# SUSTAINABLE DESIGN AND CONSTRUCTION STRATEGIES FOR RESEARCH BUILDING TYPOLOGIES


By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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While being among the most energy and resource intensive building types to construct and operate, modern research buildings have to excel beyond energy efficiency to be classified as environmentally sustainable. The design of these buildings must also incorporate complex systems and environmental considerations. These integrated architectural and mechanical systems intended to promote safety and "good science" are often at odds with sustainable design and construction principles. Due to this conflict, recent research is beginning to focus on the environmental performance of U.S. research buildings. The intent of this research has been aimed at promoting a "whole building" approach to environmental performance.

The objective of this thesis is to develop sustainable strategies specific to research buildings. The analysis of the design and environmental factors of this research will create measurements related to planning, material selection, and active systems

integration. The concept of design efficiency will be the basis of this research, and will be used as a means to achieve sustainable performance.

The methodology for this thesis will follow the conceptual stages of the design process to determine the sustainable opportunities for research buildings. Within these stages, the broad category of a research building will be defined in terms of its components. These components will then be designed and analyzed for sustainable performance through design efficiency. The measures used for this analysis will be based on environmental, economic, and functional issues. How these three components interrelate will become the basis of an environmentally sustainable research building.

# CHAPTER 1
# INTRODUCTION

Throughout history, building typologies have been identified as a reflection of society's goals and technical abilities. The 21st century culture can regard research-building typologies as the embodiment of this spirit. They encompass our economic and intellectual abilities in a form that is highly complex both programmatically and technologically (Carlisle 2000 p.1). This complexity comes at a high price to the environment. As large-scale consumers of energy and producers of hazardous wastes, research buildings are starting to be analyzed in both the public and private sectors for possible means of sustainable design through energy efficiencies. The objective of this thesis is to develop sustainable strategies specific to research buildings. The analysis of the design and environmental factors of this research will create measurements related to planning, material selection, and active systems integration. The concept of design efficiency will be the basis of this research, and will be used as a means to achieve sustainable performance.

As a species, humans rely on the environment for survival. Habitats were first constructed for safety and protection from the forces of nature. These habitats have since evolved to create structures for economic stability and search for knowledge. However, these activities have not gone unnoticed by nature. The depletion of natural resources for energy and materials has grown exponentially with the increase in the world's population. The scars of this depletion are left on the world's forests, plants, and animals.

This is in addition the damage the current environment is doing to humans as well. Cancers and toxic poisonings can be directly attributed to the environments humans have created to protect themselves from the forces of nature (Kibert and Guy 1997, p.7).

The construction industry is the defining force in the shaping of the environment. In the United States, the construction industry generates 6-12% of the GNP, 7-10% of all economic activity, and employs 5% of the workforce directly and 10% indirectly. The creation of buildings by this industry is directly related to power plant construction and operation as well as solid waste generation. The magnitude and size of the construction industry's impacts on the environment and people is disproportional when compared to other industries as illustrated in Table 1-1 (Kibert and Guy 1997, p.9).

Table 1-1: Impacts of modern buildings on people and the environment

| Problem | Building's Share of Problem | Effects |
|---|---|---|
| Use of Virgin Minerals | 40% of raw stone, gravel, and sand; comparable share of other processed materials such as steel. | Landscape destruction, toxic runoff from mines and tailings, deforestation, air and water pollution from processing |
| Use of Virgin Wood | 25% for construction | Deforestation, flooding, siltation, biological and cultural diversity losses |
| Use of Energy Resources | 40% of total energy usage | Local air pollution, acid rain, damming of rivers, nuclear waste, risk of global warming |
| Use of Water | 16% of total water withdrawals | water pollution; competes with agriculture and ecosystems for water |
| Production of Waste | Comparable in industrial countries to municipal solid waste generation | landfill problems, such as leaching of heavy metals and water pollution |
| Unhealthily Indoor Air | Poor air quality in 30% of new and renovated buildings | Higher incidence of sickness-lost productivity in tens of billions annually |

Source: (Roodman, Malin, and Lenssen 1995, p.23)

Energy efficiencies to reduce these impacts are by no means easily achieved in research buildings. These buildings typically consume 5 to 10 times more operating energy per square foot than office buildings. Additionally, research buildings have 15% more embodied energy than office buildings as shown in Figure 1-1 (Carlisle 2000, p.1). Such energy usage clearly demonstrates the need for critical analysis. New regulations and organizations have being enacted by the federal government to drive this analysis. The intent of these activities is the development of sustainable research buildings. The primary actions have been the following:

- U.S. executive order (13123) removes the exemption of federal laboratories from energy efficiency goals, sets a 25% savings target, and calls for baseline guidance to measure progress (Sartor 2000, p.1).
- A new U.S. EPA and U.S. DOE initiative, Laboratories for the 21st Century, establishes voluntary performance goals and criteria for recognition (Sartor, Piette, and Tschudi 2000, p.1).

The objective of this thesis is to develop sustainable strategies specific to research buildings. Research buildings as defined by this thesis are those buildings created by public or private organizations that involve research personnel working directly with hazardous materials in a laboratory setting. The focus of this research will be related to the design of the laboratory component of research buildings. As this is the programmatic area that generates the highest need for operating and embodied energy, this thesis propose a more efficient design of the laboratory. The analysis of the design and environmental factors of the laboratory will create measurements related to planning, material selection, and active systems integration of the research building. The concept of design efficiency will be the basis of this research, and will be used as a means to achieve sustainable performance.

For the purpose of this research, the concept of building sustainability will be based on the principle defined by the United Nation’s World Commission on Environment and

Development (WCED). The proceedings of this group, published in 1987, defined sustainability as “providing for the needs of the present generation without compromising the ability of future generations to meet their needs” (WCED 1987). This thesis will use this definition as a basis to evaluate the strategies related to design, material selection, and the active systems integration of the research building.

The means of attaining research building sustainability can be traced through the stages of the design process. The first strategies for sustainability become present in the pre-design phase of the design. In this phase, large-scale conceptual questions are explored that relate to regulatory bodies, environmental issues, and financial constraints. All of these considerations must be at the scale of the laboratory, the research building, and the larger context in which they exist. These issues will be explored and strategies will be defined in Chapter 2 of this thesis.

How these environmental issues integrate with functional issues will be the subject of Chapter 3. This section will define the functionality that must occur in research buildings, and the possible sustainable opportunities that also exist. These opportunities will be explained though a module of the laboratory, and the possible design efficiencies that can be created will be explained in terms of their environmental impact.

While sustainable material issues apply to all building types, research buildings have a disproportionate level of embodied energy. The multiple issues involved in this level of embodied energy will be discussed in Chapter 4. These issues will also be related to life cycle costing. Again the laboratory module will be used as a means of testing conceptual strategies.

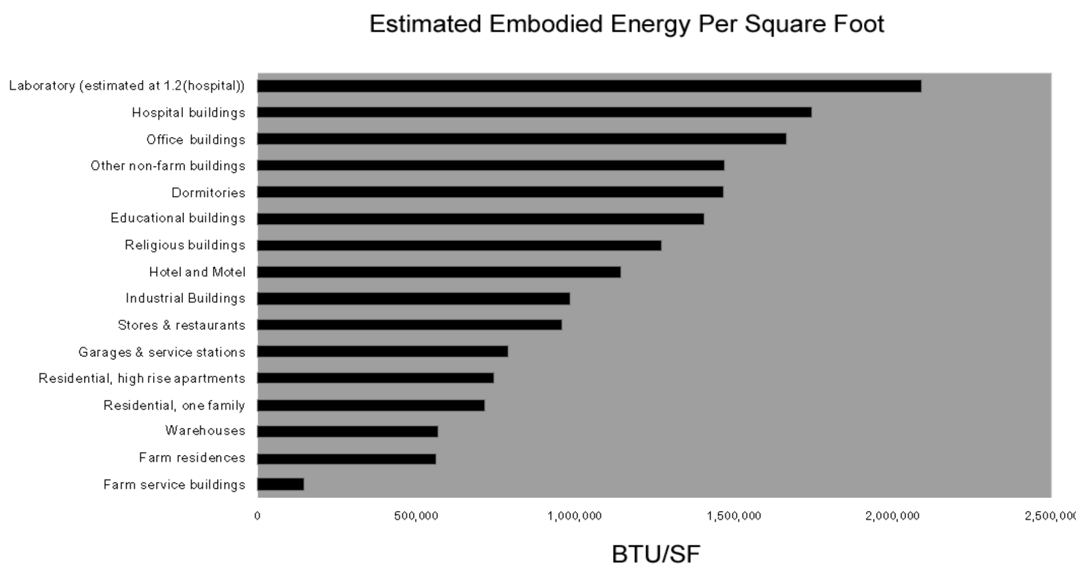



Figure 1-1. Estimated embodied energy per square foot (BHKR 2000, p.12).

Beyond the passive design strategies related to design efficiencies and material selection, active building systems must also be discussed. The intent of Chapter 5 is to list the specific sustainable strategies that relate to active systems in the laboratory building. While the design of the HVAC, energy, and water systems are beyond the scope of this thesis, the relation of these systems to whole building design in considered in terms of active energy usage and conservation.

The integration of these separate issues into measurable tools will be explored in Chapter 6. New assessment tools are being developed both for sustainable buildings and laboratories. The primary assessment tool for the U.S. is the Leadership in Energy and

Environmental Design (LEED) standard developed by the U.S. Green Building Council. This standard is also being further elaborated to include laboratory specific ratings. This elaboration, entitled "Labs for the 21$^{st}$ Century," is defining a means for building owners and designers to go beyond the code minimums, and determine an optimum range of performance for laboratories in research buildings.

In addition to the recommendations for the design and environmental factors specific to research buildings are the opportunities for future research. The concept of design efficiency, as define by this thesis, will be used to conclude the intent of developing sustainable strategies and measurements related to design, material selection, and active systems integration.

The contribution of this thesis to the existing body of knowledge for research building design is in the relation to sustainable integration. Current research in energy efficient laboratory design has focused on component-based solutions as a means to reduce energy usage. This thesis will look at the broader concept of sustainability as it relates to the phases of the design process for research buildings. This broader concept will explore means to reduce material and energy usage through design integration of multiple considerations. These considerations will all be based against life-cycle cost and safety factors.

# CHAPTER 2
# SUSTAINABLE RESEARCH BUILDING PRE-DESIGN FACTORS

Sustainable research building design is an iterative process involving multiple stages of analysis. The pre-design stage of the planning process can be thought of as the time when project goals and limitations are determined. In addition to the issues all building projects face, research building projects face unique environmental pre-design factors. These goals and limitations exist both inward and outward between the project and the community/regulatory agencies. Such an exchange requires designers to set goals, benchmark their progress, interact with the community on zoning and approval issues, assist owners in the decision to renovate or built new, and ultimately consider a much larger context than the building site.

## Goal Setting

Goal setting in the sustainable research building context is the process of first determining needed objectives that exceed requirements, and developing a means of achieving these goals. Regulatory agencies, time, or financial constraints can create the objectives.

## Benchmarking and Case Studies

Benchmarking is the process of measuring the limits the project is intended to incorporate. For sustainable research buildings, benchmarking can have multiple meanings that are specific to each project. As these issues have emerged and evolved, measurement tools and mechanisms have been created to aid designers. While the specifics of these measure tools will be discussed later, they are another resource in the pre-design planning.

**Zoning and Community Factors – A Regulatory Context**

As centers of research and experimentation, research buildings receive and create hazardous materials. The path of these materials back to the environment has become regulated by multiple overarching acts created by the US government. While all of these acts control the manner in which construction related activities affect the environment, three are directly related to the hazardous nature of research buildings in the community. As shown in Table 2-1, the Clean Air Act, the Federal Water Pollution Control Act, and the Superfund Amendments and Reauthorization Act all concern the research materials deposited back into the environment, and the right of the community to know of their existence.

- **Clean Air Act of 1970**, **1977, 1987** – As the Clean Air Acts concerns air quality and its effect on humans, it addresses the exhaust systems of research buildings. Potentially harmful gases are created in laboratories, and vented to the building exterior. The manner of exhaust and type of gases are regulated by this act. This must be considered in the pre-design phase for the type of research planned for the project, the effects it could potentially have on the environment, and how these effects could be mitigated or eliminated (NRC 2000, p.62).

- **FWPCA** – Federal Water Pollution Control Act covers the improvement and protection of water quality. As laboratories release contaminated waste water back into the environment that have been contaminated, measures must be planned for early in the pre-design process that allow for acceptable water conditions to be maintained before release back into the environment (NRC 2000, p.62).

