Ushering in the New Age of Laboratories: Smart Labs in Practice

Preprint

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Ushering in the New Age of Laboratories: Smart Labs in Practice

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National Renewable Energy Laboratory

ABSTRACT

Ventilation is a defense mechanism to mitigate airborne hazards produced during research activities in laboratories. As a vital component of maintaining healthy, safe, indoor air quality, laboratory ventilation systems can fall victim to ineffective operation, posing a risk to researchers. Furthermore, system inefficiencies can lead to up to 50% wasted energy (Brase 2016).

By providing a framework to improve safety and energy efficiency through optimized ventilation and operations, the Smart Labs Toolkit guides laboratory stakeholders through a straightforward holistic approach to achieve a dynamic Smart Labs program. A Smart Labs program employs a combination of physical, administrative, and management techniques to plan, assess, optimize, and manage high-performance laboratories.

Grounded in the Smart Labs methodology, the National Renewable Energy Laboratory (NREL) implemented a successful Smart Labs program to oversee the design, construction, maintenance, and operations of its individual laboratories. To accomplish this effort, NREL's key stakeholders created an internal partnership to align NREL's existing laboratories with Smart Labs principles and solidify organizational roles for the safe and efficient operation of laboratory assets. The program provides approaches for organizations to develop and implement decarbonization strategies focused on laboratory building design and operation. This paper outlines lessons learned, and best practices employed by NREL to develop a crosscutting Smart Labs team, and effectively communicate and achieve safety and energy goals. Strategies include specific Smart Labs best practices, such as implementing a pilot Laboratory Ventilation Risk Assessment—a systematic process for identifying risk from airborne hazards and informing dynamic demand-based ventilation to enhance safety and energy efficiency.

Introduction

Air is essential to human existence; especially in the realm of the built environment, indoor air quality plays a key role in the health, well-being, and productivity of building occupants. In research laboratories, the consequences of poor indoor air quality are typically higher than in other building spaces, making them a proving ground for effective ventilation strategies. Some research activities can generate hazardous airborne contaminants that can pose both immediate and long-term risks to the health of laboratory researchers.

A common misconception across the laboratory industry is that higher ventilation rates yield more-effective mitigation of risk to airborne hazards. However, overventilation can cause turbulence in the space, leading to excessive energy consumption, and result in other issues. Overventilation is especially impactful on laboratory facilities with low tolerance to risk, where it can potentially cause more problems than the benefits it provides.

Ventilation can account for 40%–85% of total energy use in laboratory buildings (International Institute for Sustainable Laboratories 2020a). Figure 1 shows the end use load distribution in a typical laboratory building.

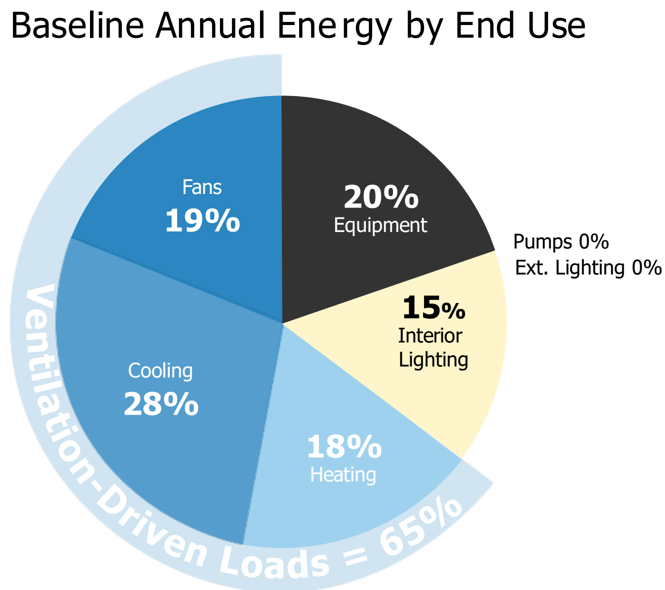

Figure 1 Energy use by end-use type in a typical laboratory building. Values were calculated from the OpenStudio energy model developed for the NREL Research and Innovation Laboratory (Group 14 Engineering, PCB 2021). (Image Credit: Amanda Kirkeby, NREL)

Because of the higher energy loads associated with laboratories, the impact of lab facilities on the total energy use of a campus is significant. According to the Commercial Building Energy Consumption Survey (CBECS), the average energy use intensity of a laboratory space is 318.2 kBtu/ft^2, 3 times that of an office (116.4 kBtu/ft^2). Therefore, improvements in laboratory facilities can yield significant opportunities for achieving cost savings, reductions in emissions, and resilience of operations. For example, the University of California Irvine realized total energy savings across 10 academic labs by effectively implementing a Smart Labs Program (Brase 2016).

