The Sustainable Research Lab

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The Sustainable Research Lab

Welcome to the 2016 Sustainable Research Lab report from the editors of *R&D Magazine* and *Laboratory Design* and sponsored by Siemens. Sustainability in the design and construction of new or renovated research labs is an increasingly important concept in the lab community. Operating labs more cost effectively, reducing the waste generated by labs, reducing the amount of natural resources used to construct and operate labs and increasing the lab's productivity and ability to recruit and retain staff are all goals of sustainability. In fact, lab sustainability continues to grow in significance from the standpoint of owners and operators and as government regulations and standards guide lab designers and architects.

This guide to The Sustainable Research Lab is one more tool that lab designers can use to assist them in the application of current and future sustainable technologies, sustainable operating capabilities and their costs—and to help them understand what the future holds for the development of new sustainable products and design tools.

It is based on a reader survey performed in mid-2016 by the editors of *R&D Magazine* and *Laboratory Design*, which was deployed to scientists and engineers working in academic, industrial and government research labs. We invite you to read and study this report and use it to help design, construct and operate your next sustainable research lab.

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Editor's Note: The analysis, tables and charts presented in this report summarize responses to surveys on The Sustainable Research Lab performed by the editors of R&D Magazine *and* Laboratory Design *in 2016. All graphics and data are copyright by Advantage Business Media, 2016.*

Resources

American Institute of Architects (AIA)
www.aia.org

American Institute of Steel Construction (AISC)
www.aisc.org

Association for Assessment and Accreditation of Laboratory Animal Care International (AAALAC)
www.aaalac.org

Building Research Establishment Environmental Assessment Method (BREEAM)
www.breeam.org

Canada Green Building Council
www.cagbc.org

Centers for Disease Control and Prevention (CDC)
National Institute for Occupational Safety and Health (NIOSH)
www.cdc.gov/niosh

Center for the Built Environment
www.cbe.berkeley.edu

Energy Star
www.energystar.gov

Green Building Initiative
www.thegbi.org

J. Craig Venter Institute
www.jcvi.org

KlingStubbins – Sustainable Design of Research Laboratories
www.klingstubbins.com

Laboratory Design
www.labdesignnews.com

National Institute of Building Sciences (NIBS)
Sustainable Buildings Industry Council (SBIC)
www.nibs.org

NIBS 2021 Vision Task Force
NIBS National BIM Standard US Version 2
www.nationalbimstandard.org

R&D Magazine
www.rdmag.com

Siemens Building Technologies
www.buildingtechnologies.siemens.com

Rochester Institute of Technology
www.rit.edu/research/sustainability_labs.php

Whole Building Design Guide – A Program of the NIBS
www.wbdg.org

U.S. Department of Energy (DOE)
www.energy.gov

National Renewable Energy Laboratory
www.nrel.gov

Office of Energy Efficiency and Renewable Energy
www.eere.energy.gov

Office of Health, Safety & Security
www.hss.energy.gov

U.S. Environmental Protection Agency (EPA)
www.epa.gov

Labs and Research Centers
www.epa.gov/aboutepa/index.html#labs

U.S. General Services Administration (GSA)
www.gsa.gov

U.S. Green Building Council (USGBC)
www.usgbc.org

Green Building Certification Institute (GBCI)
www.gbci.org

Sustainability Strategies

Costs will continue to be the driving factors in the implementation of sustainable research labs.

Defining sustainability in the context of creating a new or renovated research laboratory consists of many different aspects. Reduced costs, environmental and natural material implementations, reusability and recycling, waste management/elimination and increased efficiencies and productivities are all involved in the sustainability of research labs. Technically, sustainability is simply defined as the ability to continue a defined behavior indefinitely. Sustainable lab design and operation goes beyond that simple definition by tying it integrally with the ability to reuse and recycle materials, create operational capabilities that minimize the use of energy, utilities and other resources—all the while creating a research environment that produces state-of-the-art innovative products and processes that create design platforms that build upon and enhance the enterprise's financial and competitive growth capabilities.

Modern research laboratories are some of the most complex facilities ever constructed. They often contain traditional office and business support capabilities, but they also can include pilot production facilities, extensive long-term testing sites, traditional chemistry labs, extreme engineering physical equipment, a multitude of lab equipment and instrumentation, environmental testing systems, military and advanced weapons development systems, radiation and high-energy physics labs, electronics and communications labs, software development labs, biological, animal testing and holding cells, and even the most secure containment systems in the world for isolating and investigating biological organisms that have no known cures. Sustainable systems, equipment and procedures are now considered for inclusion into all of these types of labs.

First Steps

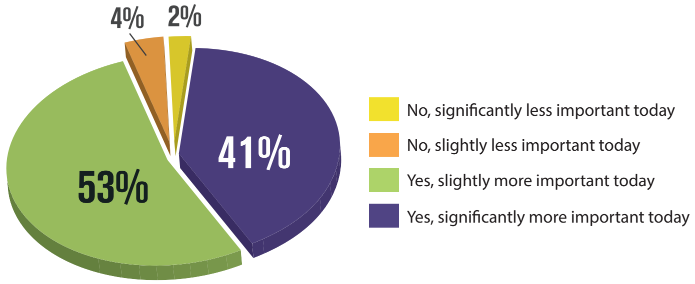
Developing the strategies for creating a sustainable new or renovated research lab begins by establishing and documenting all of the specific scientific, technological, financial/economic and product development goals of the new research facility and its managing enterprise. Detailing each of these goals into their individual components can then be used to identify how sustainable systems, materials and processes should (or should not) be addressed and implemented into each.

However, just identifying all the physical aspects of a new/renovated research lab should not be the end in itself. Creating a sustainable lab design and structure should also include how the lab occupants—the researchers, scientists and engineers—can perform their work in a sustainable manner. Does the new facility support the researchers' ethical practices, their responsible research, and is it a great and exciting place to work? These are all sustainable features of the new/renovated research lab as well.

An aspect that also should be given considerable study in the early strategic analyses of sustainable design is the monitoring, analysis, maintenance and constant improvement of the installed sustainable systems to ensure that they are doing their job and to document and investigate areas that may need additional work or retrofits.

Sustainability is a relatively new, but growing, concept in the design, construction and operation of new or renovated research labs. A reader survey conducted by *R&D Magazine/ Laboratory Design* in August 2016 found that sustainability is a more important aspect of lab design today than it was just five years ago in 2011. The survey revealed that 94% of the respondents stated that sustainability is more important today (Chart 1).

Chart 1 - ***Is Sustainability More/Less Important Than In 2011?***



The actual origins of sustainable development can be traced back to Herman Daly, a senior economist at the World Bank who developed economic policy guidelines related to sustainable development. Daly gave examples of environmental sustainability in 1990 which included: 1) for renewable resources, the rate of harvest should not exceed the rate of regeneration; 2) the rates of waste generation should not exceed the assimilative capacity of the environment; and 3) for non-renewable resources their depletion should require comparable development of renewable substitutes. These have become the basic tenets of the current sustainable design movement.

Sustainable development was further escalated in the research arena in 1990 with the creation of the Buildings Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom, which ranked building systems, components and materials based on the carbon impact of each decision. BREEAM was a predecessor of the U.S.'s LEED (Leadership in Energy and Environmental Design) program established by the U.S. Green Building Council (USGBC) in 2000.

Current Trends

COSTS – Sustainable design in the context of the design and operation of research labs has evolved further than the original Daly/BREEAM/LEED concepts. While holding true to those original environmental concepts, current sustainable lab design analyses and strategies take a more focused approach on the financial and cost aspects of building or renovating and operating a new research lab. One of the questions in our survey ranked the importance of various aspects of building and operating a research lab (Chart 2).

The survey respondents ranked the operating costs of the lab as their most important aspect, with the research facility cost being the third most important aspect. Quality of research was ranked second; hence there may be, at times, some conflicts between the costs of developing a sustainable design and the quality of research.

