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Applying design and construction standards to successfully build a cleanroom

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Cleanrooms are a vital part of laboratories and the microelectronics industry, especially semiconductor manufacturing. To maintain and assure quality, there are specific standards that apply to these spaces and guide the process of constructing and operating the rooms. While adhering to these requirements makes designing and constructing a cleanroom more complex than conventional construction projects, the standards serve as a blueprint for the successful completion of a cleanroom that will meet the exacting demands of the end-user.

The need for an international standard that covered cleanroom environmental

continued on page 5

An ISO 8/Class 100,000 cleanroom, measuring 1,100 sf, completed by C1S Group for a medical device manufacturer.

Important differences between zebrafish facilities and traditional animal vivaria

Erik Sanders, B.S. RALAT
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Those who have found themselves involved in the process of building a zebrafish facility can attest to just how different the process and final results can be when compared to a traditional laboratory animal vivarium. What follows are three important differences, and some explanation as to why these discrepancies exist.

First, the composition of the design and build team typically includes a great deal more involvement with the PI, the laboratory/facility manager and the capital equipment vendor. Where the design and construction of a rodent facility might be overseen by a department of comparative medicine or existing animal core group, the investigators using the zebrafish model typically have a great deal more involvement in the day-today operations of the facility, including animal husbandry and thus are much more involved throughout the entire

continued on page 8

Modern zebrafish facility with focused lighting and Tritone automated feeder. Note the focused lighting over the bench tops. Image: Erik Sanders.

Sustainability matters

By MaryBeth DiDonna, Editor

I recently attended the annual I²SL Conference in Kansas City, Mo. The International Institute for Sustainable Laboratories promotes the principles of sustainable laboratories and related high-technology facilities, carrying through from the design phase, to the engineering phase, to operation.

I was able to meet and talk with industry professionals, view new products, and make new connections. Many attendees and presenters at the show are loyal readers of *Laboratory Design*, and some are just getting familiar with the publication. You can expect to see bylines in future issues from some of your old favorites, as well as a few new names.

I also sat in on a number of interesting sessions dealing with a variety of topics—to name just a few, a symposium on laboratory benchmarking, occupant safety and satisfaction concerns, HVAC system strategies, duct pressure control, thermal comfort and glazing techniques, flexibility in laboratory design, renovation and retrofitting, building information modeling experts also presented case studies on academic buildings, new technology and tools, startup labs and healthcare facilities. Presenters fielded questions from attendees who wanted to know more about specific processes and techniques.

The desire for sustainable buildings reflects a need for energy and cost savings, as well as the use of natural resources. Most companies are not made of money, so every dollar counts. Cities and even the suburbs are growing exponentially, therefore designers and builders need to get creative when they're dealing with a limited amount of space.

Global warming is a serious issue that needs to be dealt with swiftly, and the laboratory design industry is doing its part by implementing eco-friendly techniques and striving for LEED status and maybe even Net Zero status whenever possible. Flexibility is also needed in these facilities—if expansion or renovation is needed in the future, it's vital that the lab be able to accommodate these changes without sacrificing the sustainability elements implemented in the first place.

You will see sustainability issues discussed in each issue of *Laboratory Design*, as it's a crucial part of the industry. Additionally, the topic will be covered in depth in our November/December issue, which revolves exclusively around the theme of sustainability. LD

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Applying design and construction standards to successfully build a cleanroom

continued from page 1

parameters and practices emerged after various countries developed their own standards, creating confusion. The International Standards Organization devised ISO 144641, which defines a cleanroom as "A room in which the concentration of airborne particles is controlled and which contains one or more clean zones." The standard also calls for constructing the space in a manner that minimizes the introduction of particles and to control additional parameters such as temperature, humidity and pressure within the cleanroom as necessary.

Cleanroom classifications are based on the number of particles equal to and greater than 0.5 per micron (µm) in one cubic foot of air. The standard of cleanliness required is dependent on the task performed in the room, so the more susceptible the product is to contamination, the higher the standard. The standard also determines the type and frequency of testing, such as for particle count, air pressure and air flow, required to be in compliance. Finally, the cleanroom design must account for the equipment and finishes used because each contributes to the amount of particulate in the space.

The essential characteristic of a cleanroom is that it is a building within a building. These controlled environments have completely separate systems for heating, ventilation and air conditioning (HVAC), lighting, flooring and walls. They do not share any exterior walls with the main building and do not have direct outside access. The cleanroom also has a differential pressure to the interior of the building that must be maintained at all times in order to mitigate infiltration of particles from an adjacent, less clean space into the cleanroom.

The first step in the cleanroom design process involves creating the Utility Matrix (UM), which outlines detailed specifications on each piece of equipment used in the cleanroom. This document, which is crucial to the cleanroom design, must be created and approved with the participation of the cleanroom operator/user. The UM can be developed directly by the operator, if the expertise exists in-house, or an outside consultant can be brought in to assist in development of the cleanroom layout and process flow. Once it's completed, designers will use the UM to design the specific support systems required for the cleanroom. The UM remains an important document even after facility construction and should be continually updated throughout the life of the cleanroom.

HVAC AND MAKE-UP AIRS

The UM provides the basis for designing the HVAC/mechanical system, which is the largest component of the construction cost of a standard cleanroom facility, constituting as much as 25 percent of the total facility cost. These systems consist of recirculation air, chilled and hot water, process exhaust and makeup air systems. Although the exhaust system represents a smaller portion of the HVAC cost, it is arguably the most critical to the operational success of a cleanroom. Determining the proper amounts of exhaust for each cleanroom and support area drives the design of the make-up air (MUA) systems. The exhaust quantities are determined by careful analysis of the room, codes and emergency requirements. By definition, the exhaust system in a hazardous production material (HPM) facility must be designed and installed to remove any potentially hazardous fumes that may escape from fabrication or support equipment.

