   b. In addition, the overall system pressure drop should be analyzed so that the fan power does not exceed the limits specified in Table 3.

<u>Enhanced AHU-2 - Enthalpy Wheel with Heat Recovery Chiller for Pre-cool and Reheat</u>

In order to adequately dehumidify the supply air using only chilled water for cooling and dehumidification, the supply air must be cooled to 12.8°C (55°F). To avoid over-cooling, the air must be reheated before being supplied to the space. This enhanced option utilizes a heat recovery chiller that generates hot water for reheating while also generating cooling water to pre-cool the air. This approach is depicted in Figure 3.

1. Pre-cooling Coil

   a. **In order minimize the effects of the additional coil on the low-pressure drop system, it** is recommended that the pre-cool coil meet all of the same requirements as those recommended that the main chilled water cooling coil described earlier in this guide.

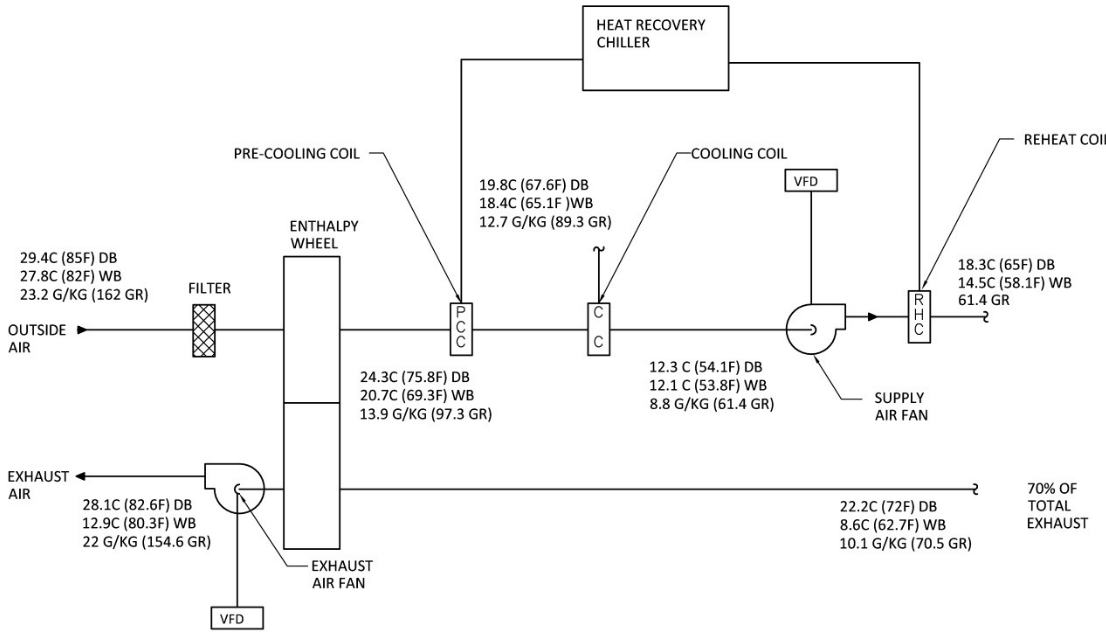


Figure 7: Air handling unit with heat recovery chiller diagram

2. Reheat Coil

   a. It is recommended that the reheat coil impart no more than 12 Pa (0.05”) of additional pressure drop on the system.

3. Heat Recovery Chiller

   a. A water loop from a coil located downstream of the enthalpy wheel to the evaporator coil in the chiller provides pre-cooling of the supply air. A second water loop from the condenser coil of the chiller to a coil downstream of the final chilled water coil in the air handler rejects the heat from the chiller to the supply air, thereby, providing reheat. The water flow and temperature through the reheat coil is controlled to maintain a humidity setpoint.

Enhanced AHU-3 – Wrap-Around Heat Pipe

In this option, the wrap around heat pipe is an air-to-air heat exchanger located upstream and downstream of the cooling coil. There is no contact between the exhaust and supply air with this option and therefore, it can be used in systems with exhaust that can’t be passed through an enthalpy wheel. Heat pipes are pipes that are filled with a liquid that can be vaporized. Heat is absorbed by the heat pipe and the liquid in the pipe turns to vapor. The vapor rises to a second section of the pipe and the vapor condenses back to liquid as the heat pipe gives off the absorbed heat. The system diagram is shown below, and more description of each coil is given after the diagram.

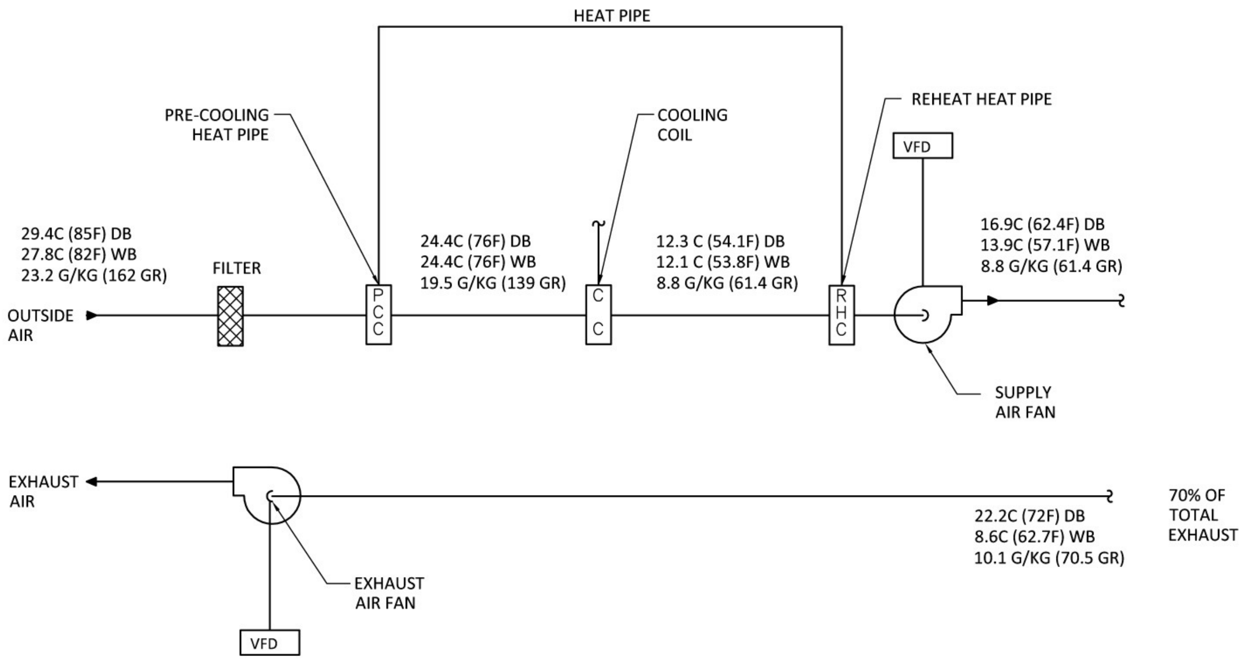


Figure 8: Air handling unit with wrap-around heat pipe diagram

1. Pre-cooling Coil

   a. The pre-cooling coil sensibly cools the incoming airstream before the main cooling coil. This reduces the dry bulb of the air entering the cooling coil and reduces the energy used by the main cooling coil.

   b. **In order minimize the effects of the additional coil on the low-pressure drop system,** it is recommended that the pre-cool coil meet all of the same requirements as those recommended that the main chilled water cooling coil described earlier in this guide.

2. Reheat Coil

   a. Heat from the pre-cooling coil is transferred by the heat pipe to the reheat coil downstream of the cooling coil. This can eliminate additional reheat because the supply air is reheated with the heat pipe reheat coil such that it will not overcool the space.

   b. It is recommended that the reheat coil impart no more than 12 Pa (0.05”) of additional pressure drop on the system.

Exhaust Devices

The intent of an exhaust system is to capture contaminants at the source and safely discharge them to the outside of the building. Source capture is always preferable to dilution of the room air as the primary means of ventilation due to its superior efficiency in both contaminant capture and energy use. Thus, local exhaust devices are the “primary barrier” protecting laboratory personnel from hazardous operations in the lab while the room serves as a “secondary barrier”. As a result, effective hooding is critical in protecting laboratory personal and reducing airflow and, consequently, energy used in the exhaust system.