Employing the Smart Labs Process

Implementing changes in mission-critical spaces can require significant upfront capital expenditures and can be challenging to implement. Research organizations may face a lack of funding, uninformed management, lack of awareness of the true state of operations, uninformed researchers, or policies inhibiting changes in critical research environments. To help organizations navigate these challenges, the U.S. Department of Energy (DOE) Federal Energy Management Program (FEMP) developed the Smart Labs Toolkit (Federal Energy Management Program 2022). The Toolkit guides users through a systematic process based on the best practices of partners of the DOE Better Buildings initiative's Smart Labs Accelerator; in 2018, those partners realized savings of 103 billion Btus and an average portfolio energy consumption improvement of 11% (U.S. Department of Energy Better Buildings Program 2022). This systematic process, known as the Smart Labs process, employs a programmatic approach coordinated by a team that spans an organization's structure. The approach involves four phases – Plan, Assess, Optimize, and Manage. As illustrated in Figure 2, the Plan phase defines a road map, initiating an ongoing cycle of Assess, Optimize, and Manage.

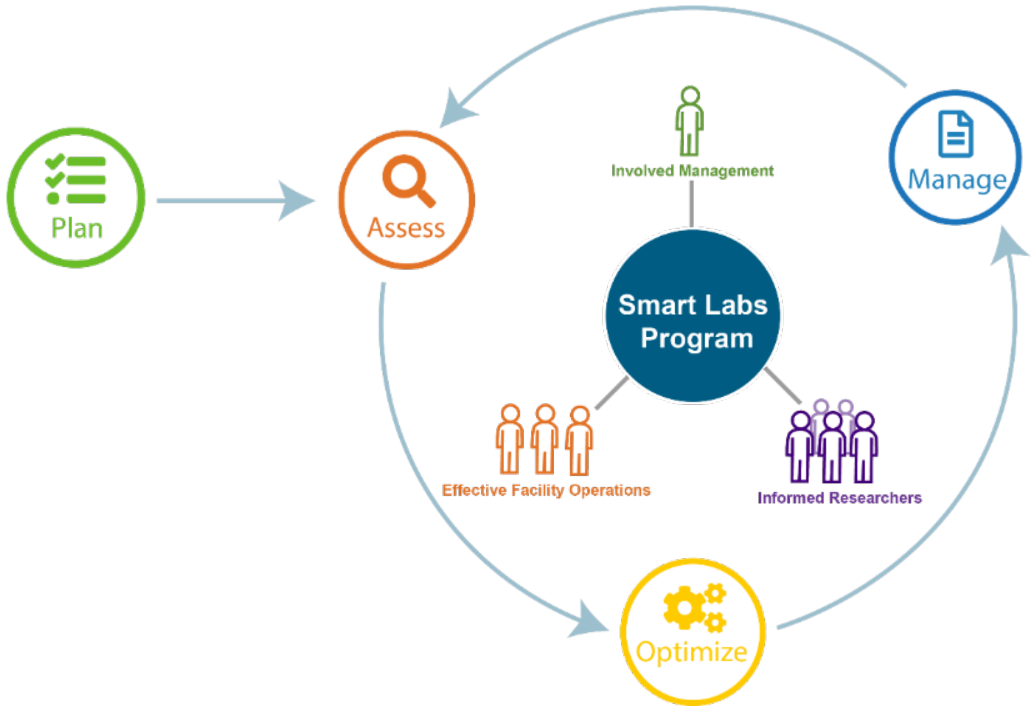

Figure 2 Smart Labs Toolkit process showing how to approach development of high-performance safe and sustainable labs. (Image Credit: Amanda Kirkeby, NREL)

The Smart Labs approach involves four phases:

- **Plan:** A team of key stakeholders is formed, efforts are prioritized, baseline metrics are collected, and a road map for a Smart Labs program is outlined.
- **Assess:** A thorough assessment of lab facilities is performed to identify improvement measures, including assessments for ventilation, energy, water, and resilience. A scope of work is developed for performance improvement measures.
- **Optimize:** Improvement measures are implemented to optimize operations. Improvements range from no- or low-cost upgrades and recommissioning of systems to full system replacement or significant renovations. A building management plan is then developed to inform continued operation of the optimized laboratory systems.
- **Manage:** Lab facilities are managed in an ongoing, dynamic way. The building management plan outlined in the Optimize phase defines parameters for ongoing assessments, with guidelines for tracking performance metrics, managing change, and maintaining persistent savings over time.

As illustrated in Figure 2, the plan phase defines a road map and initiates an ongoing cycle of assessing, optimizing, and managing the laboratory's building performance.

Ventilation as a Central Element

Air is the primary carrier of heat, moisture, contaminants, and airborne hazards in and around laboratory buildings. As a result, the ventilation system serves a central role in ensuring the safety of researchers within the laboratory environment. A key metric when defining ventilation requirements within a lab is the ventilation effectiveness—the measure of effective removal of airborne contaminants from the space. Strategies for achieving high ventilation effectiveness are illustrated in Figure 3.