A review of the Exhaust System Impact reveals the critical nature of starting the design process with the correct exhaust quantities. The exhaust flow rates are given in the UM and the MUA quantities are determined to cover the air exhausted from the building plus surplus air to pressurize the cleanroom (MUA=EXH+10%). MUA requirements dictate the amount of chilled water and heating water required from the central plant, thus affecting the overall size and number of chillers and boilers. Exhaust air quantity also has impact on heat removal from the cleanroom, thus affecting the size of the sensible cooling coils and recirculation air system.

The MUA system is integral to successful cleanroom design because it not only replaces the air that is exhausted from equipment, clean spaces, and support rooms, but is also responsible for controlling the humidity levels throughout the clean spaces. Most importantly, the MUA system maintains pressure control throughout the facility. The clean spaces will typically be positively pressurized with respect to surrounding areas while the gas and chemical rooms will have negative pressure with respect to surrounding spaces. Clean areas will also see a pressure cascade going from highest pressure in the cleanest zones. This means the highest level cleanroom will have the highest pressure while an adjacent cleanroom with a lower classification will have lower pressure, the attached gowning room will have still lower pressure, and the non-cleanroom space will have the least pressure. See Table 1 for an example of a pressure cascade.

Table 1: Example cleanroom pressure cascade.

Classification (FPM, BVE)	Filter velocity Overpressure: (sp. "wg)	Overpressure: (sp. "wg)	Air direction	Filter coverage (%)
ISO 3 (Class 1)	100	+0.10"	Laminar	100
ISO 4 (Class 10)	90-100	+0.08"	Laminar	90-100
ISO 5 (Class 100)	50-70	+0.05"	LAM/NON	50-90
ISO 6 (Class 1,000)	30-50	+0.05"	Turbulent	35-65
ISO 7 (Class 10,000)	10-30	+0.03"	Turbulent	20-50
ISO 8 (Class 100,000)	5-20	+0.03"	Turbulent	10-30

RECIRCULATION AIR SYSTEM

The cleanroom recirculation air system is a major part of the HVAC cost for a cleanroom and must be designed to provide sufficient clean and conditioned air to the space in order to maintain the cleanroom classification during full operation of the room (see Table 2). The ceiling filter coverage and the efficiency of the filters primarily determine the cleanliness of the supply air delivered to the cleanroom. Figure 1 provides general guidelines for cleanroom construction; however, the final design must be determined with the end user requirements. The driving factor in cleanroom recirculation is continuous dilution and removal of unwanted particles in the cleanroom. While the MUA units handle the moisture removal and pressure control in the clean space, sensible cooling coils are utilized within the cleanroom recirculation air system to "trim" the temperature to meet the tight tolerances. There are three viable options for recirculation air systems, each with its own advantages and disadvantages. These options are recirculation air handlers, VLF fan towers and filter fan units

Recirculation air handling units (RAHUs) are usually a lower cost option for a recirculation air system. They are typically located on a fan deck or perimeter of a cleanroom, which provides maintenance accessibility from non-clean space. Disadvantages of RAHUs include high noise levels—rarely below 70 dB(A) and higher energy usage. These large units also take up critical facility space, whether at the fan deck level or in an adjacent mechanical room, and fan deck RAHUs can raise the height of a building.

Vertical Laminar Flow (VLF) fan towers rely on laminar airflow to control particulate contamination through the vertical profile of the cleanroom. Laminar airflow refers to air moving at the same speed and in the same direction, with little or no cross-over air streams that can randomly deposit particles. Usually located on the perimeter of a cleanroom, VLF fan units fit in the same area required for sensible coils and a return chase, which allows for maintenance accessibility either from the subfloor beneath the cleanroom or from an adjacent chase. VLF fan units are usually a lower cost option for large, open ballroom cleanrooms with filter coverage greater than 50 percent. Used in conjunction with variable frequency drives (VFDs) equipped with large premium efficiency motors they have lower energy usage. While installing small, mini-VLF fan towers of around 12,000 cfm is relatively easy, large VLFs greater than 75,000 cfm are difficult to install. Like RAHUs, these systems can be noisy, with sound levels of 65 dB(A). VLF fan units also require a more costly and time-intensive gel ceiling grid and a positive pressure plenum can lead to particles or gel leaking into cleanroom space.

Filter fan units are located on top of the cleanroom ceiling grid in the plenum space, so these systems don't take up facility floor space and offer maintenance access from below or above. These units offer quiet operation, with noise levels as low as 55 dB(A) or less easy to achieve. Units using the latest DC motor models offer high reliability, with mean time between failures approaching 10 years, and have very low energy usage. They have a negative pressure plenum that forces any leaks up into the plenum not into the cleanroom and a gasketed ceiling grid can be used. Filter fan units are easy to install and very cost competitive when coverage is less than 50 percent, but typically a high quantity of units is required for greater coverage or for large cleanrooms.

CLEANROOM CONSTRUCTION PROCESS

Building out a cleanroom and adjacent environments is a multi-stage construction process and particular protocols must be maintained at each stage of the construction to insure the integrity of the cleanroom. The stages are Stage 0—Regular Construction; Stage 1—Clean Construction; Stage 2—Pre Cleanroom Construction; and, finally, Stage 3—Active Cleanroom. Following are the important steps in each stage.