Fume Hoods

The fume hood is the "primary barrier" in chemistry labs. It is a ventilated enclosure designed to capture, contain, and exhaust fumes, gases, vapors, mists and particulate matter generated within it. It generally consists of side, back, and top enclosure panels, a work surface, an access opening (called a "face"), a sash (or sashes), and an exhaust plenum equipped with a baffle system for airflow distribution. There are many kinds of fume hoods but the most energy efficient types are as follows:

1. High Performance, Low Face Velocity Fume Hood
    a. This fume hood uses a baffle control system that varies the position of a rear baffle in accordance with the sash position. When the sash is substantially closed, the baffle is moved to the rear of the fume hood so that the airflow is mostly horizontal to the back of the hood and above the work zone. As the sash is opened, the baffle is moved forward so that the turbulence at the rear of the hood is reduced, creating a floor sweep effect in the work zone. By varying the position of the baffle in the back of the fume hood, the turbulence created in a conventional fume hood at low sash heights is minimized, which reduces spillage of fumes and vapors from the hood. Studies suggest that this type of hood can contain at lower face velocities, down to as low as 0.25 m/s (51 fpm).
2. Variable Air Volume (VAV) Fume Hood
    a. The VAV fume hood is an energy-saving adaptation of the conventional fume hood (see below) that varies the exhaust air volume according to the sash position to maintain a constant face velocity. The energy savings are a result of reduced energy for conditioning the supply air, and reduced fan energy for both the supply and exhaust air when the fume hood sash is partially or fully closed. In order to achieve energy savings with VAV fume hoods, there must be times when either the laboratory is unoccupied or the fume hoods are not being used, and the laboratory occupants must be educated to keep fume hoods closed when they are not in use. VAV fume hoods typically make use of a small bypass opening (airfoil sill) to ensure that a minimum amount of air continues to enter the fume hood, even when the sash is completely closed.[16]
3. All fume hoods located in CleanTech One will utilize **both** energy reducing features described above, so shall be Combined High Performance/VAV Fume Hoods controlled to maintain a constant face velocity of (0.30 m/s) 60 fpm.

During the commissioning process the tenant shall evaluate performance for each installed fume hood using the method prescribed in ASHRAE 110 – 1995 – Method of Testing Performance of Laboratory Fume Hoods. The criteria for passing the test shall be established by the tenant's Health, Safety and Environmental (HSE) Officer during design development.

Because fume hoods can be a large component of the exhaust airflow requirements, close attention should be paid to specifying fume hoods that minimize airflow; a detailed discussion of fume hood types is provided later in this document. The following fume hood guidelines are recommended:

1. For a low fume hood density space (one 1830 mm (6 ft) wide (or smaller) hood in the laboratory room) :
    a. Use VAV hoods.

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[16] ASHRAE, Laboratory Design Guide, 2000, pp. 67-72.

b. Size the exhaust flow for the flow required at the full open sash position.

c. Provide automatic sash closers for the hood.

2. For moderate fume hood density space (two 1830 mm (6 ft) wide hoods (or equivalent)/84 m^2 (900 ft^2):

a. Use Low FV hoods.

b. Size the exhaust flow for the flow required for full open sash position.

c. Provide automatic sash closers for the hood.

3. For high fume hood density space (three or more 1830 mm (6 ft) wide hoods (or equivalent)/ 84 m^2 (900 ft^2):

a. Use VAV low FV hoods or VAV fume hoods.

b. Fume hood diversity may be used to size the exhaust system and air handler.

c. Provide occupancy sensors in the room and lower the airflow rates when room is unoccupied. All air supplies to a laboratory using hazardous material shall be exhausted directly to outside.

Bio-Safety Cabinets

Bio-safety cabinets (BSCs) are the "primary barrier" in microbiological and biomedical laboratories (BSLs). As in fume hoods in wet chemistry laboratories, BSCs are the major driver of ventilation rates in these types of laboratories. The proper selection of a BSC requires thorough knowledge of the processes and materials used in the laboratory. Guidelines for their selection are specified in the Biosafety in Microbiological and Biomedical Laboratories and are reproduced in Table 5.[17]

Table 5: Criteria for Selecting a BSC[18,19]

	No Work with Biological Hazards	**Working at BSL 2 Level**	**Working at BSL 3 Level**	**Working at BSL 4 Level**
No Work with Volatile Toxic Chemicals		Class II, Type A BSC	Class II BSC	Class II, Types B1 or B2 BSC; Class III
Work with Minute amounts of Volatile Toxic Chemicals	Chemical Fume Hood	Class II, Type A2 BSC with Canopy	Class II BSC	Class II, Types B1 or B2 BSC; Class III
Work with Volatile Toxic Chemicals in Microbiological Work	Chemical Fume Hood	Class II, Types B1 or B2 BSC	Class II, Types B1 or B2 BSC	Class II, Types B1 or B2 BSC; Class III
Work with Volatile Toxic Chemicals	Chemical Fume Hood			Class II, Types B1 or B2 BSC; Class III

[17] U.S. Department of Health and Human Services, Biosafety in Microbiological and Biomedical Laboratories, 5th Edition, (Table 1 in Appendix A), 2007.

[18] David S. Phillips, ThermoFisher Scientific, presentation at Labs 21 Conference, September 21, 2011

[19] U.S. Department of Health and Human Services, Biosafety in Microbiological and Biomedical Laboratories, 5th Edition, 2007 p. 310.

The following is a summary of the BSC types and their design requirements:

1. Class I BSC

   a. The Class I BSC provides personnel and environmental protection, but no product protection. It is similar in terms of air movement to a fume hood, but has a HEPA filter in the exhaust system to protect the environment (Figure 9). In the Class I BSC, unfiltered room air is drawn in through the work opening and across the work surface. In many cases, Class I BSCs are used specifically to enclose equipment (e.g., centrifuges, harvesting equipment or small fermenters), or procedures with potential to generate aerosols (e.g., cage dumping, culture aeration or tissue homogenation). The following are general guidelines for the use of Class I BSCs:

      i. Hard duct the BSC exhaust to the building exhaust system.
      ii. Provide Bag-in Bag-out HEPA filtration system upstream of the exhaust fan.
      iii. Interlock the BSC fan, if provided with one, with the building exhaust fan.

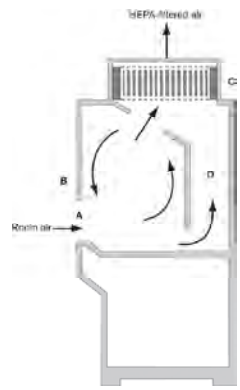

Figure 9: Class I BSC

2. Class II BSC

   a. The Class II (Types A1, A2, B1 and B2) BSCs provide personnel, environmental and product protection. Airflow is drawn into the front grille of the cabinet, providing personnel protection. In addition, the downward flow of HEPA-filtered air provides product protection by minimizing the chance of cross-contamination across the work surface of the cabinet. Because cabinet exhaust air is passed through a certified HEPA filter, it is particulate-free (environmental protection), and may be recirculated to the laboratory (Type A1 and A2 BSCs) or discharged from the building via a canopy or "thimble" connected to the building exhaust. Exhaust air from Types B1 and B2 BSCs must be discharged directly to the outdoors via a hard connection.

   b. Design Guidelines for Class II cabinets are as follows:

      i. Do not exhaust Class II, Types A1 and A2 BSCs to the outside. An exception is the Class II, Type A2 BSC enclosing operations using hazardous volatile chemicals. These devices shall be exhausted to the outside.
      ii. Specify BSC with a backward curve centrifugal fan.