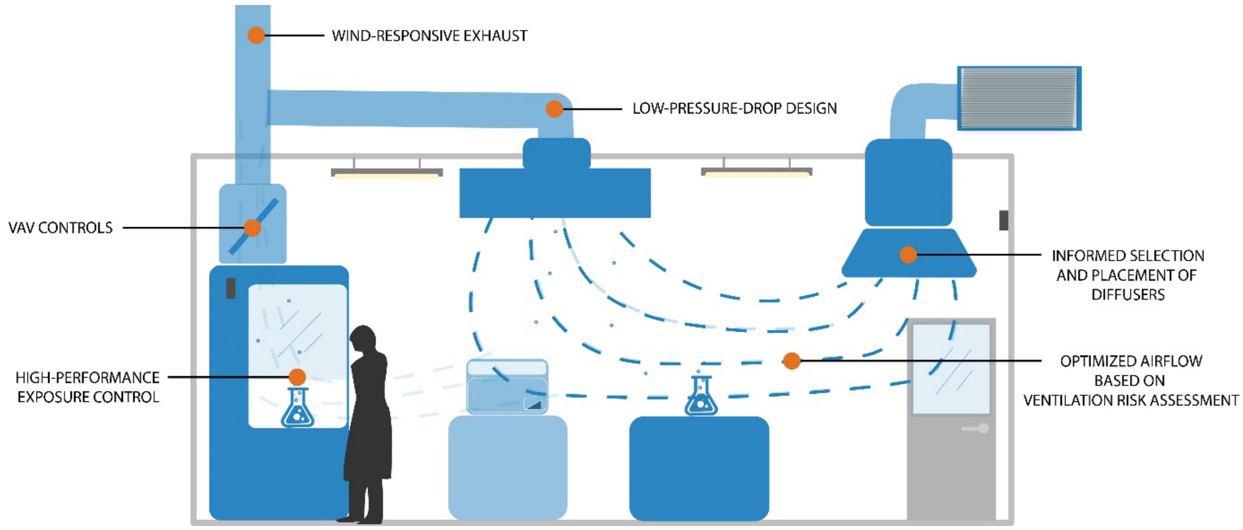

Figure 3 Key strategies for achieving high ventilation effectiveness in laboratory environments. (Image Credit Amanda Kirkeby, NREL)

In the ideal laboratory environment, supply air enters the lab environment through supply diffusers and sweeps across the space toward exhaust devices, removing contaminants from the space, as seen in Figure 3. This directional flow of air through the space begins with an informed selection of diffuser location and type, and placement of equipment within the space. To visualize the impact of different equipment on the ventilation effectiveness, a computational fluid dynamic (CFD) modeling analysis can be performed. The CFD model informs design decisions about placement of exposure control devices and furnishings throughout the space.

Once the space has been designed for optimal ventilation effectiveness, the proper ventilation rates are determined based on the hazards or chemicals associated with the lab. A central component of the Smart Labs approach is the laboratory ventilation risk assessment (LVRA) —a systematic process for evaluating the risk of exposure to airborne hazards, based on a characterization of the activities and hazards associated with the space as seen in Figure 4. Based on the evaluation of risk, the LVRA process provides recommendations for the ventilation rate needed to effectively mitigate airborne hazards within the lab. Combining this assessment with variable air volume controls and demand-control ventilation, operations can shift dynamically to raise and lower ventilation rates based on contaminant detection and occupancy within the lab (Sharp 2021).

Once initial setpoints are reached through thorough assessment, monitoring lab environments with analytics is needed to understand the operational state of the ventilation system. Through ongoing commissioning, the team can continue to assess the state of system operation and ensure it continues to operate as designed to enhance safety and optimize energy efficiency within the laboratory environment.

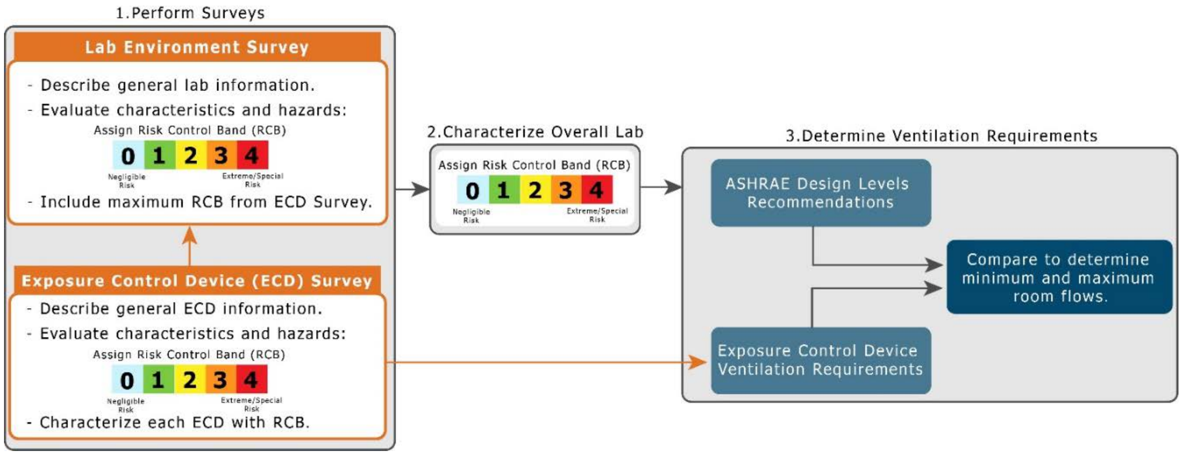

Figure 4 Laboratory ventilation risk assessment (LVRA) tool guides users through performing surveys to characterize individual labs and determine ventilation requirements based on airborne hazards present. (Image Credit: Amanda Kirkeby, NREL)