The regular construction phase is what must contractors are used to, but in the context of a cleanroom special attention should be paid to housekeeping to set the tone for cleanliness. At this stage there are no material restrictions and standard personal protective equipment, such as hard hats, safety glasses and vests, should be used. Take care to protect building materials as well. Construction workers should

Table 2: Cleanroom recirculation air design analysis.

Cleanroom Class rating	Area (SF)	Height (Ft.)	Volume (CF)	Filter velocity (fpm-low)	Filter velocity (fpm-high)	Air flow (cfm-low)	Air flow (cfm-high)	Design air change (low)	Design air change	Filter coverage (%)
ISO 8.0 (Class 100,000)	10,000	10	100,000	60.0	80	48,000	64,000	29	38	8%
ISO 7.0 (Class 10,000)	10,000	10	100,000	60.0	80	72,000	96,000	43	63	12%
ISO 6.0 (Class 1,000)	10,000	10	100,000	60.0	90	150,000	225,000	90	135	25%
ISO 5.0 (Class 100T)	10,000	10	100,000	72.5	100	290,000	400,000	174	240	40%
ISO 4.0 (Class 10)	10,000	10	100,000	72.5	100	652,500	900,000	392	540	90%
ISO 3.0 (Class 1)	10,000	10	100,000	72.5	100	725,000	1,000,000	435	600	100%

apply standard good housekeeping practices and complete daily and hourly clean-ups.

All drywall work should be complete, if possible, before the first stage of actual clean construction. During this phase, conduct daily and hourly cleanup using vacuums and start using a daily cleaning service. There should be no unnecessary trash or debris in cleanroom area and you should use multiple rugs as well as sticky mats to prevent dirt from entering. This is also when you begin to conduct particle counts.

In the second stage, control and limit access to the cleanroom area and establish a smock room/air lock for entry/exit with an air cleaner. Workers must wear booties in the area and use sticky mats on floors. There should be no wood, cardboard or paper allowed in the area. A HEPA vac is required for all cutting/drilling in the cleanroom and the air systems should be on, but not the FFUs.

The third stage, which is for punching and finishing details, is the most restrictive. It includes all the precautions of Stage Two, plus several additional steps. At this stage, access is limited and workers must be fully smocked, including wearing lab coat or coveralls, hair/beard nets, booties, and gloves, and they must use a designated smock room. In addition to operating the MUA system, recirculation air is continuously cleaning the air.

Meeting all the specific requirements for a cleanroom does increase construction costs, but this varies based on the type of cleanroom, with the tightest, most restrictive rooms costing the most. On average, the price range for cleanrooms ranges from $1,000 per square foot for a Class 1 room down to below $200 per square foot for a Class 100,000 room.

When constructing a cleanroom, it's important to not be intimidated by the process. In the end, it's still just construction. By following the plans and specs while adhering the guidelines for each phase the cleanroom construction can be executed successfully and with few problems. To facilitate the process, remember that preconstruction is extra important, so develop a detailed schedule early and manage procurement carefully. Clearly communicate the construction schedule to all parties to keep everyone on the same page. Be prepared to manage contingencies; things will change, so be flexible and adaptable.

Constructing cleanrooms is challenging, requiring careful attention to specific details in both design and construction procedure. Using the accepted industry standards and the UM as blueprints, however, will facilitate the successful completion of a cleanroom. Working in partnership with the cleanroom operator on the specific design assures that the resulting room will meet the needs of end users and enable them to achieve a desired ROI from the operating space.

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Important differences between zebrafish facilities and traditional animal vivaria

continued from page 1

process. Often, the zebrafish facilities manager not only oversees the operations, but is directly involved in all aspects of the daily care and maintenance of the colony. Additionally, the zebrafish facilities manager is often involved in either supporting research or is executing independent research aimed at refinement of husbandry methodology. The PI and manager bring first-hand knowledge of the work-flow in a zebrafish facility, which tends to be of a very different nature than that of the rodent vivarium. The capital equipment appointed to a zebrafish lab differs in almost every aspect from that of the mammal vivarium, which requires a different approach to how we include the contributions of the vendor's project management and design team.

Second, the procedure rooms or research work spaces are often found closer to the fish housing rooms. This may be due to the time-sensitive nature of many zebrafish related procedures (i.e. micro-injection of newly fertilized embryos) or to facilitate specialized screening procedures. Regardless of the reason, it is easy to understand that the challenges surrounding the care and handling of animals that require a liquid medium are challenging enough without compounding them by requiring an across-campus trip. These areas are also some of the first to be sacrificed by the uninformed when space starts to become limited, so be prepared to fight for them when it comes down to it.

Third, selecting fixtures and finishes must be based on a comprehensive understanding of the final environmental conditions. Items commonly selected and perfectly adequate in other vivaria often won't stand up to the harsh environments found in a zebrafish lab. There are areas in fish facilities that are constantly covered in or exposed to water, which can sometimes be corrosive due to high purity, or high salinity, and these are not spaces one might expect to need specialized construction, finishes and fixtures; the plant rooms and procedure rooms are two examples. The higher than normal ambient humidity typical of fish labs is another, often overlooked, condition that will wreak havoc on anything not adequately designed for the task. Floors must be made of impermeable materials, such as epoxy filled quartz aggregate, with adequate slope to trench drains, and with enough texture to provide a measure of traction to frequently wet areas. Casework, work surfaces and shelving should be made entirely from impermeable,

Extensive work areas for researchers lie only a few feet from the fish housing rooms. They feature fiberglass doors, phenolic casework with epoxy work surfaces and epoxy floors and walls. Image: Erik Sanders