Chart 2 ***- Rank the Importance Of The Following Aspects Of Building A Research Lab***

	Most Important				Least Important	Average Rank
	5	4	3	2	1	
Survey Respondents						
Operating costs	40%	46%	12%	1%	1%	4.5
Quality of research	63%	18%	13%	5%	1%	4.4
Research facility cost	42%	33%	21%	4%	0%	4.1
Staffing	39%	36%	17%	5%	3%	4.0
Capital costs	33%	37%	24%	3%	3%	3.9
Sustainability	22%	36%	25%	14%	3%	3.6
Lab flexibility	22%	33%	27%	12%	6%	3.5
Time to market	22%	32%	26%	12%	8%	3.5
Location	15%	26%	33%	17%	9%	2.9

WATER – For example, research labs are notoriously large consumers of water, using five times as much water and energy per square foot as a traditional office building. During the discovery phase of synthetic chemical processes, scale-up to manufacturing levels may require large quantities of water. It could be possible, in this example, that there may be no obvious practical solution to achieving a sustainable water source for the synthetic chemical process research. These procedures need to be considered in the initial strategy sessions to determine what water-based sustainability processes might be implemented to minimize water use without jeopardizing the overall research. Regardless of the possible conflicts, costs are and will continue to be the driving factors in the implementation of sustainable research lab designs.

ENERGY – In traditional chemistry research labs, each lab often has a number of traditional fume hoods. The energy costs to operate these fume hoods can be the largest operating costs for the research lab. The energy costs for exhausting traditional fume hoods and delivering make up air is substantial. There are alternatives to these traditional systems such as low flow, ductless and filtered ductless fume hoods, which can reduce the operating costs and even the equipment and installation costs as well—no expensive duct work is required for ductless systems. The overall cost savings (operating, equipment and installation) for modern ductless fume hood systems can be on the order of 80% even when including the filter costs and their disposal for the ductless systems.

There are, however, limitations to ductless fume hoods. They cannot handle all types of gases. They can be inadequate for processes placed within the hood that generate large volumes of gases, or heat or flames. They need to be strictly monitored to ensure the safety of the operator, and there is a risk of contamination to the operator when unloading filled filter elements. Safe and sustainable filter disposal also needs to be considered.

FLEXIBILITY – Even lower ranked aspects in building a sustainable research lab may have to be considered in the design strategies. Lab flexibility, for example, needs to be considered for possible future applications involving fume hoods. If, at some time in the future, the research being performed in a lab which was initially fitted with ductless fume hoods is found to require ducted hood systems, there could be some substantial design and cost issues. Installation of ducts to a ductless hood system in an established lab configuration can be very expensive, time consuming and may not even be possible in some structural configurations. In these situations, strategic decisions need to be made between sustainable design and flexible design with only a few options for compromises. These potential possibilities may need to be considered in the initial design of a new or renovated research lab. Of course, designing a system for future potentialities can minimize the current sustainable design and also have substantial implications.

Strategizing

The inherent complexity of the modern research lab, especially one with sustainable concepts, often negates the possibility of performing a traditional sequential design concept in favor of performing an integrated simultaneous design. As it implies, a sequential design process proceeds in an orderly sequence, generally starting with a schematic design concept, followed by design development, construction documentation, building and negotiation and, finally, construction administration—a standardized AIA (American Institute of Architects) codified process. This simplified process is iterative, bringing in experts at each stage as needed with the architect most often assuming project leadership.

But, in sustainable research lab development programs, the sequential process is not an optimal process and often is now preempted with the integrated simultaneous process. Architecture, structural engineering and MEP (mechanical, electrical, plumbing) engineering are intertwined in this complex system and mutually dependent. Key stakeholders from each level are often required to interface at each step as the program evolves. This, then, involves a simultaneous decision process where key issues, such as the water example mentioned earlier, are considered from all sides at the same time (that is, simultaneously) before the team commits to a preferred process. In this manner, each of the various team members can provide input for the design, engineering, cost and schedule, especially as it pertains to the overall sustainability of the proposed project.

This process often requires that some design tasks need to be prepared early on. Energy modeling, for example, is often performed in the design development stage of a sequential design process. This may be too late for the simultaneous process. With the simultaneous process, this step must occur much earlier to inform the other team members about the overall design requirements, and their effects on cost, overall sustainability and project scheduling.

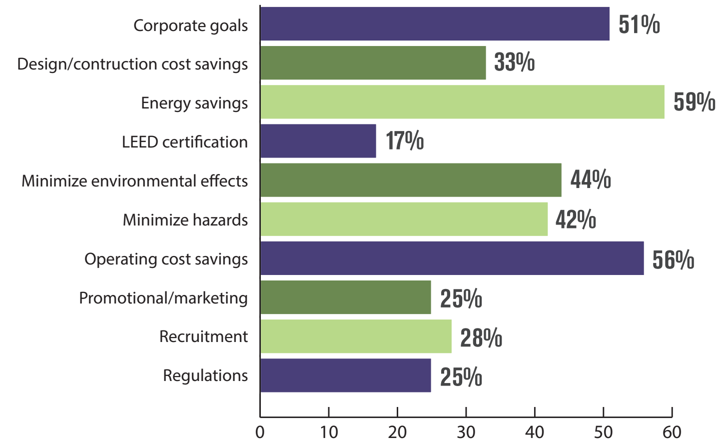
A number of inherently sustainable design considerations also need to be broached early on in the simultaneous design process so that all design team members can provide their input as to the possible interactions with the other building concepts. These sustainable considerations include things such as site selection and final orientation, glazing/fenestration, external solar controls, possible double-wall facades, overall renewable energy options, external natural landscaping considerations, reusable construction materials, building/lab water use/recycling, material and people flow throughout the building, and, of course, the cost implications of all of these considerations and options. As a matter of fact, the sustainable options being considered may often be the primary design drivers for many of the discussion points in the very early stages of an integrated simultaneous design process.

Current Status

In our reader survey, one of the queries was targeted on learning about the current status of the respondent's organization's completion of their company's sustainability goals, which is summarized in Chart 4. The most selected option was their organization's goal to increase overall safety within the research lab (59% completion toward meeting their sustainability goal). This choice, while marginally focused on the overall sustainability of the lab, is always the most selected option in any of numerous surveys that the editors of *R&D Magazine/Laboratory Design* perform. Without having the safest laboratory environment possible, all other considerations are moot.

The second most selected goal in this section was the goal to reduce waste, where the survey respondents indicated that their organizations were 46% of the way to meeting their goal for reducing waste. This is not surprising due to the overall increasing focus on recycling, materials reuse and the research lab's use of specific sustainable materials and selection processes. Glassware washers are more in vogue now compared with the use of disposable plastic ware systems.

*Chart 3 - **What Are The Incentives For A Sustainable Research Lab ?***



Materials are now selected that generate smaller levels of waste.

New analytical instruments can also use smaller sample sizes and need smaller amounts of solvents and other analytical agents. This, of course, also offers the user the option of performing a larger number of analyses (at similar overall sample volumes) and thus possibly preempting some sustainable cost and process time reductions, but increasing the overall reliability of the experimental results. All of these are considerations that can be discussed among the research lab design members at the initial design meetings, with the final design considerations agreed upon or compromised upon.

The third most selected survey choices as to where the survey respondents' organizations are with regard to completing their sustainability goals was in the area of staff retention and staff productivity. A sustainable, efficiently operating research laboratory environment is a strong incentive for ensuring staff satisfaction (and thus retention), while encouraging continuing productivity improvements.

The other results in this survey question were all within the 40% to 44% range of meeting their organizations' sustainability goals (energy use, operating costs, reduction in time-to-market, materials use, time per operation and reduction of water use in the lab).

Sustainability Incentives

There are several incentives that design teams focus on when considering the sustainability option in the design and construction or renovation of a new research lab. The first two choices by our survey respondents are related—the reduction of energy within the lab and the reduction of operating costs. By reducing energy use, the researchers reduce their operating costs (Chart 2). Fewer or more efficient fume hoods directly relates to lower energy bills and lower operating costs. More renewable energy systems directly relates to smaller amounts of various types of energy that need to be purchased, although the initial capital costs may need an acceptable return on investment (ROI) that doesn't exist for the use of non-renewable energy systems.

The third incentive for installing sustainable systems in a new research lab involves the meeting of corporate goals for being a sustainable business. By law, many federal and local government organizations already demand that new research facilities include some level of sustainable design functions, mostly directed through the USGBC's LEED program, for lack of an alternative measurement. Corporate goals include the use of sustainable functions in their promotional materials to attract new investors, or for recruitment purposes or just general corporate guidance—"being a good citizen." Corporate sustainability goals are generally flexible and without firm guidelines.