- **SARA –** Superfund Amendments and Reauthorization Act ensures a community's right to know what hazardous materials are present in their community. This act encompasses all hazardous materials processes for the research building. As the shipping and delivery of hazardous materials to and from the laboratory must pass through a community, they will need to be aware of it. Additionally, the types of materials being created in the laboratories needs to be made public in so much as these materials have the potential for contamination of the environment. This allows emergency response team to react appropriately when responding to fires, explosions, or contamination (NRC 2000, p.62).

Table 2-1. Environmental and health acts

| Environmental and Health Acts |
|---|
| **Clean Air Act of 1970 -** Set standards for automobile emissions.<br>**Occupational Safety and Health Act of 1970 -** Established OSHA and gave it the power to proclaim and enforce worker safety and health standards, conduct inspections and investigations, and require employers to keep detailed records on worker illness and injuries, and conduct Research.<br>**Federal Environmental Pesticide Control Act of 1972 -** Required the registration of pesticides and gave EPA authority to ban use of pesticides found to be hazardous.<br>**Safe Drinking Water Act of 1974 -** Set standards for maximum allowable levels of certain chemicals and bacteriological pollutants in public drinking water systems.<br>**Toxic Substances Control Act of 1976** – Allows for the EPA to gather information and evaluate potential hazards from chemical substances and regulates their production, use, distribution and disposal.<br>**Clean Water Act of 1977, 1987 -** To restore and maintain the chemical, biological, and physical integrity of the nation's waters.<br>**Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (Superfund) of 1980 -** $1.6 Billion fund to clean up toxic contaminants spilled or dumped into the environment.<br>**Emergency Planning and Community Right to Know Act (EPCRA) (SARA TITLE III) of 1984 -** Forces state and local governments to develop plans for response to unanticipated releases of certain chemicals.<br>**Resource Conservation and Recovery Act (RCRA) of 1976 amended by the Hazardous and Solid Waste Amendments of 1984 -** Set safety standard regulations for handling and storage of hazardous wastes.<br>**Federal Insecticide, Fungicide, and Rodenticide Act Amendments (FIFRA) of 1988 -** Required that all pesticides, fungicides, and rodenticides be registered.<br>**Pollution Prevention Act of 1990** – Established Office of Pollution Prevention to coordinate efforts at pollution source reduction.<br>**Clean Air Act Amendments of 1990 -** Set new requirements and deadlines of urban areas to meet federal clean air standards. |

Source: (Kibert and Guy 1997, p.62-67).

These three acts together form a communication medium that must exist between the research building project and the community. The potentially negative impact a research building can have on the community and the environment establishes a complex relation between programmatic needs and sustainable objectives.

Internal to the research building project is another set of regulations more concerned with the occupants of the building. The 1990 laboratory standard established by the Occupational Safety and Health Administration requires an institution or employer to development its own program to protect the safety and health of its employees. The advantage of this standard over other detailed prescriptive standards by regulatory agencies is the performance-based program called the Chemical Hygiene plan. This plan allows the project team to develop a safe laboratory environment specific to the type of research activities and materials to be contained in the building (NRC 2000, p.64).

All of these regulations, in addition to the more common Americans with Disabilities act, building codes, and community zoning are factors that must be satisfied in order for the granting of building permits, and the insurance of an environmentally and occupationally safe project.

## Renovation versus New Construction

The pre-design phase may also include possible recommendations on what is to be built. The project may need to be analyzed as a renovation, a new facility, or a combination of the two. As the cost and technological requirements of research buildings are so high, the reduce, reuse, recycle process becomes more complex.

### Renovation

The primary advantage to the renovation of an existing facility is potential cost and resource savings that could result from the reuse of the existing structure, enclosure, or mechanical systems. This savings becomes more difficult to financially justify on larger projects as some or all of the existing components may require substantial work to satisfy regulatory or technological constraints (NRC 2000, p.75). These additional costs to renovate over build a new facility may in some cases be necessary. One common example of this is when the building is designated a historic landmark.

**New Facilities**

Beyond the complexities that exist in the determination to build a new facility, are the environment and sustainable ideals that should be meet. These ideals are both common to all building types and in some ways specific to research buildings. The environmental context and constraints should be studied to ensure a holistic approach to site design. Additional infrastructure that will be required for the building should also be studied to look for possible alternatives.

The regulatory restrictions mentioned above may also influence site design. Distances to water source, proximity to neighbors, and prevailing winds that can carry exhaust air must all be coordinated in this phase. All of these issues are in addition to the common design issues of orientation, massing, runoff, and architectural context.

For each of these design options, the broader context of the building's environment must also be considered. Strategies to minimize impervious surfaces and automobile dependency include locating the building near mass transit or coupling with other existing infrastructual opportunities. One of the functional advantages of research building is that in some cases the research is conducted around the clock, thereby utilizing the building to a greater efficiency. This type of operations often works well on college campuses where students live within walking distance.

## Pollution Prevention Strategies

A plan for the convenient removal of all wastes created in the laboratory must be created in the pre-design phase. This should be part of a much larger concept of waste management, processing, storing, and recycling.

**Managing Hazardous Waste**

The Resource Conservation and Recovery Act (RCRA) set safety standard regulations for handling and storage of hazardous wastes. Under RCRA, the Environmental Protection Agency is responsible for enforcing regulations of hazardous wastes at all stages. The difficulty this regulation has for research buildings is that it treats them the same as industrial-scale waste generators. While there are significant deviations in the volume and type of wastes these two uses create, planners and owners must begin early at developing of an industrial-scale regulatory model to manage hazardous waste. The specifics of this model vary with the site and the type and amount of waste to be controlled.

**Controlling Chemical Vapor Emissions**

Amendments made in 1990 to the CAA allow the EPA to regulate emissions of various chemical vapors including sulfur dioxide, volatile organic compounds, hazardous air pollutants, and other ozone-depleting materials. These amendments affect institutions if they have the potential to emit one or more of the EPA-listed hazardous air pollutants in amounts greater than 10 tons per year for a single pollutant, or 25 tons per year for all hazardous air pollutants (NRC 2000, p.63). These pollutants are measured based on all emissions under the control of a common authority including laboratories, power plants, boilers, etc. This has a great impact on institutions, as a single exhaust hood must be measured relative to campus wide pollutant limitations.

**Controlling Liquid Effluents**

The control of liquid effluents from laboratories is not as difficult a design task as the control of vapor emissions. The limitations on pollutant levels into the sewer system are set by local authorities or water works, and deal primarily with the acidity of water entering the sewer system. For instance, laboratory sinks are not allowed to pass waste directly into the sewer system. Rather, sink wastewater must flow through an acid neutralizing system that adjusts pH levels prior to discharge into the sewer. This must be planned for and discussed with the local sewer authority prior to design to ensure environmental protection requirements can be met.

## Conclusion

Pre-design factors require designers to set goals, benchmark their progress, interact with the community on zoning and approval issues, assist owners in the decision to renovate or built new, and ultimately incorporate a much larger context than the building site. Sustainable considerations can guide this conceptual and regulatory process. The conceptual decisions made in this stage have larger contextual implications that can make a research building sustainable, or environmentally detrimental.

Table 2-2. Sustainable research building pre-design recommendations

| **Sustainable Research Building Pre-Design Recommendations** | |
|---|---|
| 1. | Determine objectives or goals for sustainable laboratory design, and develop a means for achieving these goals. |
| 2. | Establish a benchmark against which to compare the limits the project is intended to incorporate. |
| 3. | Review pollution prevention regulations that will relate to the project, and establish strategies to meet or exceed these. |
| 4. | Analyze the sustainable factors in the decision to renovate or build a new building. |
| 5. | Establish a plan to control liquid effluents and chemical vapor emissions from the project. |

(Table by author).

# CHAPTER 3
# LABORATORY DESIGN FACTORS

The design of sustainable research buildings requires that functional needs be closely integrated with environmental concerns. These functional needs can be thought of as both guidelines and opportunities for strategic sustainable programming. At the base of the concept of sustainability is the need to reduce. One effective way to reduce material and energy usage is to efficiently plan and design with the minimal amount of space necessary. This chapter seeks to first define those factors that guide laboratory design in the research building, and determine ways to increase sustainability though efficiency, while not sacrificing quality of life or functionality.

The key factor for efficient laboratory planning is designing for “good science”. While what constitutes good science is argumentative, the need for functional spaces is not. These spaces created though the determination of needed space typologies, the establishment of design efficiency concepts, and potentially utilizing HVAC distribution systems as organizational concepts.

## Design for Good Science

In the design for “good science,” planning must be directed at the accomplishment of key goals for functionality. These goals can be elaborated as quality of life, flexibility, capability, and spaces for interaction. As these goals are not highly specific, their basis is common to both research building and also sustainability in general.

**Quality of Life**

Quality of life issues in laboratory design and planning are those directly affect by safety and environmental conditions. Environmental conditions can be elaborated to include lighting, noise, indoor air quality, and thermal comfort.

**Safety -** The first and foremost design consideration in laboratory design should be worker safety. Beyond the standard code related issues of life safety, laboratories have highly specific risks with regard to chemical spills or contamination. These risks have to be minimized both by planning and operation procedures. The unfortunate factor in this for sustainable design is that primary safety mechanisms often involve energy intensive active systems.

**Lighting –** Directly related to worker productivity and well-being is access to natural light. All spaces where the type of work being conducted allows it should have access to natural light. While providing an amount of visual relief, this has energy efficiency implications to be discussed later in terms of both thermal issues and the amount of artificial lighting needed. The complications of this also emerge in building zoning to be discussed later.

**Noise –** Noise in laboratories is often difficult to control. This is due to the high levels of noise creating equipment operating in laboratories and the relative minor amount of sound absorption materials able to be used in the laboratory environment. While these materials will be discussed later, it is worth noting that careful planning of the location of equipment can minimized the impact on researchers.

**Indoor Air Quality –** Beyond the indoor air quality issues common to all building typologies, the chemicals used in laboratories can have significant odors or particulates associated with them. The design of the ventilation system therefore must be significant to control the indoor air quality of a laboratory and ensure safety.

**Thermal Comfort –** In addition to controlling indoor air quality, laboratories must also maintain thermal comfort. This is a significant energy usage, as maintaining safety and air quality require many fresh air changes in an hour. Dependent on the outside environment, the HVAC system may be required to temper air in extreme ranges only to pass through the building once. The sustainable strategies associated with this will be further explored in the discussion of active systems.

**Flexibility**

In building design and planning, flexibility can be thought of as the need to accommodate an acceptable range of variables. This could also be classified as a level of adaptability. These concepts parallel the World Commission on Environment and Development’s definition of sustainability by being defined in this case as the ability of a design “to meet both current and unforeseen future needs” (NRC 2000, p. 74). These needs can also include not only adjustment, but also expansion.

The primary component to flexibility is modular planning. Using an organic metaphor of growth, a cell can retain its identity as a cell, or combine with other entities to form a community. This allows multiple re-combinatory possibilities while retaining the concept of the individual.

While the need for flexibility through modular planning creates certain efficiencies, there is also a need for individual expression of programmatic themes through customization (NRC 2000, p.19). The concept being that customization should be included, so long as it doesn’t reduce the efficiency of the design. This can be accommodated by limiting the customizations to appropriated planned constraints based on modular systems of design.

Flexibility also has a cost-over-time factor to it. As there are premiums in capital costs for designing and constructing a level of flexibility, these should be weighed against the premiums that will result from future modifications and renovations. The factors that can lead to these renovations include:

- Change in focus of research – (A response to a newly threatening disease).
- Change in personnel – (A change in the size or makeup of a group or team).
- Change in environment – (A change from open space to enclosed space).
- Change in procedure – (A change from bench-top chemistry to an automated process).
- Change in technology – (A new piece of equipment is acquired) (NIH 1996, p.6).

### Capability

Another component related to sustainable design through flexibility is capability, that is, the need for services and utilities that enables good science to be achieved without undue restrictions. This may be in the form of connections to services located close to every researcher, or movable and adjustable casework and walls. These concepts allow for spaces to be rapidly reconfigured with a minimum amount of effort (NIH 1996, p.4).

### Interaction Spaces

Research building designs should also encourage occupants to communicate and interact. Coupling environmental systems with interaction spaces can create a range of common areas from atriums to elevator lobbies. Other areas to plan for interaction include corridors, tearooms, conference rooms, water coolers, and at mailboxes.

## Space Typologies

To begin planning and analyzing spaces for sustainable strategies, a core of spatial typologies needs to be elaborated for laboratories. The primary activities in a laboratory building are research and experimentation. These activities require “wet” or “dry” laboratories and support spaces. The relationship between wet and dry laboratories and the spaces that support them must be one that accommodates efficiency for the research staff. Secondary to these types of spaces are the administrative support, interaction areas, and building services located elsewhere in the research building.