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- The Roadmap for Nanotechnology
- A Material World: Exciting Advances and Implications for the Future
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- Developing Research and Education Payloads to Fly with the Emerging Commercial Sub-orbital Spaceflight Industry
- 12 Trends in the Science of Managing R&D Product Development
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- Keynote Session: Innovate the Way You Innovate!
- Emerging IP Trends for Robotics and Automation
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- New Horizons in Aviation R&D
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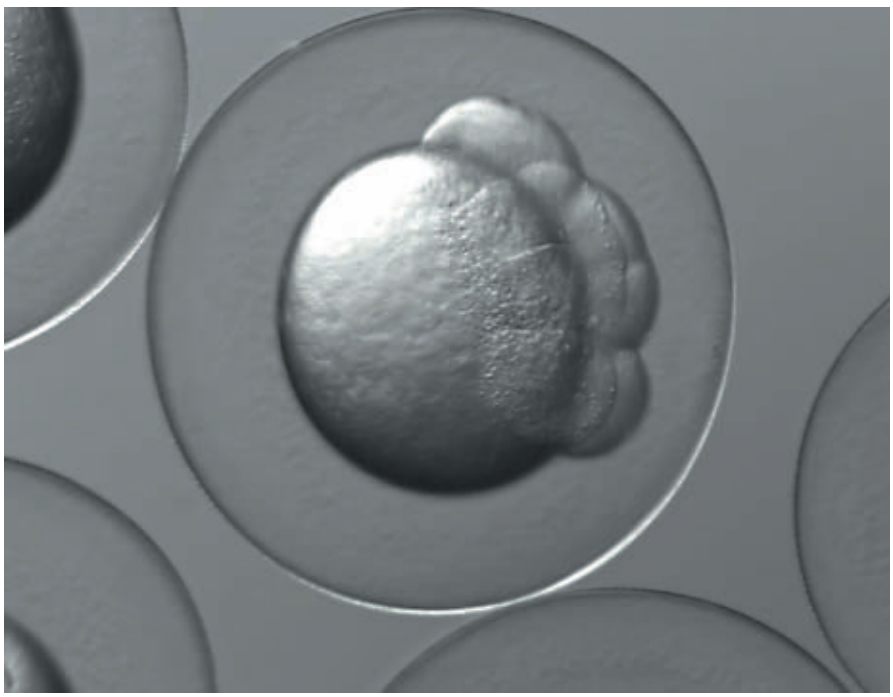
non-staining materials such as phenolic resin, plastics and epoxy resin. All metal components, such as drawer pulls, hinges, door knobs, shelf standards, etc., should be made of 316-stainless steel wherever possible, and zinc or galvanized fasteners and hardware should be avoided. Sinks in areas where fish tanks are handled should be under-mounted to permit clean sweeping of work surfaces, and cup sinks without faucets are common in procedure areas to permit the disposal of waste water at the work stations. Walls and doors are best finished with a water-based epoxy to permit future repairs to be non-threatening to the health of the fish colony. Both suspended and hard ceilings are best avoided altogether in favor of an open ceiling where the exposed utilities and infrastructure can be coated with a finish like that used on the walls and doors, and easily accessed when needed without contaminating the lab area with dust and debris.

Large, dedicated cage-wash areas, with exposed ceilings, substantial floor drainage and ample space for storage of clean tanks. Image: Erik Sanders

While modern zebrafish facilities don't necessarily look or feel like the old-school fish labs found squirreled away in dank university basements, they still require the special considerations often found wanting in their bygone counterparts. By incorporating more input from the PIs and vendors, and seeking out people and references specific to these specialized, and increasingly common laboratories, you can decrease the total time to project completion, while increasing the satisfaction of those who are involved.



8-cell zebrafish embryo. Image: Erik Sanders

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Laboratories warm up to chilled beams

SAVING ENERGY AND ELIMINATING REHEAT

Nick Searle
Titus HVAC

Laboratories are not known for their energy efficiency. These spaces can consume up to 10 times more energy than office buildings, leading facility managers and engineers to prioritize finding ways to reduce energy consumption and operating costs—without sacrificing efficiency. One way to do that is by using chilled beam systems, which have grown increasingly popular in the U.S. in the last decade. Chilled beams have proven to be viable alternatives to traditional Variable Air Volume (VAV) systems, demonstrating energy savings upwards of 20 percent in laboratories compared to VAV Reheat.

To better understand how and why chilled beams are effective in laboratories, let's examine the usage of these systems, strategies for effective design and operation in laboratory environments.

HOW CHILLED BEAMS WORK

There are two types of chilled beams, passive and active.

Passive chilled beams cool spaces using natural convective forces and include a heat exchange coil in an enclosure that is suspended from the underside of the building structure. Chilled water flows through the coil and cools the surrounding warm air; the denser cool air falls back into the space. Passive beams require separate air diffusers to carry dehumidified ventilation air into the space, usually at the floor level. For this reason, they are rarely, if ever, used in laboratories.

Active chilled beams rely on pretreated primary air delivered from central air-handling units (AHUs) to pressurize a series of small induction nozzles within the chilled beam unit. These nozzles create jets of air causing room air to be induced across a coil where flowing water heats or cools this (secondary) air.

Both passive and active beams are designed to provide sensible cooling only with the latent cooling (i.e. space dehumidification) being accomplished by the central AHUs. Depending on the lab use and loads, the primary air is delivered to the active chilled beams as constant or variable volume, with the cooling/heating output being controlled by either two position or modulating control valves to vary the water flow through the integral coils. Chilled beams can be integrated into suspended ceiling systems or hung from the structural slab for exposed use.

