International Institute
for Sustainable Laboratories®

Evaluating Laboratory Design
National Institutes of Health Building 50
Bethesda, Maryland

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Executive Summary

Building 50 on the National Institutes of Health's (NIH's) Bethesda, Maryland, campus began operations in April 2001, and was intended to replace outdated facilities and consolidate several NIH Institutes. The original design program emphasized two principal objectives: facilitating flexibility in the use of the building so as to accommodate changes in research requirements over time, and promoting efficiency in energy use.

This case study evaluates Building 50's performance with respect to these objectives through a close analysis of the architectural program, laboratory design, use of interstitial floors, utility infrastructure, and HVAC engineering. Wherever possible, original design parameters are confronted with data from current operations.

Considerable original design information has been taken from a prior case study published by Laboratories for the 21st Century (Kulak & Carlisle, 2001).

Labs 21's original case study was published to highlight a new approach to laboratory buildings, which seemed to resolve the problems of high energy consumption and lack of enough flexibility to accommodate change. The introduction to that publication summarized the design rationale for the facility (Figure 1) as follows:

> *"In an aggressive approach to energy efficiency, the building incorporates the use of daylighting, variable-air-volume (VAV), control by stakeholders of the ventilation air supply and exhaust, and energy recovery from the exhaust air stream. Using a modified interstitial space as a core design feature, the NIH building is flexible enough to accommodate change and ensure that it will be used both now and in the future."*

The building was expected to use about 40% less energy than a conventional laboratory building that was designed using ASHRAE Standard 90.1-1989, by implementing the updated ASHRAE Standard 90.1-1999. The 1999 update enhanced energy efficiency levels of buildings by simplifying energy efficiency requirements and prescriptive options for all components, in addition to performance-based approaches. The project team received numerous awards for the energy-efficient design when the facility was opened. Twenty years later, this update examines how well the facility has lived up to its goals.

Figure 1. The Louis Stokes Laboratories (Building 50), National Institutes of Health, Bethesda, MD. Source: National Cancer Institute/NIH.

Based on this analysis, this case study identifies three principal conclusions that can guide further improvements in laboratory design and performance:

- Effective design for natural light was a significant feature of Building 50's architecture. Natural light continues to enhance the experience of using the laboratories and other work spaces, even when changing technology has required some subdivision of the interior layout.
- The provision of interstitial floors for mechanical equipment was a central feature of Building 50's design and has contributed significantly to the efficiency with which the building has absorbed rapid changes in requirements for research equipment. The lesson of Building 50 is that even 30% of gross square footage may not be sufficient interstitial space.
- Secure and comprehensive data monitoring must be given attention and budget. Monitoring the consumption of energy and other natural resources will be of increasing importance as demands from technology change and global warming continue to accelerate.

Introduction

This publication evaluates the performance of the Louis Stokes Laboratory, NIH Building 50 (Building 50) in terms of its architectural and its engineering programs. Particular attention is given to two key objectives of the original proposal: facilitating user flexibility and promoting energy efficiency.

The information will be organized as follows:

Architecture

- Building 50: Origin and objectives
- Building program
- Lighting
- Laboratory design
- Interstitial floors

Engineering

- Utility infrastructure
- HVAC engineering and energy consumption

Building 50: Origin and Objectives

Building 50, first occupied in April 2001, was commissioned to replace three outdated facilities and consolidate several NIH Institutes. This new building was intended to encourage collaboration among the different lines of NIH research and to embody a new approach to the design and operation of laboratory facilities. This new approach would target two key problems observed in older laboratory construction.

Firstly, design shortcomings appeared to have led to high energy consumption and excessive operating costs; secondly, in the face of rapidly changing research practices and technology, adapting the spaces of older research facilities had proved time-consuming and expensive, curtailing their effective useful life. In contrast, Building 50 was to make use of interstitial floors to provide flexible spatial configurations and to readily accommodate extensive changes in the technology required by the users' research.

The original appraisal of Building 50, published in the year it began operation, articulated these objectives quite explicitly:

> *"In an aggressive approach to energy efficiency, the building incorporates the use of daylighting, variable-air-volume (VAV), control by stakeholders of the ventilation air supply and exhaust, and energy recovery from the exhaust air stream. Using a modified interstitial space as a core design feature, the NIH building is flexible enough to accommodate change and ensure that it will be used both now and in the future." (Kulak & Carlisle, 2001.)*

SELECTION OF DESIGN-BID-BUILD TEAM AND COMMISSIONING

The design of Building 50 was a collaboration among Hansen Lind Meyer (HLM) Architects of Bethesda; Ross, Murphy, Finklestein (RMF) Mechanical Engineers of Baltimore; and GPR Lab Planners of Purchase, New York. The government's construction quality manager was Jacobs Facilities of Arlington, Virginia, and the general contractor was the Bell Co. of Kensington, Maryland.

The Building 50 architectural/engineering team was selected on the basis of prior experience in designing similar scientific research facilities in the mid-Atlantic area. The energy effectiveness of their designs was one of the criteria. The HLM architects and RMF engineers had completed two prior projects in the region, both of which employed desiccant energy recovery wheels. In the planning documents, goals were established to do everything that was practical and feasible to conserve and recover energy in the design of the Louis Stokes Laboratories.

The construction contractors were selected for the project using a method known as a "best value" procurement. In this method, a committee scored and reviewed the qualifications of the contractors and, in conjunction with their bids, selected the contractor that they felt represented the best combination of price and technical qualifications, and thus the best value to the government. Consequently, the lowest bidder was not the one selected in either of the two phases of construction.

The construction cost totaled $76.8 million (soft costs excluded). Phase 1 of the construction—which involved clearing the site, relocating utilities, and providing more than 200 caisson foundations (drilled piers)—began in July 1997 and took seven months to complete. Phase 2, which included completion of the building frame and enclosure and the electrical, mechanical, vertical circulation, and telecommunications systems, as well as the fit-out and finishes, began in April 1998.

The construction management team established a formal commissioning phase with an outside professional commissioning consultant (Facility Dynamics of Columbia, Maryland) through the construction quality manager. A commissioning committee, which included staff from many NIH Office of Research Support (ORS) groups, completed functional performance tests to verify that the installations conformed to all contractual requirements.

Source: Kutlak & Carlisle, 2001.

Building Program

Building 50 was designed to accommodate up to 650 scientists on six floors of lab space plus a basement (combining research and mechanical spaces) and a mechanical penthouse. Each occupied floor is topped by an interstitial level to house mechanical equipment.