**Wet Laboratories**

The generic laboratory space for “wet” research consists of fume hoods, workbenches, desk space, storage, and sinks as shown in Figure 3-1. The work conducted in these areas generally involves utilizing wet solutions at the bench-top environment, and requires services ranging from lab grade water, piped gases, data connectivity, power, and safety devises. (NIH 1996, p.6)

Figure 3-1. Example of laboratory fume hood and casework at the Massachusetts Institute of Technology (photo by author).

**Core Functions (Dry Space)**

With the rapid advances in research technologies and methods, the need for specialized laboratory typologies are increasing. These typologies can include highly sophisticated instrumentation rooms and computational labs. These spaces can be classified as “dry”, as their functionality typically does not involve piped services, and acute temperature/humidity control is often required. One example of these spaces is shown in Figure 3-2.

Figure 3-2. Example of laboratory core support space (photo by author).

**Laboratory Support**

Those functions that support multiple research groups include autoclave rooms, glass-washing, constant-temperature rooms, cold rooms, computer rooms, darkrooms, developing rooms, equipment areas, bench support, radioactive work areas, storage, and tissue culture areas (NIH 1996, p.14). While each of these spaces has highly specialized variables, for the purpose of this research it can be assumed that the spaces are modular and adjacent to wet or dry laboratories.

**Office and Administrative Areas**

Beyond the primary and secondary research spaces are the administrative areas. These areas are generally office environments with conference type spaces.

**Building Support**

Like all buildings, a portion of the laboratory building area must be allocated for building services. These services can include functions such as shipping and receiving, circulation (vertical and horizontal), electrical and mechanical spaces.

**Vivariums**

Animal facilities are often included in the design of research buildings. While these can be a large component of the building, their design is highly specialized for the housing of research animals. In addition to the safety issues for wet laboratories, vivariums also have to follow protocols to prevent contamination and terrorism.

## Design Efficiency Concepts – A Bottom-Up Programming Process

One approach to research building planning is a bottom-up personnel needs assessment. This consists of categorizing and counting personnel to determine square footage requirements for research groups. A typical research laboratory can have multiple groups of researchers. These groups can combine or separate depending of the type of research being conducted. Often, a single research group consists of a principal investigator, a number of technicians, staff scientists, fellows, and students. The size of the typical group can range from 5 to 15. Additionally, each group requires a small number of administrative support personnel that may be shared with other research groups.

Another variation of this assessment is need-based rather than square footage estimated. For example, rather than assign 160 square feet to a researcher, determine the needs that they have of that area. This will commonly be 8 feet of bench space with shelves, a write-up desk, and access to equipment/support areas as shown in Figure 3-3. By looking at the components of what the researcher needs, a more efficient design can be achieved by investigating the ways research needs can overlap.

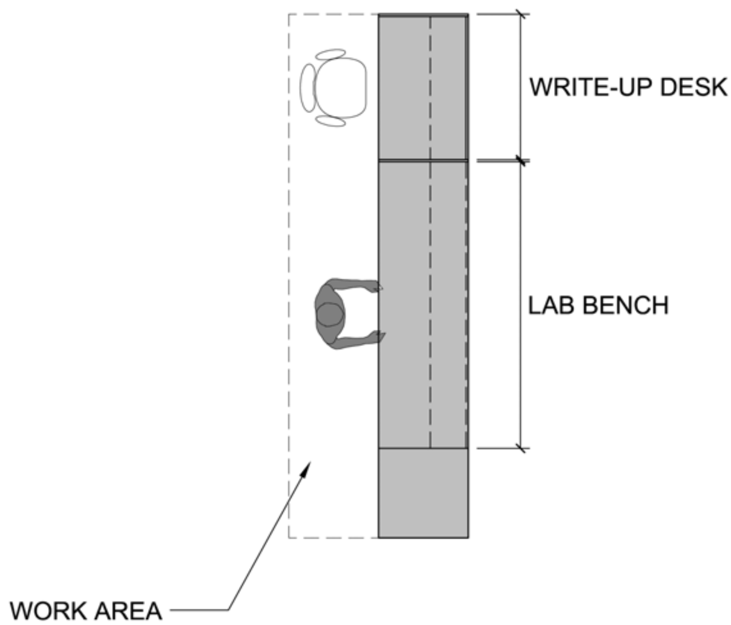



Figure 3-3. Example of typical laboratory bench space for one researcher (drawing by author).

**Lab Support Core Concept**

In order to have access to natural light, a successful strategy is to locate the laboratory bench space near the exterior of the building where possible. This presupposes that the “dry” or “core” functions described above do not need access to natural light and can be located in the inside of the building. An effective relation between the laboratory and the core functions is thus established by their adjacency. A typical size support area is shown in Figure 3-4.

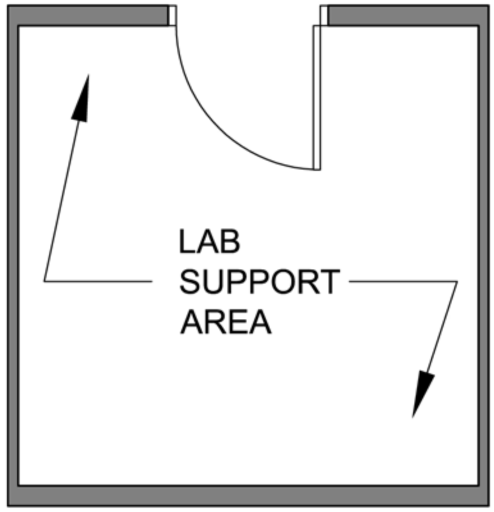



Figure 3-4. Example of laboratory core support space (drawing by author).

**Ghost Corridors**

The need for both circulation and emergency egress can be accommodated by what is called a ghost corridor. This can be described as an implied corridor that is created between the end of the lab benches and the core function rooms as shown in Figure 3-5.

**Open Laboratory**

Laboratory bench spaces should be designed so that walls can be created or removed to separate an open laboratory into smaller laboratories. Such walls should allow for the ghost core to continue from one space to the next.



Figure 3-5. Example of laboratory ghost corridor at the University of Massachusetts (photo by author).

**Laboratory Neighborhoods**

The divisions that occur between laboratories can be planned using conceptual analogies. A research group can be thought of as cellular. When that group is joined with other groups, it becomes an enclave, or a "neighborhood". While each neighborhood has specific needs, they can share certain core functions with other neighborhoods. The multiplication of the neighborhoods with their associated core functions becomes a systemic basis for conceptual design of typical laboratory floor plates.

**Equipment**

The high numbers of equipment required for research need effective space planned for them. In addition to the area for the piece of equipment, space must be reserved for access. As mentioned earlier, there may be a need for specialized equipment rooms that have specific requirements. There are also other strategies for the placement of equipment.

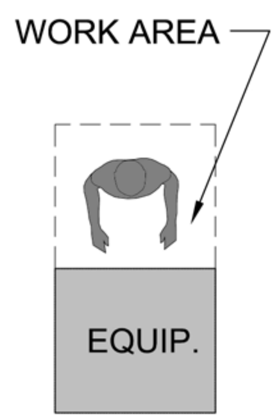



Figure 3-6. Example of area required for equipment and access space (drawing by author).

**Alcoves**

Small open rooms attached to the laboratories are areas in which equipment can easily be stored. This has the advantage of keeping equipment out of high traffic areas.

**Secondary Use of the Ghost Corridor**

The size of the ghost corridor can be increased to allow for the storage of equipment. This has the advantage of using valuable square footage for both circulation and access to equipment.

**Linear Equipment Room**

The idea of placing equipment along circulation can be taken further with the concept of a linear equipment zone as shown in Figure 3-7. This would be a main circulation corridor for the entire floor that is widened to allow for equipment storage along both sides. This has the advantage of being a highly efficient use of square footage, and separating out noisy equipment from occupied laboratories.


Figure 3-7. Example of a linear equipment corridor at the University of Massachusetts (photo by author).

**Distribution Systems as Organizational Concepts**

As research buildings are much more energy dependent than standard office buildings, the distribution of active systems must be planned early. More often than not, this planning becomes the basis for what formal typology the building becomes. Conceptually, these formal typologies can be broken down into three main categories as shown in Table 3-1.

Table 3-1. Active systems distribution categories

| **Active Systems Distribution Categories** | |
|---|---|
| **Category** | **Description** |
| Ceiling and Shaft Distribution | This concept of distribution locates vertical energy distribution services in large shafts that are feed horizontally in the ceiling space. |
| Service Corridor | Service corridors also utilize vertical shafts, but horizontal distribution occurs in a corridor at the center of the building. This allows for easy of access. |
| Interstitial Floors | The concept of interstitial floors is based on have an intermediate floor of services between two active laboratory floors. This allows services to be fed up and down to the laboratories. |

Source: (NRC 2000, p.9-13)

Of these three concepts, much research is going into the sustainable component to interstitial floors. The significant increase in up-front building costs is offset over the lifetime of the building through decreased maintenance costs, decreased modification and renovation costs, and decreased disruption of primary activities.

## Integrating Efficiency – The Laboratory Module Design

To illustrate the manner in which sustainable laboratory design can be achieved through efficiency, all of the above mentioned components have to be integrated. Totaling the building components that are not required under an efficient scheme will illustrate the reduction in material usage, the smaller interior volume to be conditioned and lighted, and the resulting reduced footprint on the ground.

Using the laboratory components of a workbench, equipment, and support spaces, we can devise a typical laboratory module as shown in Figure 3-8. For a minimal amount of efficiency, the ghost corridor will also serve as the space to access equipment. The intent of locating research space at a glazed wall for daylighting will also be included in this scheme. Finally, to establish a modular grid spacing, the module will be designed for two researchers at a 10’ overall width. These elements combined create an area of 160 square feet per researcher, which we will use as the basis of design.

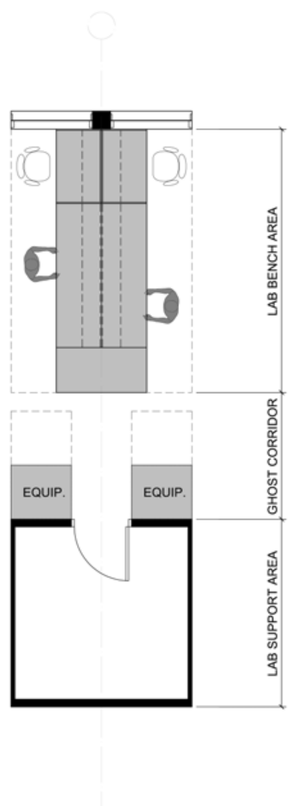



Figure 3-8. Scheme 1 laboratory module for two researchers (drawing by author).

If we reanalyze the resources that can be shared under this scenario we can derive a more efficient use of space. By keeping the same amount of bench space, equipment, and support area per researcher between the two designs, the same conditions are provided for. However, doubling the benches, and adding a linear equipment corridor can reduce the circulation that is required for all of these areas as shown in Figure 3-9.

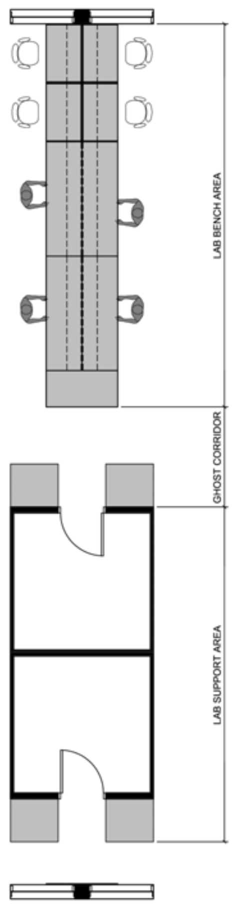



Figure 3-9. Scheme 2 laboratory module for four researchers (drawing by author).

When calculated and summarized in terms of square footage, there is a 6% reduction from Scheme 1 to Scheme 2, and a 17% reduction in exterior wall area as shown in Table 3-2.

Table 3-2. Scheme 1 and 2 square footage analysis

| Building Component | Scheme 1 Area (sq.ft.) | Scheme 2 Area (sq.ft.) | Reduction |
|---|---|---|---|
| Concrete Floor and structure | 160 | 150 | 6% |
| Finish Floor | 160 | 150 | 6% |
| Exterior wall at 9' ceiling height | 387 | 320 | 17% |
| Acoustic Ceiling Tile | 160 | 150 | 6% |
| Volume of Air at 9' ceiling height | 1440 | 1350 | 6% |

(Table by author).

