Sustainable Laboratory Design: Challenges and Solutions

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Abstract:

This paper provides a case study analysis of a biohazard laboratory that is currently being designed at Northern Arizona University in the United States. The lab will be located in a high performance sustainable building that conforms to the United States Green Building Council's LEED program. LEED (leadership in energy and environmental design) is a rapidly growing sustainable building initiative that is currently being utilized in over 12% of new commercial construction in the United States.

This paper summarizes the challenges that are inherent in the design of sustainable laboratories including planning and programming, engineering challenges, bio-hazard isolation, and low energy design. In addition the paper will summarize some the "best practices" developed by the United States government's "Labs for the 21st Century" program.

Introduction:

Around the world, university researchers are often isolated by discipline or academic specialty. Computer scientists work in computer science buildings, biologists complete their studies in laboratories, and engineers work in engineering facilities. But recent trends suggest that there is growing movement toward collaborative research, where academic researchers work together to create new knowledge.

At our university, computer scientists are currently working with genetics experts to decode gene sequences, electrical engineers are collaborating with plant ecologists to study forest health, and civil engineers are studying the botany of mangrove swamps in an effort to develop plant based water treatment systems. Bio engineering, nanotechnology, biomimcry and the mapping of the human genome are other good examples of how collaboration between academic disciplines is changing the way we develop ideas and new research.

With thoughts in mind, Northern Arizona University has recently started design on an innovative new research facility. Named the Applied Research and Development Facility (ARD), this building will be developed to provide flexible research space for environmental research groups, geneticists, and computer scientists, as well as a business incubator that will help develop new businesses from the technologies and research we develop. Our design team has called the facility "a marketplace for ideas".

ARD is also being designed as a high performance facility. A high-performance commercial building is a building with energy, economic, and environmental performance that is substantially better than standard market practice (DOE, 2004).

High performance buildings are energy efficient, so they save money and natural resources, and they have reduced impact on the environment. ARD is being designed to meet the highest level (Platinum) of the U.S. Green Building Council's LEED certification system. When completed, this building will be one of only five buildings in the world that meet the requirements for LEED Platinum.

Addititionally, the laboratory portion of the building will also act as a pilot project for the U.S. Department of Energy's recently developed "Labs for the 21st Centrury Program." Both Labs 21 and LEED are cutting edge design protocols that have been developed to maximize the sustainability and energy efficiency of the built environment. The United States Green Building Council is currently in the process of developing a protocol for sustainable laboratory design called LEED for Laboratories.

Laboratory Programming

A major part of the facility (12,000 SF) will be designed to meet the laboratory needs of our geneticists, many of whom specialize in the research of biohazards like anthrax. In the United States, research laboratories must conform with the standards for Bio Safety Laboratories (BSL) established by the Centers for Disease Control, and the National Institutes of Health.(1) These standards are categorized by number from BSL 1 (the lowest level of safety) to BSL 4 (The highest level of safety) (U.S. Institute for Health et. al, 1999).

Given the toxicity of some biological agents, and the government's growing concern over bio hazard use in terrorism, our facility will be designed to meet the requirements for BSL3. At Biosafety Level 3, emphasis is placed on barriers that will protect personnel and contain potentially infectious aerosols. For example, all laboratory manipulations are performed in a bio safety cabinets or other enclosed equipment, such as a gas-tight aerosol generation chambers. Secondary barriers for this level include controlled access to the laboratory and ventilation requirements that minimize the release of infectious aerosols from the laboratory. Some typical BSL 3 facility requirements include:

- Physical separation from access corridors
- Fully sealed laboratory envelope
- Self closing, self sealing double door access
- Negative Airflow (six - twelve air changes an hour minimum)
- Exhaust air cannot be re-circulated
- Advanced HEPA filtration systems

Since the discovery of anthrax in the U.S. Senate office building in 2001, our government has increased its scrutiny of how potential biotoxins are distributed and handled. While the security protocols are still under development, the ARD laboratories will also have to comply with new government regulations that control the security of biological laboratories.