The facility as configured today contains 551,323 gross square feet (ft^2) (51,220 m^2), including 166,232 net ft^2 (15,443 m^2) of research laboratory space and an additional 26,450 net ft^2 (2,466 m^2) in conference rooms, lobbies, and so on (Table 1 on page 4).

The 46,898-gross-square-foot basement contains mechanical and electrical support spaces and the vivarium, designed with 14 animal holding rooms of various sizes arranged in four major suites with procedure rooms. The 5,092 ft^2 (473.1 m^2) high-performance imaging suite, also in the basement, was designed to support six electron microscopes and a facility housing several large NMRs, including two of the strongest in the world. A 900-MHz machine was hoisted into place through a removable roof hatch using a special rolling-beam crane built into the ceiling.

Table 1: NIH Building 50 Space Breakdown (2020)

Program Element	Net or Gross ft^2
BSL-2 laboratory/office/support areas[1]	141,850
BSL-2 imaging Suite (EM and NMR)[2]	5,092
BSL-3 suite	1,263
ABSL-2/ABSL-3 vivarium[1]	18,027
First-floor conference suite, break rooms, other conference rooms, main lobby[1]	16,901
Upper floor lobbies and meeting rooms[1]	9,549
Total net square feet	**192,682**
Interstitial levels (B1, Floors 2-6)[1]	255,296
Other[3]	103,345
Total gross square feet[4]	**551,323**
Ratio of net to gross square feet, including interstitial space and "other"	**35%**

1. Source: Present author based on data from the NIH Facility Management System (FIMS), 2020. (BSL-3 Suite is historic data.)
2. Area calculated from basement floor plan, 2000.
3. "Other" includes circulation, toilets, stair towers, elevator shafts, mechanical and electrical rooms, and structural elements like columns.
4. Gross floor area is as reported in the NIH FIMS (551,323), and includes net floor area, "other," and the interstitial levels.

The labs are primarily designed for work at Biosafety Level 2 (BSL-2) as defined by the BMBL 2020, meaning they are suitable for work involving moderate-risk infectious agents or toxins that pose a moderate danger if accidentally inhaled, swallowed, or exposed to the skin (CDC/NIH, 2020). Design requirements for BSL-2 laboratories include negative airflow (airflow into laboratories from areas of lower biological hazard to those of higher biological hazard), laboratory sinks, eye wash stations, emergency showers, and doors equipped with closer hardware.

The facility also contains several specialized areas, including Biosafety Level 3 (BSL-3) infectious disease research suites; a nuclear magnetic resonance spectrometer (NMR) laboratory; electron microscopy (EM) suites; and animal research facilities (ARF) that provide barriers to protect animals and containment for infectious disease research.

The animal research facilities are designed for work in Animal Biosafety Level 2 and 3 (ABSL-2, ABSL-3). ABSL-2 is suitable for work involving laboratory animals infected with agents that are associated with human disease and that pose moderate hazards to personnel and the environment. ABSL-3 is suitable for work involving indigenous or exotic agents that may cause serious, or potentially lethal, disease through the inhalation route of exposure.

Specialized design features include extensive sealant application at all joints, acoustical separation, vibration dampening, heightened air changes per hour, air pressure differentials between rooms, no reversal of airflow, commissioning/validation of ventilation design, and fail-safe design of ventilation controls and alarms.

Current laboratory design standards at the NIH are detailed in the Design Requirements Manual (National Institutes of Health, 2020).

Table 2: Building 50 Space Assignments

NIH Institutes	Space Assignment (ft^2)
National Heart, Lung, and Blood Institute (NHLBI)	49,612 (29%)
National Institute of Allergy and Infectious Diseases (NIAID)	48,023 (28%)
National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK)	23,069 (13%)
National Human Genome Research Institute (NHGRI)	20,909 (12%)
National Institute of Athritis and Musculoskeletal and Skin Diseases (NIAMS)	18,253 (11%)
Director's Reserve	4,345 (3%)
National Institute of Biomedical Imaging and Bioengineering (NIBIB)	2,779 (2%)
National Cancer Institute (NCI)	2,705 (2%)
Office of Management, Events Management Branch (ORS_EMB)	2,270 (1%)
Division of Facilities, Maintenance and Operations (ORFDO_DFOM)	253 (<1%)
Total	**172,218 (100%)**

The facility is currently occupied by fewer than 500 people, based on a spot survey of assigned seating in floor plans shared by NIH (Table 2). The major institutional tenants include the National Institute of Allergy and Infectious Diseases (NIAID), the National Heart, Lung and Blood Institute (NHLBI), and the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK). These scientists perform structural and cell biology research in the areas of allergy and infectious diseases; heart, blood, and lungs; diabetes, digestive system, and kidneys; the human genome; arthritis and the muscular-skeletal system; eyes, dental, and hearing; and skin diseases.

Space program information is now updated through a Facility Management System that tracks space assignments by NIH Institutional Client (IC) and space type. Space assignments by IC have not changed as much as the space types and performance requirements. Renovations from BSL-2 open labs to BSL-2 closed labs have required tight temperature and humidity controls and avoidance of temperature fluctuations.

Information from the Office of Research Facilities administrators suggests that, in one way or another, 100% of the building's laboratories and research animal spaces have been renovated since they were first occupied. Indeed, some spaces have been renovated several times in response to the accelerating pace of change in research programs and scientific needs. This history strongly suggests that the building program has succeeded in its objective of readily accommodating changes in user needs.

The low net-to-gross ratio for floor space is especially noteworthy in this context. Previously regarded as an indicator of inefficiency, here it signals the designers' commitment to providing interstitial spaces (accounting for over 45% of total gross area) to ensure that the maintenance and replacement of equipment can be carried out with minimum disruption of laboratory operations.

Lighting

From an architectural standpoint, the key sustainable design feature in the building is the innovative method of capturing daylighting by ending the modified interstitial floors approximately 12 ft (3.7 m) back from the window walls and using a curved ceiling to take advantage of the full floor-to-floor wall height of 18 ft (5.5 m) and the double-height windows. The resulting daylighting

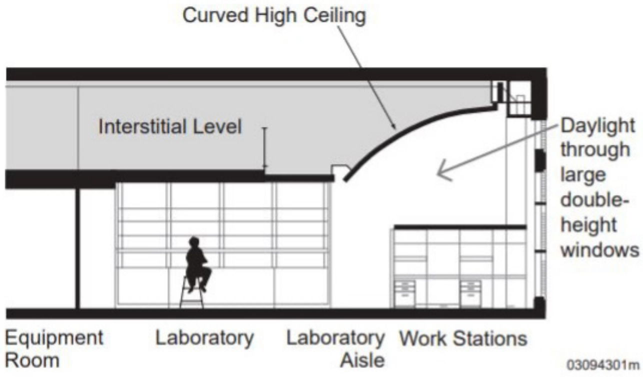

Figure 2. Cross section of laboratories and workstations shows daylighting through double-height windows. Source: HLM Design, Inc.

is sufficient to light the office space as well as the lab bench areas, which are approximately 30 ft (9.1 m) in from the window walls (Figures 2 and 3).