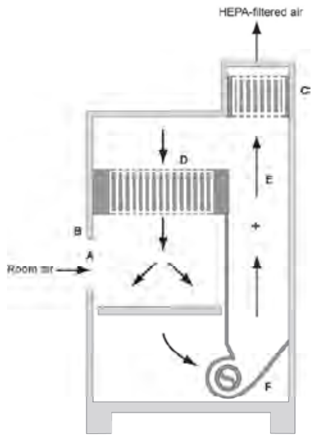

Figure 10: Class II, Type A1 BSC

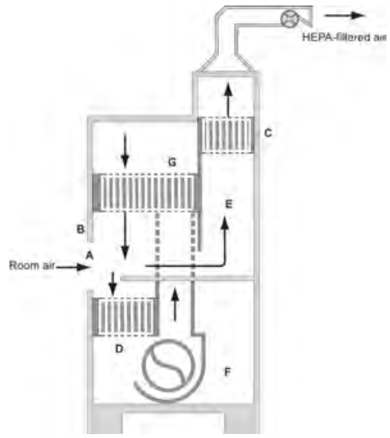

Figure 11: Class II, Type B1 BSC

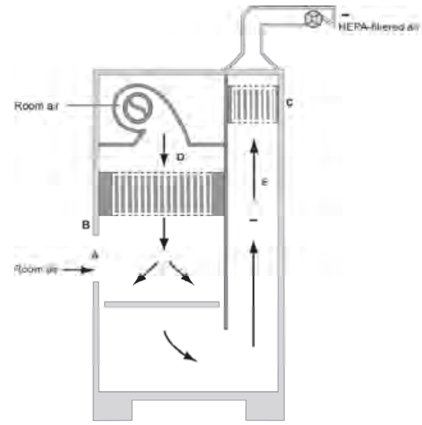

Figure 12: Class II, Type B2 BSC

iii. For Class II, Type B2, BSC provide automotive speed control of fan to maintain airflow.

iv. If the Class II, Type A2, BSC is exhausted to the outside, it shall be connected to the laboratory exhaust via a canopy connection supplied by the BSC manufacturer. The exhaust system serving this cabinet must provide a constant duct pressure at the BSC connection. The airflow of the building exhaust must be sufficient to maintain the flow of room air into the gap between the canopy unit and the filter housing.

v. Class II, Type B1 and B2, BSCs shall be hard ducted to the laboratory exhaust. A Bag-in, Bag-out HEPA filtration system shall be provided upstream of the exhaust fans. The exhaust fan motor shall be connected to the building emergency power system. An interlock between the BSC fan and building exhaust shall be provided. Finally, provide an alarm for fan failure. This shall be accomplished by measurement of exhaust flow from the BSC.

3. Class III BSC

a. The Class III BSC was designed for work with highly infectious microbiological agents and for the conduct of hazardous operations and provides maximum protection for the environment and the worker. It is a gas-tight enclosure with a non-opening view window. Access for passage of materials into the cabinet is through a dunk tank, that is accessible through the cabinet floor, or double-door pass-through box (e.g., an autoclave) that can be decontaminated between uses. Reversing that process allows materials to be removed from the Class III BSC safely.

b. Design Guidelines for Class III cabinets are as follows:

i. Class III cabinets shall be exhausted by systems dedicated to them.

ii. The exhaust system shall maintain the cabinet under negative pressure, minimum of 124 Pa (0.5” w.g.).

iii. Fan failure alarm shall be provided.

Other Hood Types

In many cases a tenant will require specialised point source hoods, such as snorkels (or termed extractor arm) or enclosing hoods that are not defined as fume hoods because they do not have a moveable front sash. The advantages of point source exhaust devices over a laboratory fume hoods are their relatively low price, ability to be customized to the needs of lab personnel, and high capture efficiencies.

In the case of a snorkel hood, the articulating arm allows its user to position it at any angle over the process. The drawbacks of this device are its difficulty in being fitted with automatic controls to reduce airflow consumption when not needed and the need for personnel to be educated in its proper use. An example of a snorkel is shown in Figure 13. This hood should only be used for non-hazardous laboratory operations.

Specialised point source hoods should comply with the following recommendations:

1. Each hood shall be supplied with a manual shut-off damper to allow the laboratory user to stop the exhaust flow to the hood when it is not in use.
2. The hoods should be manifolded to the primary exhaust system and be provide with automatic controls, such as electronically operated branch duct dampers, which maintain the branch and main duct static pressure setpoints.

Figure 13: Snorkel exhaust hood.[20]

Cage Racks

1. Laboratories in microbiological and biomedical laboratories may have space dedicated to animal holding. These rooms will contain caging systems for the animals. The purpose of the caging systems is the following[21]:
    a. Protect the health and well-being of the animals.
    b. Protect support staff from antigens released or shed by the animals.
    c. Minimize the exposure of animals to pheromones released by other animals in the space.
2. A guideline of 10 to 15 outdoor air changes per hour (ach) has been used for secondary enclosures (animal holding rooms) for many years. Although it is effective in many settings, the guideline does not consider the range of possible heat loads; the species, size, and number of animals involved; the type of bedding or frequency of cage changing; the room dimensions; or

[20] Photo from Fumex website.
[21] ASHRAE, 2011 Applications Handbook, p. 16.15.

the efficiency of air distribution from the secondary to the primary enclosure. In some situations, such a flow rate might over-ventilate a secondary enclosure that contains few animals and waste energy or under-ventilate a secondary enclosure that contains many animals and allow heat and odor to accumulate. As such, lower ventilation rates might be appropriate in the secondary enclosure or room, provided that they do not result in harmful or unacceptable concentrations of toxic gases, odors or particles. Active sensing of contaminants in the secondary enclosure and varying the air change rates based on the room environmental conditions is one approach that can be considered to meet these requirements in a more energy efficient manner.

3. Ventilated cage racks are preferred over static or open cage racks since they may allow for lower room air change rates, provide better conditions for the animals and can reduce the frequency of cage changes.

Exhaust System

The exhaust and supply air systems must work in concert to minimize energy consumption. The primary goal of automatic controls for these systems is providing only the necessary quantity of air at the correct conditions. As a result, proper application of sensing and controls elements is essential in achieving a successful controls system. For exhaust systems, the following controls elements are required to achieve this:

1. Measurement of exhaust flows. The application of VAV controls for fume hoods provides this at each VAV fume hood. However, other hood types, such as snorkel hoods, require the measurement of exhaust branch flow and static pressure. The flow measurements are used as data inputs to adjust supply flows to maintain room pressure criteria and alarms if the flows do not the setpoints.
2. Measurement of supply airflow and duct static pressure. This provides input to the controls system to maintain room pressure criteria and correct duct airflow and alarms when the airflow is below the setpoint.
3. Supply and exhaust electronically-actuated dampers.
4. Room pressure, dry bulb temperature, and (if required by the tenant) room relative humidity measurement.
5. Exhaust system volume and pressure control.

Duct and Pipe Design

The energy needed to move fluids is significantly affected by the resistance to flow, or pressure drop. The Labs21 Design Guide recommends that the design team establish a system-wide maximum pressure drop target and pursue strategies to achieve this goal. For example, consider specifying slightly oversized supply ducts to both reduce pressure drop and anticipate future needs. Avoid devices that create large, and often unnecessary, drops such as balance valves and fittings. For similar reasons, use low face-velocity coils and filters. In particular, always use high-efficiency particulate (HEPA) filters with the lowest pressure drop available.[22]

[22] Labs 21, Laboratories for the 21st Century: An Introduction to Low-Energy Design, p. 8.

Duct Design

The duct design process shall utilize both the duct velocity (V) and pressure loss criteria (ΔP) defined in Table 6 and size the duct based on the governing criteria - that is the criteria that results in the larger duct size. Typically, velocity governs at larger duct sizes and pressure loss governs at smaller duct sizes.

Table 6: Duct Sizing Criteria

Duct System	Pressure Loss	Velocity	Comments
Medium pressure supply (upstream of air terminal units in VAV system)	ΔP ≤ 1.6 Pa/m (0.2"w.g./100')	V ≤ 7.6 m/s (1,500 fpm)	
Low pressure supply downstream of air terminal units only	ΔP ≤ .49 Pa/m (0.06"w.g./100')	V ≤ 5.1 m/s (1,000 fpm)	When cmh>6,800 (cfm>4,000) velocity governs. When cmh<6,800 (cfm<4,000) pressure loss governs.
Return	ΔP ≤ 0.65 Pa/m (0.08"/100')	V ≤ 5.1 m/s (1,000 fpm)	With discretion, the duct velocity may be increased to 9.1 m/s (1,800 fpm) (for example duct located within shafts).
Laboratory Exhaust	ΔP ≤ 2.0 Pa/m (0.25"/100')	V ≤ 10.2 m/s (2,000 fpm)	If duct is to carry particulate (e.g. duct, lint, powder) the velocity must be increased. Refer to the ASHRAE Laboratory Design Guide.
Toilet & General Exhaust	ΔP ≤ 0.65 Pa/m (0.08"/100')	V ≤ 5.1 m/s (1,000 fpm)	
Transfer Air	ΔP ≤0.25 Pa/m (0.03"/100')	V ≤ 1.5 m/s (300 fpm)	

The duct system design shall create a pressure drop that allows the Fan Power Limits defined in Table 7 to be achieved.