Minimization of environmental effects can also be a strong sustainability incentive. This is especially true when local government guidelines dictate the minimization of waste materials, or economically penalize the use of excessive amounts of water in water-deprived areas, or restrict the amounts of gas/fumes to the environment, especially in urban areas.

The minimization of hazards is also a strong incentive and ties directly into the equally strong topic of lab safety mentioned earlier. This is particularly true in research labs that deal with hazardous materials or processes, such as military weapons labs, biological disease research facilities, chemical processing or treatment labs, mining labs, extreme physical testing labs, animal testing facilities and even many biopharmaceutical or biochemical laboratories.

If done intelligently, the development of a sustainable research lab can also include design and construction cost savings which are strong incentives to the lab owner and operator. These savings can include the creation of natural landscaping, the use of locally available construction materials, the siting of the facility close to traditional shipping and transportation routes, the implementation of green roofs and materials, and the siting of a facility in temperate, rather than extreme, environments.

Chart 4 - ***Where Is Your Organization In Its Sustainability Goals?***

	Completion					Average Completion
	10%	25%	50%	75%	100%	
	Survey Respondents					
Reduce energy use	25%	24%	32%	14%	5%	40%
Reduce waste	16%	27%	29%	21%	7%	46%
Reduce water use	20%	25%	32%	16%	7%	44%
Reduce operating costs	18%	27%	33%	18%	4%	42%
Reduce materials use	19%	27%	30%	17%	7%	43%
Reduce time per operation	21%	26%	31%	18%	5%	43%
Reduce time-to-market	24%	23%	30%	18%	5%	42%
Increase staff productivity	18%	23%	32%	23%	4%	45%
Increase staff retention	23%	20%	27%	22%	8%	45%
Increase sustainable funding	29%	28%	28%	11%	4%	36%
Increase lab safety	9%	17%	24%	33%	17%	59%

Budgeting for Sustainability

Energy use is the most commonly accepted indicator of the sustainability of research.

Budgeting for building a new or renovated sustainable research laboratory is—like the research laboratory itself—a complex undertaking. Some of the basic individual aspects and components, such as site preparation, foundation work and MEP, are relatively straightforward and comparable to those tasks and materials for a traditional lab—some may even have sustainable components, such as recycled material content or locally sourced materials. Other aspects, such as the implementation of renewable energy systems are specialized systems with site-specific requirements and costs. And still other tasks, such as natural landscaping, specialized air moving and heat recovery systems, sophisticated instrumentation and equipment and solar lighting systems, may entail consultation with outside experts and equipment suppliers for their involvement in the budgeting of these systems and their installations.

It should be noted that general research lab construction costs vary considerably between geographic locations and by specific research functionalities due to variable labor and materials costs. The lab construction costs per square foot, for example, can vary by more than 20% between labs constructed in New York City and Seattle. These costs are similarly variable for sustainable functions applied to research laboratories. Biomedical research labs, for example, generally cost about $470/sq ft, analytical chemistry labs cost about $400/sq ft, Class 100 Cleanroom labs cost more than $1,000/sq ft and BSL-3 labs cost about $550/sq ft, all without the specialized equipment and systems that each requires (lab costs courtesy of HLW International LLP). The costs of sustainability functions added onto these generalized laboratories are mostly lab-specific for different applications. In general, the cost of implementing a sustainable function into a research lab environment is more than the cost of a comparable non-sustainable function.

It should be noted that average construction costs have increased approximately 2% to 3% per year for the past five years, according to HLW studies. This followed a period of slow lab construction activity where average costs were static for about four to five years, going into the recessionary period of 2009 to 2010.

Overall research laboratory construction costs (traditional) are broken down as follows in the table below. Sustainable add-on costs would be added to each of these functions as appropriate.

Architecture	36% to 40%
HVAC and Controls	15% to 18%
Structural Construction	11% to 13%
Overhead and Profits	10% to 11%
Electrical and Security	9% to 11%
Plumbing and Fire	6% to 9%
Site and Civil	2% to 4%

These cost allocations can vary substantially for different disciplines. The example shown above is that for a typical biochemistry research laboratory.

Expected/Real Sustainable Costs

The expected cost of a very generalized sustainability-implemented research lab is on average about 14.8% more expensive than a traditional research lab for the same application, according to the survey respondents from a reader survey conducted by *R&D Magazine* and *Laboratory Design* in August 2016 (Chart 5).

Only 7% of the survey respondents actually expected the cost of a sustainable research lab to cost up to 10% less than that of a traditional research lab. More than twice as many survey respondents (16%) actually expect the design and construction cost of a sustainable research lab to be more than 30% more expensive than the cost of a traditional research lab in the same application and geographic location.

However, according to survey respondent researchers with actual experience in implementing sustainable research labs, the actual cost of a generalized sustainability-implemented research lab is slightly more than what was expected. The cost, on average, is 16.25% more expensive; no one experienced a cost less than that of a traditional research lab and about 15% of the survey respondents still saw that the design and construction costs of a sustainable research lab were more than 30% more than the cost of a traditional research lab (Chart 6).

Chart 5 - ***What is Your Expected Cost of a Sustainable Research Lab Compared to a Conventional Lab?***

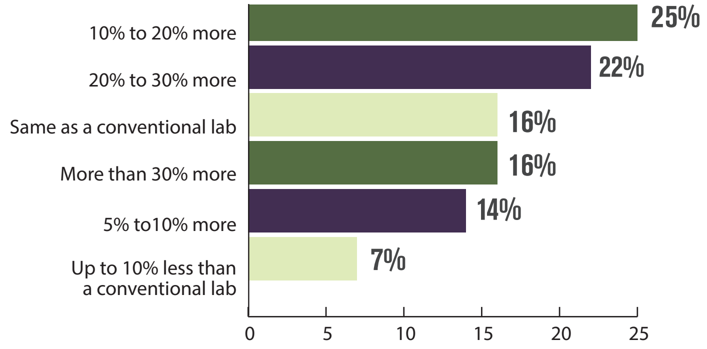
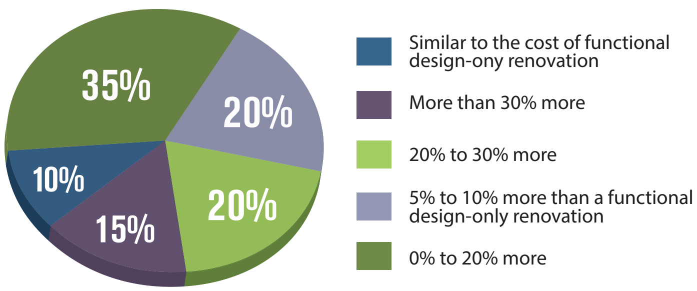


Chart 6 - ***What Is The Cost for Implementing A Sustainable Renovation For A Research Lab?***



Capital Investments

The overall construction cost of a new sustainably implemented research laboratory is often categorized as a capital investment, with the individual basic components included as integral parts. Whether those parts are traditional designs or sustainable designs is mostly irrelevant to the overall financial analysis. The overall cost and the individual sustainable components are decided upon during the initial strategy discussions that were described in Section 1 (Sustainable Strategies) of this report. Line item costs are obviously identified for each of the individual components, such as glazing, fume hoods, interior and exterior water systems, landscaping, specific HVAC systems, flooring, roofing, solar panels (if identified), lighting systems, waste management systems and all the rest. Return on investment (ROI) is rarely used for this overall capital investment—it is too complicated and the individual components are mostly too interwoven with each other to be specifically identifiable.

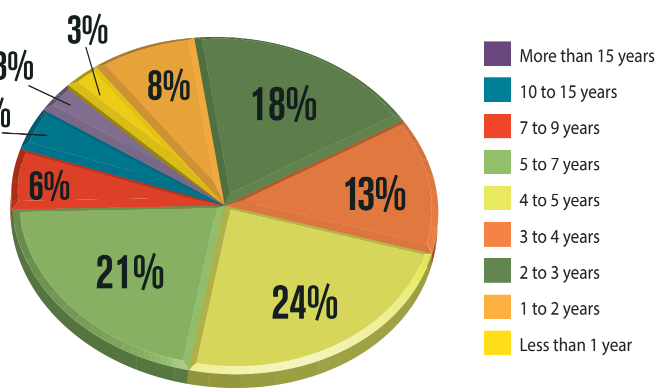
However, when a specific sustainable system can be specifically identified with a traditional operating cost, such as an energy cost, then an ROI analysis can be performed on the specific system to determine its overall viability compared to the cost of a traditional alternative. The ROI of a ductless fume hood system compared to a traditional ducted fume hood system is logical example. The ROI of the ductless system can be easily and quickly calculated by designers based on the past energy costs of the traditional ducted system. In this example, the ROI is expected to be more than 400% after just one year—annual energy costs per fume hood can be $4,000 to $8,000 per year based on the local climate and ductless fume hoods can save 50% to 75% per fume hood.