This analysis could be illustrated further to look at the ways these laboratory modules could be grouped together. Continuing to use Scheme 1, the first option is to keep extending the overall width for additional researchers as shown in Figure 3-10. Using a maximum amount of 24 researchers, the final area of this scheme can be compared to others in terms of square footage, and exterior wall efficiency.

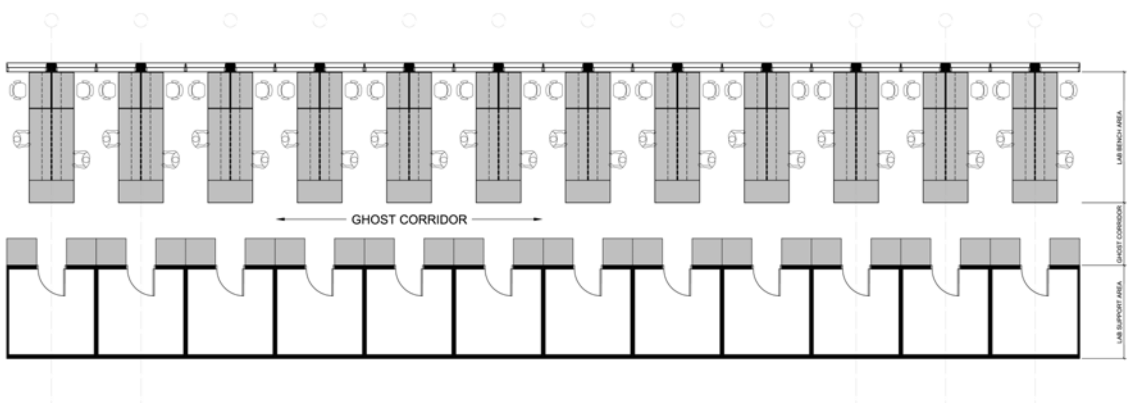



Figure 3-10. Scheme “A” laboratory module for 24 researchers (drawing by author).

A further derivative of this module is to double the module vertically, and extend the plan horizontally as shown in Figure 3-11. Again using a maximum amount of 24 researchers, this concept creates additional circulation along the center. This will increase the overall square footage without increasing the amount of amenities provided.

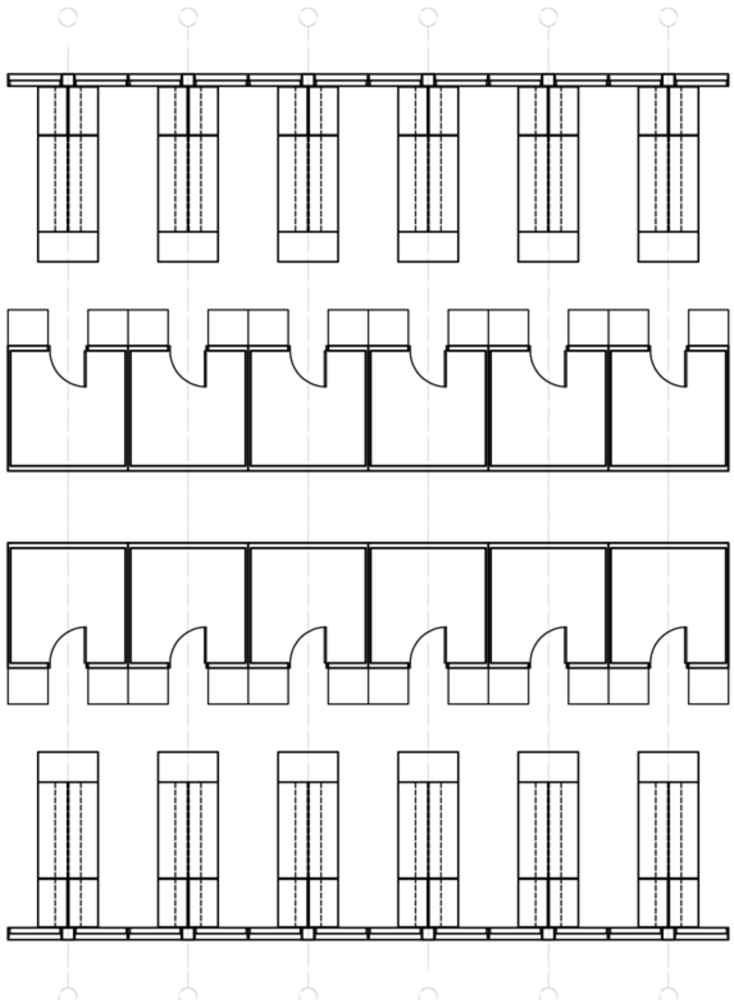


Figure 3-11. Scheme “B” laboratory module for 24 researchers (drawing by author).

A third and final design will use the efficient module of Scheme 2 created earlier. This scheme will be double the module vertically and allow it to extend horizontally until 24 researchers are fit into the space as shown in Figure 3-12. The circulation space at the center of the scheme will be used as a linear equipment corridor for efficiency.

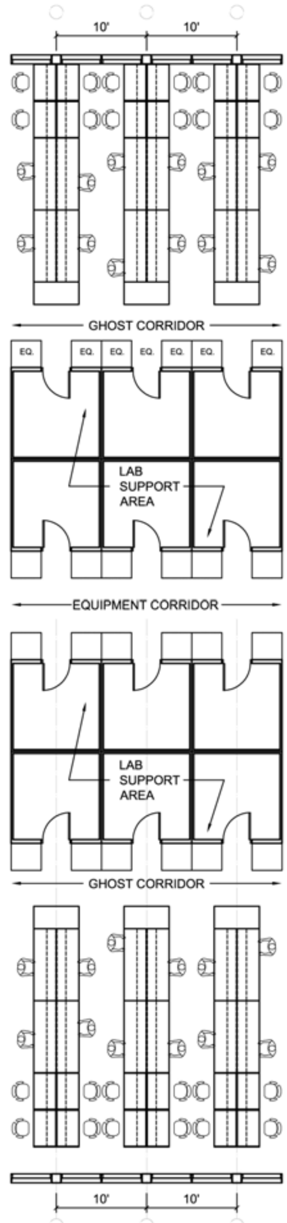



Figure 3-12. Scheme “C” laboratory module for 24 researchers (drawing by author).

These three schemes can now be compared in terms of their efficiency. With the dual intend of reducing material usage, and maintaining functionality, we can analyze the schemes based on square footage and perimeter wall area efficiency as shown in Figure 3-13.

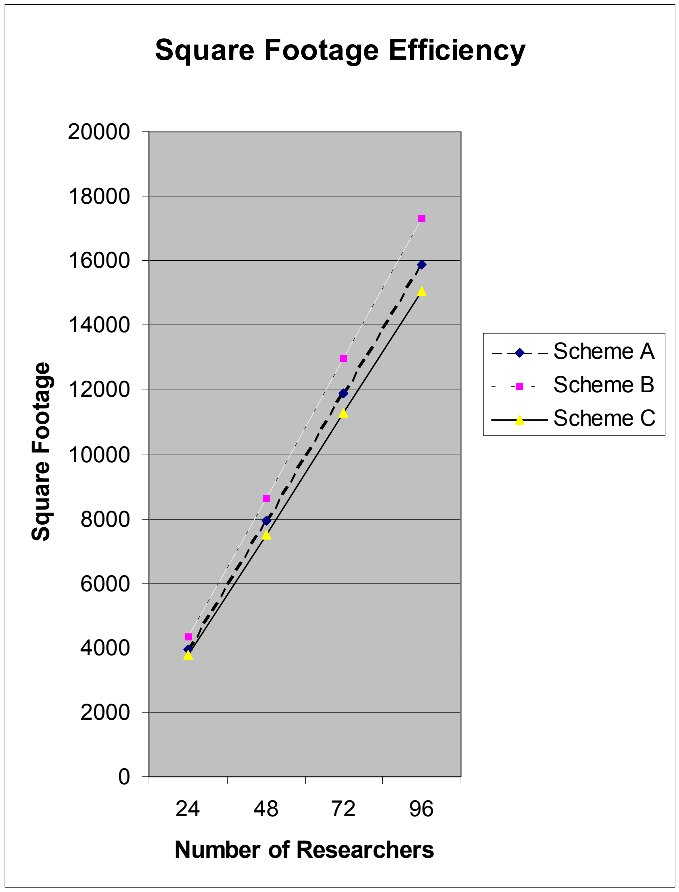



Figure 3-13. Scheme A, B, and C square footage efficiency (chart by author).

While the square footage efficiency slowly increases above 6% as more researchers are added between the schemes, something more dramatic occurs when the exterior exposure efficiency is considered as shown in Figure 3-14.

Both Schemes B and C start out high due to the addition of more circulation at the core of the plan. However, Scheme C rapidly becomes more efficient as the amount of researchers in the space is increased. This efficiency translates into a reduced amount of exposed surface to the exterior, thereby reducing material and operating costs.

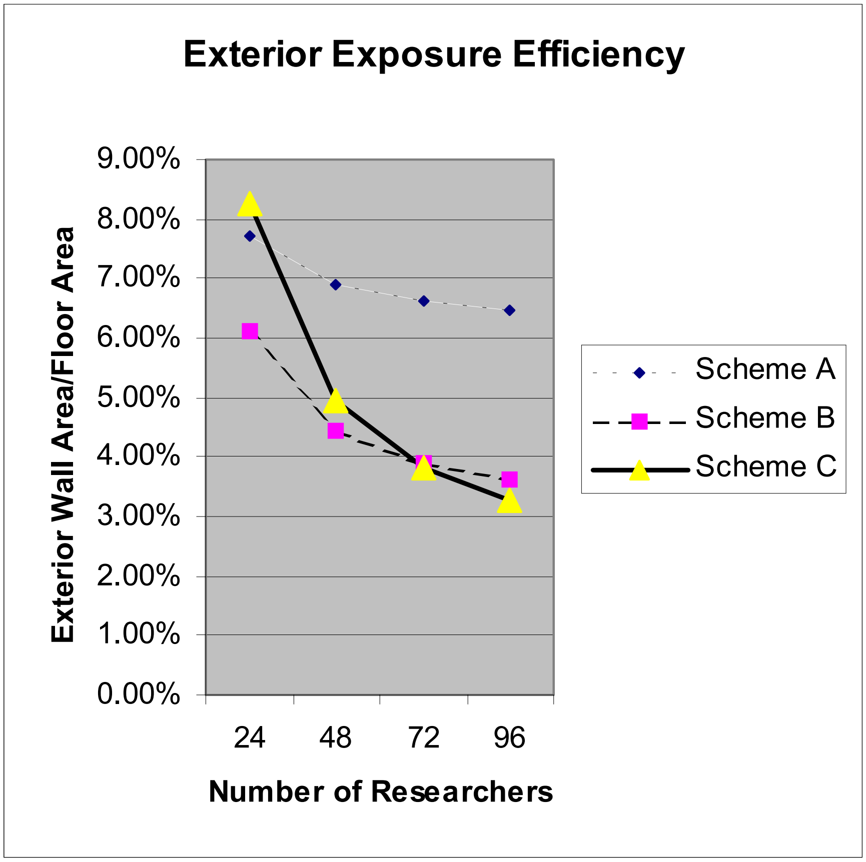



Figure 3-14. Scheme A, B, and C exterior exposure efficiency (chart by author).

**Conclusion**

This chapter has explored those factors that guide research building laboratory design with the intent of increasing sustainability though efficiency. The factors listed are based in both function concepts and quality of life concerns. The common concept to sustainability in this exploration has been the reduction of building materials through design efficiency. The integration of these functional concerns with environmental issues is a sustainable strategy that must be maintained throughout the all of project phases.

Table 3-3. Sustainable laboratory design recommendations

| Sustainable Laboratory Design Recommendations | |
|---|---|
| 1. | Design laboratory spaces using functionality as the basis of design. |
| 2. | Design laboratory spaces for a controlled amount of flexibility and capability. |
| 3. | Design spaces to encourage good science through interaction spaces. |
| 4. | Determine the needs of laboratory occupants to establish possible efficiencies of shared spaces. |
| 5. | Design laboratory modules to increase efficiency by reducing square footage and material needs. |

(Table by author).