Above approximately 8 ft (2.4 m), the office spaces are glazed and share daylighting with the open lab area. Over time, more office spaces have been introduced, making the transom glazing an important design feature for maintaining daylighting in the labs.

In the original design, this natural lighting was supplemented by florescent light fixtures. The florescent fixtures have been replaced by light-emitting diode (LED) fixtures with T-8 lamps and electronic ballasts. LED exit signs and motion sensors had been installed in break rooms, conference rooms, and bathrooms as part of the original project.

Interviews with current tenants confirm that access to natural light continues to be a highly valued feature of working in this building, in spite of the modifications that are described in the following section.

Laboratory Design

Each lab floor was designed with a footprint of about 36,000 ft^2 (3,345 m^2) and two exterior balconies. The lab space on each floor was organized into six “neighborhoods” of open-plan lab modules grouped around a central support core (Figure 4 on page 8). Entrances to each neighborhood include proximity card readers to control access. These neighborhoods preserve the feeling of the older, smaller buildings that the scientists wanted Building 50 to retain. In general, the original open modules have been preserved over the years.

Each lab neighborhood contains seven or eight open lab modules, and each module has an equipment room toward the core of the building, adjacent to the open lab peninsula bench (which is about 16 feet long). The lab bench casework was designed to have 40% movable cabinets to allow users to adjust the bench layout. However, in recent renovations to lab casework, non-mobile units have been selected to maximize storage space.

At the end of the peninsula lab benches is an aisle separating the benches from the workstations, which are located along the windowed exterior wall. As described in the previous section, this ensures that the workspaces have direct natural lighting (Figures 2 and 3 on pages 6 and 7).

Each module features enclosed corner offices at both ends of the windowed wall; today, these remain as originally provided. However, walls have been added parallel to some lab benches to separate neighborhoods into smaller lab groups or to create additional support labs.

This layout responded successfully to users’ requests for workstations with windows, computer space, and daylighting. Nevertheless, recent renovations have eliminated open labs in several module-sized spaces to accommodate enclosed imaging laboratories or molecular laboratories (Figure 6 on page 9). Imaging labs require light control to provide blackout conditions. To this end, the rooms were equipped with optical curtains

Figure 3. View of an occupied lab, showing lab modules at left and workstations on the window wall at right. The higher ceiling over the workstations was made possible by stopping the interstitial service floors above the lab modules, rather than extending them to the exterior wall. Source: Author.

and acoustical separation from adjacent space. The molecular laboratories also require a degree of thermal and humidity control that the original double-height-windowed spaces could not provide.

Again, it is worth noting that while the original design features regarding daylight have required modification due to changing research needs, the availability of interstitial spaces has been a key enabler of significant changes in lab type.

Interstitial Floors

A modifiable interstitial space, located over each occupied floor, is provided by a suspended light steel deck with a clear height of 7 ft (2.1 m). Most of the HVAC, electrical, and plumbing equipment, as well as telephone, LAN, and alarm system ladder trays, are located in this tightly packed space. The supply and exhaust ductwork runs lengthwise along each side of a central corridor.

As discussed above, the interstitial deck stops at the end of the lab benches, over the aisle between the lab bench and the workstations adjacent to the windows.

These interstitial spaces were designed to allow maintenance and construction workers to access the utility systems without entering the labs.

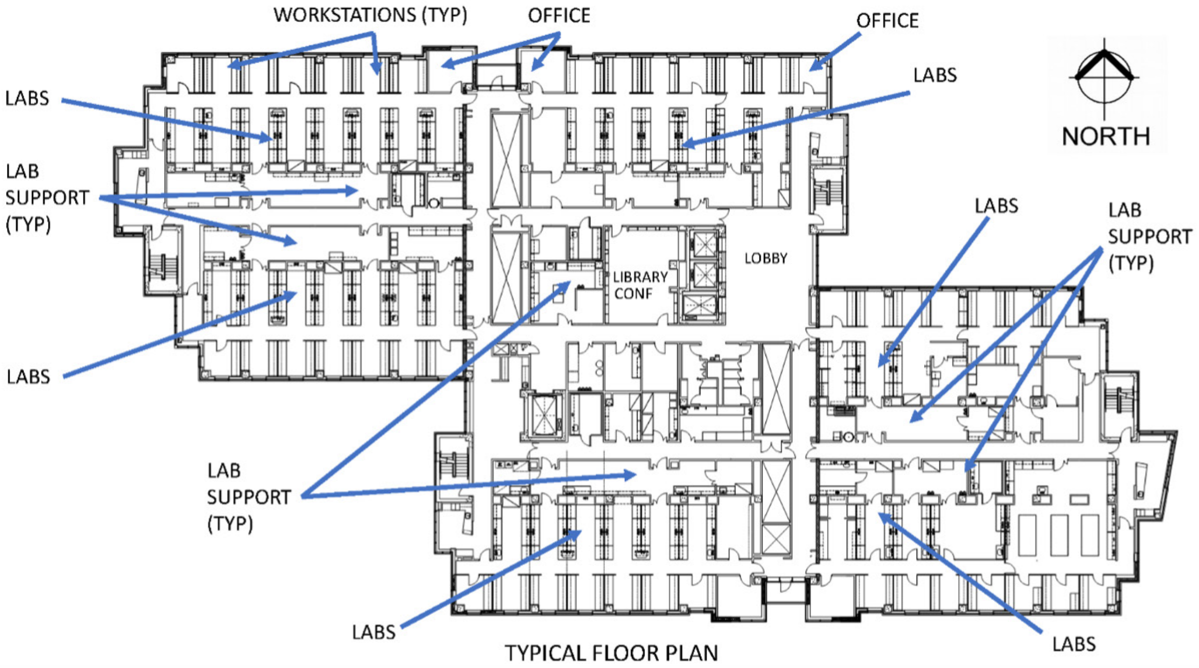

Figure 4. A typical floor plan for Building 50. Source: Kutlak & Carlisle 2001; original design by HLM Design, Inc.; redrawn by present author.