Because chilled beams provide most of a space's sensible cooling, the central

air handling system can be much smaller than usual since its primary purpose is to provide the ventilation air and latent cooling to the space. This effectively decouples the sensible cooling from the ventilation requirements. And since chilled beams have no moving parts, maintenance is limited to infrequent cleaning of the coils.

LABORATORY HVAC ENERGY USE

The ventilation requirements for laboratories are different from the needs of a typical office building. Minimum ventilation rates are dictated by safety requirements rather than cooling or heating loads, while maximum rates are determined by either the make-up air requirements for the fume hoods or the sensible cooling requirements of the space (if the equipment cooling load is high). There are special requirements for laboratories where chemicals or gases as present as well. They cannot use recirculating AHUs, so the ventilation air must be 100 percent outdoor air at all times.

Overall, these parameters can result in an air system sized for ventilation air changes rates from 6-to-12 or more, depending on the lab use and equipment loads.

A traditional "all-air" system will typically deliver cool air to the building at around 55 F when there is demand for OA dehumidification, or to satisfy the sensible cooling requirements of the highest load lab in the building. This often results in a mismatch of ventilation air and cooling requirements, forcing the zone VAV boxes to reheat the cooled air to prevent over-cooling the space when sensible loads are low. Even more reheating occurs when ventilation air is increased to provide make-up air for the fume hoods, resulting in lower efficiency.

And decreased efficiency hurts the bottom line: Energy studies have shown that cooling and reheating air can account for as much as 20 percent of the total HVAC energy costs in laboratories.

ELIMINATING REHEAT AND SAVING ENERGY

Active chilled beams can help boost energy efficiency in a number of ways.

One is by eliminating most of the reheat energy resulting from decoupling ventilation and cooling demands. With active chilled beams the ventilation air can be delivered at a warmer temperature through a 100 percent outside air AHU, commonly known as a dedicated outdoor air system (DOAS). With the DOAS primary air set to around 65 F to 70 F space overcooling is far less likely to occur, even in labs calling for high volumes of make-up air for the fume hoods. The water coils within the chilled beams provide cooling or heating capacity on a zone-by-zone basis. During OA dehumidification hours, the DOAS unit removes moisture by cooling the air to 55 F or below and is reheated with energy recovered from the exhaust air using enthalpy wheels, heat pipes or run around coils.

Another is through using water to transport heat, resulting in an air system size reduction of 60 percent compared to VAV Reheat. This feature reduces overall fan energy consumption and is ideal for laboratories with high sensible loads and low fume hood densities.

The increased efficiencies associated with chilled beams also help laboratories maximize their space. The reduced reheat and boosted transport efficiencies of water mean the main plant items (chillers, boilers and AHUs) can be smaller than with a traditional system's. The duct distribution system is also more compact, which reduces service congestion in the ceiling interstitial. Finally, a smaller system can translate into lower first costs for an HVAC system compared to VAV Reheat.

There is a challenge with using chilled beams in labs, however: the need for dual chilled water temperatures. Specifically, a low temperature circuit (LTCHW, 40 F to 45 F) for the DOAS and medium temperature circuit (MTCHW, 56 F to 58 F) for the active chilled beams. The most common strategy is to design a closed secondary loop separated by a plate and frame heat exchanger, ensuring that the LTCHW cannot accidently find its way into the active chilled beams. That could potentially cause condensation on the coils.

BUILDING HUMIDITY CONTROL

The best chilled beam system designs equip the building with a small number of room dew point sensors. This allows the building management system to monitor the humidity across the building and reset the DOAS air dew point or reschedule the MTCHW loop temperature if the space dew point rises above a preset temperature. Facilities engineers can use the room dew point sensors to precisely control the amount of OA latent cooling at the DOAS unit to further reduce energy costs, an operational strategy that is more difficult to accomplish with a VAV Reheat system. Despite being used in early system designs; pipe mounted condensation sensors are rarely used today since room dew point monitoring provides enough advance warning of potential condensation.

CHILLED BEAMS MISCONCEPTIONS

Despite growing in popularity over the last 10+ years, there are still a number of persisting myths and misconceptions about chilled beams. For instance, despite there being several successful installations in the likes of Florida, Hawaii and even the Caribbean, there is still hesitancy among designers and owners to use the system in humid climates because of condensation concerns. The reality is the system can be used in any building where the space humidity can be controlled; however, energy savings will not be realized in applications where the internal latent gains are high, such as wet labs. In other cases, engineers may be reluctant to consider active chilled beams because they are simply unfamiliar with the design of these systems.

Cost is also a concern. Mechanical contractors unfamiliar with chilled beams will be wary of underpricing a system they have never previously installed, but several case studies have shown chilled beams have been installed cost competitively with traditional systems.

CONCLUSION

It didn't happen overnight, but a larger number of engineers and facility managers have realized—and are realizing—the advantages chilled beam systems can offer to laboratory applications, specifically in terms of energy and space savings. Debunking misconceptions and educating laboratory owners on the construction of and design using chilled beams is the first hurdle to overcoming barriers to adoption. Then it's about showing what the technology can do. Those who have installed these systems have realized greater energy efficiency, substantial cost savings and improved performance.

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Energy matters: Taking stock

Michael Chonko, PE, CEM
SMRT Architects and Engineers

Reducing energy consumption, costs, use of non-renewable resources and streamlining building systems maintenance have become standard goals for every facilities professional, lab manager or C-suite leader today. Regardless of the recent downward trajectory in energy costs, most facilities professionals are committed to taking the long view, weighing impacts on the environment, as well as projected payback, when considering sustainability investments.