The total number of ductless fume hood systems is now estimated to be in excess of 25% of all fume hood systems.

Most lab designers are familiar with ROI, their calculations and the relative ROI values per device—full 100% ROIs at less than five years is generally acceptable for most systems/devices. Some analysts suggest using a total life cycle cost methodology for comparing sustainable systems to conventional systems which is more complex. Total life cycle costs include calculations involving the initial purchase price, laboratory improvement costs, additional utility costs, maintenance costs and disposable system costs, among other factors.

One question in our survey inquired as to what was an acceptable ROI for their sustainable research labs (Chart 7). The average value from the survey respondents was 4.58 years. However, 31% stated that they would accept a ROI between 5-15 years. Just 3% of those surveyed said that an ROI of more than 15 years would be acceptable.

Chart 7 - ***What is an Acceptable ROI For A Sustainable Research Lab?***



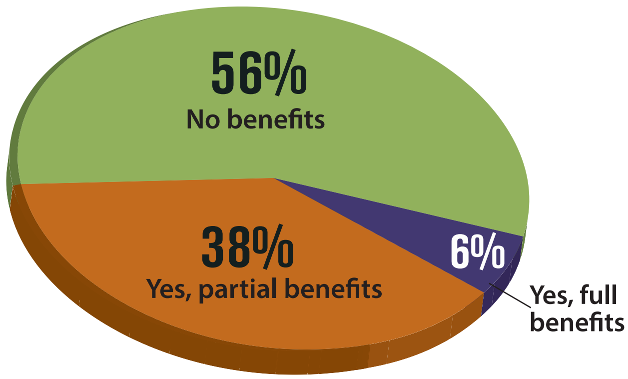
Renewable Energy

Renewable energy systems are another class of sustainable systems that can have relatively straightforward ROI calculations performed on them. Renewable energy systems consist primarily of solar panels and wind turbines used to generate electric power that can be used by the research lab and, in rare instances, parts of which can also be fed into the overall electric grid, thereby earning credits from the electric utility. Solar panels are predominantly used for individual locations (research laboratories) while wind turbines are used in "wind farms" to feed into the electric grid. Solar panels are more reliable, require less monitoring, require less maintenance and are simpler to install. Wind turbines have a substantial initial capital investment, but once installed provide a higher output and lower cost per generated kW. Both configurations have intermittent output based on weather conditions and time of the day. Energy storage companies such as Tesla provide utility-scale battery Powerpacks which, while a relatively new company, have already been delivered. With the use of the Powerpacks or equivalents, solar panels and wind turbines can provide sustainable electric power continuously to the research laboratory, with back-up provided by connections to the traditional electric grid.

The supply of solar panels has become very competitive with two of the top 10 suppliers now located in the U.S. (First Solar and SunPower). The top 10 suppliers have about 50% of the global market share for solar panels. Four of the top 10 suppliers are in China, two are in Taiwan, one in Canada (Canadian Solar) and one in South Korea. China supplies solar panels to about 36% of the U.S. residential market, while First Solar and SunPower supply about 18% of the residential market. Most solar installers no longer have to go to the lowest price supplier, since prices from all suppliers have become very competitive and continue to drop in price on an annual basis. Solar panel installers now find a balance between solar panel price and quality from the panel suppliers to recommend to their clients. Solar panel growth is accelerating in the U.S. with more than 2,000 MW installed in Q2 2016 and the overall installed capacity expected to exceed 32 GW by the end of 2016.

Local governments have provided sustainable energy rebates intermittently over the past several years. The federal government offered one-year rebates in 2008, while some local governments still offer them. When queried about this, 44% of our survey respondents indicated that either partial or full government benefits or rebates were available for installing renewable energy systems for their new or existing research laboratories (Chart 8). More than half (56%) of the survey respondents, however, stated that no rebates were available in their areas.

Chart 8 - ***Does Government Provide Sustainable Benefits/Rebates For Renewable Energy Systems?***



Tracking and Monitoring

Creating checklists for the detailed design and construction aspects of your new or renovated research laboratory is a convenient way to monitor their progress, according to Katherine Everett at SMRT Architects and Engineers. She recommends creating a checklist containing the components of project planning costs, basic architectural and engineering costs, specialty consulting costs and fees, construction costs, fit-up costs, miscellaneous expenses and contingency costs. The sustainable aspects of each of the sections of this checklist can be included to monitor the sustainable development costs versus the overall budget.

The macro- and micro-programming aspects of different laboratory spaces within the overall research facility (identified during the strategic planning process) can also be used to document and monitor progress in the sustainable portions of the design and construction of the new or renovated research laboratory process. Macro-programming identifies such aspects as building organization, floor plate efficiency, equipment requirements and program space for sustainable operations. Micro-programming identifies such laboratory operations as lab air changes, plumbing, power, filtering systems, indoor temperature and relative humidity, lighting, exhaust devices, utilities and MEP redundancies.

Tracking systems should also be established that can accommodate unexpected or future changes in the overall sustainable functioning or design of the research laboratory. Space may need to be allocated at the shipping dock, for example, to accommodate multiple dumpsters for future waste stream separations. This may also be carried over into additional waste receptacles in the alcoves of individual labs when waste streams might need to be further separated into different materials categories. Obviously, future changes are next to impossible to predict, but will surely occur.

The energy models and simulations created during the initial strategy planning processes can also be integrated into a cost and schedule monitoring system to further identify compliance with the sustainable projections that were initially designed into the research lab. With new inputs as the project proceeds, the energy models and simulations can be updated to provide a closer match to the final results. These updates are essential to program managers and administrators to understand the overall sustainable concepts and their sensitivities to operational parameters.

Energy modeling protocols have become a commonly accepted method of determining energy use. Site-specific energy models are often calibrated to reported utility meter data and can be used to quantify and calibrate retrofit measures and energy-saving sustainable designs. These models have proven accuracies and can be used in parallel with other new or existing models for verification and validation of the new measurements being collected. The ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) Performance Rating Method (PRM) contained in Appendix G of ASHRAE Standard 90.1 has become the most commonly used building energy modeling protocol in the U.S.

Energy use is the most commonly accepted indicator of the sustainability of research laboratory. Energy use is also one of the most instrumented aspects of a commercial building. There are numerous components that can be metered to collect this plethora of data. Energy metering data can be collected from electric sources, natural gas sources, potable water, gray water, steam, heating systems, hot and chilled water systems and condensed water. Electric metering data can also be collected from air handling systems and HVAC systems. Thermal metering of cooling tower makeup water or other HVAC systems can also be collected. Electric metering data can also be collected from lighting loads, instrumentation systems, physical and chemical testing systems, along with that of glassware washers and animal cage washers.

All of this and more data can be collected starting at various stages of the design and construction process. Which ones are aggregated into the final modeling system will need to be identified early on in the design process to ensure that the correct sustainability values are collected and documented.

Sustainable Design Concepts – Passive

Smarter passive sustainable decisions essentially cost the same as conventional design decisions

Passive sustainable design concepts as applied to the design and construction of new or renovated research laboratories pertain to those designs that have few moving parts and few overall direct costs associated with the design. They are "low-hanging fruit" with inherently simple designs that relate to decisions made that are sustainable by themselves. They represent more sustainable decisions than sustainable technologies (covered in the next section of this report).

Passive designs relate to the siting of the building on a plot of land that enables the sun and prevailing winds to provide the most cost-effective value for thermally operating the building or structure. Many passive designs relate to siting concepts and the overall positioning of the structure to take as much advantage of its environment as possible. A passive sustainable design approach essentially costs the same as what the developer has to pay for accomplishing essential tasks in a conventional design. A passive sustainable design accomplishes the same effect as a conventional design, but in a smarter, more sustainable manner.

