Laboratories for the 21st Century: Case Studies

Case Study Index

Laboratory Type
- ☑ Wet lab
- ☑ Dry lab
- ❑ Clean room

Construction Type
- ☑ New
- ☑ Retrofit

Type of Operation
- ❑ Research/development
- ❑ Manufacturing
- ☑ Teaching
- ❑ Chemistry
- ❑ Biology
- ❑ Electronics

Service Option
- ❑ Suspended ceiling
- ❑ Utility service corridor
- ❑ Interstitial space

Featured Technologies
- ☑ Fume hoods
- ☑ Controls
- ☑ Mechanical systems
- ☑ Electrical loads
- ❑ Water conservation
- ❑ Renewables
- ☑ Sustainable design/ planning
- ❑ On-site generation
- ☑ Daylighting
- ❑ Building commissioning

Other Topics
- ❑ Diversity factor
- ❑ Carbon trading
- ❑ Selling concepts to stakeholders
- ☑ Design process

LEED Rating
- ❑ Platinum
- ❑ Gold
- ❑ Silver
- ❑ Certified

Haverford College/PIX19379

Marian E. Koshland Integrated Natural Science Center at Haverford College, Haverford, Pennsylvania

Introduction

The Marian E. Koshland Integrated Natural Science Center (KINSC) reflects the commitment of Haverford College's faculty and administrators to providing a productive, flexible, and motivating learning environment. When the evolving space requirements of the institution's natural sciences departments began to exceed those of the existing facilities, the faculty and administrators started to investigate the benefits of co-locating all the college's natural sciences activities. They recognized

EPA United States Environmental Protection Agency

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Federal Energy Management Program

that most science graduates' careers will require knowledge in disciplines other than their degree areas, and that participating in a wide range of scientific experiences is in the students' best interests. The planners wished to create an environment that provides state-of-the-art research facilities and promotes interactions within the laboratory as well as among degree disciplines. As a result, the 185,423-ft^2 (gross) KINSC was designed and constructed. This distinctive academic center includes laboratory, classroom, office, and supporting spaces to house all of the Haverford College natural science departments.

The KINSC's unique mechanical system conditions the facility's makeup air separately from the air that maintains thermal comfort. Energy wheels precondition the makeup air to space-neutral conditions (the temperature and relative humidity levels desired for comfort within the building). Individual fan-coil units located within each space or building zone further condition a portion of this makeup air to maintain desired thermal conditions in each space. There is no need for reheat because the air entering the fan-coil units is at space-neutral conditions. Because the conditioned makeup air is distributed through a network of plenums, there is very little ductwork in the building. Designers estimated that the KINSC system saves 52% in cooling and heating energy annually for the entire facility as compared to a system using 100% outside air, variable air volume (VAV) fume hoods, and no energy recovery. When compared to a similar conventional laboratory system that incorporates sensible energy recovery, the comparable thermal energy savings are still 45%.

"The response to the new KINSC has been outstanding. The people who use the building love it." Norman Ricker, client (former Director of Physical Plant), Haverford College, Haverford, Pennsylvania

This study is one in a series produced by *Laboratories for the 21st Century* ("Labs 21"), a joint program of the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE). The program is geared toward architects and engineers who are familiar with laboratory buildings, and encourages the design, construction, and operation of safe, sustainable, high-performance laboratories.

