Appendix L—Sustainability

Introduction and Issues

Sustainability is the ability to satisfy current needs without depleting resources needed for the future. The phrase “triple bottom line” (e.g., “people-planet-profit”) is often associated with sustainability to explain the benefits of balancing the financial bottom line with environmental and social goals in order to find effective solutions that can stand the test of time without compromising human health.

While safety remains of utmost importance in design and/or operation of a laboratory, minimizing waste and safeguarding long-term human health through protection of the environment is a high priority. Design, construction, and operation of sustainable laboratories requires a holistic approach that considers the interconnectedness of building systems. The project delivery process can be optimized with an integrated design approach and by establishing multi-disciplinary evaluation of issues regarding both the current uses and the potential future uses of a building.

Laboratories consume more resources and energy per square foot than other commercial buildings. Factors influencing laboratory energy consumption include: continuous operation, ventilation needs at exhaust devices, energy-intensive and heat-generating equipment, and use of water for steam sterilization and other processes. Furthermore, critical research and containment requirements in laboratories often require electrical power system redundancy to remain fail-safe.

This appendix outlines potential opportunities to increase the efficiency of the laboratory portion of buildings to achieve energy and cost savings, decrease pollution, and optimize material resource use. The appendix also highlights strategies to improve indoor air quality and lighting in order to increase productivity, improve worker comfort and well-being, and reduce maintenance issues related to occupant comfort.

Strategies for Existing Laboratories and Operations

Sustainability approaches within laboratories usually focus on design and construction of new facilities. However, improvements to operational and management practices of existing laboratories can yield meaningful savings and conserve material resources.

Commissioning

Commissioning, a process to verify systems are working as intended, has demonstrated median savings of 15% in existing buildings; laboratories have shown an average payback of retro-commissioning costs of one year or less.[1] Facility Managers might consider retro-commissioning, starting with an audit to assess energy and water consumed in the laboratory. When auditing, include retro-commissioning of equipment when possible. Systematic evaluation of equipment can identify problems that developed as equipment aged or as building uses changed. For example, recalibrating a temperature sensor is inexpensive but improves diagnostics and/or monitoring. Correcting a variable-frequency drive motor controller that operates at an unnecessarily high-speed saves energy and money over time without incurring significant first-cost.

Water and Energy Efficiency

Evaluate measures to improve energy and water efficiency in response to findings from the audit. Simple measures, such as upgrading to energy-efficient lighting or implementing after-hours airflow reduction (i.e., setbacks), can be taken. Conserve water by adding shut-off sensors and clearly labeling fixtures with instructional signage for occupants.

Evaluating Energy Efficiencies Using Audits

Develop a strategic approach prior to implementing the audit. Expand the audit process to evaluate material waste and to determine the effectiveness of any waste management strategies already in place. Follow the guidance in an approved or appropriate document such as Document 203, Health Care Waste Management Audit Procedures—Guidance, which was developed with the support of the CDC.[2]

1. Compare the percentage by weight of recyclable and non-recyclable items to total waste to evaluate effectiveness of recycling strategies.
2. Identify and focus strategies to reduce major contributors to the waste stream.
3. Donate unneeded, but functional, equipment instead of sending it to a landfill. Properly decommission and disinfect any potentially contaminated items prior to donating.
4. Evaluate recycling potential in terms of procurement goals. For example:
    a. An audit in a non-containment laboratory showing an abundance of PPE gloves could lead to a procurement preference for nitrile gloves since nitrile gloves not used with infectious materials are potentially recyclable.
    b. Establish purchasing guidelines to define minimum or recommended amounts of recycled plastic in conical centrifuge tubes.
    c. Purchase reusable autoclavable reagent reservoirs, where feasible, to reduce plastic waste.
5. Include vivaria in waste inventories. Consider the following where appropriate:
    a. Compost non-infectious bedding and discarded feed instead of landfilling or incinerating it.
    b. Change cage bedding based on use or ammonia level vs. on a schedule.

Energy Use in Laboratories and Potential Initiatives

Plug-in equipment such as autoclaves, centrifuges, and freezers account for up to half of the energy used in a typical laboratory. In addition to generating heat during operation, freezers consume a significant portion of that energy demand. Consider creating an internal competition or participating in the International Laboratory Freezer Challenge, a competition designed to promote sample integrity and reduce costs and energy.[3] Implement the best practices outlined in the Challenge's protocol: clean refrigerant coils to optimize performance; create searchable inventories to shorten the time freezer doors are open and reduce time spent locating samples; and reset Ultra-Low Temperature (ULT) Freezers from -80℃ to -70℃ to reduce energy consumption without having a discernible impact on temperature stability.[4] If equipment needs replacement, opt for more efficient models. See 3. Strategies for New and Renovated Laboratories, below, for recommendations.