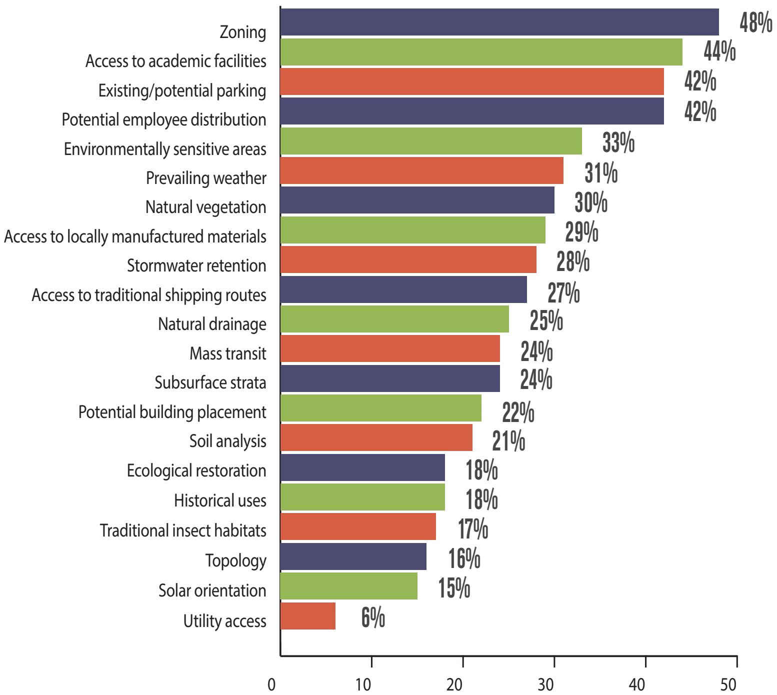
Sustainable Siting

Designing and developing a sustainable research lab begins with the ground that it is expected to be built on—or in other words, the site. There are a number of passive energy-saving designs that can be created based on the specific characteristics of the site, such as solar orientation for heating or cooling the building or positioning it to maximize the efficiency and output of renewable energy solar panels or maximizing/minimizing the effects of prevailing wind patterns. Natural drainage patterns can also be considered that support the development of sustainable landscaping designs and prevent issues with extreme weather events. And the selection of a specific site also can be made that supports materials shipping, staff access and parking, utility access and fire/police access—all factors that impact the sustainability of the completed research lab and all done in a passive, decision-making process, rather than an active, technology-based manner.

But the actual implementation of these and other site-based sustainable procedures brings up a large number of questions concerning the site itself. Is the site a greenfield, brownfield or greyfield site? Greenfield sites consist of agricultural land considered for urban development and generally are safe. Brownfield sites are lands that previously were used for industrial or commercial development and could be complicated by the presence of a hazardous substance, pollutant or contaminant. And greyfield sites are economically obsolescent, underused assets typified by the acres of empty asphalt that often accompanies them and again pose the possibility of contamination or other detrimental issues—it didn't work out for the previous tenants, why didn't it and are there risks involved with it?

The list of various site-specific concerns was queried in

Chart 9 - ***What Site Specific Considerations Factor Into The Design Of A Sustainable Lab?***



R&D Magazine's and *Laboratory Design's* survey (Chart 9) with four, quite different, responses that stood out. The top response, with 48% of the respondents choosing it, was "zoning" followed by access to academic facilities (44%), existing/potential parking (42%) and potential employee (geographic) distribution (42%). The variation in these responses exemplifies the wide range of issues concerned with site selection. The issues involve political jurisdictional concerns, weather patterns and trends, topographical patterns, soil constituents, solar orientation, the local socio-economic environment, natural and artificial resources, biological inhabitants and more.

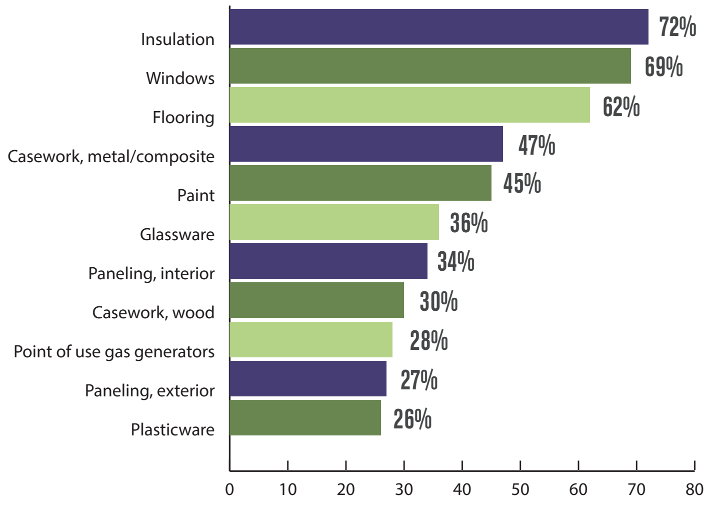
Once all the soil borings, building configuration decisions and alternative selections, traffic patterns, sizing and routing of utilities, jurisdictional resolutions and all the rest are determined, lab designers and engineers can evaluate the potential passive sustainable designs that can be made and determine the savings from each. Some of these passive design decisions could include:

- The optimal building orientation on the site for best solar daylighting to reduce the electric lighting load and reduce the interior heat gain loads.
- Determination of the appropriate plants, positioning and settings to minimize the need for water, maintenance and drainage systems, while creating a pleasing, self-maintaining environment.
- The optimal solar panel product selection, positioning and building placement to maximize the amount of electrical power generated with the minimal amount of maintenance and longest life cycle.
- Design, placement and construction of vehicular access and parking systems, along with appropriate creation of renewable energy support systems (electrical charging stations) for expanded future applications.
- Integration of underground soil-based cooling and storage systems as appropriate within the site environs for overall support of the lab interior heating and cooling systems.
- Design and creation of below-grade storm water management systems.
- Design and integration of below-grade utility and resource delivery systems.
- Finalization of the external new research lab configuration and specific placement based on an integration of multiple exterior passive sustainable systems.
- Design and implementation of solar shading systems to reduce the interior heat gain load.
- Create an externalized circulation system (where appropriate) to minimize the conditioned new research lab footprint.
- Create a system for rainwater harvesting that feeds landscape irrigation, fire water supplies and potential interior gray-water needs.

Passive Interior Sustainability

One of the most obvious passive sustainable systems that can be employed in the design of a new research facility is in the type of materials used in the construction. When queried about this topic, more than two-thirds of our survey respondents chose insulation, windows and flooring as their top choices for materials that should be considered in sustainable systems (Chart 10). Casework and paints were secondary choices by nearly half of the respondents. The specific difference in standard commercial materials and sustainable research lab materials is that research lab materials need to have a level of chemical resistance that the other materials do not have. For biological labs, there is likely to be a requirement for resistance to harsh anti-bacteria cleaning regimens.

Chart 10 - ***What Sustainable Materials Do You Consider In The Design Of A New Research Lab ?***



Windows are a critical component in sustainable building design. Despite new insulation systems, most of the energy flows in and out of a building through its windows. New systems, driven by technology advances in windows for consumer products, can be used to provide heating, cooling and lighting for increased sustainability and researcher productivities. Framing for these window systems is available in various materials, but fiberglass is one of the most energy-efficient and low-maintenance systems available. There is a wide range of insulated glass systems available including triple-pane high-insulation systems. Most systems employ low-e glass with thin-film coatings for either high-heat gains or low-heat gains depending on the specific sustainable application the lab managers have chosen. Argon gas insulated gas systems are also available for even higher performance.

Insulation is also a strong material for thermal control of the research environment. Natural insulation materials are more sustainable in that they are low impact, renewable and have low embodied energies. Most can be reused, recycled and are fully biodegradable. They are non-toxic, allergen free and can be safely handled and installed. Natural insulation materials include sheep's wool, flax and hemp, cellulose, wood fiber and expanded clay aggregate. While natural insulation materials are highly sustainable, they are up to four times more expensive than conventional synthetic insulation materials.

The criteria for being a sustainable flooring material is that it should last longer, wear better and require less frequent replacement than non-sustainable flooring materials. Traditional laboratory flooring is selected to minimize or eliminate seams which could collect unwanted contaminates. This has resulted in the use of sheet linoleum or broadcast epoxy, which was expensive and difficult to repair. However, research laboratories are particularly prone to experiencing floor damage from spilled chemicals, solvents and even acids. Some commercial linoleum flooring manufacturers have enhanced the sustainability of their laboratory floor offerings by integrating a top coat which minimizes wear. For many labs today, these sheet goods can be replaced rubber, vinyl or linoleum square tiles which are more affordable and more easily replaced, thereby possibly being considered as more sustainable from a damage resistance standpoint.