Table 7: Fan Power Limitations[23]

	Limit	Constant Volume	Variable Volume
Option 1: Fan System Motor Nameplate kW	Allowable Nameplate Motor kW	$kW \le L/S_S \cdot 0.0017$	$kW \le L/S_S \cdot 0.0024$
Option 2: Fan System input kW	Allowable Nameplate Motor kW	$kW_i \le L/S_S \cdot 0.0015 + A$	$kW_i \le L/S_S \cdot 0.0021 + A$

[a] where:

L/S_S = the maximum design supply airflow rate to *conditioned spaces* served by the *system* in liters per second
kW = the maximum combined motor *nameplate* kW
kW_i = the maximum combined *fan* input kW
A = sum of ($PD \times L/S_D/650000$)
Where:
PD = each applicable pressure drop adjustment from Table 6.5.3.1.1B in Pa.
L/S = the design airflow through each applicable device from Table 6.5.3.1.1B in liters per second

[23] ASHRAE, ANSI/ASHRAE/IES Standard 90.1-2010, Energy Standard for Buildings Except Low-Rise Residential Buildings, p. 50.

Supply Air

The design shall comply with the following:

1. Air diffusion design in all human occupied spaces, with the exception of laboratories (see below) shall follow the procedures described in the most current edition of the ASHRAE Fundamentals Handbook.

2. In laboratories with fume hoods or other local exhaust devices, air diffusion design will be by radial diffusers. An exception to the radial diffuser requirement will be made for designs incorporating active chilled beams. The diffuser layout shall meet the following criteria:

    a. Diffusers shall be located no closer than 1.2 m (4 ft) from the hood face.

    b. The terminal throw velocity of supply air jets should be less than the hood face velocity, preferably no more than ½ to 2/3 the face velocity.[24]

3. If a desiccant wheel or reheat are used to dehumidify the supply air stream at the air handler, thereby eliminating the requirement for latent cooling in the space, terminal temperature control shall be by cooling coils. Two means of achieving local temperature control without reheat are:

    a. Local cooling coils. If the space airflow is driven by ventilation loads, such as fume hoods, local chilled water coils shall be used for zone temperature control.

    b. Active chilled beams. If thermal loads determine the airflow than active chilled beams shall be used for zone temperature control.

    c. The chilled water coils and active chilled beams shall be provided with a condensate drain pan piped to the cistern on Level 1. The drain pan shall meet the same requirements as drain pans in air handling units.

4. If the tenant is decoupling support space, such as offices and storage, from laboratory space, the supply air to the air office shall be provided by a dedicated air handler or from the laboratory air handling unit, if the air from the office can be transferred to the laboratory space as supply air or returned to the air handler. The latter approach has been discussed in the literature and has been demonstrated to reduce energy consumption by 20 to 40%[25]. The engineer shall not use once-through 100% outside air to condition support space.

5. Ductwork will be sealed to SMACNA Class "A" requirements.

6. Terminal Devices

    a. Supply air terminal devices, such as VAV boxes and coils, shall be specified with a maximum pressure drop of 37 Pa (0.15" w.g.) at the full open damper position and shall not be more than 5% of the total duct system pressure drop. In addition, VAV boxes shall be pressure independent.

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[24] Gerhardt Knutson and Knowlton Caplan, RP-70, Development of Criteria for Design, Selection, and In-Place Testing of Laboratory Fume Hoods and Laboratory Room Ventilation Air Supply, Final Report, ASHRAE, p. 24.

[25] Y. Cui, M. Liu, K. Conger, "Implementation of the Laboratory Air Handling Unit Systems (LAHU)", Proceedings of the Third International Conference for Enhanced Building Operations, Berkeley, California, October 13-15, 2003

7. Duct insulation shall be as described in Table 8.

Table 8: Minimum Duct Insulation Thickness[26]

Exterior (m2·K)/W ((h·ft2·°F)/Btu)	**Unconditioned Space (m2·K)/W ((h·ft2·°F)/Btu)**	**Indirectly Conditioned Space (m2·K)/W ((h·ft2·°F)/Btu)**
R1.06 (R-6)	R-0.62 (R-3.5)	none

Lab Exhaust

1. With some exceptions, such as hoods housing operations using perchloric acid or radioisotopes, hood exhaust can be manifolded to a common exhaust duct and routed to rooftop exhaust fans. Manifolding provides additional dilution of the exhaust stream and improved dispersion at the roof discharge compared to individually exhausted hoods and shall be used for tenant exhaust systems. This approach is mandatory unless the tenant can show that individually vented hoods are required. Redundancy shall be designed into the exhaust fan system to provide capacity during a fan failure.

2. Exhaust ductwork material shall be compatible with contaminants being discharged and shall be sealed to SMACNA Class A requirements. Additional requirements for exhaust duct are as follows:

   a. No flexible duct shall be used in laboratory exhaust systems.

   b. If PVC coated spiral wound galvanized steel duct is used:

      i. All connectors shall be constructed of PVC coated galvanized steel materials with stainless steel fasteners installed in accordance with the manufacturer's recommendations for runs, joints and connections.
      ii. All joints and connectors shall be fastened and sealed in accordance with manufacturer's standards using PVC materials to assure an air-tight joint.
      iii. Any dents, mars or scratches to either the interior or exterior PVC coating that occur during shipment or construction shall be repaired and surfaces refinished with duct manufacturer's PVC touch-up kit.

   c. If spiral wound stainless steel is used, all joints shall be continuously welded.

   d. All laboratory exhaust system ducts located within the building downstream of the exhaust fan shall be welded stainless steel (welded at the longitudinal seams as well as at the joints). Do not provide flexible connections downstream of a laboratory exhaust fan located within a building.

3. The exhaust discharge shall be elevated above the adjacent roof by not less than 3 m (10 ft). The discharge volume shall be constant and shall be discharged at a minimum velocity of 15.2 m/s (3000 ft/min)[27]. If variable volume fume hoods are used, the discharge velocity and volume flow will be maintained by introducing outside air into the exhaust stream upstream of the exhaust

[26] ASHRAE, Standard for the Design of High-Performance Green Buildings, 189.1-2009, p.80.
[27] AIHA/ANSI, Z9.5-2003, Laboratory Ventilation, p. 48.

fans and maintaining the flow by automatic means. Further, if the exhaust stream is deemed to contain hazardous components additional analysis, such as wind tunnel modeling or computational fluid mechanics models, should be used to determine the requisite exhaust discharge height and velocity.

4. Induced flow exhaust fans, with performance certified under AMCA 260, shall be used.

Pipe Design

As in air distribution systems, sizing pipes to minimize pressure drop is essential to minimizing the energy use in the system. Guidelines for sizing pipe are provided in Table 9.

Table 9: Recommended Fluid Velocities in Pipe

Service	Minimum	Maximum	ΔP
Compressed Air – Utility/Service	1.5 m/s (300 ft/min)	6.1 m/s (1,200 ft/min)	34.5 kPa Max ΔP (5 PSI Max ΔP)
Chilled Water – General Service (345kPa-1000kPa) (50 – 150 psig)	1.5 m/s (5 ft/sec)	3.0 m/s (10 ft/s)	27.6 kPa (4 PSI)
Water – Feed (>1000kPa) (>150 psig)	2 m/s (6.5 ft/sec)	3.7 m/s (12 ft/sec)	
Water – Suction Line	1.2 m/s (4 ft/sec)	2.4 m/s (8 ft/sec)	

NOTES:

- This table indicates reasonable velocities only.
- The velocities are for 12 mm (½") through 914 mm (36") pipe sizes.
- In most cases, the minimum velocity should be considered for the smaller line sizes and the maximum velocities considered for the larger line sizes.

1. The minimum pipe insulation shall be as listed in Table 10.

Table 10: Minimum Pipe Insulation Thickness[28]

Fluid Design Operating Temp Range °C (°F)	Insulation Conductivity		Nominal Pipe or Tube Size in mm (in.)				
	Conductivity kW/(h-m²°K) (Btu·in./(h·ft²·°F))	Mean Rating Temp °C (°F)	<25 mm (<1 in)	25 to < 38 mm (1 to <1½ in)	38 to < 102 mm (1½ to <4 in)	102 to <203 mm (4 to <8 in)	>203 mm (>8 in)
Heating Systems (Hot Water)							
60.6-93.3 (141-200)	1.42-1.65 (0.25-0.29)	125 (125)	38 (1.5)	38 (1.5)	38 (1.5)	51 (2.0)	51 (2.0)
40.6-60.0 (105-140)	1.25-1.59 (0.22-0.28)	100 (100)	25 (1.0)	25 (1.0)	38 (1.5)	38 (1.5)	38 (1.5)
Domestic and Service Hot Water Systems							
40.6+ (105+)	1.25-1.59 (0.22-0.28)	100 (100)	25 (1.0)	25 (1.0)	38 (1.5)	38 (1.5)	38 (1.5)

[28] ASHRAE, Standard for the Design of High-Performance Green Buildings, 189.1-2009, p. 80.