Identify areas of potential inefficiencies related to occupant behavior in laboratory areas. For example:

1. Explore the impact of shutting chemical fume hoods using variable air volume controls when not in use. Harvard University implemented a "Shut the Sash" Program, which calculated utility savings of $200,000–$250,000 per year in the Department of Chemistry and Chemical Biology (houses 278 chemical fume hoods).[5]
2. Turn off autoclaves (except for constant-bleed autoclaves or those that are equipped with a sleep mode) at night and over weekends.
3. Forgo the drying stage in tunnel washers for Vivarium cages and allow cleaned cages to air-dry.

Good practices emphasize laboratory-specific operations and control strategies while better practices improve the ventilation design process with advanced computer or physical modeling techniques.[6]

Most energy use in laboratories is related to ventilation. Use tracer gas tests following the ASHRAE Laboratory Design Guide to calculate the air-changes per hour in an existing laboratory. Conduct airflow simulations to evaluate scenarios regarding spills or aerosols to reveal opportunities for improvement in ventilation component efficiency. Introduce neutrally buoyant helium-filled soap bubbles to a space to provide a visual evaluation of laboratory airflow. As the bubbles reach room temperature, they follow tiny air currents.

Develop "Green Chemistry" initiatives and protocols to reduce chemical waste at the source. Reduce or eliminate the use of hazardous chemical reagents, solvents, and products to save space and water while reducing hazardous waste and carbon dioxide releases. Understand the toxicology of chemicals in use as well as the principles of Green Chemistry outlined by the EPA.[7] Conduct an inventory of hazardous chemicals in use and develop a systematic process to reduce or eliminate those chemicals using alternate methods or replacing them. Explore databases regarding alternative methods and alternative chemicals such as the "Green" Alternatives Wizard, which is a searchable online database developed by the Massachusetts Institute of Technology (MIT).[8] Try to use chemicals that are less toxic, biodegradable after use, do not deplete ozone, and/or do not form smog. Consider less hazardous chemical alternatives, such as the use of fluorous solvents instead of chlorinated ones.

Eliminate chemicals when feasible. Allow glass to dry instead of using acetone. Avoid use of reaction solvents if crushing solids together will suffice.

In addition to the strategies above, consider use of general operational and maintenance guidance provided in well-established green building rating systems.[9–13]

Strategies for New and Renovated Laboratories

A sustainable design approach should result in a project with improved utility of spaces, enhanced occupant comfort and well-being, right-sizing of equipment, and protection of the environment.

Pre-Design

In terms of sustainability, the most critical activity in laboratory planning begins before the design phase. The goal of pre-design activities is to provide information necessary for a design team to develop a robust programming document, which is the cornerstone of a sustainable, high-performance building.

Define design intent by developing an Owner's Project Requirements (OPR) document. Identify performance requirements from the perspective of stakeholders including the researchers, directors, technicians, operators, community, and any other parties that will be affected by the outcome of the laboratory design. Carefully outline the stakeholders' specific requirements for the proposed use of each space. Differentiate between an actual requirement and a wish-list.

In addition to addressing aspects of safety requirements, define the requirements and base assumptions about the use of the laboratories and other spaces. Include the hours and conditions when a space is likely to be occupied, partially occupied, or unoccupied. Identify areas where worker schedules are most predictable. This will allow coordination to evaluate lighting or other system controls that may be shut off or adjusted automatically to save energy. Comment on the acceptable time-period for system start-ups during unanticipated or emergency use. Include considerations for potential changes in laboratory uses or sizes over time. This enables a design team to explore the possible impact on support utilities such as supply and exhaust of air as well as various configurations of laboratory benches/casework. Establish goals for energy and water efficiency. Include comments on how success in meeting those goals will be measured. Identify laboratories that do not need a narrow range of humidity and/or thermal control. *Laboratories for the 21st Century*[14] estimates that too narrow a range of acceptable humidity can increase energy use by as much as 25%. Identify spaces where daylight is appropriate and does not hinder the proposed research. This enhances workers' well-being and reduces the need for artificial illumination during the daytime.

Design

Engage a design team with proven experience in designing sustainable laboratories. Require an "Integrative Process" meeting to be attended by key laboratory personnel, facility managers, and as many members of the design team as feasible. This meeting will support development of a formal program for use by the design team as they develop design and construction documents. At the meeting, collectively review the OPR described above. Have attendees discuss their concerns and strategies for all primary objectives stated in the OPR. Establish a protocol that requires consideration of multiple factors in addition to safety. This includes life-cycle cost, flexibility, site conditions, indoor environment, environmental impact, renewable energy, and the efficient use of water, energy, and materials. Determine how success of meeting the OPR will be measured at each subsequent phase of the project.