The ceilings in sustainable research laboratories pose a particular problem. Most labs do not have a process for wiping down or scrubbing ceilings, either in drop ceiling or open ceiling configurations. In these situations, standard commercially available acoustical ceiling tiles work well in a sustainable environment—they are affordable, have more recycled content than other ceiling tiles and are easier to recycle. Both fiberglass and mineral fiber are good tile materials with the only difference being in the acoustical performance.

Casework can be considered a passive sustainable research laboratory component in that casework suppliers have changed or reformulated their manufacturing processes to make their products more sustainable by addressing the materials they're made of, the construction process and even the shipping supplies and finished products. Sustainable options now exist for plastic laminate, metal and wood research laboratory casework. The processes used to make casework more sustainable included developing highly chemical resistant finishes (for wood cabinets) with no hazardous air pollutants (HAPs) and minimal volatile organic compounds (VOCs), while developing and using adhesives and glues with low VOCs. The products themselves were manufactured from natural resources with minimal wastes using advanced robotic equipment and using wood wastes to heat the manufacturing environment.

Solar Shading

Solar shades have become an established component in maintaining the sustainability of new research laboratories. *R&D Magazine's* 2016 Laboratory of the Year is the University of Illinois Urbana-Champaign Electrical and Computer Engineering Building (ECE) in Urbana, Illinois, which is intended to serve as a sustainability prototype. Targeting LEED Platinum, the ECE is one of the largest net-zero energy buildings of its kind in the United States with numerous features helping it meets that goal. The roof of the ECE has solar arrays along with its connected parking garage. The building also features several passive heating and cooling features, including a terracotta exterior and a massive array of solar shades.

R&D Magazine's 2015 Laboratory of the Year was the South Australian Health and Medical Research Institute in Adelaide, Australia. The dramatic and distinctive exterior of this laboratory was sheathed in a triangular gridwork of sun shades which were designed from calculations of the South Australian's solar path. The shades were designed to maximize shielding of the intense sun, while still providing adequate lighting for the health and medical research within the laboratory.

The Consolidated Forensic Laboratory for the District of Columbia was a Special Mention Winner in the 2013 *R&D Magazine* Laboratory of the Year program. This five-story LEED Platinum laboratory included a full-height curtain wall on the south side with movable sun shades that allowed researchers to take advantage of the natural light for their research. In addition to the glazed solar shading system and the high-efficiency curtain wall, other sustainable features included an efficient HVAC system with chilled beams and energy recovery air handling units. Runoff from the green roof and remaining hardscape was funneled into a cistern sized for a 100-year storm. This water is used for cooling tower make-up, reducing annual potable water consumption by more than 2 million gallons.

Sustainable Design Concepts – Active

The cost of new sustainability systems are likely to increase over the next several years as new, more sophisticated and expensive sustainable technologies are developed.

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Active sustainable design concepts, products and technologies for the creation and construction of new or renovated research laboratories make up the majority of potential cost and materials savings for improving the new facility's overall sustainability. Active systems involve large air handling systems, heating, cooling and environmental control systems, high performance and renewable energy systems, water and waste management systems, building monitoring and control systems, data management and processing, materials handling and processing systems as well as safety and security monitors, devices and systems.

There is the potential for large savings to be obtained in most of these devices and systems because they already consume large amounts of energy and resources and also come with relatively large initial investments in time and money. And because of their large size, there also are a lot of case studies and resources to investigate as well as suppliers, installers and products to choose from in the selection process.

According to our recent *R&D Magazine* and *Laboratory Design* survey on sustainability, the largest challenge in creating a new or renovated research laboratory is the increasing cost of the sustainable features (Chart 11).

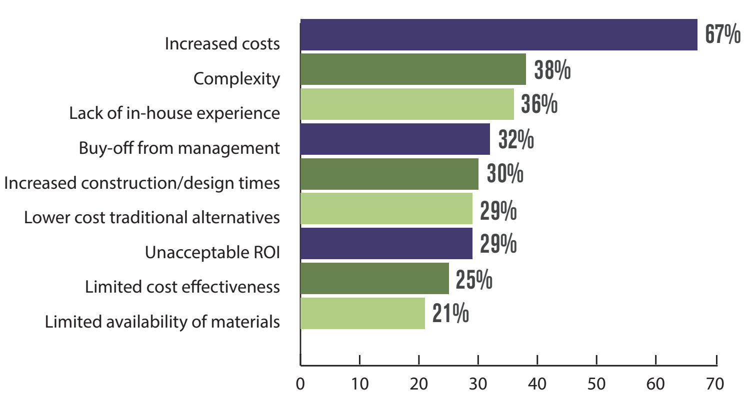
Two-thirds of the survey respondents chose this response, while the next largest response was the increasing complexity of the sustainability equipment and systems, which was chosen by about 38% of the respondents. Most of the simple sustainability technologies have already been implemented, and anything that builds on those technologies is generally more complex and more expensive to build and implement.

While noted earlier that sustainability in the design and construction of research labs has grown considerably over the past five years, the costs and complexity of these systems has similarly increased. As a result, the current average of five years for an ROI on a sustainability investment is likely to increase, but still expected to be acceptable in most cases since more than a third of our survey respondents are still willing to accept sustainability-based ROI paybacks in excess of five years.

Sustainability in Lab Equipment

While there is generally a large focus on building-based sustainability systems, there also is a growing interest in improving sustainability on the lab equipment side. Researchers and lab designers are attempting to make the buildings more sustainable by reducing the heat that is generated from the equipment and research systems within the lab. Up to 30% of a lab's energy use goes toward plug use (lab equipment), according to architects at SmithGroupJJR. Some sterilizers,

Chart 11 - ***What are the Largest Challenges In Creating A Sustainable Research Lab?***



for example, are now equipped with a chilled water cooling element that allows the sterilizer to be cooled using the research lab's process cooling instead of tap water. This can reduce the water quantity required by up to 90%.

Most glassware washing equipment can also be directly vented to the outside, minimizing the amount of heat being rejected into the laboratory space. The latest washing systems have hydraulics designed to maximize water flow and pressure, shorter cycle times, double-insulated chambers for optimal heat absorption, different wash applications and water intake monitors that adjust to the load size. There also are new ultra-low temperature freezers (-80C), utilizing

*Chart 12 - **What Challenges Limit You From Meeting Sustainable Goals?***

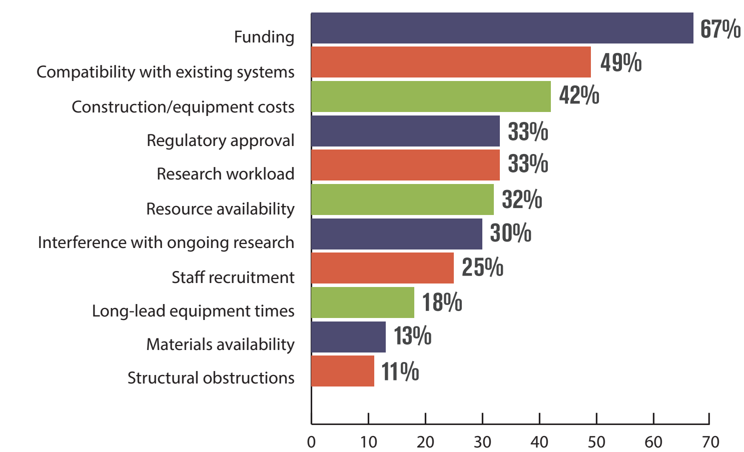
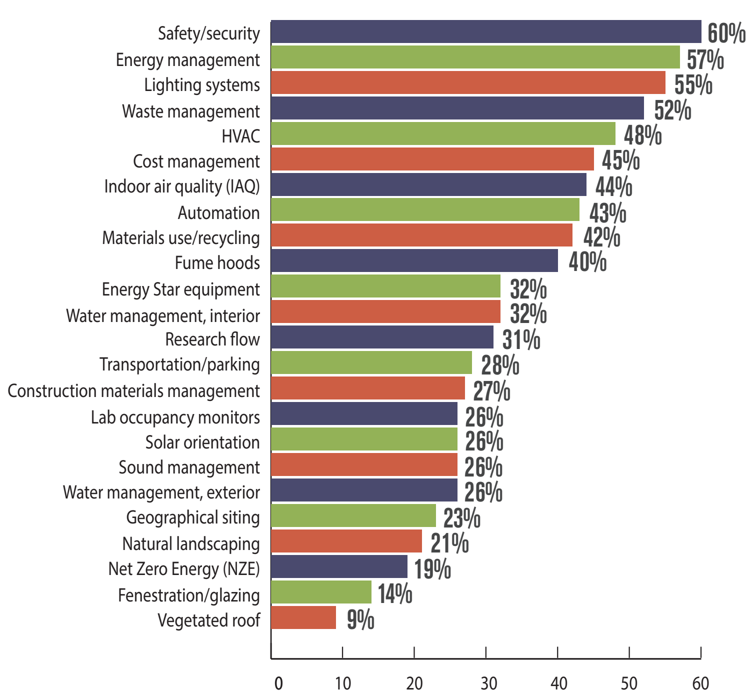