Tools for Implementing Smart Labs

Laboratories are complex and require structured, on-going management, as outlined above. The Smart Labs Toolkit brings together best practices, lessons learned, and resources into one location to guide lab managers, facility and engineering staff, environmental health professionals, researchers, and other staff to operate laboratory facilities as energy efficiently as possible. Following the four phases of Plan, Assess, Optimize, and Manage, the Toolkit outlines a process to achieve and operate safe and efficient high-performance labs.

As part of the Smart Labs Toolkit, the LVRA tool guides facility staff through the LVRA process, outlined in Figure 4, which involves two surveys—one of the lab environment and one of the exposure control devices within the lab—to characterize the risks associated with each exposure control device (ECD). The LVRA user guide describes the process in detail (International Institute for Sustainable Laboratories. 2019).

The Smart Lab Toolkit is also paired with the HVAC Resource Map for Laboratories, which provides a broad range of technical resources and guidance on HVAC strategies specific to high-performance laboratories (National Renewable Energy Laboratory 2021a). For example, the resource map includes tools such as the Laboratory Fume Hood Energy Modeler, which can be used to estimate annual fume hood energy use and costs to create comparative energy-use scenarios that contribute to the development of improvement measures (Lawrence Berkeley National Laboratory, n.d.).

By bringing resources, tools, and best practices learned from leading organizations in the high-performance laboratory industry into a central location, the Smart Lab Toolkit helps organizations access the information and guidance they need to successfully implement programmatic approaches that improve safety and reach their decarbonization goals.

Smart Labs at NREL

The DOE Better Buildings initiative's Smart Labs Accelerator challenged research organizations across the United States to push the boundaries of smart, efficient, and safe laboratory operation and design practices. The Smart Labs Accelerator, which occurred from 2017 to 2020 worked with universities, federal agencies, and national laboratories to expand and advance these efficiency and safety strategies in real-world applications and to gather lessons learned and resources in a central location. A participant of the Smart Labs Accelerator, the Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) in Golden, Colorado, took up the challenge to integrate Smart Labs principles into its laboratory design and operations. NREL's 12-building South Table Mountain campus, which was the focus of this effort, embodies the living laboratory concept by using the campus itself as a research instrument. NREL's Intelligent Campus Program was responsible for implementing the Smart Labs effort at NREL. The Intelligent Campus program creates a relationship between operations and research, and it has been instrumental in building out NREL's energy management information system (EMIS), which was a key resource in developing a Smart Labs program. The EMIS includes analytics and trends in energy and water data, which demonstrate ongoing performance and allows operators to optimize campus operations (Federal Energy Management Program 2021).

The Smart Labs Program at NREL is an important driver of decarbonization implementation strategies in the Net Zero Carbon Labs Pilot at NREL. In the Net Zero Labs Pilot: NREL Roadmap to Decarbonization, implementation of a Smart Labs Program on the NREL campus provides a potential impact of a 5–15% reduction in Scope 1 emissions (National Renewable Energy Laboratory 2021c). This significant emissions reduction stems from the initial success of the NREL Smart Labs program pilot projects outlined above.

Initially, NREL's Smart Labs efforts arose from internal conversations about improving the laboratory's energy efficiency. Sustainability and mechanical engineering staff reached out to the International Institute for Sustainable Laboratories (I2SL), a professional society focused on building more sustainable laboratories. Through the relationship with the Smart Labs Accelerator, NREL was able to send operations and safety staff to multiple trainings and events with other national laboratories to learn more about Smart Labs practices. Early on in this process, NREL staff leading the Smart Labs efforts realized that policy and procedural changes would be required to ensure the success of the program, specifically changes in policies owned by environment, safety, health, and quality (ESH&Q) office. These policy changes continue to be a challenge in rolling out a fully developed Smart Labs program.

After realizing the importance of operational and safety changes—regarding both technical and policy requirements—needed to advance a Smart Labs program, specific policy leads from the ESH&Q office were brought into the program and process. Additionally, new team members, including professional industrial hygienists, chemical purchasing and waste management, and gas detection experts were brought onto the Smart Labs team. Industrial hygienists were able to specifically address both the safety aspects of a Smart Labs program related to ventilation and the decision-making process for determining safe operations with various experiments across NREL. ESH&Q staff who have developed policies and procedures could explain the decision-making process for ventilation requirements in a laboratory, and they could identify the changes needed to address any ventilation requirements.