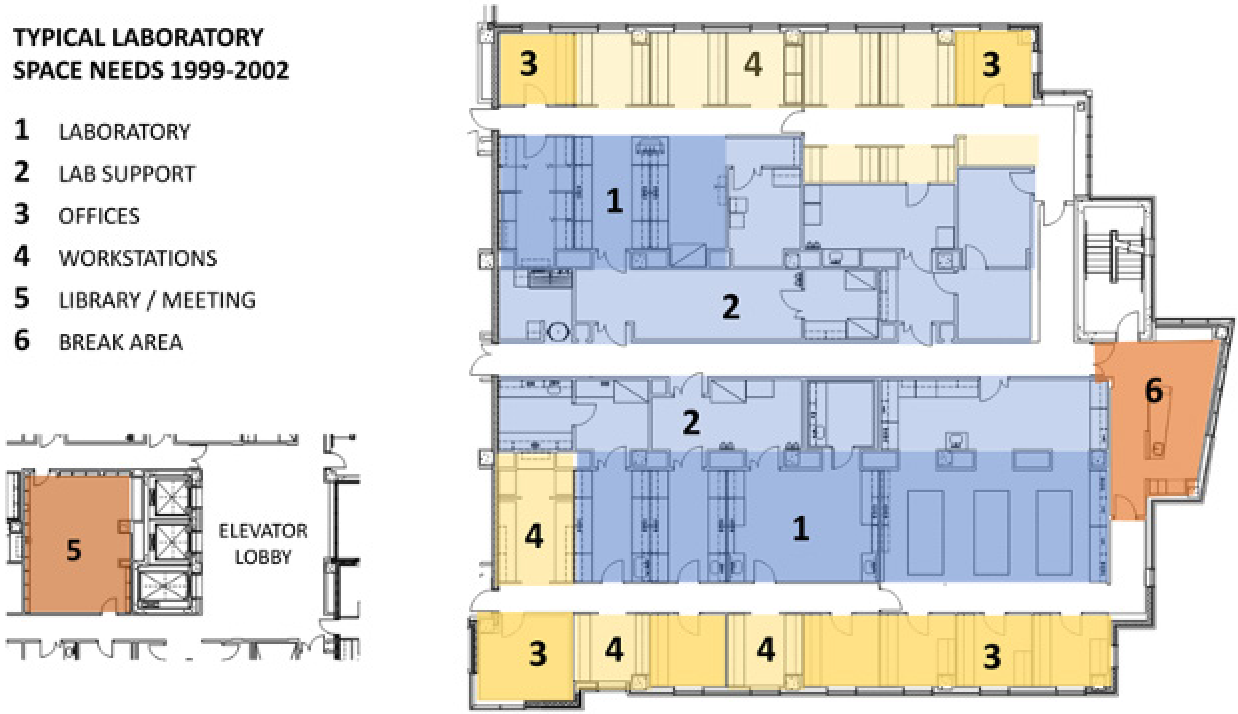

Figure 5. Typical original lab space needs. Source: Author.

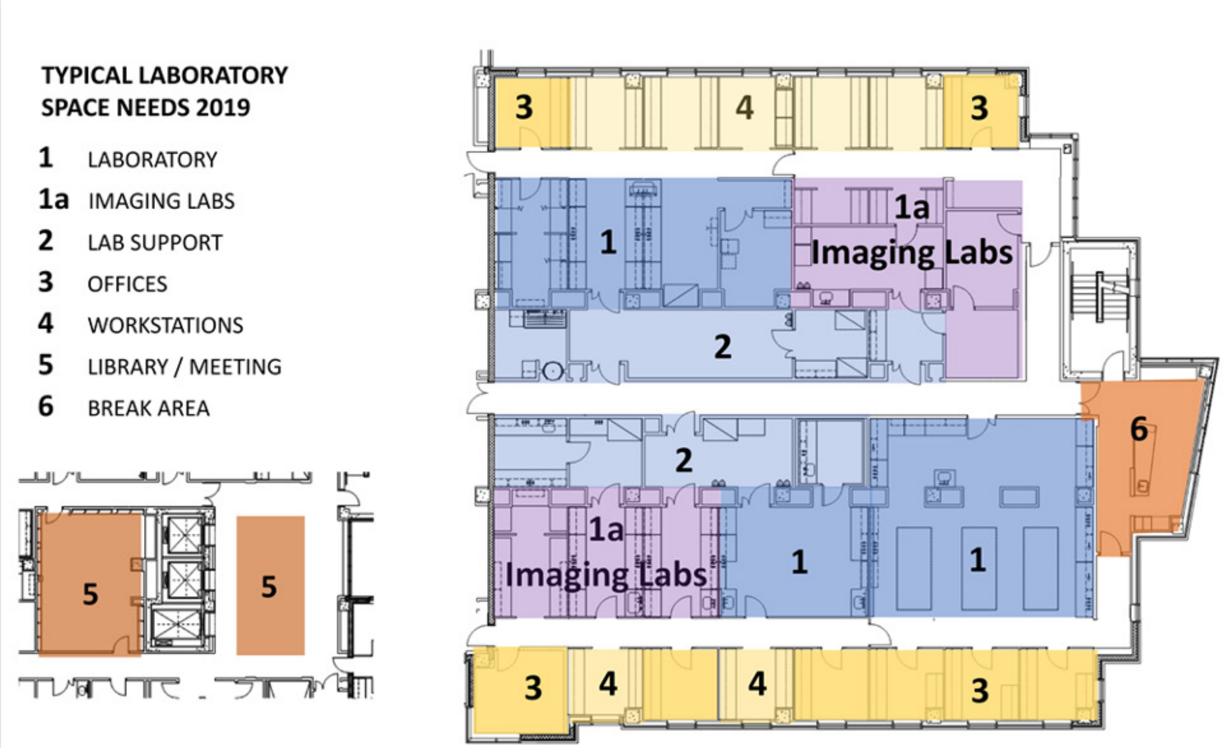

Figure 6. Modifications to add meeting space in lobbies and imaging laboratories (all floors). Imaging labs are often equipped with laser tables due to the vibration sensitivity of confocal microscopy or fluoroscopy. Source: Author.

During renovations, general construction could be accomplished without affecting laboratory operations. The history of Building 50 indicates that these objectives were largely accomplished.