*Chart13 - **What Sustainability Features Should Be Included In A New Resarch Lab?***



proprietary technologies, that reduce energy use by 35% to 60% over traditional models. And while manufacturers claim there is a 20% initial price premium for this new equipment, the total cost of ownership is expected to be 30% less over the freezer's lifetime.

The use of ductless fume hoods instead of ducted fume hoods raises the lab's plug loads and exhausts filtered air into the lab, but reduces the overall building's energy use since the air handling systems are no longer needed. Type A2 biosafety cabinets (BSCs) have lab plug loads and exhaust air directly into the lab or via a thimble connection to an exhaust connection. Type B2 BSCs, for handling more hazardous materials, exhaust only to hard ducted connections.

Challenges

The largest challenges that limit a research laboratory from meeting its sustainability goals are funding for their sustainable equipment and systems (67%), compatibility of new sustainable systems with existing systems (49%), and the overall construction/installation and equipment costs of new sustainable systems (42%) as illustrated in Chart 12.

As noted earlier, the cost of new sustainability systems are likely to increase over the next several years as new, more sophisticated and expensive sustainable technologies are developed. This means that funding will continue to be a challenge and could increase in for some organizations.

Costs, sustainability and new federal/state regulations pose their own set of challenges for new and renovated research laboratories, especially for government buildings in the future. Executive Order (EO) 13514 (issued by President Barack Obama in 2009—Federal Leadership in Environmental, Energy and Economic Performance) states that federal buildings must be designed to achieve net-zero energy (NZE) by FY2030 and that new construction and major renovations must meet the Guiding Principles for Sustainable Federal Buildings, which were issued by the Council of Environmental Quality. The EO also states that 15% of a federal agency's existing buildings and leases were to meet the Guiding Principles by FY2015. The six Guiding Principles apply to existing buildings and new construction or renovation:

1. Employ integrated design
2. Optimize energy performance
3. Protect and conserve water
4. Enhance indoor environmental quality
5. Reduce environmental impact of materials
6. Assess and consider climate change risks

Additionally, some states have passed their own sustainability regulations, stating that renovations over 5,000 GSF must now meet a LEED certification requirement.

Monitoring

Clearly, sustainability is becoming a more established design rule and will likely become a stronger requirement in future design and construction efforts. If this is true, research managers will need to monitor how well their sustainability efforts are proceeding, Current sustainability performance is monitored mostly by evaluating energy usage or energy metering devices, according to our sustainability survey respondents, chosen by 52% and 45% of the respondents, respectively (Chart 13).

Energy use, however, is not the only characteristic of sustainability. As noted in the chart, waste creation (32% of the survey respondents), occupancy (30%) and thermal comfort (29%) can also be classified as sustainability indicators.

Going forward, as sustainability becomes more established as a basic criteria for the design, construction and operation of a research laboratory, the concept of monitoring sustainability will need to become more formalized—especially when government agencies get involved, rules become established and guidelines are documented. The current monitoring systems being used are frequently flawed, inconsistent and not fully documented. Energy usage will likely become the first sustainability monitoring system that is created and formalized. Waste and water management systems will follow, with credits given for meeting some level of sustainability that as of today is still undefined.

The Sustainable Lab of the Future

As laboratory processes or systems are replaced or change, they can be created in the most sustainable manner possible.

The current research environment is a mix of old and new research labs. Only about 10% of the current labs are less than three years old, while nearly two-thirds are more than 10 years old, and more than a third are more than 20 years old, according to a *R&D Magazine* and *Laboratory Design* survey conducted earlier this year. Surprisingly, the average age of the research lab is increasing. Ten years ago, the average age of a research lab was 11 years old and today that figure has increased to 14 years.

While research labs are increasingly older with a longer time period since they were last renovated, the lab equipment and instrumentation has mostly kept pace with changing technologies. About half of all researchers surveyed indicate that their lab instrumentation systems are very current or at least near "state-of-the-art." Less than half of the researchers surveyed indicated that their lab equipment and instrumentation systems were "older" and lacking capabilities.

But when new or renovated research laboratories are designed and constructed, however, they are being created with ever increasing levels of sustainability, which is more important today than it was in 2011—and will be more important in 2021 than it is today. Sustainability is not the only change occurring in the research arena. Other things that have changed and will continue to change for traditional and sustainable labs alike include:

- A continuing evolution to team-based research
- A change from focused to multidisciplinary research
- A change from fixed lab configurations to flexible lab systems
- Changes from local communication systems to net worked systems
- Ever shortening project cycles with faster set-up times
- Increasing use of wireless communications
- Increasing use of flexible casework, utilities and support systems

This continuing research evolution plays into the hands of sustainability enhancements since as laboratory processes or systems are replaced or change, they can be created in the most sustainable manner possible. When queried about how close their labs will be to meeting their sustainability goals in five years (2021), the overall survey responses for reducing energy, waste, water, operating costs, while increasing staff retention and productivities (and the other items shown in the Chart 14) improved by between 14% to 20% on each item from the values they stated their labs were at in meeting their current sustainability goals.

Chart 14 - ***Where Will You Be in Meeting Your Sustainability Goals In 2021?***

	Completion					Average Completion
	10%	25%	50%	75%	100%	
	Survey Respondents					
Reduce energy use	8%	17%	25%	32%	18%	60%
Reduce waste	7%	16%	25%	32%	20%	61%
Reduce water use	8%	13%	29%	28%	22%	62%
Reduce operating costs	7%	15%	28%	35%	15%	60%
Reduce materials use	8%	18%	29%	30%	15%	57%
Reduce time per operation	7%	21%	23%	35%	14%	58%
Reduce time-to-market	10%	14%	26%	33%	17%	59%
Increase staff productivity	7%	14%	24%	37%	18%	62%
Increase staff retention	12%	12%	26%	30%	20%	60%
Increase sustainable funding	12%	18%	28%	29%	13%	54%
Increase lab safety	4%	9%	19%	30%	38%	73%

Current goals are from 36% to 59% toward meeting their completion, while the goals in 2021 are expected to be from 54% to 73% toward meeting their completion.

The Next Five Years

Most research laboratories have had some level of systems or equipment upgrades over the past five years (since 2011) to make them more competitive in the marketplace, reduce operating costs or replace outdated equipment. The most widely noted upgrade according to several survey results has been the implementation of new computer systems. These can involve anything from the installation of a new supercomputer to new operating systems for individual workstations, laptop upgrades for researchers or higher resolution imaging systems.

Other lab enhancements over the past five years include the installation of biosafety cabinets, and upgrades in analytical instruments, lighting systems and research staff. Lower levels of improvements over the past five years involve the addition of automation systems, networking systems, security systems and vivarium spaces.