Sustainable Design Strategies

Renovation or construction of new laboratories should avoid automatic replication of solutions from other laboratories. Solutions should be customized but adaptable. Stakeholders may benefit by becoming generally familiar with laboratory construction recommendations that incorporate sustainability topics.[15–18]

Acoustics Specific equipment and activities in each laboratory may impact communication and create noise that, if unaddressed, can increase occupant fatigue. A laboratory space with noisy equipment (e.g., fume hood) should not be designed with the same noise criterion (NC) as a dry, computational space or a classroom.[19,20]

Artificial Lighting Efficiency and Quality Moderate levels of acceptable, ambient (i.e., general) lighting combined with task lighting (where specifically needed) are key components to efficient and effective lighting design. When looking to save energy, use automatic shut-off or dim ambient lighting in spaces or zones where schedules are predictable. The intensity and color of light as well as the contrast level between lit surfaces will impact the workers' visual comfort. Lighting built into a fume hood or biosafety cabinet can be coordinated with the color of ambient lighting to enhance that visual comfort.

Flexible laboratory bay configurations requiring workbench mobility require consideration regarding bench-mounted task lighting as well as the reduced lighting level that may result when a bench has been moved away. Consideration should be given to the chemicals in use near heat-generating, under-cabinet task lights.

Evaluate the lighting aspects of laboratory bench configuration mock-ups. Mock-ups should include the proposed color(s) for the work surface, a portion of proposed ceiling, and any major ceiling elements (such as an air diffuser) that may impact the perception of light levels or visual contrast.

For additional information on New Buildings Institute Advanced Lighting Guidelines (AGL Online), please visit https://newbuildings.org/resource/advanced-lighting-guidelines. For additional information on the Illuminating Engineering Society, please visit https://www.ies.org/, https://www.ihs.com/products/iesna-standards.html or refer to the NIH Design Requirements Manual.[15]

Automated Energy Monitoring and Control System (EMCS) Projects including an EMCS can track the details of energy consumption and performance through sub-meters that relay information to the EMCS. Loads for HVAC (heating, ventilation, and air-conditioning), lighting, and plug-in equipment should be monitored separately, as should large loads like those for chillers.

Dynamic or demand control may be useful when a laboratory's Biosafety Level classification is low and chemical hazards are also low, based on risk assessments. The control reduces air-change rates when sensors indicate good air quality. Air quality is typically determined by establishing maximum thresholds of total volatile organic compounds (TVOC) and small particulates.

Biophilia Biophilia suggests that humans have an instinctive affiliation with nature and other living systems. It can be used as a design strategy. Provide visual connections to symbolic foliage, organic forms, and sunlight to foster psychological well-being and cognitive function.[21]

Chilled Beams Chilled beams are appropriate for laboratories without a high density of fume hoods or for laboratories that do not require a high rate of airflow changes. They minimize energy used for tempering air by separating the heating and cooling functions from the ventilation. The "beam" contains elements for sensible cooling using cold water (with a temperature above the dew point) that circulates through coils. Ventilation is provided by parallel elements tied to a central air handling system. The air-temperature required to condition the space with either the greatest heating or the greatest cooling load drives the design.

These systems require additional piping and are likely to incur more initial cost, but they ultimately save money due to significantly smaller central air-handling systems and ducts. There are currently limited data regarding the use of chilled beam technology in high containment laboratories.

Commissioning See Strategies for Existing Laboratories and Operations, above, for more information regarding Commissioning. Also see the ANSI Z9.[14] Standard, Testing and Performance-Verification Methodologies for Ventilation Systems for Biosafety Level 3 (BSL-3) and Animal Biosafety Level 3 (ABSL-3) Facilities.[22]

Daylight and Glare Control Natural daylight is an efficient lighting source and enhances occupant well-being. Design elements and devices to control and prevent glare are critical to worker comfort. This should increase energy savings through reduction of heat gain. Fortunately, numerous options are available for new spaces. Options may include:

1. Interior sun shading devices, such as blinds or shades, outside of laboratory space;
2. Exterior sun shading, which may be fixed or can be automated to adjust in response to time of day or sun angle; and
3. Glass that is fritted or coated with film or that changes transparency through electrochromic or thermodynamic properties. Note that this glazing can also be specified with features that reduce bird collision.