Effective management of change is a critical element of ensuring a successful and safe Smart Labs program. ESH&Q experts in chemical management and gas detection at NREL, along with industrial hygienists, were able to articulate current change management processes and identify the steps required to expand those processes within a Smart Labs context. For example, laboratories with lower hazard ratings and risks can be run at lower ventilation rates, but doing so requires in-depth and ongoing knowledge of chemicals being used in a space to ensure safety parameters can be changed should the need arise for researchers. Such change management and coordination between the operations and safety elements of an organization can be significantly improved by following the Smart Labs methodology.

The NREL Smart Labs team chose to develop a pilot program for the Smart Labs process in the Energy Systems Integration Facility (ESIF), a building constructed in 2014 that has advanced building controls and analytics. These advanced controls allow for real-time tracking of energy and ventilation within individual ESIF laboratories as well as throughout the entire facility. After analytics for the volumetric flow rate of air (CFM/sf) were developed for each laboratory within the ESIF, a discrepancy between expected and actual air change rates was noticed in two labs. The discrepancy opened a conversation about the opportunities that both the EMIS and a Smart Labs program could provide in terms of both increasing energy efficiency and improving on-going insights into the safety within the labs. The conversation occurred from perspectives encompassing both general exhaust and potential opportunities with other safety mechanisms (e.g., sash heights in fume hoods).). Through these conversations, the NREL Smart Labs team discovered that the process for determining required operational ventilation rates for individual laboratories was neither well-defined nor well-documented. Additionally, the development of the ongoing tracking within the EMIS offered a new opportunity to monitor ventilation rates, which especially interested the ESH&Q team. These discussions led to the collaborative development of a Smart Labs charter by NREL Site Operations staff and NREL ESH&Q staff, and the charter led to the rollout of a full LVRA process for the ESIF. NREL plans to finalize the pilot within the ESIF through completion of the full LVRA completion and to then use documented findings to build a portal within the EMIS to track metrics for energy efficiency and safety within laboratories.

NREL had been building toward this role out of the Smart Labs program in 2020 when the COVID-19 pandemic shifted the entire laboratory to off-site work and temporarily halted work within the laboratories themselves. As researchers returned to the laboratory under COVID-19 restrictions, NREL was still able to pursue the LVRA process in ESIF and take several steps toward the development of a Smart Labs program. While the operational and safety impacts of the pandemic paused the momentum of the Smart Labs program at NREL, the pandemic has brought new perspectives on safety and energy efficiency approaches at NREL. For example, the pandemic highlighted the importance of streamlining communication and decision-making and the critical need for resilient policies and procedures. The Smart Labs program continues to expand and be brought into other conversations about improvements in safety and laboratory energy efficiency and decarbonization. Currently, NREL Smart Labs team members include site operations staff, maintenance staff, mechanical and electrical engineering employees, facilities staff, industrial hygienists, policymakers, ESH&Q staff, IT services staff, research operations managers, sustainability staff members, and directors from Site Operations and ESH&Q.

Peer Network

As the Smart Labs Accelerator ended in 2020, the Federal Energy Management Program (FEMP) supported the work of a Smart Labs group for the DOE national laboratories. Composed of EHS&Q, facilities, sustainability, and energy staff, the group provided an open forum to discuss common challenges for national labs pursuing a Smart Labs program. One lab shared how it was reinvesting energy savings into renovating buildings. Another lab shared its process and provided a template to the other national labs for updating new construction requirements provided. NREL EHS&Q staff shared lessons they learned by working with scientists to meet joint goals, and they brainstormed safety and efficiency opportunities with the other national labs. Because the national labs share similar management structures, project financing, policies, and regulations, the discussions applied broadly across the national lab group.

NREL used this group to engage staff from the other labs on experiences and best practices. For example, industrial hygienists at NREL met industrial hygienists at Lawrence Berkley National Laboratory and Los Alamos National Laboratory, who were already considering completing their own LVRA processes. NREL staff discussed who completed the risk assessment, how many labs were completed, and how the LVRA efforts were changing policy. These conversations gave NREL's industrial hygienists a clearer direction and intention for their own LVRA pilot.

Charter

Incorporating the Smart Labs methodology into an existing organizational structure can be challenging. A champion is required to lead the charge, coordinate efforts, oversee progress, and recognize accomplishments (International Institute for Sustainable Laboratories 2020b). The champion needs to facilitate conversations and efforts, especially across the organization.

The NREL charter set out to "create a Smart Labs program to oversee the design, construction, maintenance, and operations of [NREL] laboratories" (Belmont 2020).

To act upon the charter, an internal road map was developed by the NREL Smart Labs Team to guide initial conversation and coordinate team activities. The document is frequently updated to outline roles and responsibilities as they pertain to Smart Labs efforts, describe assessment processes, and define key goals for the program.