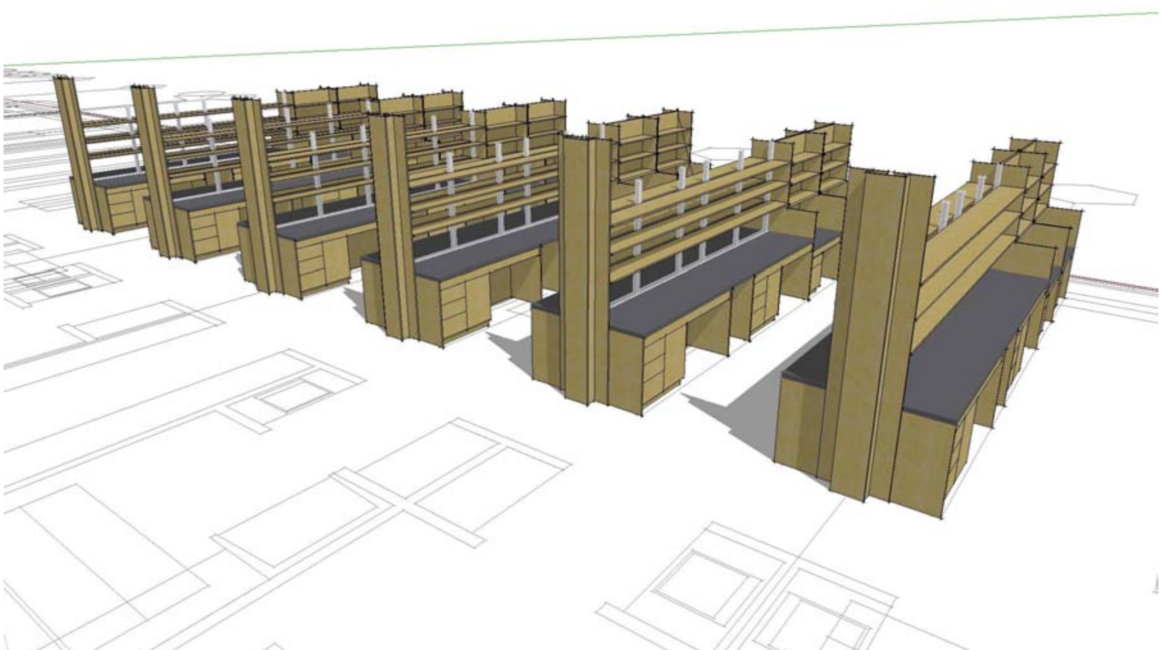


Figure 3-15. Scheme "C" rendering of laboratory benches for 24 researchers (drawing by author)

# CHAPTER 4
# MATERIAL SUSTAINABILITY – A FRAMEWORK FOR DEFINING THE LABORATORY ENVIRONMENT

Natural and man-made construction materials serve a multitude of applications in architecture. They offer the strength to withstand gravity and wind loads, with the thermal resistance to maintain indoor comfort. Materials can also symbolize aesthetic meanings through color, texture, pattern or placement. These physical properties and implied meanings have been translated into a range of construction costs and skills required for installation.

Sustainability is teaching designers to analyze materials beyond these commonly accepted factors. The concepts of embodied energy, efficiency, recycled content, reusability, and health are adding to the complexities of material selection. These environmentally weighed factors can all be traced through the life cycle of a material's extraction, manufacture, installation, and reuse or disposal.

Before analyzing the materials that define a sustainable research building, what makes a material sustainable must be defined. Efficiency and the energy life cycle will be a starting point to explore sustainable material concepts. Then a definition of how laboratory needs determine materials requirements can be found. The result of this will be what, if any, are the sustainable material opportunities in laboratories. Emerging computer applications will be used in this material analysis.

## The Efficiency Paradigm

As illustrated earlier, the first sustainable strategy should be requiring energy reduction through efficient design. Efficient materials design should be conceptualized in terms of what one is trying to achieve. In the laboratory module example in Chapter 4, certain research components per occupant were achieved. This concept can be extended further to the point that researchers are not looking for an energy intensive building, but rather a building that offers a safe, comfortable environment. This point of view places the sustainable responsibility on the designer to choose materials that satisfy comfort and safety needs, while reducing the amount of energy related to the building.

## The Energy Life Cycle

The energy used by a building can be characterized into two main components, embodied energy and operating energy. As stated before, research buildings use a vast amount of operating energy to power equipment, run HVAC systems, and operate lights. These are the operating energy components, or the end use of a direct energy supplied from an outside source. Embodied energy is the energy embedded in a material as shown in Figure 4-1). This includes the amount of energy required to extract the material from the environment, manufacture the material product, install the material during construction, and transport the material between these phases. (Kibert and Guy 1997, p.210)

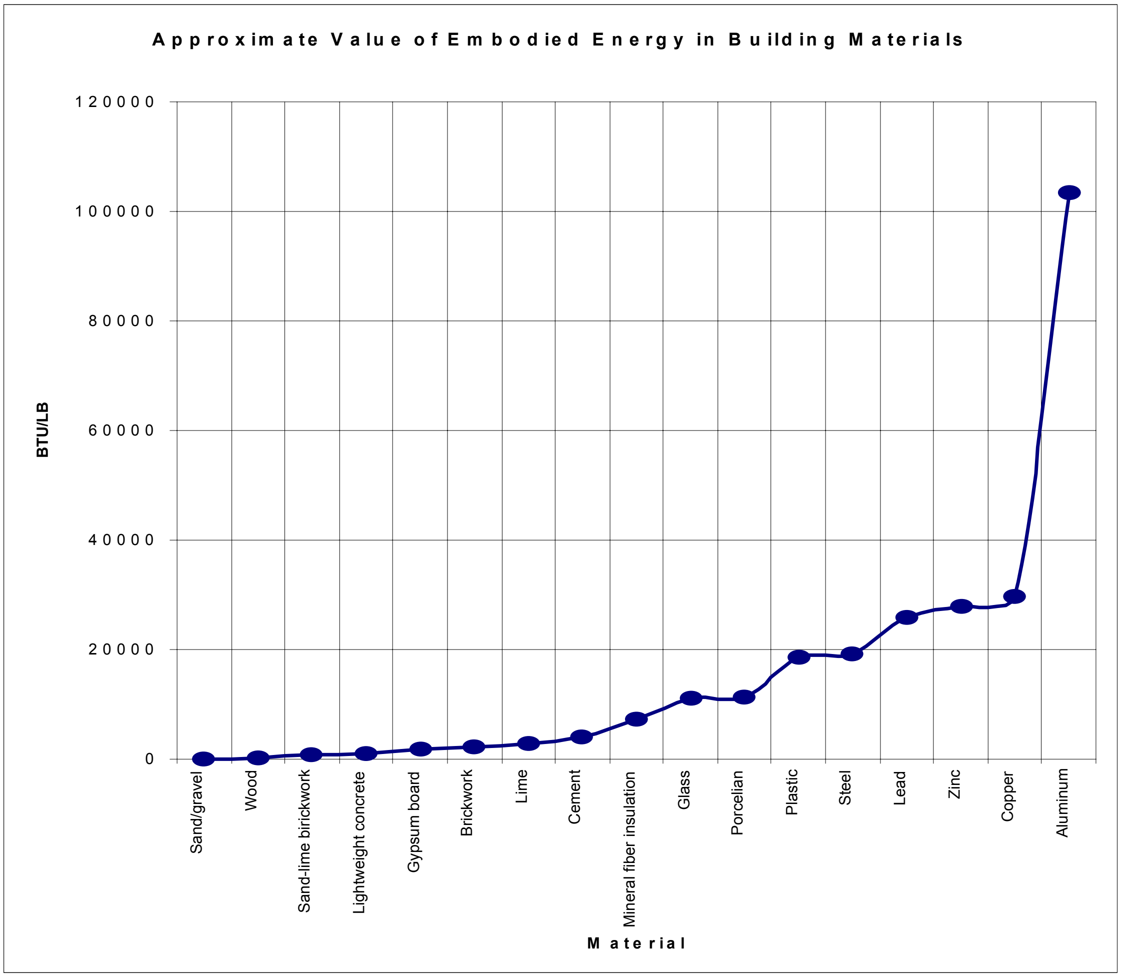



Figure 4-1. Approximate value of embodied energy in building materials (AIA 1994, p.743).

The relation between operating and embodied energy varies from building to building. An example of this relation can be shown in the typical North American home as shown in Table 4-1. Embodied energy can constitute as much as 20% of the total life energy used by the home, especially high when considering a useful life of 40 years for most homes. This can be further explained as 10 years of operating energy is the energy equivalent of the one year it requires to create, transport, and install the materials of a house. The largest amount of production energy, 80-90% is in the production and transportation of the material, with just 10-20 percent being used in the actual construction process. (Kibert and Guy, 1997, p.210)

Table 4-1. Embodied energy versus operating energy for North American homes

| Embodied Energy versus Operating Energy | | | |
|---|---|---|---|
| | Heating Energy MM Btu/year (Gj/year) | Embodied Energy MM Btu (Gj) | Embodied Energy in years of Heating Energy |
| Home type, location | | | |
| Conventional, Vancouver | 101 (107) | 948 (1,000) | 9.4 |
| Energy-efficient, Vancouver | 57 (60) | 1019 (1,075) | 17.9 |
| Conventional, Toronto | 136 (143) | 948 (1,000) | 7 |
| Energy-efficient, Toronto | 78 (82) | 1019 (1,075) | 13.1 |

Source: (Malin 1993, p.1).

## Sustainable Material Concepts

The translation from natural material to building component presents environment impacts on the earth and complex questions for designers. The desire to construct a building of lasting importance can extend beyond the construction site to the worldwide environmental conditions that are by-products of the material process. These specific environmental hazards, as well as strategies to avoid them can be incorporated into the selection of materials for the laboratory context.

### Environmental Hazards of the Manufacturing Process

The manufacture of natural and man-made elements into construction materials has environmental impacts that go beyond the realm of architecture. The generation of gases that could permanently alter the environment, the creation of toxics that can poison humans, and the mountains of waste being generated and stored in landfills are leading to a reevaluation of the effect architecture has on the environment. These potential dangers can also be starting points of material analysis.

**Greenhouse warming gases**

To further explore the criteria for sustainable materials selection, the life cycle of materials must be evaluated, and key strategies for sustainability mapped at each stage. One overarching factor that exists in all of the phases is the creation of greenhouse-warming gases. These are the gases such as carbon dioxide that trap infrared radiation from the sun in the earth's atmosphere, contributing to global warming. Among the effect of this are the environmental threat of increased worldwide water levels. These greenhouse-warming gases are often released by the fuel energy embodied in the manufacture and transport of a material.

Table 4-2. Carbon dioxide emissions by fuel type

| Carbon Dioxide Emissions by Fuel Type | |
|---|---|
| **Fuel Type** | **lb/million BTU** |
| Coal | 210 |
| Oil | 190 |
| Natural Gas | 118 |
| Electricity from Coal | 694 |
| Electricity from oil | 628 |
| Electricity from Natural Gas | 388 |

Source: (Kibert 1999, p.123).

**Toxics**

While greenhouse-warming gases are not immediately harmful to humans, other toxics created by materials can be. At the manufacturing stage, these toxics can be in the form of gases released into the atmosphere that cause harm to our respiratory systems, or released into the water causing ecological damage and contamination. As mentioned earlier, the EPA closely regulates allowable levels of toxics and their disposal. Designers should aim to not only choose materials that meet these allowable EPA levels, but to also select materials that generate no toxic by-products. While difficult to use exclusively, such materials do not can into question what is an acceptable level of toxics to put back into the environment.

**Waste**

Another factor is the amount of waste or non-usable by-product created by the material. Industrial ecology is looking for ways for couple manufacturing processes to use the waste from one material as a component in the manufacture of another material. While this is a creative way to deal with a problem, sustainable material selection should go further to specifying only those products that generate minimal, if any, amounts of waste. This therefore reduces the need to find other creative solutions to deal with waste disposal.

**Material Selection Strategies**

The strategies that can reduce the potential environmental impacts mentioned above for designers are again related to reduce, reuse, and recycle. First reducing the need for materials, and second selecting materials that are made locally can conserve energy. The durability of a material is important, as this will reduce cost and energy depending on how often it has to be replaced. Another cost component is the effects material breakdown has on the indoor air quality and the relation to employee health. Finally, the reuse or disposal of a material should be explored. All of these are components of materials that can be explored through life cycle costs.

**Material reduction**

When looking at ways to reduce energy use, or the harmful side effects of materials manufacturing, reducing the amount of materials will have the greatest effect. This can be at the scale of the building, such as the decision to not build a new building or at the scale of the laboratory module where a percentage of the materials needed to achieve a certain goal was reduced.

While we can reduce the amount of materials needed, there still have to be new materials utilized. A sustainable strategy at this phase is to use materials that are renewable, or can be easily replaced by the environment. An example of this would be the ability to re-grow trees after we have extracted the amount of wood necessary. This is not the case with material should as metals. These types of materials require clearing the earth and extracting the material. Once extracted, the earth cannot easily recreate the material.