Fluid Design Operating Temp Range °C (°F)	**Insulation Conductivity**		**Nominal Pipe or Tube Size in mm (in.)**				
	Conductivity kW/(h-m^2°K) (Btu·in./(h·ft^2·°F))	Mean Rating Temp °C (°F)	<25 mm (<1 in)	25 to < 38 mm (1 to <1½ in)	38 to < 102 mm (1½ to <4 in)	102 to <203 mm (4 to <8 in)	>203 mm (>8 in)
Cooling Systems (Chilled Water, Brine, and Refrigerant)							
4.4-15.6 (40-60)	1.25-1.59 (0.22-0.28)	100 (100)	25 (1.0)	25 (1.0)	38 (1.5)	38 (1.5)	38 (1.5)
<4.4 (<40)	1.25-1.59 (0.22-0.28)	100 (100)	25 (1.0)	38 (1.5)	38 (1.5)	38 (1.5)	51 (2.0)

2. Calculating pressure drop for liquid and gas systems shall be as follows:

   a. The piping or duct system is broken into discrete parts, called nodes. Each node is clearly identified. Isometric sketches are sometimes used to visualize the system.

   b. All components in the system are itemized and a table is developed summarizing the system.

   c. Friction losses (due to pipe length) and dynamic losses (due to fittings) are calculated. Friction losses are calculated by means of the Darcy-Weisbach equation. The friction factor used in the Darcy-Weisbach equation is found with the Colebrook equation. Friction charts developed employing these equations can be used to determine friction losses. For liquid pipe systems, dynamic losses can be found by using loss coefficients or by employing equivalent lengths. For air systems dynamic losses can be calculated using the coefficients found in the ASHRAE Duct Fitting Data Base.

3. In some laboratories, chilled water is required for both air-conditioning and process cooling. However, the temperature requirements of these applications are often quite different. Typically, 7.2°C (45°F) water might be needed as part of an air-conditioning cycle to provide adequate dehumidification, while 15.6°C (60°F) water might suffice for a process cooling need. Because chillers work more efficiently when producing higher temperature fluid, install a dedicated chiller to meet process requirements rather than tempering chilled water produced from the building chilled water system. The chiller performance shall exceed the requirements listed in ASHRAE Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings.

ELECTRICAL SYSTEMS

General Requirements

The densities listed Table 11 shall not be exceeded.

Table 11: Densities for Electrical Load Calculations

Room Type	Lighting (w/sq m)	Receptacles (connected) (w/sq m)	Receptacles (demand) (w/sq m)	Illumination Level (lux)
Laboratory	15.0	43	31.2	538
Corridors	6.8	5.4	0	323
Equipment Rooms: Electrical and Mechanical	8.6	21.5	10.75	269
Server and Communications Equipment Room	8.6	50	37.4	269
Open Offices	8.6	43	31.2	538
Enclosed Offices	10.75	43	31.2	538

- Emergency Lighting Load Density: Emergency lighting feeder and panel capacity will be designed on the basis of 3.24 volt-amperes per square meter of gross space.
- Feeder and Panel Capacity: Lighting feeder and panel capacity will be designed on the basis of 38.15 volt-amperes/sq. m.

Systems

1. Electric Service
    a. The Building Owner will provide electrical service to the Tenant Space. Tenant shall provide metering and the main distribution switchboard for the Tenant's space.
2. Distribution
    a. Separate feeder systems and sub metering will be provided for each of the following loads:
        i. HVAC Systems: 400/230 volt, three-phase, four-wire, 50 hertz.
        ii. Lighting: 400/230 volt, three-phase, four-wire, 50 hertz for LED, fluorescent and HID lighting
        iii. Lab Receptacles: 400/230 volt, three-phase, four-wire, 50 hertz
        iv. General Purpose Receptacles: 400/230 volt, three-phase, four-wire, 50 hertz general purpose receptacles.
            (A) Branch circuit design will be based on a maximum of 2,400 volt-amperes per 15-ampere, 230 volt circuit and 3200 volt-amperes per 20 ampere, 230 volt circuit.
3. Motors of ½ HP and larger will be served at 400 volt service, three phase, three-wire. Motors less than ½ HP will be served at 230 volt service, single-phase.
4. Lighting: Lighting will be complete with fixtures, ballasts and/or drivers, lamps and accessories.
    a. Indoor:
        i. Recessed high efficiency fluorescent or LED fixtures will be used in offices, laboratories, large offices.

ii. High efficiency fluorescent or LED downlights will be used for accent and decorative purposes in selected areas.
iii. LED downlights will be used in lounges, toilet rooms and select areas.
iv. High efficiency Fluorescent or LED strips will be used in storage, mechanical spaces, etc.
v. All lighting will operate at 230 volts.
vi. Energy saving lamps and electronic ballasts for fluorescents fixtures will be specified.
vii. Lighting Control: Provide for the following control requirements:

(A) A lighting control system panel shall be provided to control all lighting within the tenant space.
(B) Provide light reduction control in all locally controlled spaces.
(C) Provide occupancy sensors in enclosed offices, classrooms, conference/meeting rooms, lunch room, break rooms, restrooms, janitor's closets and office support areas.
(D) Daylighting zone control shall be employed. Daylighting control shall employ automatic dimming.

b. LED and Fluorescent Lamps

i. In many cases either LED or fluorescent lamps can be used. The choice of either will depend on many factors. Below is a list of considerations in choosing between the two technologies:
ii. Fluorescent Lamps (See examples below)

(A) Older, established technology with many current fixtures that are designed to be used with fluorescent lamps
(B) Lamps are easy to replace
(C) Available in a wide range of color temperatures
(D) Require ballasts for operation and dimming ballasts for dimming
(E) Lamps contain mercury and must be disposed of with hazardous materials
(F) Lamp life from 10,000 to 20,000 hours
(G) Luminous efficacy of 46 to 104.2 lm/watt (Depends on the lamp)

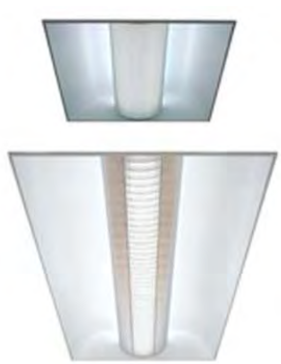


Figure 14: Examples of Fluorescent Fixtures

Figure 15: Fluorescent Lamp

iii. LED Lamps (See examples below)

(A) Newer technology with a more limited fixture choice
(B) Higher cost
(C) The range of available lamps are being expanded rapidly
(D) Lamps do not require a ballast and are dimmable
(E) Lamps do not contain mercury
(F) Lamp life of 50,000 hours
(G) Luminous efficacy of 55.1 to 93.1 lm/watt (Depends on the lamp)

Figure 16: Example of an LED Fixture

Figure 17: LEDs behind the Lens of a Downlight

5. Receptacles

a. Provide occupancy sensors for printers/copiers and vending machines receptacles.

PLUMBING AND WATER SYSTEMS

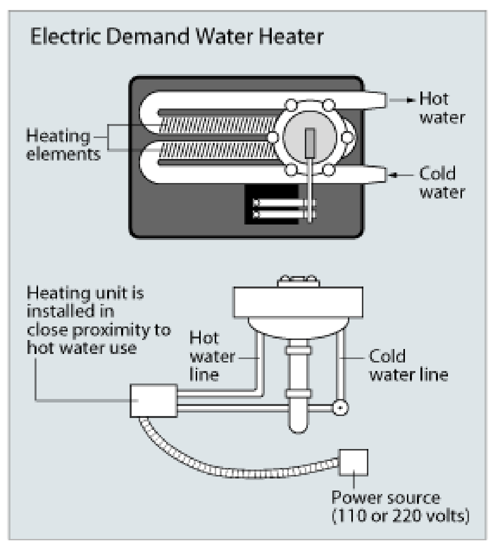
Water conservation is an integral and important part of a green building. Potable water is a limited resource which requires significant energy to clean, treat and convey to facilities. As the population increases so does the demand for potable water. In many cases the infrastructure is not available to expand consumption which increases the importance of water conservation. By limiting the use of potable water the amount of effluent from the facility is also reduced. Once again significant energy is used to clean the water before it can be reintroduced back into the ecosystem.