The charter is shared with the cross-cutting team to and includes the following sections:

- Goals
- Prioritization of buildings
- Timeline and plan
- Stakeholders with listed responsibilities
- Lab condition assessment
- Key performance indicators
- Stakeholder team
- Building inventory
- Signatures of Site Operations and EHS&Q Directors.

The charter document made it possible to articulate the goals of the Smart Labs program more clearly to NREL leadership and garner buy-in from both Site Operations and ESH&Q staff. This document has been helpful, and it has been updated and referenced as the Smart Lab program progresses at NREL.

NREL Design Standards Updates

Incorporating Smart Labs requirements in all new lab buildings and all renovations of existing lab spaces is essential to implementing a Smart Labs program. NREL, like most organizations, has building design standards. A multidisciplinary group led by the NREL sustainability/Smart Labs coordinator and consisting of NREL mechanical engineers, a controls/data analytics specialist, and a Smart Labs consultant updated the NREL design standard. The updates include meeting the recommendations of the ANSI/AIHA/ASSE Z9.5

standard and the Smart Labs Toolkit, such as requiring lab variable air volume (VAV) systems, the use of a LVRA process to determine occupied and unoccupied ventilation rates, and the use of effluent modeling to determine the location and height of exhaust stacks to limit effluent entrainment to acceptable levels. The design standards also include NREL-specific requirements, such as designing ductwork for the highest anticipated flow, using low air pressure drop design, using occupancy/vacancy controls for lighting and ventilation systems, and using ASHRAE Classification of Laboratory Ventilation Design Levels to determine laboratory ventilation design levels. The requirements of the Design Standards are summarized in the NREL Smart Labs Checklist (National Renewable Energy Laboratory 2021b).

My Green Lab Progress

My Green Lab is a nonprofit organization promoting sustainable laboratory operations around the world. The Green Lab certification program engages researchers in a process to identify sustainable operations within a laboratory setting including energy, water, chemical, and waste management (My Green Lab 2022). NREL chose to tie this certification option with the Smart Labs program because it provides a way to make immediate changes in the laboratories, engages research staff in the ideas of energy and water efficiency in the laboratory space, and is a tool to recognize staff commitment to sustainability efforts. Engaging research staff is an important aspect of a successful Smart Labs program. Researchers make regular decisions about sustainability and energy and water consumption in a lab based on the equipment they purchase, the processes and chemicals they use, equipment run times, and waste management decisions. Such daily and ongoing decisions can positively or negatively affect both the safety and the sustainability of the laboratory. Researchers who understand the systems and buildings where they work and are aware of their impacts in the laboratory are an important asset in building or renovating laboratory spaces.

To initiate a pilot Green Lab certification pilot program, the NREL Smart Labs team initially engaged research operations managers from multiple facilities. Doing so allowed NREL to more easily identify laboratories that could be interested in the certification and ensured individual researchers did not have to ask permission to participate in the program, creating an easier pathway for participation. The managers identified five laboratories that would be interested in participating in the pilot program.

NREL also had multiple meetings with My Green Lab and encouraged NREL staff to take the free My Green Lab online training course. Those meetings and trainings better prepared NREL for the certification process. Having a central point of contact to coordinate the effort was essential to making the project successful. With so many stakeholders from the five laboratories involved in the certification process, having one point of contact ensured the process continued moving forward. This was especially important during the COVID-19 pandemic with many people working remotely and having limited access to the laboratories. It was also helpful to identify specific points of contact in each laboratory to ensure someone had a relationship with people in the labs and could connect with them about completing the survey that began the certification or answering questions about the certification process.

NREL is currently completing the first survey from My Green Lab, which will set the baseline for the pilot program. The laboratories will then have approximately 6 to 9 months to determine which additional steps, if any, they would like to take to improve their certification status. Once all phases are complete, NREL will determine ways to get more laboratories certified in the future.

Laboratory Ventilation Risk Assessment

As a key component of researcher safety, the laboratory ventilation risk assessment (LVRA) is a central to the NREL Smart Labs program. Starting with the ESIF laboratory building in the Smart Labs pilot, the initial LVRA consisted of two separate surveys. One, led by the lead industrial hygienist, focused on assessing the ventilation risk from research activities. The second, led by the facilities staff, focused on documenting the system operations serving the laboratory in question.

Using the LVRA tool in the Smart Labs Toolkit as a guide, industrial hygienists simplified the data collection to the specific information needed to provide a transparent documentation of the hazards within a space with clear translation to the ventilation rates recommended to mitigate exposure. This simplification of the tool, in collaboration with the FEMP Smart Labs program, led to the improvement of the LVRA tool that now allows organizations to perform this process in-house, reducing the cost of the process and including ESH&Q staff in the assessment process (International Institute for Sustainable Laboratories 2021).