Nevertheless, over time, the expansion of specialty labs requiring the installation of new air handling units, dehumidifiers, and other equipment has resulted in the crowding of the interstitial spaces. There is now very little space to remove and replace HVAC equipment during renovations. This crowding imposes additional cost on projects that must now precisely size equipment in terms of its capacity and dimensions to fit in the space available. A further source of additional cost is imposed by the need to remove, replace, and retro-commission functioning equipment in an adjacent lab, when a lab renovation requires new equipment.

These interstitial mechanical floors introduced a feature that set a standard for new laboratory buildings at the NIH Bethesda campus. Although these floors are now more crowded than the original design envisaged, the history of continual laboratory upgrades to support new science would have required more radical and more costly reconstruction if the interstitial floors had been excluded.

Considering the crowded interstitial spaces today, there is very little space to remove and replace HVAC equipment during renovations. One source of additional cost to projects is the need to precisely size equipment for its capacity and dimensions to fit in the space available. Another source of additional cost is the need to shift functioning equipment to permit installation of new equipment for an adjacent lab renovation.

There is clearly an argument for including even more interstitial spaces in laboratory buildings than was originally provided in Building 50. It is also clear that this involves additional up-front costs. Nevertheless, a cost-benefit analysis will often show that the extended useful life of the construction will provide benefits that outweigh the additional costs. In some cases, public commitment to sustainable construction represented by providing extensive interstitial space may come into tension with the financial constraints on commercial users. Experience suggests that buildings designed and built by public authorities that are leased to commercial users may contribute to resolving this tension.

Utility Infrastructure

The major utilities, which are supplied from an adjacent campus central utility tunnel, are the chilled water supply and return; high-pressure steam and condensate return; and city water and compressed air. A basement mechanical room serves as the utility point of entrance and contains pumps and chilled water, steam, heat exchanger, and fire protection equipment. Adjacent to this main mechanical room are the the main electrical transformer room, containing switchgear, and the emergency transformer room, containing switchgear and emergency transfer switches. The emergency generator is in an at-grade enclosure next to the loading dock.

The piping distribution originates in the basement mechanical room and extends upward through the building in four major shafts. The mechanical penthouse on top of the building contains the main air-handling units, exhaust fans, elevator machine rooms, and other systems.

Piped utilities for the labs originally included vacuum, air, natural gas, carbon dioxide, lab industrial water, lab waste, secondary chilled water, reverse osmosis water, and nitrogen gas. An internal building clean steam system services the autoclaves and humidifies the building. Liquid nitrogen has been provided to limited specific locations in the NMR, freezer room, and EM suites in the basement. An exterior tank farm is adjacent to the loading dock.

Over the course of 20 years, the demand for liquid nitrogen freezing increased beyond the house system's capacity. Equipment areas are now filled with low-temperature freezers and LN2 dewars to provide reliable back-up for the storage of high-value specimens.

Figure 7 and Figure 8. Typical interstitial space, 2019. Source: Author.

Other original house systems have been replaced by local gas cylinder banks that are closer to the lab equipment and benches where the services are needed. This switch was made to increase reliability and savings, as each Institute and Center in the building pays for gas usage.

Building 50's consumption of steam and chilled water was not specified as a target in the original design, hence performance parameters were not included in the 2001 case study. This is regrettable, since recent data suggest that chilled water alone now accounts for 40% of total energy consumption in Building 50. However, the building administration does, in fact, monitor data on total energy consumption, including that from piped-in steam and chilled water, and has data covering the period 2010-20. These data are discussed in the following section.

HVAC Engineering and Energy Consumption

The single largest consumer of electricity in the laboratories is the equipment that supplies and moves the large amount of ventilation air required to maintain a safe environment. The HVAC design was thus focused on fulfilling this requirement in an energy efficient manner.

The key technologies in fulfilling this dual mandate were:

- Variable air volume (VAV) supply and exhaust systems
- VAV fume hood systems
- Variable frequency drives (VFDs) for fans and motors
- Advanced controls and automation systems
- Desiccant heat wheels for energy recovery (later removed, see page 14)

VAV Supply and Exhaust Systems With VFD Fans

For the building's supply and exhaust system and fume hoods, NIH considered both constant-volume (CV) and VAV systems, and ultimately selected VAV with VFDs on the fan system. Rather than maintaining a constant air volume in the supply air, the VFDs reduce the volume of air delivered to the space when the building is unoccupied, from a maximum of 400,000 cubic feet per minute (cfm), or 15 air changes per hour (ACH), down to 160,000 cfm, or 6 ACH. The variable-speed drives lower the speed of the supply and exhaust fans to accomplish this reduction and move less air. The VFDs do this 25% more efficiently than the standard inlet vane controls of the past. Although a VAV system has a much more complicated and expensive control system than a CV system, the VAV system uses 30% to 50% less energy than a CV system does.

The following factors were considered in evaluating CV and VAV systems. NIH design guidelines required once-through air, allowed VAV, and specified a turn-down ratio of a minimum of 6 to a maximum of 15 ACH. The load profile of the users indicated that there would be varying loads in the building. There is a moderate to high degree of variation in the climate (including temperature and humidity) throughout the year. A life cycle cost study concluded that the payback period for the VAV system was shorter than that of the CV system, even though energy costs in the mid-Atlantic region were moderate. In addition, NIH maintenance staff had the technical skills to maintain highly flexible VAV systems.

VAV Fume Hoods

Building 50 was the first NIH building to install VAV fume hoods; all the other hoods on campus at the time were CV bypass hoods. VAV hoods were more expensive and complex to design, install, and commission, but they offered the highest degree of face velocity control. Face velocity is a measurement of airflow at the front, or face, of a fume hood; it is an indicator of effective hood containment. A face velocity of 100 feet per minute (fpm) is required by the NIH DRM. Energy savings can be as high as 70% by reducing the maximum airflow from 1,000 cfm (full sash height) to the minimum of 300 cfm (with a closed sash), compared with the energy use associated with CV hoods.

To realize these energy savings, users must be trained in operating the hoods and must keep sashes closed except when the hoods are being loaded. Each fume hood has a dedicated VAV terminal unit to maintain the proper airflow at the hood regardless of the pressure fluctuations in the ductwork.

Originally, each of the 35 laboratory neighborhoods was equipped with at least one hood, for a total of 52 hoods. Since Building 50 has 246 lab modules, this was a relatively small number of hoods by NIH standards, which in 2001 averaged one hood for every two lab modules. Presumably, this low allocation was prompted by the higher cost of the VAV hoods but it has not turned out to be a problem. Over the years the need for fume hoods has declined, and currently there are only 18 fume hoods in the entire building.