The following prerequisites are required for all laboratories in CleanTech One:

6. Potable water shall never be used for process cooling applications. Given the high temperature of local potable water, it would take significant amounts of water to provide limited cooling. This wastes water and energy.

7. Room sinks shall not be used to dispose of chemicals, solvents, hazardous waste or to wash glassware. Waste generated in the lab shall be collected by lab personnel and disposed by an approved hazardous waste collection agency. For waste that can be disposed of by dilution, tenants shall provide a dilution tank that is fed by recycled water from the cistern.

8. Use instantaneous, point of use domestic water heaters. The heaters themselves are 99% efficient and have no heat losses as you would get from a storage tank type heater. They have the added advantage of instantaneous hot water. Typical piped, central hot water systems have a wait time to get hot water of 30-60 seconds to get hot water to the fixture since there are heat losses throughout the piping system. For instance if it takes 45 seconds for hot water to get to a sink at 8.4 L/min (2.2 gpm), 6.25 liters (1.65 gallons) of water would be wasted. Solar water heaters are also an option to be investigated to heat domestic hot water if the tenant is on the top floor.



9. Water-saving devices plumbing fixtures shall be provided.[29]

   a. Lavatory faucets: Maximum flow rate should be 1.3 L/min (0.35 gpm) when tested in accordance with ASME A112.18.1/CSA B125.1.

[29] ASHRAE, Standard for the Design of High-Performance Green Buildings, 189.1-2009, p. 149, p. 18

b. Metering self-closing faucet: Maximum water use should be 1.0 L (0.26 gal) per metering cycle when tested in accordance with ASME A112.18.1/CSA B125.1.

c. Sink faucets can use from 1.9 L/min up to 8.4 L/min (0.5 gpm to 2.2 gpm) depending upon the aerator/outlet used on the spout. Potable water can be significantly reduced by limiting the use of high flow rate faucets to locations only where they are required or by providing only one per area. Water can also be conserved by utilizing electronic faucets which turn off automatically when not required.

10. Automatic glassware washers shall be provided when required. Hand-washing expends 76 liters (20 gallons) of water to wash 30 items of glassware, machine washing requires only 51 liters (13.6 gallons) to wash these same items. This equals 6300 liters (1,664 gallons) of water per year. Pay-back for labs converting to automatic glassware washers that are washing more than 25 flasks per day is estimated to be two to two-and-a-half years.[30] In addition, the automatic glassware washer saves energy associated with heating the water.

11. If a reverse osmosis (RO) water system is installed it shall be a high efficiency model that minimizes the amount of wastewater or returns wastewater from the RO process back through the RO system to be filtered again.

12. Numerous forms of water filtration are available. These include particle filtration, microfiltration, ultra filtration, nanofiltration and hyperfiltration. As finer and finer particles are removed, energy use and water waste increases. Facility managers should choose the filtration as required for their processes, "over-filtration" beyond what is required should be avoided. Membrane pore sizes on filter systems can vary from 0.1 nanometers (3.9×10^{-9} in) to 5,000 nanometers (0.00020 in) depending on filter type. "Particle filtration" removes particles of 1 micrometer (3.9×10^{-5} in) or larger. "Microfiltration" removes particles of 50 nanometers (nm) or larger. "Ultrafiltration" removes particles of roughly 3 nm or larger. "Nanofiltration" removes particles of 1 nm or larger. Reverse osmosis is in the final category of membrane filtration, "hyperfiltration", and removes particles larger than 0.1 nm.

13. For photographic and X-Ray processing:

a. Install a solenoid control valve in the water supply line to shut-off water when processing is not in use and a flow meter to regulate flow so excessive water is not used during processing.

14. For vacuum systems:

a. Specify dry type equipment for vacuum systems not liquid ring. Dry type equipment systems which utilize piston, lubricated rotary vane, oil-less rotary vane and dry claw pumps do not require water to form the seal for the pump. Dry pumps are more energy efficient since they have to pump only air and not water also. Their energy use is typically two-thirds to half that of liquid-ring pumps for the same amount of air pumped. Dry claw pumps are the most energy efficient of the vacuum pump options.

15. Vivarium equipment:

a. Use cage washers that recycle water through four cleaning stages using a counter-current rinsing process. In counter-current rinsing, the cleanest water is used only for the final

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[30] From Cole Parmer website (http://blog.coleparmer.com/tag/labconco/).

rinsing stage. Water for early rinsing tasks (when the quality of rinse water is not as important) is water that was previously used in the later stages of rinsing operations.

b. Use tunnel washers for small cage cleaning operations.

c. Sterilize and recirculate water used in automatic animal watering systems instead of discharging water to the drain. Consider using water that cannot be recycled for drinking due to purity concerns in other non-potable applications, such as cooling water make-up or for cleaning cage racks and washing animal rooms.

CONTROLS AND MONITORING

Figure 18 is a diagram of the dual-wheel air handling unit and two associated labs, a thermal dominated lab and a fume hood dominated lab. The control sequences for the systems shown on the diagram follow.

1. Sequence of Operation for Dual-Wheel Air Handling Unit:

   a. It is anticipated that for areas handling hazardous materials the air handling unit will operate twenty four hours per day, seven days a week.
   b. When the air handling unit is off (for maintenance or troubleshooting) the outside air damper and the exhaust damper will close. Upon air handling unit start-up, outside air and exhaust air dampers will open.
   c. Supply fan control: The supply fan Variable Frequency Drive (VFD) speed will modulate to maintain the duct static pressure set point, sensed by a duct static pressure sensor located in the supply air duct.
   d. Exhaust fan control: The exhaust fan Variable Frequency Drive (VFD) speed will modulate to maintain the duct static pressure set point, sensed by a duct static pressure located in the exhaust air duct.
   e. To maintain a minimum exhaust air plume height, the exhaust fan VFD speed will be limited. Exhaust fan VFD lower speed limit will be determined via Computational Fluid Dynamics (CFD) re-entrainment analysis or by consulting with the exhaust system manufacturer.
   f. If the exhaust fan is running at its minimum (allowable) speed and the exhaust duct static pressure is still over its set point, the exhaust system by-pass damper will modulate to maintain exhaust duct static pressure set point.
   g. Locate the static pressure sensor from which the supply (or exhaust) fan is controlled just before the air terminal unit with the highest static pressure loss between the supply fan and the terminal unit (not always the farthest distance). If uncertain or if more than one main duct branch is present, use more than one sensor and control based on the sensor that is a greater percentage away from set point. The sensor shall be placed in a position such that the controller set point is no greater than one-third the total design fan static pressure
   h. Filter loading monitoring: A differential pressure sensor will monitor pressure drop across the air filters. System should alarm when the filter differential pressure reaches a pre-set high limit.
   i. Supply air temperature and humidity control: High quality temperature and humidity sensors should be provided at the following locations:

      i. Upstream of the enthalpy wheel
      ii. Downstream of the enthalpy wheel
      iii. Downstream of the cooling coil
      iv. Downstream of the dehumidification wheel
      v. Upstream of the dehumidification wheel (exhaust air stream)
      vi. Upstream of the enthalpy wheel (exhaust air stream)
      vii. Downstream of the enthalpy wheel (exhaust air stream)