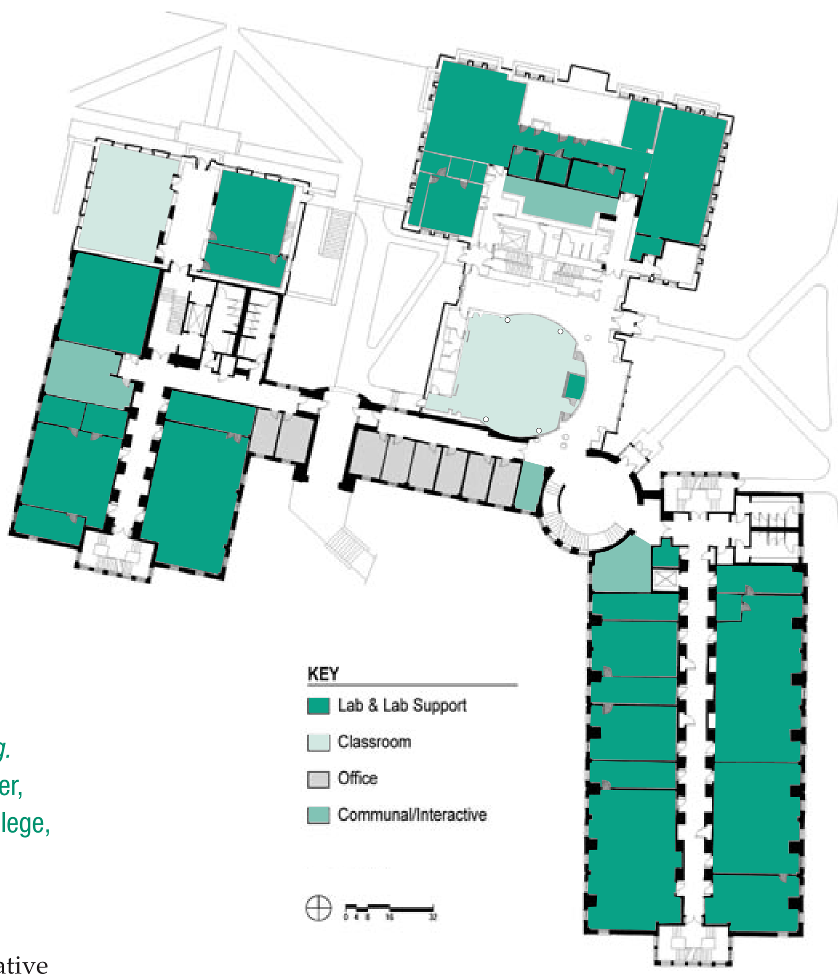

Figure 1. KINSC first-floor plan

Project Description

The KINSC in Haverford is a four-story, 185,423-gross-ft^2 laboratory and classroom building. It houses facilities for both undergraduate- and graduate-level research activities for seven natural sciences departments (biology, chemistry, physics, mathematics, computer science, and psychology). As a fully integrated, cooperative educational facility, it also contains faculty offices, communal/interactive areas, and a natural sciences library. The building construction was completed in two phases in 2001 and 2003 at a total project cost of $42.6 million ($230/gross ft^2). Ayers/Saint/Gross (ASG) Architects and Planners of Baltimore, Maryland, and CUH2A of Princeton, New Jersey, provided the architectural and engineering design services, respectively. Earl Walls Associates of San Diego, California, was the laboratory planner, and the general contractor/construction manager was Skanska U.S.A. Building, Inc. of Blue Bell, Pennsylvania (formerly Barclay White, Inc.).

Table 1. KINSC Space Breakdown
(in net square feet, unless otherwise noted)(1)

Function	Size (ft^2)	Percentage of Total Space(2)
Labs and lab support(3)	65,477	72.5
Classrooms	8,330	9.2
Communal/interactive spaces	8,963	9.9
Library	7,483	8.3
Total net square feet	90,253	
Other(4)	95,170	
Total gross square feet	185,423	

1. Includes new construction, Sharpless Hall, and Hilles Hall.
2. The percentage shows a breakdown of the net square feet only. Net square feet equals gross square feet minus "other."
3. Offices are included in the laboratory and laboratory support category.
4. Other includes circulation, toilets, stairs, elevator shafts, mechanical and electrical rooms and shafts, and structural elements like columns. The net-to-gross-square-foot ratio is 0.48.

Alan Karchmer, Architectural Photographer/PIX13967

Figure 2. The bowtie configuration of the benches in the biology laboratories facilitates interactions among students.

Alan Karchmer, Architectural Photographer/PIX13968

Figure 3. Double-sided fume hoods provide a clear line of sight to all student workstations in the chemistry laboratories.

Layout and Design

The KINSC joins the southern ends of the existing Sharpless Hall and Hilles Hall. A section of the building, known as the "Link," ties together these existing buildings and the newly constructed KINSC. Figure 1 shows the KINSC first-floor plan, and Table 1 gives a breakdown of space by function.

Laboratory Design

The laboratory designer worked closely with the Steering Committee, which consisted of Haverford College faculty and staff, to optimize the laboratory configuration and bench design to facilitate teaching. Mock-up benches were constructed during the design phase so that the Steering Committee members could test their bench design recommendations. The "bowtie" bench design for the biology laboratories was a result of this process (Figure 2). The open, double hexagonal bench design, which encourages interaction between groups ranging from 2 to 8 students, also gives a clear line of sight across the bench, further promoting conversation between groups.

The chemistry laboratory has the more conventional straight benches because chemistry students typically work on their own, instead of in the groups usually found in biology laboratories. Double-sided fume hoods used in the larger chemistry laboratories furnish a clear line of sight between the professors and the students (Figure 3).