A key lesson learned through this process concerned coordination across environmental health and safety staff and facility management staff. After two initial surveys, one by the industrial hygienist overseeing the laboratory safety and one by the mechanical engineer overseeing the laboratory operations, a joint survey of the lab was performed with both the industrial hygienist and facility staff. This initiated a conversation about optimizing for both safety and energy efficiency. By including both perspectives in the survey, both teams met their criteria in identifying measures to improve safety and facility operations.

The LVRA connects safety in a space with the operation of a given system, thus integrating key staff in the assessment and decision-making process so that system operations and safety procedures complement each other. At NREL, this pilot LVRA has initiated the momentum for the development of a laboratory ventilation management program (LVMP), which will lead to ongoing, dynamic assessment of laboratories for continued optimization of operations and ensuring safety.

Application of Smart Labs Principles: Research and Innovation Laboratory (RAIL)

NREL recently began construction on a 15,000 sq. ft. laboratory building, the Research, and Innovation Laboratory (RAIL), which will have two dedicated laboratory spaces. At the beginning of the design process, NREL intentionally set out to construct a laboratory built on Smart Labs principles. NREL found that integrating Smart Labs design components into NREL design guidelines, intentionally crafting a request for proposal and statement of work with innovative and energy efficiency options, incorporating modeling in the project, ensuring a strong commissioning process, and ongoing communication and iteration on controls sequences created a successful environment for the development of a Smart Labs facility. The RAIL is under construction and is planned to be in operation by the end of 2022.

In some cases, sustainable or energy efficient building options are highlighted as individual requests in a building design process and can end up being removed from the building design or become they require additional initial capital investment. NREL opted to shift the thinking with RAIL and opted to integrate Smart Labs principles into its design guidelines. This integration embedded strategies into the design-build performance specifications and ensured a more successful Smart Labs facility overall design. As NREL developed the Smart Labs

Checklist during the RAIL design review, engineers validated the incorporation of design elements within the RAIL and any updates required for the design guidelines.

In addition to having a full variable air volume system, the RAIL will have two unique energy savings features: a direct evaporative cooling system on the make-up air and indirect evaporative cooling on the exhaust side of the system. These features will allow for energy recovery in both winter and summer. During the winter, warm air exhausted from the building will be used to preheat the make-up air through a heat recovery coil. In summer, the evaporative cooling will allow cooled air to be recovered through a heat recovery coil. As part of the request for proposal for RAIL, NREL's mechanical team included several innovative cooling strategies for energy efficiency, including the evaporative cooling system. NREL staff met with other national laboratories to learn about their innovative energy efficiency options and then included several different options in their request for proposal. Doing so allowed the design team to choose the most cost-effective and efficient solution for the project while allowing for further innovation to be considered.

The RAIL project included several modeling efforts to validate the safe and efficient design of the facility. These modeling efforts were all required as part of the design of the facility. An energy model was developed to assess the performance of the facility compared to the energy use of an ASHRAE 90.1-2019 building. The final design for RAIL achieved a 33.1% energy cost savings from the baseline and a 48.9% energy use savings from the baseline with an expected EUI of 100.8 kBtu/sf/yr. Also, four iterations of computational fluid dynamic (CFD) models were used to determine the optimal diffuser type and location in the larger of the two laboratories. The performance of the CFD model determined that the use of laminar diffusers would significantly improve the ventilation performance at sitting height and would be similar in effectiveness at standing height to other diffuser models. Finally, wind tunnel testing validated the stack height, volume flow rate, and exist velocity to safely operate a targeted minimum exhaust volume flow to provide significant energy savings while maintaining safety at RAIL. The wind tunnel testing also validated the exhaust and supply air locations for RAIL, as it is near several other laboratory buildings. These modeling efforts improved the overall building design while also validating the energy efficiency and safety features of the buildings.

Beyond the initial design, the efficient operation of a facility is critical to realizing the savings intended. Efficient operation requires an effective controls sequence and appropriate feedback within mechanical and electrical systems. Appropriate metering and connection to the building automation system allow for ongoing validation that the system is operating correctly. NREL included extensive requirements for metering, motioning, and controls for the RAIL, and these will be further validated through the commissioning process. NREL also required controls and sequencing to be reviewed at 50% design to allow for robust discussion by NREL and the design team. Given that the RAIL is being built on a performance-based contract, it was especially important to have experts on the NREL team thoroughly review controls and sequencings to ensure the efficient operation of the building starting on opening day. For example, original design included a chilled water pump to be run throughout the year for freezer protection. The NREL team pointed out that because the system had a heat recovery and a heat coil before the cooling coil, using a different monitoring point—a sensor in front of the heat coil instead of outside air temperature—could provide the same protective capacity and reduce overall run time. In some instances where NREL and the design team could not agree on sequencing for the controls, NREL requested the systems allow for flexible operations instead of a specific sequence. The incorporation of flexibility and the ability to change operations based on programming instead of infrastructure was important to NREL to continue to iterate and expand on best system operational practices for Smart Labs in the future.