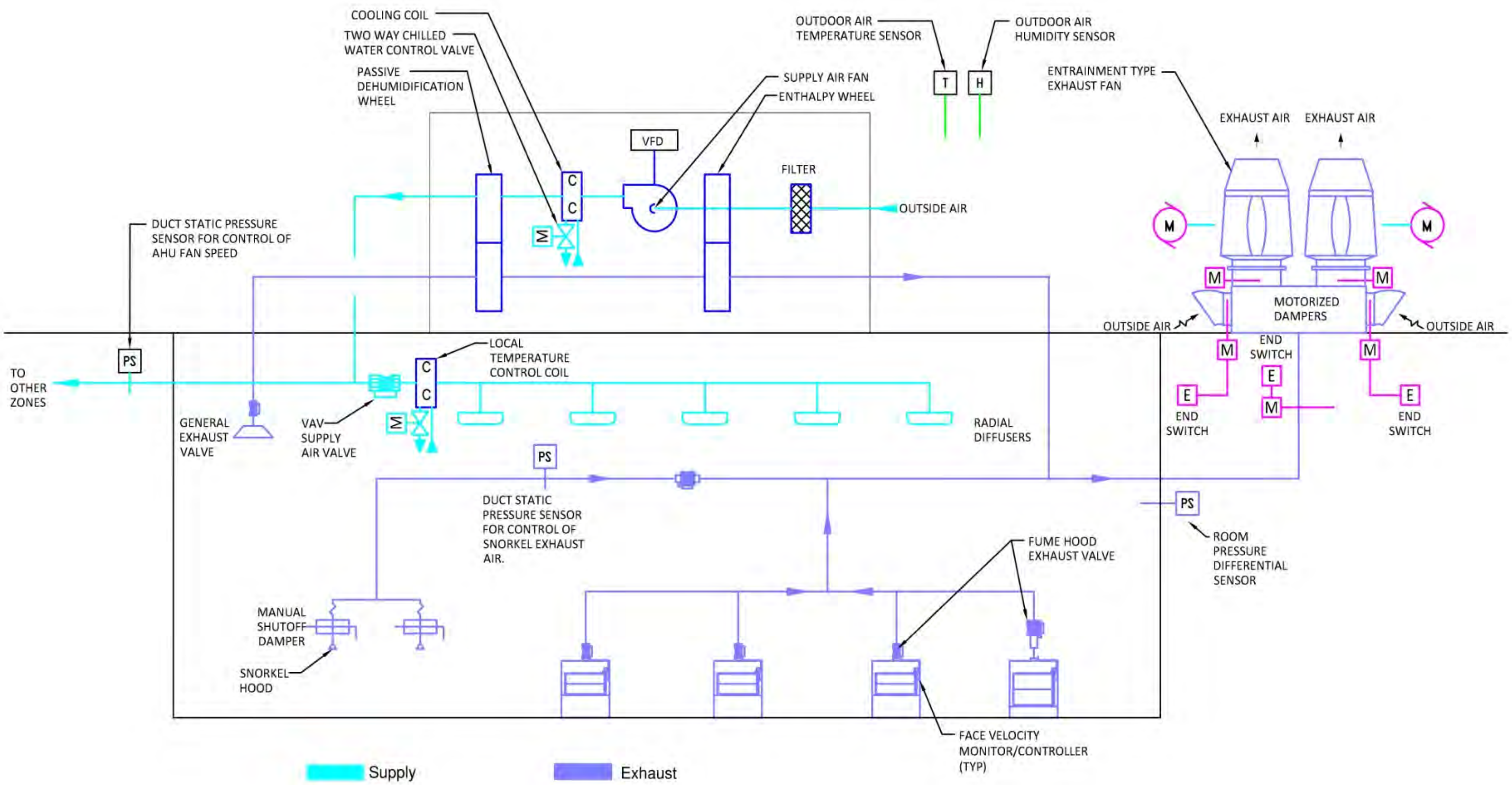

Figure 18: Dual-wheel air handling unit and associated labs diagram

j. The chilled water cooling coil control valve will modulate to maintain a supply air temperature set point of 12.8°C (55°F) downstream of the cooling coil.

k. The passive dehumidification wheel rotation speed will adjust to maintain a supply air relative humidity of approximately 65% RH at 16.4°C DB/12.2°C WB (61.6°F DB/53.9°F WB).

l. The air handling unit digital controller shall be capable of communicating in a fully integrated manner with the Johnson Controls Base Building energy management system.

m. The supply and exhaust fan Variable Frequency Drives shall be fully integrated with the Building Management.

n. The air handling unit digital controller shall be able to perform all control and monitoring functions even when Building Management System network communications are lost.

2. Room Controls:

a. "Thermal Dominated Laboratory"(no fume hoods):

i. Primary (outside) airflow modulates (by use of laboratory air valves) in conjunction with the chilled beam or fan coil chilled water valve to maintain space temperature set point.

ii. Exhaust airflow modulates (by use of laboratory air valves) in conjunction with the supply airflow to maintain the required exhaust-to-supply air offset.

iii. A "Demand Based Control" environmental monitoring system will allow the supply and exhaust air to the space to be reduced to as low as 2 to 4 ACH as long as the measured critical variable (TVOC, particles etc.) is below a set threshold. See earlier discussion of demand-based control.

b. "Fume Hood Dominated Laboratory":

i. Exhaust airflow modulates (by use of laboratory air valves) to maintain the required fume hood face velocities as fume hood sash positions vary.

ii. Primary (outside) airflow modulates to provide adequate make-up air to the space and maintain the required supply-to-exhaust air offset.

iii. If the space temperature is lower than set point, then a supply air reheat coil (optional, only if deemed necessary) will add heat to the airstream to meet the space temperature set point.

iv. If the space temperature is higher than set point, supply airflow will increase and exhaust airflow will increase to maintain the required supply-to-exhaust air offset.

v. A "Demand Based Control" environmental monitoring system will allow the supply and exhaust air to the space to be reduced to as low as 2 to 4 ACH as long as the measured critical variable (TVOC, particles etc.) is below a set threshold and all fume hoods maintain a minimum face velocity. See earlier discussion of demand-based control.

c. Non-laboratory Spaces (Classrooms, conference rooms, offices):

i. Primary (outside) airflow modulates (by use of commercial grade air terminal units) in conjunction with the chilled beam or fan coil chilled water valve to maintain space temperature set point.

ii. Exhaust airflow modulates (by use of commercial grade air terminal units) in conjunction with the supply airflow to maintain the required exhaust-to-supply air offset.

iii. A "Demand Based Control" environmental monitoring system will allow the supply and exhaust air to the space to be reduced to as low as 2 ACH as long as the measured critical variable (typically CO2) is below a set threshold.

3. Sequence of Operation for Air Handling Unit with Heat Recovery Chiller:

a. It is anticipated that for areas handling hazardous materials the air handling unit will operate twenty four hours per day, seven days a week.

b. When the air handling unit is off (for maintenance or troubleshooting) the outside air damper and the exhaust damper will close. Upon air handling unit start-up, outside air and exhaust air dampers will open.

c. Supply fan control: The supply fan Variable Frequency Drive (VFD) speed will modulate to maintain the duct static pressure set point, sensed by a duct static pressure sensor located in the supply air duct.

d. Exhaust fan control: The exhaust fan VFD speed will modulate to maintain the duct static pressure set point, sensed by a duct static pressure located in the exhaust air duct.

e. To maintain a minimum exhaust air plume height, the exhaust fan VFD speed will be limited. Exhaust fan VFD lower speed limit will be determined via Computational Fluid Dynamics (CFD) re-entrainment analysis or by consulting with the exhaust system manufacturer.

f. If the exhaust fan is running at its minimum (allowable) speed and the exhaust duct static pressure is still over its set point, the exhaust system by-pass damper will modulate to maintain exhaust duct static pressure set point.

g. Locate the static pressure sensor from which the supply (or exhaust) fan is controlled just before the air terminal unit with the highest static pressure loss between the supply fan and the terminal unit (not always the farthest distance). If uncertain or if more than one main duct branch is present, use more than one sensor and control based on the sensor that is a greater percentage away from set point. The sensor shall be placed in a position such that the controller set point is no greater than one-third the total design fan static pressure

h. Filter loading monitoring: A differential pressure sensor will monitor pressure drop across the air filters. System should alarm when the filter differential pressure reaches a pre-set high limit.

i. Supply air temperature and humidity control: High quality temperature and humidity sensors should be provided at the following locations:

i. Upstream of the enthalpy wheel
ii. Downstream of the enthalpy wheel
iii. Downstream of the pre-cooling coil
iv. Downstream of the cooling coil
v. Downstream of the reheat coil
vi. Upstream of the enthalpy wheel (exhaust air stream)
vii. Downstream of the enthalpy wheel (exhaust air stream)

j. The chilled water cooling coil control valve will modulate to maintain a supply air temperature set point of 12.8°C (55°F) downstream of the cooling coil.

k. The heat recovery chiller will modulate / cycle capacity to provide warm (condenser) water in order to maintain a supply air temperature of 18.3°C (65°F) DB.

l. The air handling unit digital controller shall be capable of communicating in a fully integrated manner with the Johnson Controls Base Building energy management system (EMS).

m. The supply and exhaust fan Variable Frequency Drives shall be fully integrated with the Building Management.

n. The air handling unit digital controller shall be able to perform all control and monitoring functions even when Building Management System network communications are lost.