Sustainable Laboratory Design: Challenges

Because of these design requirements, modern research laboratories use prodigious amounts of energy and raw materials and generate high levels of toxic air and water borne waste. According to the Department of Energy "laboratories typically consume 5 – 10 times more energy per square foot than office buildings, And some clean specialty laboratories can consume up to 100 times the energy of a similarly sized commercial structures…" (DOE, 2000). Because the primary objective of sustainable or "green" design is to reduce energy and resource use in buildings, laboratories pose significant challenges to building engineers.

A large part of problem is the ventilation requirement mandated by bio safety standards. With a ventilation requirement of 6-12 air changes per hour, building systems will have to continually treat outside air with heating or cooling to condition the make up air needed for the laboratory. Because the air can be contaminated once it enters the lab, exhaust air cannot be re-circulated, and this effectively eliminates many of the opportunities for energy savings. At the same time, laboratory fume hoods, which continually exhaust air, place continual energy demands on the lab HVAC systems even when un-occupied.

Laboratories also generate significant plug loads, loads that are generated when lab equipment is connected to the building electrical system. Good examples include autoclaves, spectroscopes, computers, and cleaning equipment. While an office building will typically require .5 to 1 watt per square foot, it is not unusual to see plug loads in laboratories approach 20 watts per square foot. Moreover, most of this load is used intermittently, creating a high diversity factor, which is difficult to assess. Recent trends in building design suggest that these connected loads will continue to increase with the development of new electronic lab equipment.

This connected equipment also generates significant heat, which places additional demands on laboratory cooling systems. For instance, most computer-based lab equipment takes 120 V power and then uses internal transformers to reduce that power to a lower voltage. This power reduction generates not only generates heat, it also wastes energy. According to the National Renewable Energy Laboratory, equipment plug loads can generate heat loads of up 10 watts per square foot. When fully operational, these connected, heat-generating loads exacerbate the substantial cooling loads required for safe laboratory ventilation.

A final challenge for our building designers will be the toxic waste generated by modern laboratories. In the pursuit of science, modern researchers utilize wide variety of solvents, acids, and reduction agents to complete their research work. In aerosol form, these chemicals are often captured via fume hood scrubbers, and then transferred to the building waste water system. Other "wet bench" chemical processes generate additional toxins that flow downstream via the drain and waste system. This laboratory wastewater must often be pre-treated on site before it is released into the municipal waste water system. This creates the need for additional on site treatment equipment – equipment that requires additional energy and chemical resources.

Sustainable Laboratory Design: Best Practices

As part of the Laboratories for the 21st Century program, building scientists at the National Renewable Energy Laboratory and the Lawrence Berkeley National Laboratory have developed a significant body of work that describes how to build sustainable laboratories. Their extensive work can be found at the LBL Design Guide for Energy Efficient Research Laboratories at http://ateam.lbl.gov/Design-Guide. In the interest of brevity, this paper will provide only a short description of the best practices developed by these groups.

Setting Goals

The saying "what gets measured, gets done" is an important idea in establishing goals for the design of a sustainable laboratory. It's important to set standards for energy performance in terms of Btu's consumed, dollars saved, or pollution created. Using these metrics, project design teams can establish written benchmarks that can help form an "institutional memory" for the design process. High performance building standards – like the LEED standards developed by the United States Green Building Council – are helpful tools for organizing and tracking project performance. (USGBC, 2004). Our project included a goal setting meeting that included all design, construction, and owner's personnel.

Planning & Programming

Project management experience suggests that early programming decisions will often determine much of the final cost for a building project. For instance, decisions made about a building's site orientation will often affect the ability to use the sun effectively in the building designs. In our area, if we orient a building so that most its windows face west, we will have to incorporate additional air conditioning to deal with the solar heat gain. It is also important to remember that buildings are much easier to re-design when concepts are still on paper.

In the past, many of these early design decisions were made on the basis of "first cost; or the initial cost to design and construct a building. As a rule, these first costs don't include the operating and maintenance costs associated with a building's twenty, fifty or even a hundred-year life. When added up these total or "life cycle" costs are typically much higher than first costs. A recent study completed by the Packard Foundation contends that while the first costs of typical market building will be $10 Million U.S., the thirty year cost of that building will be around $23 Million U.S. (Packard Foundation 2002). As a result, its important to utilize life cycle cost analysis as a decision making tool for the design process.