Energy Recovery Transfer of heat energy generated in one space or system to another space or system can save substantial amounts of energy and allow for smaller, less costly heating and cooling systems. Enthalpy wheels, heat pipes, and run-around loops, which transfer heat across air streams, should be considered; concerns regarding odor, biological, and chemical contamination may preclude their use. It should be noted that the heated air must be directed towards the laboratories where the exhaust air came from to minimize the potential for any cross-contamination in the event of a leak within the transfer system.

Evaluate energy recovery from common systems that serve laboratories with varying (low and high) loads during operation. Heated air from laboratories with heat-generating equipment and occupants can be used to pre-heat a space that is too cool. Additional space may be required for some recovery systems, such as heat pipe systems or rotary exchangers (e.g., enthalpy or desiccant wheels).

Exhaust Review energy efficiency and flexibility when evaluating fume hoods. For BSL-1 and BSL-2 laboratories, consider allowing manifold exhaust.

Conducting a Computational Fluid-Dynamics (CFD) Model will evaluate airflow patterns. These performance-based simulations can be used to evaluate safety and optimize airflow in a given scenario (e.g., the time needed to clear a chemical).

Flexibility A building that is designed to be flexible will accommodate future needs without radical renovation; this could save material resources and funds.

The Whole Building Design Guide, a web-based portal with up-to-date information on planning and designing research laboratories, provides recommendations for incorporating flexibility into laboratory design.[23] Passageway and doorway width should be designed to accommodate larger equipment than originally scheduled, such as autoclaves and cage racks. Provide wide pathways between loading docks and locations for large equipment. Vertical expansion to accommodate additional fume hoods should be considered.

Greywater Reuse Non-potable (e.g., greywater) is water that has not come into contact with sewage, biological agents, radioisotopes, or toxic chemicals. Greywater may be reused outside of the laboratory for functions, such as toilet-flushing or landscape irrigation. Polished water (i.e., salts or microscopic particulates are removed) resulting from laboratory processes is a potential source of reusable water.

Ventilation The profound impact of ventilation on energy use makes evaluation of the appropriate number of air-changes in each laboratory critical. Do not automatically replicate design or air-changes from similar projects. Balance safety and energy concerns by allowing designs for spaces with less stringent safety classifications to have fewer air-changes.

In addition to the design considerations noted above, review specifications for the proposed equipment in terms of energy and water efficiency. Consider giving preference to laboratory-grade refrigerators and/or freezers and ultra-low temperature (ULT) freezers that do not exceed the maximum energy consumption; the EPA's Energy Star program provides such specifications.[24] Freezer selection in new or renovated laboratories typically has the largest impact on energy consumption of any single equipment group other than those related to ventilation. Give preference to ULT freezers that use natural refrigerants and vacuum-insulated panels. Note that an energy-efficient ULT operating at -80ºC uses more energy than at -70ºC.

Additional items to consider:

1. Evaluate specifying autoclaves that use less water in the cooling process, typically through regulation, sometimes via facility-chilled water loop when chiller capacity allows.
2. Add a system to cool effluent in retrofit situations.
3. Specify water and energy-efficient vivarium cage washers.
    a. Use final rinse water for the initial cycle and incorporate heat exchangers to recapture heat from overflow rinse water in order to reduce overall steam and cold water consumption.

4. Incorporate a recirculation system that pumps water back to the vacuum system of the autoclave.
    a. Recirculation systems and some heat exchange systems with improved autoclave functions can require more space.