Exhaust Systems

The building's separate exhaust systems are listed in Table 3 (on page 13). The largest of them is the general building system. There are no operating heat recovery systems, as the desiccant heat wheel system was maintained and retro-commissioned but was not supported and was removed and not replaced (see text box on page 14 for details).

The equipment selected for the general building system uses 100% once-through air that is tempered in eight 50,000 cfm air-handling units (AHUs). In general, exhaust exits the building 10 feet (3 m) above the roof at a discharge rate of 3,000 fpm (914 mpm).

In contrast, the use of Class II Type A2 biological safety cabinets that do not require direct connection to fume hood exhaust has increased. This is part of a trend that reflects the nature of lab work in Building 50 moving away from chemistry toward biology and molecular biology. The result is that the fume hood exhaust system now has much greater capacity than required. However, this system also continues to be used for venting corrosive cabinets,

VIVARIUM HVAC AND CIRCULATION

During the initial facility design process, the veterinary staff had requested that the vivarium be provided with a dedicated air handler, as well as a back-up elevator to separate the research animal facility ventilation and circulation from the non-animal research areas. At the time, these features were not required by the American Association for Accreditation of Laboratory Animal Care (AAALAC) for facility accreditation (AAALAC, 2011), or by the NIH DRM.

The research animal facility was equipped with a dedicated CV 50,000-cfm AHU without a heat wheel, because minute particles from the animals' fur (dander) would accumulate on, and foul the surfaces of, the wheels. Rather than adding a redundant dedicated AHU, the design team backed up the vivarium air handler by manifolding it into the lab air handlers—a move that saved several hundred thousand dollars and several hundred square feet of floor space.

A backup to the primary vivarium elevator was provided by installing a service door leading to the building's freight elevator.

Source: Kutlak & Carlisle, 2001.

fully exhausted biological safety cabinets, and chemical fumes produced from laboratory equipment like mass spectrometers and electron microscopes.

VFD Motors and Pumps

A variable-frequency drive or VFD is a solid-state device that varies the output frequency of standard 50- or 60-cycle input power to provide varying motor speeds. Since the power required to run the motors of fans and pumps is proportional to the cube of its speed, large reductions in energy occur at lower speeds.

The VFDs on the pump system operate in much the same way as they do on the VAV supply and exhaust fans, although in the pump system, the VAV terminal units are replaced by water control valves and cooling and heating coils. Differential pressure sensors in the water distribution piping system signal the VFDs to reduce the pump flows in response to a corresponding reduction in the cooling or heating coil control valves.

Building 50 continues to use VFDs on all major motors and pumps. Developments in variable-frequency motor speed controls have increased reliability and lowered costs to the extent that VFDs are preferred for most applications. Though there are many advantages, VFDs also have higher initial costs, produce some noise, and can cause harmonic distortions of current flow.

Building Controls and Monitoring Systems

Direct digital controls with pneumatic actuators are used for the mechanical HVAC building systems. NIH has maintained and upgraded the Siemens building automation system (BAS) over the years. The central computer station in the maintenance office for Building 50 is now linked to a much larger campus-wide monitoring system. Building 50's BAS started off with 3,000 distinct control points and graphic displays of AHUs, exhaust fans, fume hoods, VAV terminal units, room temperatures, room differential pressures, pumps, heat exchangers, and central utility consumption. The current system has been supplemented with additional features for redundancy and reliability.

The LED lighting fixtures are powered by a programmable control system for the building. The lighting for the entire building can be programmed to shut off at a predetermined time. This can be manually overridden by users working late.

Alarms and maintenance reminders are displayed automatically, as well as transmitted to a central campus engineering facility for remote off-shift monitoring. This enables the engineering maintenance staff to control, track, and monitor all equipment throughout the building. A second read-only computer monitor in the animal facility office allows the veterinarians to monitor, and keep records of, conditions in the vivarium.

Building 50 was the first building at NIH in which all utilities were fully metered. The ORS Division of Engineering Services facilities management staff was expected to be able to accurately record the building's energy usage. Unfortunately, data for 2001-2009 was lost as the original equipment became outdated and the data could not be transferred from the older software. With the

continued on page 15

Table 3. Exhaust Systems in Building 50

System	Type	Heat Recovery?
General building	VAV	No
Fume hoods	VAV	No
Vivarium	CV	No
Smaller exhaust systems		
BSL-3 labs	VAV	No
Cage wash	VAV	No
Fermentation labs	VAV	No
Toilets	VAV	No

SAVINGS THROUGH ENERGY RECOVERY: ORIGINAL CONCEPT

Exhaust systems generally represent the single most important and largest application of energy recovery in research facilities. In 1997, NIH selected enthalpy wheels as the method of energy recovery for general building exhaust in Building 50. Such wheels use heat-absorbing desiccant disks that rotate sequentially through, and transfer energy from, the building's general exhaust to the supply air streams. The wheels that were selected were expected to recover both sensible and latent energy, with higher rates of efficiency (at 60% to 70%) than other options for energy recovery.

The supply and exhaust air streams must be adjacent to each other to allow an energy recovery wheel to rotate through both alternately; this requires that the mechanical penthouse be high enough to accommodate taller AHUs. A common concern about heat wheels is that there is potential for cross-contamination between the air streams. Because of this concern, NIH did not exhaust the containment devices (e.g., fume hoods, biologic safety cabinets) through the wheels. The separate, dedicated containment exhaust system is not manifolded into the general exhaust.

The wheels have a self-purging system that has been proven to limit cross-contamination to 0.045%.
A test conducted in August 2001 by the manufacturer, SEMCO, at Building 50 verified that the level of cross-contamination resulting from the carry-over of contaminants from the exhaust air stream into the building's supply air stream was below the 0.045% limit.

NIH completed a life cycle cost study on all types of energy recovery systems during design. The energy recovery wheel concept proved to be the most cost-effective. A major design consideration is that the wheel was the only system that recovered latent as well as sensible energy, which is very important in the high-humidity summers of Bethesda.

NIH accepted the use of an energy recovery wheel with several limitations, including these:

- As mentioned, the Division of Safety required a separate fume hood exhaust system, which resulted in a smaller volume (roughly 20% less) of air to the wheels and thus lower energy savings.
- The Division of Engineering was concerned about insufficient building capacity if the heat wheels had to be abandoned in the future for any reason. Therefore, Division staff required that the design and sizing of the mechanical system be done without considering heat wheel factors. The result is that NIH did not realize any benefits of downsizing the base building system design to take full advantage of energy recovery wheels.