**Use of local materials**

As mentioned above, a significant amount of energy is used in the transportation of materials as shown in Table 4-3. To reduce this, materials should be chosen that are created locally where the material function allows for it.

Table 4-3. Energy efficiency by mode of transport

| **Energy Efficiency by Mode of Transport** | |
|---|---|
| | Btu/ton-mile |
| Truck | 2946 |
| Railroad | 344 |
| Barge | 398 |
| Ship | 170 |

Source: (Kibert 1999, p.126).

**Durability**

Of primary importance to research building laboratories is material durability. As chemical spills can break down some materials and cause them to have to be replaced, materials should be chosen that have a high level of durability. While these types of materials will often have a higher embodied energy, it is usually less that the amount to build something once, and have to entirely replace it due to its lack of resistance to wear.

**Indoor air quality**

Once out of the manufacturing process, materials should be looked at for their effects on the indoor environment. When installed, some materials break down and become harmful to humans. Examples of this include the removal of lead paints and asbestos, as well as the volatile organic compounds released from paints and carpets. Some industries are creating take back programs for these types of materials.

**Material reuse and recycling**

Once a material has been created and used, one must look at other possible secondary uses. These secondary uses can be categorized as recycling and reusing. The amount of energy maintained in the material should be analyzed in each of these choices.

While recycling is a type of reuse, it involves a re-manufacturing process that requires energy, and at this time only reuses a percentage of the original material as shown in Table 4-4. Higher embodied energy materials such as metals are more readily able to be recycled back into the same grade of material that lower embodied materials such as woods. The clear advantages to recycling are that is reduces the amount of energy to create virgin materials, is cheaper, and reduces the environmental impacts from mining.

A subset of recycling is recycled content. This is the process of reusing and re-manufacturing waste materials in another product. Often done with wood base products and by-products, this process creates composite materials that can be highly efficient.

Table 4-4. Energy saved by using recycled materials

| Energy Saved By Using Recycled Materials | | |
|---|---|---|
| | Energy required to produce from virgin material (million Btu/ton) | Energy saved by using recycled materials (percentage) |
| Aluminum | 250 | 95 |
| Plastics | 98 | 88 |
| Newsprint | 29.8 | 34 |
| Corrugated Cardboard | 26.5 | 24 |
| Glass | 15.6 | 5 |

Source: (Stauffer 1989, p.1).

Reuse is a higher-grade form of keeping energy in the material. While difficult to make use of in research buildings, salvage industries geared toward residential applications are increasing in number. These operations disassemble existing buildings, and reuse the materials without re-manufacturing.

**Material disposal**

There are additional, less optimum disposal methods for materials that the reuse into other materials. A good example of this is the options available for wood products. As mention above, wood is a renewable resource that can be re-used or recycled into other composite materials. Beyond this, wood can also be reused as biomass in the form of landscaping compost. This biomass can also be burned in a power plant. The last, and hopefully least used option is to let the wood enter a landfill, and end its useful life while causing potential damage to the environment.

**Life cycle costs**

Finally, in our capitalist society, materials have to be considered based on their financial costs. The sustainable financial question for designers and building owners is which material costs are the measure? There are the up-front costs to extract, manufacture, transport, and install the materials. There is also a second measure, called life-cycle costing, that looks at these up-front materials costs, the costs to maintain the material throughout its useful life, and its final disposal or reuse costs. Once combined together, these costs can vary greatly depending on the material and its application. Financially, life cycle costing represents a way to integrate the multiple phases a material goes through, and its relation to durability. Environmentally, life-cycle cost expresses a means of justifying higher up-front costs, for more environmentally sound materials.

**Information integration**

The immense task of weighing these sustainable considerations with aesthetic and financial constraints is becoming easier thanks to publications, the internet, and computer applications. The careful weighing of all of the factors requires an immense amount of empirical data that is becoming combined in sophisticated ways.

The first comprehensive guide to sustainable materials was the Environmental Resource Guide by the American Institute of Architects. While not listing proprietary products, it analyzes the environmental effects of generic materials through their life cycle. This information can be a starting point to restrict material selections to those that satisfy a narrow range of environmental performance criteria.

Information technology based on sustainable materials is also growing and becoming more robust. From internet database to computer software, this technology is allowing rapid information gathering, sorting, and dissemination to designers. Perhaps the most promising of these advances is the development of life cycle analysis computer software. Two of these applications, BEES 3.0 and Athena 2.0, analyze economic and sustainable factors based on user preferences.

The Building for Environmental and Economic Sustainability (BEES) version 3.0 offers a means to analyze U.S. average performance results for generic and manufacturer-specific product alternatives. While not a replacement for careful material analysis by the designer, this software offers a means of rapidly sorting multiple factors in a graphic manner (Malin 2003, p.174).

The Athena Environmental Impact Estimator 2.0 is a building elements or systems analysis tool. Unlike BEES, which compares products, Athena computes financial and environmental information based on a conceptual model of a specific building design. This information is formalized into graphic representations (Malin 2003, p.174).

**Sustainable Materials Selection for the Laboratory Module**

In Chapter 3, the effect efficiency has on square footage analysis for design purposes was demonstrated. To further illustrate this concept in terms of sustainability, the material cost, embodied energy, and other environmental concerns should be explored.

A cost analysis for three common laboratory flooring materials using the laboratory schemes A and C will demonstrate the weight up-front costs have on a materials selection as shown in Table 4-5.

Table 4-5. Flooring cost analysis

| Flooring Cost Analysis | | | | | | |
|---|---|---|---|---|---|---|
| | Scheme A | | | Scheme C | | |
| | Area (sq.ft.) | Cost/sq.ft. | Total | Area (sq.ft.) | Cost/sq.ft. | Total |
| Generic Linoleum | 160 | $3.16 | $505.60 | 150 | $3.16 | $474.00 |
| Generic Terrazzo | 160 | $20.95 | $3,352.00 | 150 | $20.95 | $3,142.50 |
| Generic Vinyl Composition Tile | 160 | $1.67 | $267.20 | 150 | $1.67 | $250.50 |

Source: (RS Means 2002).

Based on this analysis, cost alone would dictate the selection of generic vinyl composition tile. Additionally, once the life-cycle costs listed above are factored in, generic vinyl composition tile would remain the best selection as shown in Figure 4-2. This is due to the high first cost of terrazzo, even when it has no future costs, as it is a highly durable material.

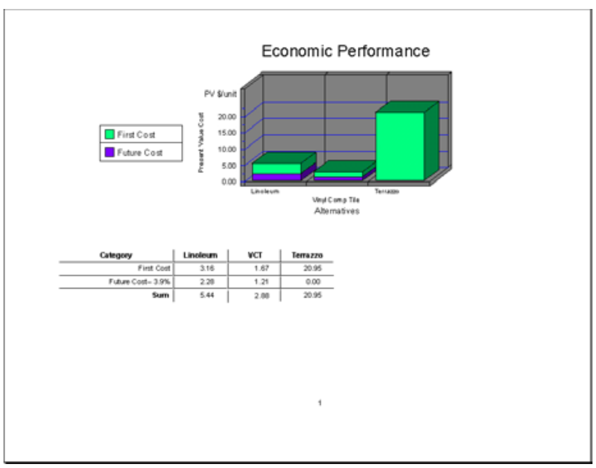
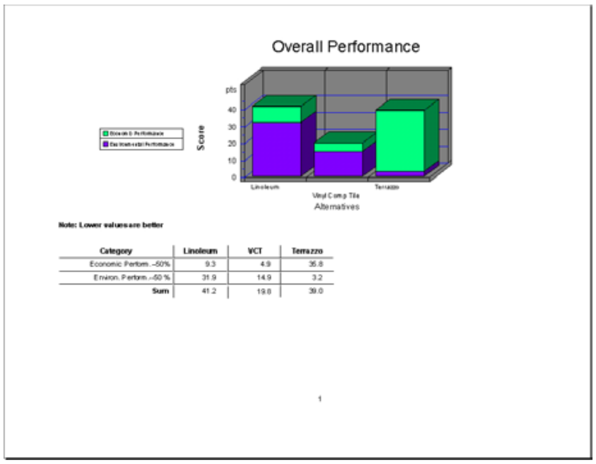



Figure 4-2. Computer analysis of economic performance of these flooring materials by BEES 2.0 software program.

Once environmental concerns are factored in, there is a slightly different result as shown in Figure 4-3. Overall, generic vinyl composition tile would remain the best selection as a result of its low first and future costs. In terms of environmental considerations, terrazzo would be the best choice of the three as its manufacturing has minimal effects on the environment when compared to generic vinyl composition tile.




| Category | Linoleum | VCT | Terrazzo |
|---|---|---|---|
| Economic Perform.–50% | 9.3 | 4.9 | 35.8 |
| Environ. Perform.–50 % | 31.9 | 14.9 | 3.2 |
| Sum | 41.2 | 19.8 | 39.0 |

Figure 4-3. Computer analysis of overall performance of these flooring materials by BEES 2.0 software program.

There is also a fourth flooring choice. Back to the concept of reducing material usage, a finish floor may not be needed. Exposed concrete will perform as well as these other flooring options in terms of durability. The cost and environmental impact would be zero, as the concrete floor would be under any of the other flooring options. This same concept of do nothing could also apply to other material choices including acoustic ceiling tiles.

## Conclusion

Through the example of the laboratory module, a sustainable materials selection process can be defined. Using the emerging computer technology available, designers can now make more informed decisions integrating the factors inherent in sustainable materials selection. By using this process to identify the primary points of energy consumption in a material, the environmental impact of the laboratory building can be minimized. This reduction in embodied energy can also factor in the common material selection principles of cost, strength, and thermal value.

Table 4-6. Recommendations for sustainable laboratories material selection

| **Recommendations for Sustainable Laboratories Material Selection** | |
|---|---|
| 1. | Reduce the amount of materials necessary through efficient design. |
| 2. | Select locally made materials to reduce transportation energy expenses. |
| 3. | Select durable materials for the laboratories that will not have to be replaced often. |
| 4. | Select materials that maintain safe levels of indoor air quality. |
| 5. | Make use of reused or recycled materials. |
| 6. | Factor material disposal into the selection process. |
| 7. | Determine life cycle costs of different material options. |
| | Make use of information integration programs such as BEES 2.0 and Athena to effectively select materials for environmental and economic considerations. |

(Table by author).

# CHAPTER 5
# SUSTAINABLE ACTIVE SYSTEMS DESIGN

The manner in which the material choices and programmatic design shape the building is largely contingent on the active systems requirements of a research building. Of the vast amount of overall energy consumed by research buildings, the majority is utilized to operate building systems to ensure occupant safety and research ability. These are requirements that cannot be reduced or overlooked. However, by conceptualizing the active systems design as a holistic and integrated approach, there are multiple opportunities to reduce energy usage. This requires designers to look for means of integrating several active and passive systems to create efficiency not just based on using energy efficient end-use devices such as lights and toilets. The active building systems of structure, energy, HVAC, and water should be conceptualized as sustainable opportunities when integrated into a holistic design strategy.

## Flexible Structural Systems

The underlying architectural element of any building lies in the structural system. While not an overtly active system, the building superstructure has intrinsic passive sustainable opportunities. Embodied energy can be reduced based on the flexibility of the structural design and the supporting materials chosen. While these opportunities are common to all building types, flexibility and material properties become the infrastructure embedded in a sustainable laboratory strategy.

While not being able to adjust itself, structure must allow for other designs and systems to operate with as many combinations as possible. Typically, the special requirements of laboratory casework determine the module for the structure. This 10' module discussed earlier can also be used as a size for spaces within the building.

Consideration should also be given to the possibility of reusing the building after its life as a laboratory. The modular spacing of beams and columns generally will not deter such a reuse. Additional, the floor to floor height should be designed under the same concept. Sufficient space should be allowed for occupancy, as well as the vast amount of services that need to travel horizontally through the building.

The structural materials and system chosen can bear a great amount on the embodied energy in a building. While there are a number of factors that go into structural system selection, embodied energy can also be used as a factor in this decision. For example, concrete structural systems have a much lower embodied energy than steel for the same application.

In addition to the embodied energy factor, concrete has thermal advantages over steel. As concrete is a thermal collector, it will store the heat energy that is generated throughout the day. This heat can be released at night when temperatures are lower, and the building is less occupied. This allows for a lag time in the morning when all of the equipment is turned back on before the building begins to heat up. In addition to concrete, water, plaster, and masonry have similar thermal properties.