Effective life cycle decisions are best made by an integrated design and construction team that includes the owner, design architects, engineers, construction managers, trade subcontractors and vendors, and building commissioning agents. Working together, this group uses an iterative process to evaluate design decisions that will affect the performance of the entire building. As an example, the site location of a building often influences day lighting opportunities that can reduce artificial lighting that in turn can reduce cooling loads. Cooperative "whole building" design process creates opportunities that can maximize the energy efficiency, water conservation, flexibility, and productivity of a facility; opportunities that are often lost or ignored when design groups work in isolation.

Isolate Laboratory Spaces from Service Spaces

Because laboratories require 100% outside air, every square foot of space will require extensive energy usage. As such, designers can minimize HVAC requirements by separating office and support spaces from laboratory areas. Our project will isolate the laboratory components on the top floor of the building. At this location the stack effect of rising warm air will allow us to use preconditioned air from other spaces to help meet the prodigious air supply needs for the laboratory areas.

Utilize Efficient HVAC distribution

Typically, fan energy requirements are a product of duct system design. Complicated duct systems with extensive elbows, transitions, and shapes, can increase air resistance, which compromises the efficiency of fan motors. Duct and piping systems should actually be over sized to reduce resistance and increase fan and pump efficiency.

If the building is properly configured, tempered return air from non-critical areas like offices can often be used to meet ventilation requirements for lab sectors of the building, minimizing the need to condition large volumes of outside air.

To maximize HVAC efficiency in laboratory facilities, it is important that designers consider duct and mechanical equipment locations early in the design process. This requires a highly integrated design approach that includes all members of the project team.

Our project will incorporate an "interstitial" mechanical space that is located above the laboratory floor. This space will include all of the fume hood fans and motors, filter banks, piping and controls required for the laboratory proper. Placing this equipment in its own area reduces installation costs and allows for efficient and timely operations and maintenance.

Right Size Equipment

During a recent tour of a newly completed building, the facility engineer complained about the size and redundancy of the mechanical systems. He complained that engineers have a tendency to design systems to meet worst-case scenarios and to compensate for design flaws and installation errors. Over designed HVAC systems increase long term energy use, and create equipment short cycling problems, which leads to increased maintenance costs.

A better strategy is to carefully "right size" equipment by specifying equipment that can operate efficiently at variable loads. Good examples are screw chillers, module boilers, variable drive motors, and variable air volume devices – equipment that can be configured to work efficiently under changing load conditions.

Concentrate on Fume Hoods

Recent studies suggest that in large laboratories, a typical fume hood will consume as much energy as an entire house. To maximize energy efficiency in a laboratory it is critical to carefully review the number, size, and location of each fume hood. Typically, lab designers are required to specify equipment that will isolate chemical contaminants by maintaining a constant flow – or face velocity across the front of the fume hood. Today, Variable air volume hoods can modulate the conditioned air that is exhausted through the hood, significantly reducing long-term energy usage. Additionally, newly developed laminar flow hoods use reduced face velocities to contain toxins, and this reduced air flow can significantly minimize energy use.

Commissioning and Monitoring

One of the key features of sustainable design and construction is the commissioning process. Commissioning is a systematic process that insures that the facility has been built to meet or exceed the design specifications for the facility. In whole-building commissioning, and independent agent works with the design team from the start of the project to develop measurement protocols for energy performance, equipment installation, control operations and other key building functions. These protocols are summarized in a document that describes how the building should work, and more importantly how the building can be operated and maintained to achieve peak performance. At the end of the project, the commissioning agent uses this commissioning plan to test and verify that all building components and processes meet the design specifications.

Natural systems are adept at using feedback loops to monitor current conditions and adjust their systems to meet changing conditions. But building conditions are rarely static, and to maintain optimum performance building engineers should continually monitor building operations. Our facility engineers will use the energy goals set during preliminary design to establish useful benchmarks for measuring and controlling our building's operations. New advances in direct digital controls (DDC) and energy monitoring and control systems (EMCS) can be used to develop useful feedback loops that can be used to monitor and control changing building conditions.

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