In my last column, "Developing a Comprehensive Energy Master Plan" (http://bit.ly/2cPEi1d), we looked at developing a Comprehensive Energy Management Plan (CEMP), which is becoming the standard in today's world of complex, often 24/7, critical facilities. This article will map some key steps to undertake as you begin developing your Comprehensive Energy Management Plan, to facilitate improving both performance and your bottom line.

BUILD YOUR CASE

It's said the journey of a thousand miles begins with a single step. In most organizations today, that first step is building your business case.

Labs can be crudely classified as "energy hogs," certified as such by a few frequently cited statistics. Labs commonly use more than five times the energy per square foot than in an office building. According to Nature magazine, labs generated 5.5 tons of plastic waste in 2014, which equates to 83 percent of the total plastic waste recycled worldwide a couple of years prior. The University of California, Santa Cruz, analyzed their campus electrical usage in 2012, finding that labs consumed 47 percent of all electricity campus-wide—a figure reduced since establishing their Green Labs Energy Efficiency initiative. My Green Lab, a non-profit, estimated last year that 1.2 billion square feet of lab space existed in the U.S. alone. In today's STEM based economy that square footage is growing exponentially—as labs, generally considered one of the highest energy using facility types, are constructed, rehabbed and retrofitted at a dizzying pace to meet today's research demands.

What makes a lab an energy hog? While a variety of reasons contribute to this distinction, some common reasons include their abundant use of equipment that generates heat, 24/7 operations and accessibility, the need for fail-safe redundancy and back-up systems, and demands to manage exhaust, air handling and containment.

Efforts to reduce energy consumption and increase the sustainability of labs can be classified into two broad categories: those associated with the physical plant (including the performance and impact on its building systems) and those directly related to occupant behaviors. While we'll touch on the latter, the focus of this article will be on the former.

As a facilities or operations professional, it's critical to build your case for developing a CEMP which requires investment in both assessing the current status and opportunities for energy savings within the physical plant, and

Evaluation of the building envelope, including existing energy features such as solar shades and photovoltaic panels, constitutes a major component of a Comprehensive Energy Management plan. All images: Randall Perry; Courtesy of SMRT Architects and Engineers.

Documenting the condition and functioning of the building envelope, including the roof, and building systems including ventilation, are key when developing a Comprehensive Energy Management Plan.

Boilers and other components of a lab's HVAC system, as obvious elements of a building's energy system, require consistent attention and maintenance as part of a Comprehensive Energy Management Plan.

the "low-hanging fruit" associated with occupant behaviors and cultural norms. Both offer impact and payback.

Should you have the opportunity to build a greenfield laboratory facility, the wide ranging choices you'll make, beginning with your site selection and its utilization, to the building envelope, mechanical systems and lab equipment, offer stunning possibilities to manage your comprehensive energy footprint.

The base of any comprehensive energy management plan (CEMP) effort begins with a thorough understanding of the lab owner's goals and operating philosophies. This information forms the ultimate parameters of the CEMP you'll develop.

At the end of the day, a strong business case for developing a CEMP will not only justify capital expenditures, but provide a running start towards an ongoing maintenance plan.

Fundamental thinking about energy expenditures have shifted dramatically in

the past decade. Instead of considering energy expenditures as an overhead cost, we now managing energy costs as direct, controllable expenditures.

In my last column I wrote, "To build your case, it's important to take stock of your current energy costs and consumption, the facility's mechanical and electrical infrastructure, maintenance program, anticipated expansions, planned process changes, the state of equipment, current regulatory requirements (and proposed regulations) and energy futures."

GET THE RIGHT CONSULTANTS ON BOARD

Laying the foundation for, and developing, a CEMP calls for professional engineering help, but it's important to qualify and select an engineering firm with significant experience in building systems, laboratories and the development of CEMPs. This is not the time to hire your best friend, who happens to be a PE.

KNOW THYSELF

One scenario to avoid is chasing after multiple energy systems upgrades, enhancements or new technologies that don't fit with your lab, your organization, your end users or your maintenance capabilities.

Prior to undertaking your engineering investigation and analysis, develop a matrix of energy system options. Then, working with your facilities and lab management personnel, as well as your engineering consultant, take some items off the table. Remove anything that would detract from your primary operational objectives, is outside your financial range or maintenance capabilities, or deploys technology that your organization is uncomfortable with, for whatever reason. Spending time chasing down and analyzing systems that don't fit is a bit like a dog chasing its own tail.

This exercise also sets the stage for a working relationship within the team that is collaborative, interactive and iterative—therefore typically generate the most successful results.

DATA IS KING

Gathering the required data to lay the foundation for a CEMP can be a tedious chase for details and numbers, rather like one long dumpster dive into your facility's operational history. However, a thorough analysis of your facility's condition, operational expenses and building systems will provide the foundation upon which one builds projections, develops energy reduction goals, potential infrastructure improvement plans and associated costs, and projected payback.

Research and review the utility bills—and the associated rate structures—for the past year. This will provide baseline data.

Examine the heating degree (HDD) and cooling degree (CDD) days, as well as geographic and weather data, juxtaposed against the energy costs and consumption.

Before heading out to conduct an on-site audit, examine any existing facility documentation such as floor plans, as-built drawings, and the operating schedule of the laboratory.