A unique constraint put on laboratory building structures is vibration free environments. Many of the complex instruments used in laboratories require vibration isolation from other equipment that may transfer through the structure. The building must be designed to either withstand this vibration possibility at all locations, or create vibration free zones. Such zones are often created at the building core where rigidity and structural stability is more easily achieved.

## Energy Efficient Systems

The active energy systems of a building require operating energy, rather than embodied energy for power. The operational needs of research buildings require lighting, power outlets for computers and equipment, as well as powering other active systems. The vast need for power in a research building requires designs that are systemically efficient, rather than just using efficient equipment and devises. Such systemic efficiency can be found in renewable energy, energy modeling, changing of use and programs, as well as work schedule related opportunities.

### Renewable Energy Opportunities

The energy that is given by the sun directly to the earth is considered renewable. The intent of sustainable research building design as defined here is not to reduce the amount of energy used, it's to reduce the effect of energy production on the environment. Utilizing renewable energy in the form of solar power has the greatest effect on this, as there are minimal environmental effects of usage. For research building design, solar water heating, photovoltaics, solar air heating, and daylighting are all ways to incorporate renewable energy.

### Solar water heating

The direct heating of water from the sun can be used in laboratory buildings for differing scales and uses. The technology for heating is based on the end use, and defined by the temperature of collection as shown in Table 5-1. Once the end use is defined, solar water heating systems can be sized based on past water heating needs.

Table 5-1. Solar water heat collector types

| Solar Water Heat Collector Types | |
|---|---|
| Low temperature collectors | Swimming pools, ventilation pre-heat, snow melting. |
| Mid-temperature collectors | Commercial hot water, cafeterias, radiant slab space heating. |
| High temperature collectors | Electrical generation, water and space heating, industrial processes. |

Source: (HOK 2002).

**Photovoltaics**

The conversion of solar energy into electrical power requires the use of photovoltaics panels. While not highly efficient or made of sustainable materials, photovoltaics can reduce overall energy loads. Often designed as rooftop panels, new technologies are integrating photovoltaics into the build components such as the exterior cladding. Photovoltaics are particularly good for laboratories in areas with high utility costs, or located in remote areas that are difficult to get power distribution.

**Solar air heating**

A manner of using solar power to reduce the energy to heat a building is with solar air heating systems. These allow air to be convected though a solar heat absorber and passed into distribution ducts into the building. For effective use, they must be located with a southern exposure to the sun. These systems have a very low cost, and require virtually little or no maintenance. A 2 to 4 year payback is common for these systems when compared with electrical usage required to heat the same air load. The typical application is for the preheating of ventilation air into the building, and can be bypassed for summer operation to reduce overheating (Van Geet 1999, p.3)

**Daylighting**

Daylighting can be defined as the controlled admission of natural light into a structure. Beyond the amenities of natural light to the occupants of a building, daylighting reduces the need for electrically powered lights and the heat they generate. Daylighting strategies must be carefully designed to reduce glare. This is more readily accomplished by working with southern exposure glazing with high windows. The northern orientation can be used for views and minimal daylighting. The east and west exposures should be minimized as daylight from these exposures is difficult to control. To maximize the advantages of daylighting, open laboratories should be located on the building perimeter as shown in Figure 5-1. The components of daylighting should include low-E glazing, sunshades, and properly designed light-shelves. Additionally, light and occupancy sensors at the building perimeter not tied into building systems can be used to maximize lighting efficiency.

**Energy modeling**

Computer and full scale energy modeling of laboratory modules helps in the fine-tuning of building orientation, massing, glazing, space layout, and finishes. The primary advantages of energy modeling for designers are in the measure of how well multiple systems interact together, and in the coordination of these systems. Computer applications such as those created by the US Department of Energy can aid in the computer modeling of the spaces. Full scale modeling of a typical laboratory area should be done in a similar orientation if possible.

Figure 5-1. Example of research space adjacent to natural light at the University of Massachusetts (photo by author).

**Bioinformatics and Automated Research**

While not a strategy that designers control, programmatic changes by researchers are also reducing energy usage. These programmatic changes are a shift from open laboratory areas with chemicals and high-energy requirements for air-changes, to areas for bioinformatics and automated research. This type of research requires less need for the air-changes that consume much of a building's energy load. However, this type of research also requires additional cooling and electricity due to the increased number of computers being used.

**Nighttime Setbacks**

There are also schedule related opportunities for energy reduction. The one that is most common in research buildings is nighttime setbacks. These setbacks occur on the building systems automatically at times when the building is less occupied. While more difficult to do in buildings that have round the clock operations, nighttime setbacks should have some ability to be overridden. This can be accomplished with personal controls to override the building system so that a late night user is comfortable.

### Sustainable Heating, Ventilation, and Air Conditioning Systems

The primary use of energy in a research building goes into the immense requirements placed on the heating, ventilation, and air-conditioning systems for the laboratories. These requirements go beyond providing thermal comfort for the occupants to ensuring safety. Unfortunately, this safety comes in the form of massive amounts of exhausted air that must be heated or cooled, and passed though the building once. This requirement of 100% outside air can be compared to the typical requirement for offices, which is 25% fresh air, with 75% of the conditioned air being re-circulated as shown in Figure 5-2.

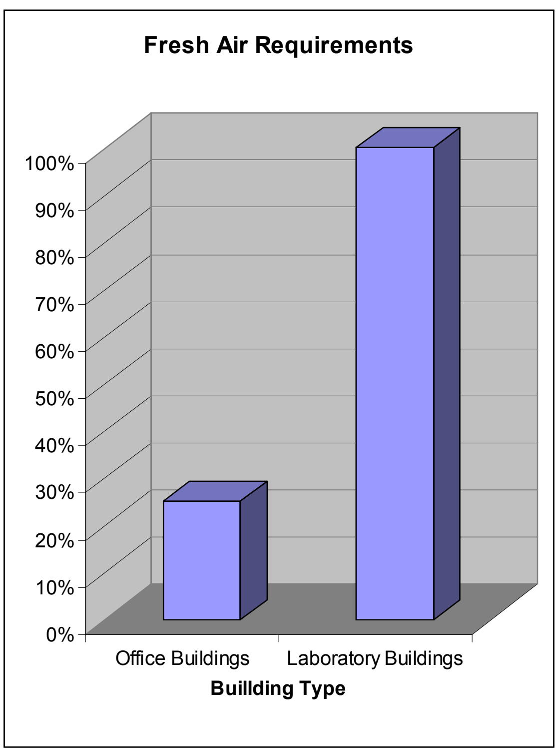



Figure 5-2. Fresh air requirements of laboratories and office buildings (chart by author).

The manner in which HVAC systems commonly operate in research building laboratories is heated or cooled outside air is first distributed into the laboratories and other zones of the building. This air is then directly exhausted by equipment called fume hoods. Careful design of the system can reduce the energy load by optimally sizing equipment and analyzing the air change requirements. Design concepts such as cascading air from office to lab modules and distributing air through casework can utilize the physical properties of heat transfer. Additionally, the components of the system such as exhaust hoods can be chosen for system efficiency, while other active systems of heat recovery and co-generation can re-capture waste heat before it exits the building. All of these strategies can work together to decrease energy requirements, and maintain indoor air quality.

**Right Sizing by Zones**

The 100% outside air requirement in research buildings apply to those areas that have a potential safety hazard such as the laboratory. The areas such as offices and conference rooms only require 25% fresh air. Functionally, this allows some efficiency by planning common zones together. As an example, placing several small offices in the laboratory zone should be avoided, as this would be wasteful of the 100% fresh air required in these zones.

**Establishing Air-Change Requirements**

The current design standard for distribution air changes is OSHA standard 1910. This standard calls for 4-12 room air changes per hour. This can be reduced for laboratories that are not extremely toxic. Current studies are showing that safety is more controlled by air distribution rather than air changes. System design should allow for the minimum amount of supply air to make up for the exhaust requirements. By using a distribution side safety design, air conditioning requirements can be reduced by using fan-coils rather than ventilation for cooling. This is a more flexible design for future adjustments and renovations, as fan-coil units are easier to add or remove than a new building ventilation system (HOK 2002).

**Cascading Air from Offices to Lab Modules**

To further the concept of zoning the building to take advantage of different air change requirements, designers should explore cascading air from offices to laboratory modules. This allows the 100% outside air requirement to be satisfied by drawing exhaust air into the laboratory from offices where there are no contamination safety hazards. Therefore, the air is used twice, thus reducing the overall energy load that is attributed to ventilation. The specific design of this requires offices to be positively pressurized, while laboratories are negatively pressurized. This pressurization ensures the correct flow of air from a low-hazard environment to high-hazard laboratory.

**Distributing Air through Casework**

Another air distribution strategy is to take advantage of the tendency of heated air to rise. This can be accomplished by bringing supply air into the laboratory low (possibly though casework) and allow it to rise naturally, thereby reducing the heating or cooling required to condition the lab. This concept also reduces the "push" that is required to distribute air throughout the lab when it is brought in high (HOK 2002). This is an effective strategy for laboratory environments that require large amounts of heating. For environments requiring cooling, other strategies must be used.

**Hood Design**

As the primary means of exhaust for laboratories is safety hoods, the selection and design of these devices should be carefully analyzed. Safety hoods are cabinet-like devices used by a researcher to perform experiments safely. Air from the lab is passed into the cabinet, and directly exhausted out of the building. The typical use of a hood is to allow a researcher to sit at a bench in front of the hood, and perform work inside of the cabinet. This work can be done with a glass safety sash open or closed, depending on the hazard of the experiment. Some methods of energy reduction at the hood are:

- Limiting the sash face opening size.
- Reduce the velocity of air at the sash face.
- Use variable air volume controls with occupancy sensors at the hood.
- Use of special local exhaust hoods at higher hazard areas.

**Heat Recovery Systems**

The high amount of fresh air that must be conditioned and passed through the lab one time wastes vast amounts of energy. Systems designed to extract some of this energy from the air are called heat recovery systems. These systems work by capturing the excess heat generated from equipment, lights, and people in the exhaust air and transferring it to the fresh incoming air. Despite most of the heat being in the air exhausted from the hoods, this air cannot be used for reheat, as hood exhaust will corrode system components, and may recirculate into the supply air.

Heat recovery systems can capture up to 50% of the non-hood waste heat. The type of heat these systems can capture is both sensible (temperature) and latent (moisture). Extreme care must be given to not allow cross contamination of exhaust air into the supply air systems (HOK 2002). See Table 5-2 for the various types of heat recovery systems.

**Co-Generation**

One of the small advantages of the amount of energy required for research buildings is the possibility of co-generation. As roughly 30% of the fuel used by power companies becomes energy, the other 70% is released into the environment as waste energy. Co-generation allows for laboratories to tap into the waste heat produced by a generator or other electrical device to generate heat for use in other means, thereby creating two forms of energy from one source device.

Table 5-2. Heat recovery systems

| Heat Recovery Systems | | |
|---|---|---|
| **Type** | **Description** | **Heat Type Recovered** |
| Plate type | Thin metal sheets are placed in the exhaust air steam, and transferred to the supply air stream. | Sensible heat only |
| Heat pipe | Horizontal tubes with liquid refrigerate in air streams transfer heat between streams. | Sensible heat only |
| Run around coils | 2 air to liquid heat exchangers are placed in the air steams. | Sensible heat only |
| Recovery wheels | Large heat absorbing desiccant disks removes sensible and latent heat from exhaust and passes it to supply. | Sensible and latent heat |

Source: (HOK 2002).

All of these systems are contingent on maintaining indoor air quality. While this is affected by many factors including material off-gases or contaminates being released into the air, active systems are required to exhaust and maintain the air quality. Beyond the energy saving strategies mentioned above, indoor air quality has potential savings though labor costs. As studies have shown, healthy indoor air quality limits absenteeism and improves worker productivity. With the high salary ranges of researchers, this has life cycle cost effects on the owner as shown in Figure 5-3, and should be factored into the design strategies (Simpson, Leary, and Grimble 2000, p.10).

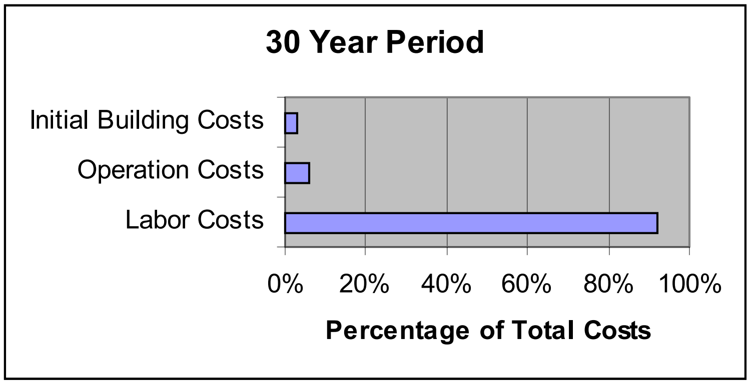



Figure 5-3. Building and labor costs by percentage (Simpson, Leary, and Grimble 2000, p.10).