The enhancements over the past five years involve relatively traditional systems. Many of these are likely to see continued growth over the next five years, including more computer upgrades, sustainability-based reductions in operating costs and the continued replacement of outdated equipment and instrumentation. But enhanced sustainability systems and devices are likely to also be seen included in the

Chart 15 - ***What Sustainable Features Will You Implement By 2021?***

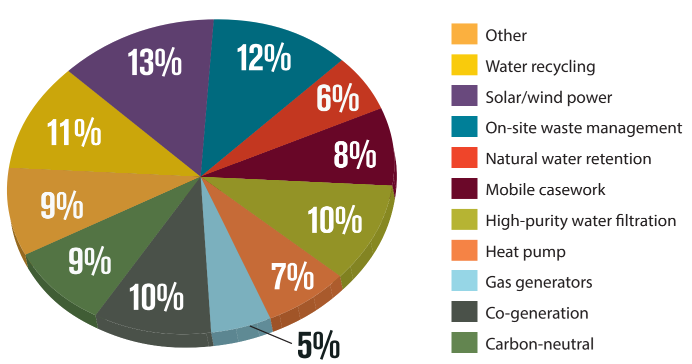


Chart 16 - ***Will Your Lab Have Sustainable Upgrades By 2021?***

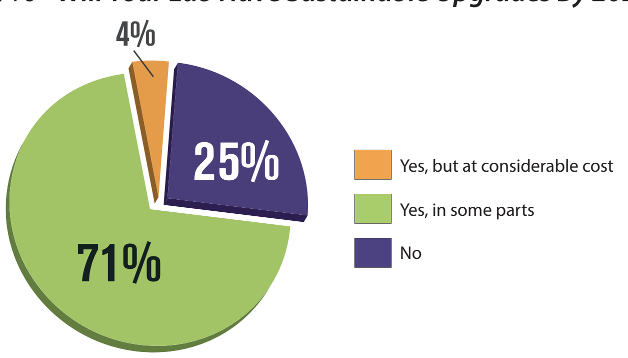


Chart 17 - ***When Do You Expect To Build A New/Renovated Lab?***

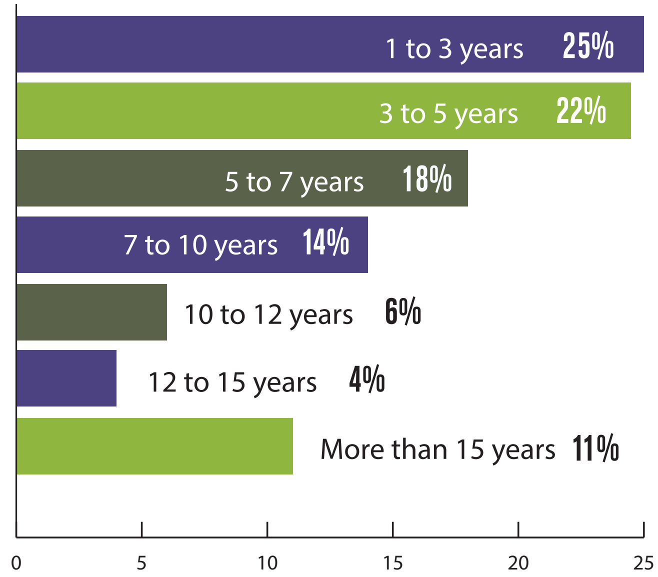


Chart 18 - ***Will Your New Lab Have Sustainable Features?***

New/Renovated Lab Built	Sustainable Features	No Sustainable Features
1 to 3 years	69%	31%
3 to 5 years	67%	33%
5 to 7 years	84%	16%
7 to 10 years	77%	23%
10 to 12 years	81%	19%
12 to 15 years	64%	36%
More than 15 years	77%	23%

research lab of 2021, according to the results of the recent *R&D Magazine* and *Laboratory Design* survey. Included in the research lab-based sustainable systems expected by 2012 are solar panels and wind turbine-based renewable energy systems, chosen by the survey respondents as the most likely sustainable feature to be installed in their 2021 research laboratory (Chart 15). Many relatively new research labs already have solar panels (mostly) or wind turbines (small amount) installations in their research labs. This number will increase, especially as federal regulations kick in over the next several years and mandate their inclusion in government labs, while influencing their installation in industrial research labs.

Other sustainable enhancements—in declining order of implementation by 2021—include on-site waste management systems (relatively few currently exist); water recycling systems; co-generation power sources (a moderate number of expensive, moderate efficiency systems currently exist); high-purity water filtration systems; and carbon-neutral energy systems. About 75% of all research labs are expected to have some level of sustainable upgrade by 2021 (with the systems noted in Chart 15) as highlighted in Chart 16.

While most research labs will have some level of sustainability upgrades over the next five years, slightly less than half of the researchers surveyed expect to build a new or renovate a research lab during that period, according to our survey (Chart 17). The average length of time until our survey respondents expect to build new or renovate a research lab is about 6.5 years, with more than 20% of the survey respondents taking more than 10 years to reach that point. And of those researchers building or renovating their research labs, they're expected to include and install some significant level of sustainable systems in those labs (Chart 18).

The Sustainability Conundrum

Historically, sustainability is a relatively low-ranked design characteristic of new and renovated research lab design and constructions, according to previous *R&D Magazine* surveys. Lab storage, for example, traditionally receives a 30% higher response rate in surveys, lab maintenance receives a 40% higher response rate, and laboratory bench top space concerns receive a 25% higher response rate. The common perception is that implementing sustainable features into a research laboratory environment is an expensive undertaking and that the payback can be substantially longer than that for installations in their conventional counterparts. The largest sustainability challenge is in funding for its equipment cost counterpart. The cost of implementing increasingly expensive sustainability systems will continue to be debated in the research lab initial strategy sessions over the next five years with increasingly weaker paybacks, despite all the positive comments for its implementation.

The current and expected future forecasts for global economic growth are positive, but only weakly positive. In the U.S., federal funding for research—including the design and construction of new/renovated research labs—is expected to increase between 1.5% and 2% annually for the next five years, as it is for most of the European Community countries according to the October 2016 issue of the International Monetary Fund's World Economic Outlook. Economic growth in Asia is substantially stronger and funding expectations in those areas are not expected to be as much of a concern, although their growth rates also appear to be slowing slightly.

Sustainable Leadership

Despite concerns over the decreasing cost effectiveness of sustainability implementations in the design/renovation and construction of research laboratories, sustainability programs are still likely to continue to be pursued at an increasing rate. As noted in this report, there are federal guidelines for increasing sustainability in government buildings for the next 15 years, ending with the requirement for net-zero energy requirements for all new building by FY2030. The guidelines have few mentions of the costs of implementing these actions or budgeting recommendations for how to get there.

One of the stronger incentives for implementing sustainable systems in a research lab is corporate goals. This incentive does not appear to be going away and will likely continue to be a driver in being a sustainable "good citizen" and driving continued funding for implementing sustainability initiatives, even if they are not as economically attractive as they might have been in the past.

Changes Since 2014

The editors of *R&D Magazine* and *Laboratory Design* published a similar report as this current report, "Sustainable Laboratory Design and Construction," which was included in the June 2014 issue of *Laboratory Design*. These two reports covered mostly different topics on sustainability, however, with the current report being more targeted at practical sustainability solutions. Still, it is possible to point to some changes since 2014. Items that have changed slightly over the past two years include lower cost expectations for building a sustainable lab today than it was expected to cost two years ago.

Also, while energy costs (from primarily petroleum sources) are significantly lower in 2016 than they were in 2014, the focus on sustainability in 2016 is stronger than it was in 2014. Research and design programs today focus on reducing energy use through sustainable design implementations, the implementation of renewable energy initiatives and enhancing energy efficiency through hardware and software upgrades.

A whole program approach also appears to be more important in 2016 than it was in 2014, when the focus was more on individual components and systems (2014), rather than the current focus on the whole research lab package (2016).

Additionally, LEED v4 was just released in 2014 and there may have been some trepidation to support it because of the increased complexity, the cost of LEED and some new sections on community issues. These hesitations appear to have evaporated and LEED v4 is now well accepted throughout the community and appears stronger as a design guide throughout the world than it ever has been in the past.

Monitoring and control of sustainability features in a research laboratory have not changed substantially over the past two years. They are still just as important in 2016 as they were in 2014 and the technologies appear to be mostly similar, except with a bit more focus on automation in 2016 than in 2014.

Site selection and design as it relates to the sustainability of a new or renovated research laboratory may also have become slightly more important over the past two years. The number of issues and concerns in site selection have increased and come to the forefront of study and investigation as being strong factors that affect the overall sustainability of the new or renovated research laboratory. These analyses have now been more thoroughly formalized and documented.

Finally, the research labs themselves have continued to evolve over the past two years with the current facilities ever more complex, ever more sophisticated and ever more technologically relevant in the R&D community. 2016 laboratories are new, fresh and relevant in the sustainability arena—2014 laboratories, in contrast, already appear to be "old" and in need of substantial upgrades.