THE TOOLS OF THE LABORATORY TRADE

Obtaining and reviewing a complete equipment and tools data set—hoods, freezers, centrifuges, incubators, hotplates, spectrometers, computers, furnaces and vacuum pumps are just some of the energy consumers in a lab—should be part of developing a laboratory specific CEMP. We'll take a deeper look at the energy implications of these tools of the trade in a future column. But keeping close tabs on making daily operations as efficient as possible, while investing in updated equipment utilizing a considered, timely approach can go a long way.

Common lab equipment utilizes a surprising amount of energy on a daily basis. And, while the inventory and usage patterns of most lab equipment typically fall outside the normal purview of the facilities team, documenting and including this information can lead to significant energy savings.

FACILITY CONDITION AUDITS

Auditing existing conditions in a laboratory and the building it's housed in are at the heart of developing a CEMP. Review the condition, energy performance and opportunities for improvement of the following:

- The building envelope, including roofs, walls, foundation, insulation, glazing, sun shading and any external energy features such as solar panels;
- Building systems, including heating, ventilating, air conditioning, plumbing, electrical and waste (particularly if pumps are utilized in the waste system). Pay particular attention to ventilation systems, as outside air use is a major driver of energy consumption in laboratories;
- Lighting, including opportunities for daylighting and efficient lighting controls; and
- Building management systems.

A VIRTUOUS CYCLE

Analyzing, adapting and improving the energy performance and sustainability of labs and other facilities is a never ending effort, with course corrections driven by today's requirements for flexible lab space, continually improving building systems technologies and evolving regulations. Regardless of these external factors, setting up a scheduled revisit and review of your CEMP optimizes building performance and laboratory efficiencies. It's a virtuous cycle.

RESOURCES

There are a number of resources providing baseline information when attempting to minimize the energy consumption of a lab, increase its sustainability and stay abreast of both technology developments and regulatory changes.

Many universities have developed programs, and offer information gleaned from both external studies and firsthand experience gleaned from their own lab facilities. While information sources are too numerous to list, a few good places to start include the International Institute for Sustainable Laboratories (www.i2sl.org); National Institute of Building Sciences: Whole Building Design Guide (www.nibs.org); The Association of Energy Engineers (www.aeecenter.org); and a variety of books which can be obtained through AEE, including *Energy Management Handbook, 8th Edition* by Steve Doty and Wayne C. Turner; *Creating a Strategic Energy Reduction Plan* by Scott Offermann; and *Guide to Energy Management, 8th Edition* by Barney L. Capehart, Wayne C. Turner and William J. Kennedy.

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Blood storage applications require advanced cooling systems

LOOK FOR CUSTOMIZED SOLUTIONS TO ENSURE TEMPERATURE, RELIABILITY AND REDUNDANCY

Dave Nichols
Century Refrigeration

Large-scale blood product storage is among the most difficult laboratory and medical refrigeration challenges. To comply with regulatory requirements and avoid contaminating this very high-value product, cooling equipment must achieve extremely low temperatures and maintain these temperatures steadily. They must also use the safest refrigerants, be designed for maximum reliability and redundancy and be easy to maintain. Customized refrigeration solutions engineered specifically for blood storage applications are the best way to achieve these goals.

By relying on several smaller compressors to achieve the proper temperature, rather than a single centralized unit, blood storage applications can achieve full redundancy and better protect valuable products at a lower capital cost. Image: Century Refrigeration

ACHIEVING THE PROPER TEMPERATURE IS THE MOST DIFFICULT ASPECT OF BLOOD PLASMA STORAGE

Blood plasma storage refrigeration systems face unique demands, but by far the most critical is achieving the consistent low temperature required by regulatory guidelines.

Centers for Disease Control (CDC) guidelines state that blood plasma can be stored for up to 3 to 7 years under proper conditions, which is defined as stored at a consistent -35 F to -40 F. Systems must be able to maintain these temperatures even during maintenance. Since compressors must operate at 10 F below the desired storage temperature, plasma storage refrigeration compressors must reliably operate at -50 F. Refrigeration systems must use components specifically selected for their ability to operate in such extreme temperatures.

For example, the selection of fan motors with special low-temperature grease is a requirement. To lend additional strength and reliability at these temperatures, the copper tubing typically used in plasma storage cooling systems may be as much as twice as thick as in standard refrigeration equipment. In addition, the coils used must function at -50 F, while being subjected to periodic defrosting at temperatures of roughly 100 F, which leads to a great deal of expansion and contraction. The coils must be able to cope with these temperature extremes and still provide the necessary performance and reliability. As a result, coils for these applications are typically designed with as few as four fins per inch. Condenser coils are also designed as low as 8 fins per inch, far lower than in standard refrigeration equipment. The reduced number of fins make the coils less likely to clog and easier to clean.

SAFE REFRIGERANTS AVOIDS RISK OF CONTAMINATION

The sensitive nature of blood product requires the use of refrigerants that are unlikely to leak and cause costly dam-

age through contamination. The extremely low temperature demands of blood plasma and other blood product storage also affects refrigerant selection, since many refrigerants cannot flow well at such low temperatures. The refrigerant must also be deemed safe for use in medical cooling systems.

For example, ammonia is a poor choice for blood plasma storage applications. If ammonia were to leak into the plasma storage area of the refrigeration system, all the affected plasma could be contaminated and lost. This is far too costly a risk to take, especially for large-scale blood product storage applications. Other refrigerants, including R-507, can perform appropriately at the low temperatures required and also pose a lower safety and contamination risk.