## Sustainable Building Water Systems

The use of water in research buildings has minimal energy requirements, but environmental considerations that are passed on to our ecosystems. As with any building, water usage should be minimized to reduce the impact of building construction and operations on the environment. There are several key strategies for water reduction in laboratories. These involve the reuse of condensate from HVAC systems, water reduction components such as local water polishers and flow control devices, and rainwater harvesting.

### Reuse of Condensate

In the heating and cooling of supply air for the laboratory, higher than average amounts of condensate water are removed from the air. This water can be reused by piping it into cooling towers for makeup water. This reduces both the fresh water requirements on the building, and limits the amount of water to be returned into sewer systems.

**Components**

Building water reduction strategies include both efficient devices such as toilets and the use of local water polishers instead of manifold deionized water systems. While the selection of efficient toilets is a common to all buildings, the use of local water polishers is more of a systemic concept. Typically, manifold deionized water systems are used for the entire building to purify water to the levels required. The use of local water polishers requires less water than manifold systems, are more energy efficient to operate, and therefore have a lower life cycle cost. Additionally, installing flow control devices in the laboratory sinks helps to reduce overall water consumption (HOK 2002).

**Rainwater Harvesting**

Another strategy that will reduce the water demands of the research building is the use of rainwater harvesting. This involves the capture of rainwater from the exterior of the building and passing into a separate water supply system for specific uses. The water components that this system can supply include toilets, site irrigation, mop sinks, and HVAC cooling towers.

## Conclusion

To reduce the effects of energy consumption on the environment, sustainable designs for research building laboratories must work with both active and passive systems. While multiple design considerations will exist for all of these systems, specific strategies can be incorporated to increase efficiency. Embodied energy and flexibility are passive design components of sustainable selection of structural systems. To lower energy demands, renewable energy systems can be incorporated as active or passive systems. HVAC systems can be designed with multiple strategies to minimize the energy requirements of tempering 100% outside air. Finally, active water systems can be included in the design to reduce the fresh water demands of the building on the environment. All of these concepts should operate together in a holistic manner with the intent of reducing the effects on the laboratory building on the environment, justified though life cycle cost analysis.

Table 5-3. Recommendations for sustainable active systems design

| Recommendations for Sustainable Active Systems Design | |
|---|---|
| 1. | Select structural systems that allow for future flexibility with a low embodied energy content. |
| 2. | Make use of renewable energy opportunities such as solar water heating, photovoltaics, solar air heating, and daylighting. |
| 3. | Employ energy modeling programs to efficiently and optimally design the laboratory. |
| 4. | Incorporate nighttime setbacks into the HVAC and lighting systems to reduce wasted energy. |
| 5. | Rightsize the HVAC system requirements by functional zones with optimum air-change requirements. |
| 6. | Cascade air from office to lab modules, and distribute heat through the casework so it can naturally rise. |
| 7. | Effectively select and design exhaust hoods to minimize the amount of waste air exhausted. |
| 8. | Make use of heat recovery systems to recapture heat from exhausted laboratory air. |
| 9. | Make use of cogeneration where possible to recapture waste heat from electrical devices. |
| 10. | Increase worker productivity by maintaining a high level of indoor air quality. |
| 11. | Reduce water needs by reusing condensate from the HVAC system, select high-efficiency plumbing components, and make use of rainwater harvesting. |

(Table by author).

# CHAPTER 6
# INTEGRATING CONSENSUS, PROGRAMS TO ENSURE SUCCESS

As the question of sustainable design practices becomes more complex, additional tools are becoming available to designers. In an effort to both integrate the vast amount of information and provide a means to measure success of a completed project, several assessment programs have been developed. The primary of these for America is the Leadership in Energy and Environmental Design (LEED) standard developed by the U.S. Green Building Council. The application of this rating system to research buildings is being accomplished through a joint effort of the US Environmental Protection Agency and the US Department of Energy. This joint effort, entitled "Labs for the 21st Century," is defining a means for building owners and designers to go beyond the code minimums, and determine an optimum range of performance for laboratories.

## Building Performance Assessment

The question of building performance in a sustainable context is emerging to the forefront of environmental issues. Concepts of how and what to environmentally assess have become widely adopted programs. The primary components of these assessment programs are information integration, performance analysis, and implementation. The manner in which these components are specified varies among the different programs gaining acceptance.

As the many issues involved in the design and construction of any type of sustainable building involve a multitude of information, a means of integration must be part of any performance assessment tool. This integration can be in many forms, but the primary purpose is to establish a common communication tool. This communication can be used to facilitate design goals or post-occupancy assessments.

The manner is which this information is gathered related to the building is required for the assessment analysis. There are three stages to this information gathering. The first is determining which criteria to measure. The second is benchmarking. The third is comparison or ranking in relation to some type of scale. Each of these stages has become integrated into the LEED rating program.

**The LEED Green Building Rating System**

The most widely accepted assessment tool currently used in the United States is the Leadership in Energy and Environmental Design (LEED) standard developed by the U.S. Green Building Council (USGBC). Initiated by the council's membership of building industry representatives, the rating system is intended to be based on accepted energy and environmental principles. Additionally, the standard is an attempt to bridge the gap between effective practices and emerging concepts.

> LEED is a voluntary, consensus-based, market-driven building rating system based on existing proven technology. It evaluates environmental performance from a 'whole building' perspective over a building's life cycle, providing a definitive standard for what constitutes a green building. (USGBC 2001, p.1)

The LEED standard classifies building performance into four levels of certification – platinum (highest), gold, silver, and LEED-rated. These levels of certification are based on the scoring a building would receive from its accumulated points in the categories listed below in Figure 6-1. The credits that make up the categories are identified by the rating system as the intent, requirement, and technologies or strategies to achieve the credit.

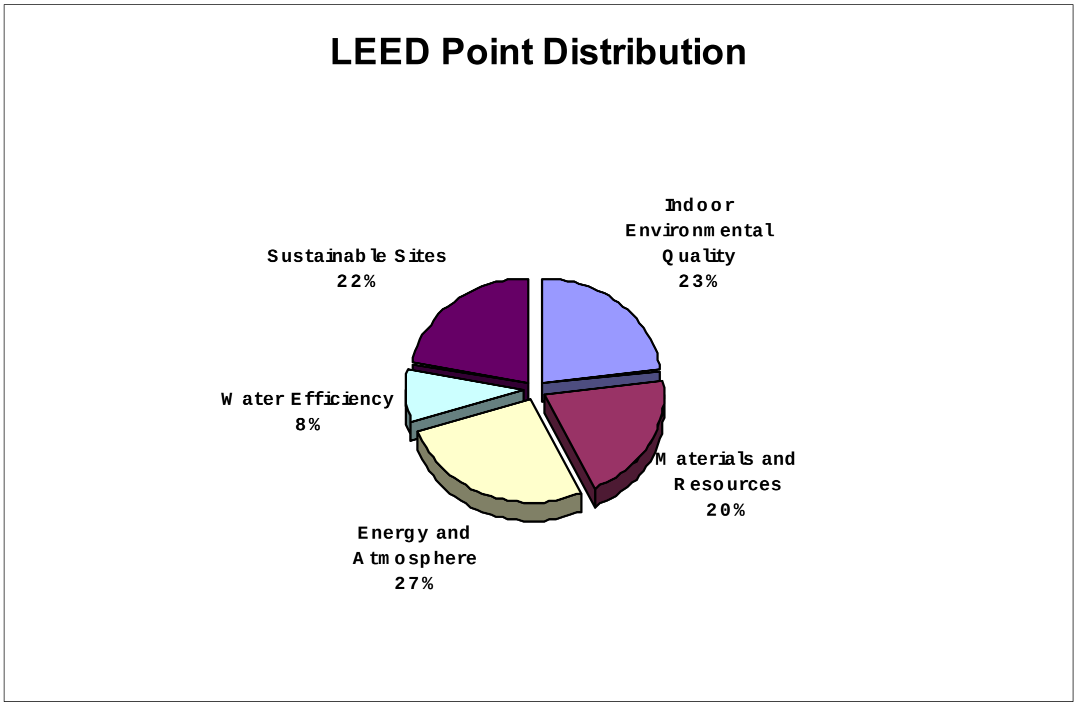



Figure 6-1. LEED Point Distribution (USGBC 2001, p.23).

The administration of LEED certification is primarily performance based. The process is self-evaluating, and self-documenting. However, certification is done by the USGBC. The certification is currently being used for a growing array of state and local government incentives, as well as project marketing exposure. This is in addition to the benefits of building a sustainable project that is validated by a third party.

Currently on the second version (2.0), the LEED rating system is being expanded to include existing buildings, multiple buildings, core and shell buildings, interiors, and residential buildings. The integration of these building types will be included on the next version (3.0) expected to be released in 2005. This forthcoming version will have a greater impact on research building projects, as the interior use of the building will now be detached from the general building issues (USGBC 2001, p.21).

## Labs for the 21st Century

An emerging group directly related to the development of sustainable laboratories is the Labs for the 21st Century program. Sponsored by the U.S. Environmental Protection Agency and the U.S. Department of Energy, it is a voluntary program dedicated to improving the environmental performance of U.S. Laboratories. The Labs for the 21st Century program outlines this objective as improving laboratory energy and water efficiency, encouraging the use of renewable energy sources, and promoting environmental stewardship.

The major activities of the program thus far have been the development of tools to support the design, construction, and operation of high-performance laboratories. These tools have included design guides, case studies and benchmarking activities, as well as a performance rating system.

At the convergence of the Labs for the 21st Century initiative and the USGBC's LEED rating system is Labs21 Environmental Performance Criteria (EPC). Based on the LEED system of points, the EPC expands the categories to include attributes essential to the sustainable design of laboratories. This results in a higher possible building score, which is taken into account by the building use. To date, this performance rating system has not been accepted as a "LEED for Laboratories."

## Conclusion and Future Research

For laboratory designers, the LEED rating system and the Labs for the 21st Century program offer a means to integrate sustainable practices into building design and evaluation. With the potential release of the "LEED for Laboratories" currently being developed, sustainable laboratories will hopefully become the norm rather than the exception. Future research and benchmarking of laboratories will aide in the sophistication of these tools, and their eventual acceptance into the design profession.

# CHAPTER 7
# CONCLUSION AND FUTURE RESEARCH

This thesis has outlined strategies to go beyond energy efficiency in sustainable design for research buildings that are among the most energy and resource intensive building types to construct and operate. With the creation of a laboratory module, this thesis has documented the design and environmental factors specific to research buildings with the intent of developing sustainable strategies. The strategies have involved a conceptual integration of design, material selection, and active systems. The basis of this research has been within the context of design efficiency as a means to achieve sustainable performance.

During the pre-design stage of the planning process, certain regulatory and financial constraints have become apparent. These issues incorporate a much larger context than the building site, and are guided by sustainable considerations and conceptual processes. Community and governmental interests control the regulation of the laboratory building in this process. These interests have been expressed as they relate to conceptual sustainable planning.

Beyond the conceptual planning, functionality must be resolved for the laboratory building to be both sustainable and efficiency. The integration of these functional concerns with environmental issues is the primary sustainable strategy of this research, and is expressed in all project phases. Using the basis of a laboratory module, area and material reductions have been explored as a basis for both efficiency and quality of life.

Through the example of this laboratory module, a sustainable materials selection process has also been outlined. Using the emerging computer technology available, more informed decisions were made for laboratory flooring materials selection. These decisions went beyond up-front costs, and began analyzing energy consumption in a material as a basis of selection. This selection process minimizes the disproportionate amount of embodied energy present per square foot in a laboratory building.

In addition to the passive strategies of design and material selection, active system strategies for sustainability have been outlined. To further reduce the effects of energy consumption on the environment, specific strategies for the laboratory have been expressed to increase efficiency. These strategies have included renewable energy systems, efficient HVAC systems, and secondary recycled water systems and devices.

Opportunities for future research in this topic include actual data collection and measurement of materials, environmental factors, and active system design for research buildings. This data collection and analysis should occur for existing research buildings with the intent of influencing new designs. Computer models based on applications being developed for laboratory design should also be explored as a means to optimize sustainability. Further, the retrofit of existing laboratories to increase sustainable performance is an area of research opportunities.

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