Every teaching laboratory has Americans with Disabilities Act (ADA) accessible workstations.

Utility Servicing

Four vertical interior shafts in each of the building's east and west wings are the conduits through which the utilities are run. These shafts also serve as the plenums through which space makeup air is delivered. Pipes and other utilities run horizontally from these shafts via a uni-strut-type rack system mounted to the ceiling. Utilities are in a standard stacked configuration with the air distribution on top, piping in the center, and data and electrical conduits on the bottom to give an organized appearance in the spaces without finished ceilings. Makeup air is distributed through corridor ceiling plenums as well as the vertical interior shafts. Data cable trays and lighting electrical conduits are also routed through the corridor. Exhaust air is ducted through separate exterior vertical shafts.

The vertical shafts and plenum distribution design strategy maximizes the ceiling height. The floor-to-floor height for most parts of this building is 13.5 ft, but ceiling heights range from 10.5 ft to 15 ft (these vary according to floor and wing). Only the corridors have ceilings installed below the maximum floor-to-floor height to accommodate the horizontal makeup air plenums. All piping, ductwork, and other utilities outside the corridors are exposed to maintain the feeling of tall ceilings.

Mechanical rooms are located in the enclosed penthouse on the fifth floor of the east wing and in the basement of the west wing of the newly constructed portions of the KINSC. An existing mechanical room in the Sharpless Hall basement remains in use.

The building receives steam service from the campus central plant, where most of it is converted to hot water. The remainder provides humidification. Two dedicated 240-ton chillers supply chilled water to the building. There are 386 gross square feet of building area per ton of chiller capacity in this building, which is very similar to common office building capacity requirements. Haverford College turns off the chillers and drains and shuts down the cooling towers during the winter months to conserve energy.

Communal Spaces

Communal spaces are liberally located throughout the building to serve as comfortable and convenient areas where students and faculty can congregate. Each communal space contains comfortable seating and a white board or chalkboard. These spaces are designed to foster an environment that encourages communication among the students and faculty of the various scientific disciplines housed within the building.

Design Approach

Consensus building was the foundation of the KINSC design process. The ASG-led design team and the KINSC Steering Committee met regularly throughout the project design phase. A variety of tools were employed to help meeting participants fully understand the meaning and impact of an “interdisciplinary” education. The design team tested proposed building design solutions with larger campus-wide issues of scale, massing, campus circulation, and building orientation. Three-dimensional “blocking and stacking” models, flow diagrams, and bubble diagrams allowed design team and committee members to visualize space interactions and conceptualize building massing.

The design team and the committee established up front that minimizing building operating costs was a primary project goal. Minimizing these costs is directly tied to energy efficiency, especially in a laboratory building. Because conditioning laboratory ventilation air is a principal source of energy consumption, KINSC designers decided to use energy recovery systems, which require co-locating the supply and exhaust air streams, early in the design process. This necessitated coordination between the architectural and engineering designs throughout the design phase.

During the early design phase, the planners also considered the fume hood locations, recognizing how the fume hoods interacted with other mechanical system components and adjusting the building design to optimize overall mechanical system performance. For example, the organic and general chemistry laboratories, the most-used laboratory spaces in the building, are located on the top floor of the east wing. Locating these laboratories just under the KINSC mechanical room shortened the fume hood exhaust system, which accommodates the large number of fume hoods that these laboratories require as efficiently as possible at the lowest cost.

Technologies Used

Site Related

The building project adheres to sustainable design practices that minimize disturbances and impacts to the site and regional environments. The new facility is constructed on a previously disturbed site and the building is physically attached to two existing historic buildings (Sharpless Hall and Hilles Hall). To make room for the KINSC on the site, two additional buildings were moved a short distance instead of being destroyed.

Heating, Ventilating, and Air-Conditioning (HVAC)

The most groundbreaking energy efficiency design feature of the KINSC is the strategy used for laboratory ventilation and space conditioning. A series of energy wheels condition the exhaust and makeup air to create space-neutral air. Individual fan-coil units (FCUs) located within each space or building zone further condition a portion of this makeup air to maintain desired thermal conditions in each space. Reheat is not needed because the air entering the FCUs is at space-neutral conditions. The conditioned makeup air is distributed through a network of plenums. Distributing the air through plenums minimizes the need for ductwork and minimizes air pressure drops. Designers estimate that the strategy consumes 52% less energy than an air-handling unit system that uses 100% outside air.