Ultimately, the heat wheel equipment did not work as planned, and energy recovery systems were ultimately disallowed for lab buildings at NIH. Energy saving technologies currently allowed at NIH include chilled beams, solar panels, and geothermal energy.

Source: Kutlak & Carlisle, 2001.

construction of new buildings, such as the Porter Neuroscience Research Building (PNRC) in 2014, the NIH created an Energy Monitoring group that established a common platform for energy monitoring that allows comparisons of energy usage over time and between NIH buildings.

Energy Consumption

This section will examine how the design and equipment choices detailed throughout this report have impacted Total Energy Consumption (TEC) in Building 50. For this purpose, TEC is understood to be the sum of the usage of electricity, steam and chilled water.

The basic available data are shown in Table 4 and Figure 9 on page 16. The summary conclusion is that TEC has risen by about 8%, when comparing 2010-11 with 2019-20. Before evaluating this increase, three important constraints must be taken into account.

First, while the original design program for Building 50 emphasized energy efficiency as a key objective, expected performance ranges and predicted values were only established for the electrical equipment and for total electrical consumption. As a result, we lack design benchmarks for evaluating the energy consumption required by the use of piped-in steam and chilled water.

Second, building administrators did in fact monitor the consumption of all three sources of energy from the first year of Building 50's operations. However, the data from 2001-09 were lost. As a result, the analysis in this report is based on the more recent data from 2010-20, and this clearly limits most assessment of the building's early years.

Third, inspection of the electricity consumption column in Table 4 (on page 16) makes clear that the data for 2017-20 show identical numbers for each of four years and therefore cannot be relied on. It appears that there has been some flaw in the data recording system, and the analysis that follows must be regarded as provisional until this anomaly can be fixed. Nonetheless, electricity consumption for the years where we have reliable data show little year-on-year variation. This suggests that our key conclusions will be robust, and will require little modification when corrected data become available.

The modestly increasing trend of TEC obscures the quite different trajectory of the three sources of energy consumption.

Electricity, which amounts to about 30% of TEC, has averaged about 64k mmBtu in total per year and, as mentioned, shows little annual variation. This is equivalent to a yearly consumption of about 217k Btu per square foot. Table 5 on page 18 shows the expected range and performance values predicted for the electrical equipment in 2001. The expected annual total consumption was 230k Btu per square foot, suggesting that Building 50 is performing well within the expected range. In spite of the caveat imposed by the unreliable data for 2017-20, this suggests that the energy efficiency measures described in previous sections have largely succeeded.

Steam, although not included as an energy parameter in the original design, currently accounts for about 30% of Building 50's TEC. The level of consumption has tended to decline over the past 10 years so that consumption in 2019-20 amounts to only 75% of that in 2010-11.

Chilled water usage has been the main source of the observed overall increase in TEC. Use in 2019-20 runs nearly double that of 2010-11, and it now accounts for about 40% of TEC.

Technology changes and global climate change appear to be the key drivers of these shifting consumption patterns.

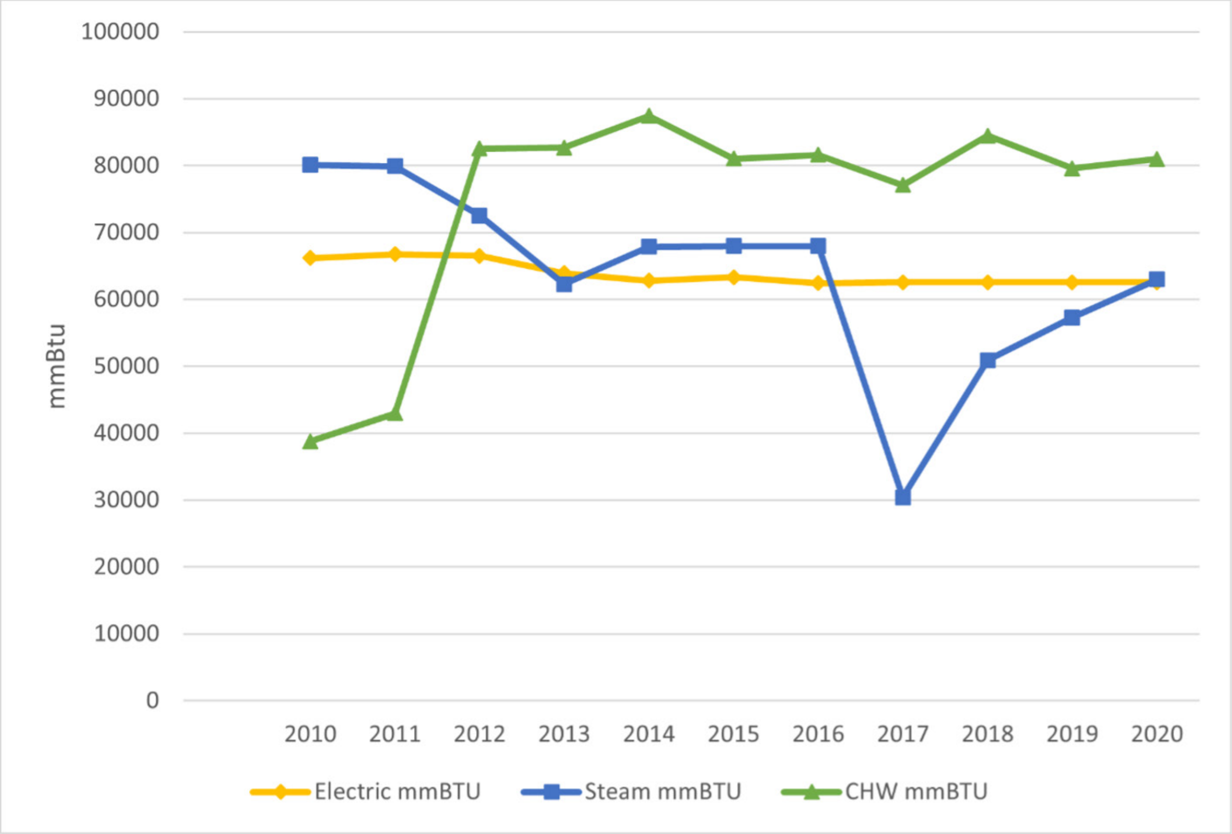

Figure 9. Building 50 energy consumption for the period 2010 to 2020 . Source: Present author, based on data supplied by Energy Management Branch, NIH.