Monitoring Via Sub-Metering

Sub-meters do not control anything, but do provide vital information to the facility operator to maximize equipment operational efficiency. In order to effectively account for the laboratory's energy usage, determine its CO_2 footprint, or benchmark performance against goals and other, similar facilities, the proper selection of sub-meters is essential.

Sub-meters can allow the facility manager to:

- Allocate energy use/cost
- Enable demand response
- Identify load shedding opportunities
- Validate power quality
- Track infrastructure capacity
- Measure greenhouse gas (GHG) emissions
- Measure data to improve operational efficiency
- Provide data for benchmarking
- Provide a tool for ongoing commissioning

At minimum, the following meters are <u>required</u>:

1. Chilled water energy use (requires measurement of flow, supply, and return temperatures)

2. Electricity usage for

   a. Each main utility service to tenant

   b. HVAC

   c. Lighting

   d. Receptacles

Additional sub-metering is highly recommended for the following sub-systems:

1. Air handling unit energy demand/consumption (calculated for each unit)
    a. Airflow
    b. Outside air temperature and humidity
    c. Supply air temperature and humidity
    d. Fan motor electrical usage
2. Exhaust fan electrical usage
3. Lighting electrical usage
    a. For each lighting panel
4. Receptacle (plug load) electrical energy usage
    a. For each panel
5. Process equipment electrical energy usage for <u>major</u> individual pieces of equipment
    a. Coolers/freezers
    b. Process chillers/pumps
    c. Data centers
    d. Large laboratory equipment
6. Water consumption

The data collected shall be archived in a spreadsheet form to allow trending, reporting and graphical presentation of this data. This metered data shall be shared with the Base Building EMS.

It is highly recommended that this data be input into the Labs21 Energy Benchmarking Tool.

The tenant is encouraged to consider holding a sub-metering charrette during the design process to identify sub-metering requirements.

SPECIALISED ROOMS

Cleanrooms

In some cases laboratory processes require a cleanroom environment. Examples include photonics and semiconductor laboratories, some microbiology laboratories and laboratories where active pharmaceutical ingredients (API) are manufactured or mixed.

The cleanroom classification determines the airflow requirement for the room. Thus, the first step in minimizing energy use in a cleanroom is specifying the correct cleanliness classification. The classification for cleanrooms is promulgated in ISO 14644-1—Cleanrooms and associated controlled environments—Part 1: Classification of air cleanliness.

The following steps are required in the design cleanroom design:

1. Program the space to minimize the area requiring the maximum level of cleanliness. Some methods of doing this include:
    a. Use barrier isolation technology to enclose the process.
    b. Use anti-rooms for entry and cascade the cleanroom levels from the dirtiest to cleanest spaces. The cleanest space shall occupy the smallest footprint.
2. Select the appropriate class of cleanroom for the process
3. Model the contaminant generation and transport in the space to determine the correct particle dilution required for the cleanroom classification. Contaminant generation and transport can be modeled numerically using computational fluid dynamics. This will allow the airflow to be tailored the process and cleanliness classification. For example, many labs are still designed using rules of thumb which require a prescribed air exchange rate for a cleanliness classification. This basis of design method is not founded in science and has been developed over years of experience. However, it typically results in significant overdesign of the airflow rates. Using modeling as a basis of design will typically result is substantially lower system capacity.
4. Use demand-controlled ventilation to control the level of airflow in the space. Particle counters in the cleanroom provide an input to the room controller that is used to vary the volume of airflow for required to dilute the air the necessary cleanliness level.
5. Measure pressure differential to control airflow direction, as opposed to airflow offsets.
6. Specify the lowest pressure drop final HEPA/ULPA filters.
7. Provide pressurized plenums in lieu of ducted supply systems.
8. Reduce system effects at fan inlets.
9. Select the AHU using the design basis described in this document.

Mini-Environments/Containment Rooms

The layout of a cleanroom has an impact on its energy consumption. The layout that requires the lowest quantity of recirculation air within the cleanroom will result in the lowest energy consumption using minienvironments, or locally isolated environments, can have a significant impact on the energy consumption of a laboratory-type facility containing a cleanroom. The greatest benefit of minienvironments is that they enable the laboratory to operate at much lower power consumption levels by decreasing the air volume that must be conditioned and reducing the installed air handling capacity.

Cold/Warm Rooms and Environmental Rooms

These spaces are typically prefabricated rooms that are field-erected. The following requirements shall be followed:

1. Locate these rooms in a way that they can be shared by as many lab users as possible.
2. Locate all heat rejection devices, such as condensing units in split refrigeration systems, to the roof.
3. Wall design shall use high density foam insulation.
4. All refrigerants shall be low ozone depletion potential and low global warming potential.
5. Specify water-cooled refrigeration systems, if practical.

Walk-in Freezers

Two requirements guide the selection of the freezers:

1. Locate heat all heat rejection devices, such as condensing unit, to the roof.
2. All refrigerants shall be low ozone depletion potential and low global warming potential.

Hazardous Chemical Storage Room

1. These rooms are spaces that are fire-separated from laboratory and support space. The greatest energy use in these rooms is associated with the ventilation rates. ASHRAE Standard 62.1-2010 requires 7.5 $L/S{\cdot}m^2$ (1.5 cfm/ft^2). Thus, reducing the footprint dedicated to hazardous storage will minimize the energy use associated with these rooms.

Data Closets/Rooms

1. Use chilled water for data closet/room cooling.
2. Use optimized hot and cold aisles.
3. Use variable speed fans on air-handling equipment.
4. Use energy efficient power supplies.
5. Use server efficiency strategies such as blade servers, server virtualization, and server power management.

COMMISSIONING

Laboratories, more than most other building types, are highly complex and consume significant amount of energy to operate. Each is a uniquely crafted sophisticated machine that must function reliably and efficiently from the first day of operation in order to provide the necessary environment for successful research. To achieve this reliability and efficiency it is essential that laboratories receive comprehensive, third-party commissioning.

"The Commissioning Process is a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria."[31]

The objective of commissioning is to ensure that systems are installed, functionally tested and capable of being operated and maintained to perform in conformity with the design intent and the Owner's needs.

To achieve CleanTech One's sustainability and energy efficiency objectives, commissioning will be thoroughly integrated into the project delivery process, from pre-design phase through design, construction, turn over, occupancy and operations.

The independent third party commissioning process shall follow the New Construction Building Commissioning Best Practice guideline by the Building Commissioning Association as summarized below:

https://netforum.avectra.com/temp/ClientImages/BCA/7e4ffc3d-bad0-453c-9012-00eb7c7dfa70.pdf

Pre-Design:

1. Owner selects and designates a commissioning authority for the project.
2. Develop the owner's project requirements (OPR).
3. Develop the commissioning scope, schedule and budget.
4. Develop a commissioning plan.
5. Review the building, space, laboratory space function/utilization program.
6. Attend project planning meetings.

Design Phase:

1. Conduct a design phase kickoff meeting.
2. Review the project "Basis of Design", schematic design documents, design development documents and construction documents. Three reviews are advisable with a minimum of two reviews are required, at 50% complete construction documents and 100% for-review construction documents.
3. Review/update the OPR.
4. Update the commissioning plan.
5. Develop commissioning specifications for inclusion in the project documents.

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[31] ASHRAE, ASHRAE Guideline 0-2005, The Commissioning Process, p. 2.

Construction Phase:

1. Conduct a construction phase kickoff meeting.
2. Review submittals.
3. Facilitate a controls integration meeting.
4. Develop construction checklists.
5. Develop functional performance testing procedures.
6. Conduct regularly scheduled construction phase site inspections (minimum 2 per month).
7. Develop and maintain a master issues log.
8. Review startup reports.
9. Review completed construction checklists.
10. Review testing, adjusting and balancing plan and report.
11. Coordinate, execute and document the functional performance testing.
12. Review as-built documents, operations and maintenance manuals and warranties.
13. Integrate commissioning into the project schedule.
14. Review/update the OPR.
15. Update the commissioning plan.
16. Prepare a systems manual.

Occupancy and Operations Phase:

1. Maintain the master issues log.
2. Provide occupant training.
3. Participate in lessons learned workshop.
4. Optimize system operation and efficiencies.
5. Complete seasonal and deferred testing.
6. Update the system manual.
7. Begin implementation of on-going commissioning program with full system re-commissioning every five years.
8. Conduct warranty phase survey review of operations and maintenance and occupants.
9. Benchmark the building/systems energy performance and review with the owner and project team.
10. Review/update the OPR.

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