References

1. Mills E, Bourassa N, Pipette MA, Friedman H, Haasl T, Powell T, et al. The Cost-Effectiveness of Commissioning New and Existing Commercial Buildings: Lessons from 224 Buildings. In: National Conference on Building Commissioning; 2005 May 4–6. p. 1–22.
2. Health Care Without Harm [Internet]. Health Care Waste Management Audit Procedures—Guidance; c2018 [cited 2018 Dec 14]. Document 203. Available from: https://noharm-global.org/documents/health-care-waste-management-audit-procedures-guidance
3. freezerchallenge.org [Internet]. International Laboratory Freezer Challenge; c2018 [cited 2018 Dec 14]. Available from: https://www.freezerchallenge.org/
4. Emerging Technologies Coordinating Council [Internet]. Ultra-Low Temperature Freezers: Opening the Door to Energy Savings in Laboratories; c2016 [cited 2018 Dec 14]. Available from: https://www.etcc-ca.com/reports/ultra-low-temperature-freezers-opening-door-energy-savings-laboratories
5. Harvard University [Internet]. Cambridge (MA): Shut the Sash Program; c2018 [cited 2018 Dec 14]. Validating Cost and Energy Savings from Harvard's Shut the Sash Program: Tackling Energy Use in Labs. Available from: https://green.harvard.edu/programs/green-labs/shut-sash-program
6. Bell GC. Laboratories for the 21st Century: Best Practice Guide. Optimizing Laboratory Ventilation Rates. Washington (DC): U.S. Environmental Protection Agency; 2008.
7. U.S. Environmental Protection Agency [Internet]. Washington (DC): Green Chemistry; c2017 [cited 2018 Dec 14]. Basics of Green Chemistry. Available from: https://www.epa.gov/greenchemistry/basics-green-chemistry#twelve
8. ehs.mit.edu/greenchem [Internet]. "Green" Alternatives Wizard; c2018 [cited 2018 Dec 14]. Available from: http://ehs.mit.edu/greenchem/
9. BREEAM® [Internet]. San Francisco (CA): Refurbishment and Fit-Out Technical Standard; c2018 [cited 2018 Dec 17]. Available from: https://www.breeam.com/refurbishment-and-fit-out
10. BREEAM® [Internet]. San Francisco (CA): New Construction Technical Standards; c2018 [cited 2018 Dec 17]. Available from: https://www.breeam.com/new-construction
11. LEED Reference Guide for Building Design and Construction. Washington (DC): U.S. Green Building Council; 2013.

12. LEED Reference Guide for Building Operations and Maintenance. Washington (DC): U.S. Green Building Council; 2013.
13. International WELL Building Institute. The WELL Building Standard®. Version 1.0. New York: Delos Living, LLC; 2014.
14. Langerich S, Lilly E, et al. Laboratories for the 21st Century: Best Practice Guide. Commissioning Ventilated Containment Systems in the Laboratory. Washington (DC): U.S. Environmental Protection Agency; 2008.
15. National Institutes of Health [Internet]. Bethesda (MD): Office of Research Facilities; c2018 [cited 2018 Dec 17]. Design Requirements Manual. Available from: https://www.orf.od.nih.gov/PoliciesAndGuidelines/BiomedicalandAnimalResearchFacilitiesDesignPoliciesandGuidelines/Pages/DesignRequirementsManual2016.aspx
16. International Institute for Sustainable Laboratories [Internet]. Washington (DC): U.S. Environmental Protection Agency, Department of Energy; c2018 [cited 2018 Dec 21]. Labs21 Tool Kit. Available from: http://www.i2sl.org/resources/toolkit.html
17. wbdg.org [Internet]. Washington (DC): Whole Building Design Guide; c2018 [cited 2018 Dec 17]. Available from: http://www.wbdg.org/
18. Energy.gov [Internet]. Washington (DC): Office of Energy Efficiency & Renewable Energy; c2018 [cited 2018 Dec 17]. Federal Energy Management Program. Laboratories. Available from: https://www.energy.gov/eere/femp/energy-efficiency-laboratories
19. Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools. ANSI/ASA S12.60-2010. Acoustical Society of America. Accessed 2018 Dec 17: https://successforkidswithhearingloss.com/wp-content/uploads/2012/01/ANSI-ASA_S12.60-2010_PART_1_with_2011_sponsor_page.pdf
20. Lab Manager [Internet]. Canada: LabX; c2018 [cited 2018 Dec 17]. Laboratory Acoustics. Available from: https://www.labmanager.com/lab-design-and-furnishings/2011/11/laboratory-acoustics#
21. Terrapin Bright Green [Internet]. New York: Terrapin Bright Green, LLC; c2014 [cited 2018 Dec 17]. 14 Patterns of Biophilic Design: Improving Health & Well-Being in the Built Environment. Available from: https://www.terrapinbrightgreen.com/reports/14-patterns
22. Testing and Performance-Verification Methodologies for Ventilation Systems for Biosafety Level 3 (BSL-3) and Animal Biosafety Level 3 (ABSL-3) Facilities, ANSI/ASSE Z9.14 (2014).
23. Whole Building Design Guide [Internet]. Washington (DC): Design Recommendations; c2017 [cited 2018 Dec 17]. Research Laboratory. Available from: https://www.wbdg.org/building-types/research-facilities/research-laboratory

24. Energy Star [Internet]. Washington (DC): U.S. Environmental Protection Agency, Department of Energy; c2016 [cited 2018 Dec 17]. ENERGY STAR® Program Requirements for Laboratory Grade Refrigerators and Freezers. Available from: https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20V1.1%20Lab%20Grade%20Refrigerator%20and%20Freezer%20Program%20Requirements.pdf