Table 4. Total Energy Consumption, Building 50, 2010-2020

YEAR	ELECTRICITY MMBTU	STEAM MMBTU	CHILLED WATER MMBTU	TOTAL ENERGY USE MMBTU	ELECTRICITY % OF TOTAL	STEAM % OF TOTAL	CHILLED WATER % OF TOTAL
2010	66,175	80,090	38,789	185,054	36%	43%	21%
2011	66,736	79,896	42,957	189,589	35%	42%	23%
2012	66,507	72,511	82,528	221,546	30%	33%	37%
2013	63,929	62,300	82,649	208,878	31%	30%	40%
2014	62,809	67,883	87,433	218,125	29%	31%	40%
2015	63,288	67,973	81,043	212,304	30%	32%	38%
2016	62,400	67,973	81,607	211,980	29%	32%	38%
2017	62,532	30,404	77,100	170,036	37%	18%	45%
2018	62,532	50,922	84,475	197,929	32%	26%	43%
2019	62,532	57,264	79,565	199,361	31%	29%	40%
2020	62,532	62,976	80,984	206,492	30%	30%	39%

So far as electricity is concerned, these two drivers have moved in opposing directions. As Building 50's HVAC equipment has reached end-of-life, administrators have installed new equipment with much-improved energy ratings. Lighting, which was only expected to account for about 11% of electricity consumption in 2001, probably accounts for an even lower percentage now. LED lighting and improved control systems have tended to reduce electricity consumption.

On the other hand, global climate change has imposed an increasing burden on the HVAC equipment. The engineers in charge of the original HVAC specifications used 4,704 heating degree days and 1,137 cooling degree days as design parameters applicable to Bethesda, Maryland. By 2021, the local parameters had shifted significantly, with only 4,654 heating degree days, but with 2,491 cooling degree days, resulting in a net increased energy burden for the HVAC system.

The changing consumption of chilled water and steam has largely been driven by changes in the equipment used in the laboratories. Increased use of laser imaging, refrigeration, and ultra-low temperature freezers for medical and biological research has tended to increase the consumption of chilled water while reducing the need for steam.

Conclusions

A rigorous evaluation of the performance of a design program after 20 years of operation faces a startling variety of obstacles. As this case study has demonstrated, these obstacles include data loss, and the difficulties of accounting for the impact of an accelerating sequence of technology changes and major shifts in user research agendas and operational requirements, as well as global climate change.

Nonetheless, it is apparent that Building 50 has performed credibly in the face of these changes. Moreover, we can identify, on the basis of the analysis of this report, important specific conclusions that will support further improvements in the design programs of laboratory facilities.

1. **Effective architectural design for natural light** responds to user demand, as well as energy efficiency. It continues to enhance the experience of using the laboratories and other work spaces, even when changing technology has required building operators to subdivide the interior layout and reduce the original open-plan design.
2. **Provision of interstitial floors** remains a critical feature of a building flexible enough to respond to changing research needs. Even though these floors impose additional up front costs, they reduce the cost and disruption of subsequent equipment changes, and extend a building's useful life. The lesson of Building 50 is that even 30% of gross square footage may not be sufficient interstitial space. It is hard to see how a laboratory without extensive interstitial space could qualify as a sustainable design.
3. **Secure and comprehensive data monitoring** must be given attention and budget. Monitoring the consumption of energy and other natural resources will be of increasing importance as demands from technology change and global warming continue to accelerate. Back up systems, alarms and regular maintenance for the data monitoring arrangements should be given the same priority as those for critical mechanical equipment.

Table 5. Building 50 Electricity Usage Parameters and Expectations (2001); Realized Results 2010-2020

System	Design Parameters	Expected Electricity Usage (Based on Design Data)
Ventilation (sum of wattage of all fans and exhaust fans)	1.25 W/cfm (1) 1.36 cfm/gross ft^2 (2) (2.15 cfm/net ft^2)	30 kWh/gross ft^2 (48 kWh/net ft^2)(3)
Cooling plant	1,900 tons	15.0 kWh/gross ft^2 (4)
Lighting	1.6 W/gross ft^2	7.25 kWh/gross ft^2 (5)
Process/plug	3 W/gross ft^2 (receptacles) 5.7 W/gross ft^2 (lab equipment)	15.2 kWh/gross ft^2 (6)
Heating plant	12,253 MBH heating plant capacity	Not available
Total Annual Electricity Usage	**REALIZED 2010-2020 Average 216K Btu/gross ft^2**	**EXPECTED 2001** **230 K Btu/gross ft^2 (7)**

Notes

1. [101 hp (supply) + 115 Hp (exhaust)] x 746 W/hp ÷ [50,000 cfm (supply) + 77,500 cfm (exhaust)] = 1.25 W/cfm

2. Total cfm required for all six floors is 400,000; 400,000/294,532 gross ft^2 = 1.36 cfm/gross ft$_2$; 400,000 cfm/186,062 net ft^2 = 2.15 cfm/net ft^2

3. (1.25 W/cfm x 1.36 cfm/gross ft^2 x 8,760 hours) x 2/1000 = 15 kWh/gross ft^2 (multiplied by two to account for both supply and exhaust)

4. 0.8 kW/ton (estimate) x 1,900 tons x 2,890 hours / 294,532 gross ft^2 = 15.0 kWh/gross ft^2 (assumes cooling runs 33% of the hours in a year)

5. 1.6 W/gross ft^2 x 4,534 hours/1,000 = 7.25 kWh/gross ft^2 (assumes lights are on 87.2 hours/week); 1.7 VA/gross ft^2 x 95% power factor = 1.6 W/gross ft^2

6. 8.7 W/Gross ft^2 x 1,752 hours/1,000 = 15.2 kWh/gross ft^2 (assumes plugs and lab equipment operate 20% of the time and 9.6 W/net ft^2 x 0.9 power factor = 8.7 W/gross ft^2)

7. Estimated data are presented in site Btu (1 kWh = 3,412 Btu). To convert to source Btu, multiply site Btu for electricity by 3. (Note: Bethesda has approximately 4,704 heating degree days and 1,127 cooling degree days, using 1997 data for Baltimore.)

Sources: Original parameters from Kuklak & Carlisle 2001; Realized usage, present author's calculation based on data supplied by NIH EMD.

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Author

Mitsy Canto-Jacobs, AIA, NCARB, NCIDQ, leads the Sciences Practice Area for Gensler in the Southeast region.

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