DESIGN FEATURES THAT FOSTER RELIABILITY, REDUNDANCY AND EASE OF MAINTENANCE

Many systems are designed as a single, large, central unit, which is not a good choice for blood product storage. If the compressor in such a unit fails, or even begins to run below its intended capacity, the entire facility can go down, leading to the loss of a large amount of high-value blood products.

A more suitable design is to divide the cooling among a number of smaller compressors. This significantly reduces the overall impact of a single compressor losing efficacy or going down entirely. In addition, systems with a number of smaller compressors are easier and less expensive to make fully redundant. Full redundancy is ideal in blood plasma and other blood product storage applications, given the extremely demanding and precise CDC regulations they are subject to and the high value of the products themselves. Fully redundant systems allow for maintenance to take place as necessary, without concerns over system failure.

In addition, this design reduces overall maintenance demands and makes it easier for end users to perform necessary maintenance. As a result, the system can be restored to functionality quickly in the event of most issues, without having to wait for the OEM to send service technicians. Effective monitoring systems add to the systems' reliability and low downtime, enabling operators to detect issues early on.

For example, Century Refrigeration of Pryor, Okla., customized a system for a blood and plasma storage facility that required ultra-low room temperatures of -40 F. The condensing units had to be installed using the limited amount of space available. Unit coolers had to be installed in the penthouse, requiring refrigerated air to be distributed over 80 feet with a 90 degree turn down, creating a high static pressure application.

The facility had been operating using an ammonia refrigeration system, and the owner had health and safety concerns about using ammonia. They wanted to eliminate the potential for loss of product inventories due to a possible leak in the ammonia refrigeration system.

To reduce these risks, the company supplied a new system that uses ten dual-circuited condensing units with 30HP two-stage Bitzer compressors. The compressors operate on refrigerant 507a, minimizing potential product loss from an ammonia leak. The Century condensing units maximized system redundancy and reliability while minimizing footprint. They were matched with dual circuit Century PFE blast freezer unit coolers with Ultracase coils

Condensing units must be customized for blood product storage applications in order to be able to operate at temperatures as low as -60 F. Image: Century Refrigeration

utilizing copper tube sheets. The system used amperage monitoring and pressure/temperature transducers to provide overall system control. The control and monitoring system was designed to be completely compatible with the existing building automation system. The resulting system had built in redundancy, with 20 percent additional standby capacity.

CUSTOMIZATION IS THE BEST OPTION

The demands of blood product storage are too great, and ultimately too application-specific, to support the use of off-the-shelf refrigeration technology. To guarantee success, blood product storage refrigeration systems should be custom-designed, with individual components custom-selected and sized to sustain the necessary low temperatures, avoid contamination and product loss, and simplify maintenance.

When designing new or replacement blood product storage cooling systems, it is always best to work with a refrigeration technology company that can provide expert, customized design, manufacturing and support.

Dave Nichols, Account Manager at Century Refrigeration (a division of RAE Corp.) of Pryor, Okla., is a refrigeration expert with over 52 years of experience in the industry. He began working on the refrigeration of "pop boxes" with the 7-Up Bottling Company, and completed his certificate in Air Conditioning and Refrigeration Technology from Oklahoma State University in 1969. Dave has worked as an employee or representative for RAE Corp. since 1978. www.raecorp.com LD

Moderna Therapeutics Clinical Manufacturing Facility, Norwood, Mass.

- **Cost:** $110 million initial investment
- **Size:** 200,000 sf
- **Project team:** Steve Harbin, Moderna's SVP of Manufacturing and Operations (internal lead); DPS Engineering (engineer and architect)
- **Description:** Moderna Therapeutics, a clinical stage biotechnology company, is building a state-of-the-art Good Manufacturing Practices (GMP) clinical manufacturing facility in Norwood, Mass.

To support and manage this anticipated breadth of clinical studies, Moderna's Norwood facility will enable the manufacture, quality, control and supply of clinical grade mRNA therapies and vaccines for Good Laboratory Practices (GLP) toxicology studies as well as Phase 1 and Phase 2 clinical studies.

At the site, Moderna will carry out all manufacturing activities—from raw material production to active pharmaceutical ingredients (APIs), formulation, filling and finish.

The clinical supply facility will host GMP manufacturing and quality control; the company's Personalized Cancer Vaccines unit; preclinical technical operations and testing; and general administrative functions to support these teams. At the facility's opening, the annual GMP manufacturing capacity will be 40 GMP mRNA lots and is expected to scale up to over 100 GMP mRNA clinical scale lots annually in the future. Approximately 100 of Moderna's current 460 team members will move from the company's three existing locations in Cambridge, Mass., to the Norwood facility. In addition, Moderna plans to hire more than 100 new employees for the Norwood site.

In addition to the Norwood facility, other key components of Moderna's early development engine include its collaborations with leading research organizations Charles River Laboratories, to support GLP toxicology studies, and Pharmaceutical Product Development, LLC (PPD) to support Phase 1 and Phase 2 studies. The company is also building a highly automated and digital enterprise to seamlessly integrate and orchestrate cloud-based IT systems to manage and industrialize the complex planning and execution of its mRNA pipeline scale-up at every stage of development. In addition, Moderna has amassed deep institutional expertise in the U.S. and global regulatory landscape. The ability to share and apply learnings from ongoing regulatory interactions across its ecosystem of internal therapeutically focused ventures and external partners generates a network effect that benefits Moderna and its partners, helping to advance programs through regulatory processes.

- **Completion date:** Early 2018
- **Contact:** Stephen W. Harbin, Senior Vice President, Manufacturing and Operations at Moderna Therapeutics; Steve.Harbin@Modernatx.com

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