As a living laboratory, NREL is committed to continuing to optimize its systems and laboratories beyond the initial design. Once construction is completed, the RAIL will undergo an extensive commissioning process to validate the entire design of the facility. NREL also intends to complete a LVRA for the two laboratory spaces to create a baseline of operations. Commissioning and baselining through the LVRA will be the final stages of construction and will kick off the long-term operation of the RAIL. NREL will continue to iterate and learn from this building process as the RAIL becomes a fully operational Smart Lab.

Conclusion

Implementation of Smart Labs strategies is integral to optimizing energy efficiency and enhancing indoor air quality and thus improving safety for researchers. Additionally, energy efficient laboratories can directly support organizational decarbonization goals. Smart Labs' programmatic four-phased approach—plan, assess, optimize, and manage—to optimize laboratory operations systematically changes operational procedures that dictate laboratory operations, researcher behavior, and facility management. With a priority of occupant safety, Smart Labs strategies can also reduce resource intensity of research at a laboratory. The implementation of a Smart Labs program at the National Renewable Laboratory highlights key practices essential to successfully achieving ongoing savings and operational improvements through the Smart Labs program. First and foremost, a champion is needed to move a Smart Labs program forward, initiate key conversations, and coordinate crosscutting efforts. Building the program from a grassroots approach, with engaged staff to champion each component of the program, is a successful strategy for gaining traction across the organization that can bolster the Smart Labs team efforts. Leveraging the knowledge of peer networks with group brainstorms and working groups with similarly structured organizations can help laboratories navigate similar challenges and collaboratively determine best approaches. Modest advancements in complicated lab spaces can add up quickly to yield great enhancements for safety and energy efficiency. Especially in lab spaces with complicated operations that make it challenging to know where to start, finding success in initial smaller projects can build momentum for continued greater overall success.

The Smart Labs Program at NREL is a key driver of decarbonization implementation strategies in the Net Zero Carbon Labs Pilot at the NREL. In the road map to net-zero emissions, implementing a Smart Labs Program has a predicted emissions impact of a 5–15% reduction in Scope 1 emissions (National Renewable Energy Laboratory 2021c). This significant reduction emissions stems from the initial success of the NREL Smart Labs program pilot projects outlined above.

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References

Belmont, Suzanne. 2020. “Smart Labs Charter.” National Renewable Energy Laboratory. Internal.

Brase, Wendell. 2016. “Smart Laboratories Cut Energy Consumption More Than Half.” The Regents of the University of California. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/tools/UCISmartLabsInitiative_Feb222016.pdf.

Federal Energy Management Program. 2021. “Energy Management Information System Powers NREL’s Intelligent Campus.” U.S. Department of Energy (DOE), Energy Efficiency & Renewable Energy (EERE), Federal Energy Management Program (FEMP). https://www.nrel.gov/docs/fy21osti/77462.pdf.

———. 2022. “Smart Labs.” Smart Labs. 2022. https://www.energy.gov/eere/femp/smart-labs.

Group 14 Engineering, PCB. 2021. “NREL RAIL CD Whole Building Energy Model.” Group 14 Engineering, PCB. Internal.

International Institute for Sustainable Laboratories. 2019. “LVRA User Guide.” Smart Labs Toolkit. https://smartlabs.i2sl.org/pdfs/lvra-user-guide.pdf.

International Institute for Sustainable Laboratories. 2020a. “Assess.” The Smart Labs Toolkit. 2020. https://smartlabs.i2sl.org/assess.html.

———. 2020b. “Introduction to Smart Labs.” The Smart Labs Toolkit. 2020. https://smartlabs.i2sl.org/introduction.html#champion.

———. 2021. “Laboratory Ventilation Risk Assessment Tool.” International Institute for Sustainable Laboratories. https://smartlabs.i2sl.org/assess.html#lvra-deliverables.

Lawrence Berkeley National Laboratory. n.d. “Laboratory Fume Hood Energy Modeler.” Web Application. https://fumehoodcalculator.lbl.gov/.

My Green Lab. 2022. “My Green Lab Certification Program: A Commitment to Sustainable Science.” My Green Lab. 2022. https://www.mygreenlab.org/green-lab-certification.html.

National Renewable Energy Laboratory. 2021a. “HVAC Resource Map for Laboratories.” HVAC Resource Map for Laboratories. 2021. https://hvacresourcemap.net/#/laboratories.

———. 2021b. “NREL Smart Labs Checklist.” National Renewable Energy Laboratory. Internal.
———. 2021c. “Net Zero Labs Pilot: National Renewable Energy Laboratory.” National Renewable Energy Laboratory.
Sharp, Gordon. 2021. “Best Practices Guide: Energy Savings with Demand Based Control.” International Institute for Sustainable Laboratories. https://www.i2sl.org/documents/I2SLBestPractices_CuttingLabEnergyUse_September2021.pdf.
U.S. Department of Energy Better Buildings Program. 2022. “Smart Labs Accelerator Factsheet.” https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/BB%20SLA%20Factsheet%20Results%208_25_20.pdf.