The KINSC system avoids the need to both cool and heat all the air delivered to the laboratories. A total energy

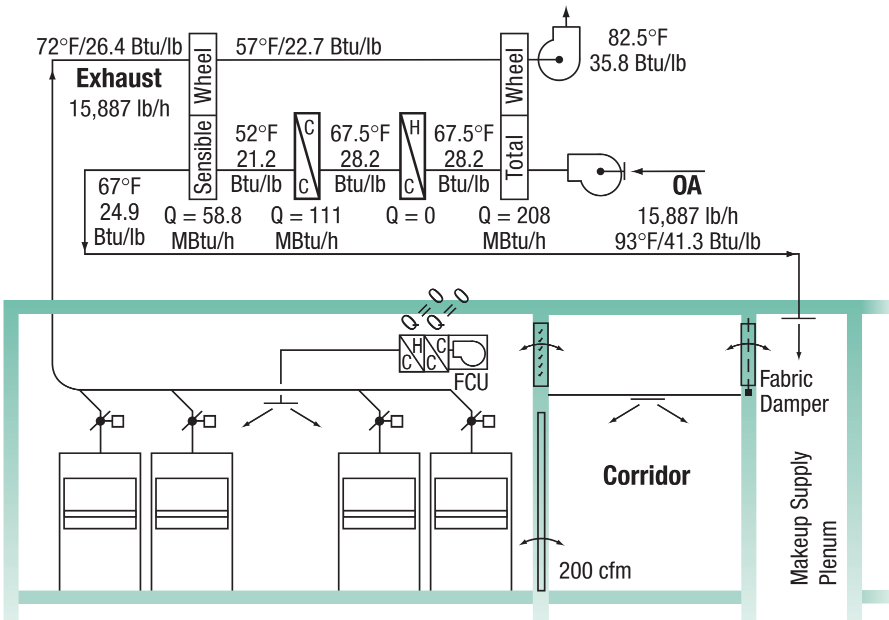

Figure 4. KINSC laboratory makeup air and comfort conditioning system. Values shown in this figure are based on the following assumptions: laboratory area of 650 ft^2; four VAV fume hoods, each operating at an open 900 cfm exhaust; four people working in the space, operating internal lighting and equipment load of 5 W/ft^2; and a summer envelope cooling load of 2400 Btu/h.

wheel and a sensible energy wheel work in series with heating and cooling coils to condition all incoming outside air to space-neutral conditions. Figure 4 illustrates how the energy wheels are integrated into the makeup air-conditioning system. Designers specified a special 3-Å molecular sieve desiccant to ensure minimal cross contamination between the exhausted laboratory air and the air delivered to the spaces.

The space-neutral conditioned makeup air is distributed through a building plenum delivery system, which consists of vertical shafts that are open to the corridor ceiling plenums on all floors. The fume hoods and general building exhaust system passively draw the air from the corridor plenums and deliver it into the laboratories. The air travels through back-draft dampers that are made of fabric and installed in the wall partition between the lab and the corridor. These self-adjusting dampers maintain a negative pressure of approximately 0.03 in. in the laboratory, compared to the corridor. When a laboratory door is open, the back-draft damper instantly shuts, ensuring inward airflow through the door for improved containment.

A simple control scheme combined with the back-draft damper maintains the desired laboratory differential pressures. This design avoids the need for a VAV box, differential air pressure controls, and a reheat coil on the supply air ductwork. The design results in a first cost savings and a low supply air pressure drop, which saves on fan energy.

Fan coil units in each laboratory sensibly condition only the quantity of air needed to maintain comfortable space conditions. Thermostats in each laboratory control the FCUs and the FCUs operate only during occupied hours. Each FCU serves just one laboratory to avoid cross contamination of fumes among the laboratories.

The KINSC laboratory HVAC system design has many advantages beyond heating and cooling energy savings:

- Ductwork is minimized. Fume hoods and general building exhaust system passively draw the makeup air from the plenums and into the laboratories. The only supply air ductwork that is needed introduces the space-neutral air into the plenums and then delivers the supply air from the FCUs in each space. Ductwork is also used to direct the fume hoods' exhaust air into the laboratory exhaust air system.
- No condensation is present in the FCUs. The FCUs provide only sensible conditioning because the energy wheels previously accomplished all of the required dehumidification. Avoiding condensation in the FCUs eliminates the need to install a system to remove condensate, along with the possibility of fan coil equipment deterioration problems resulting from moisture buildup.
- Control, balancing, and startup are simpler. A standard flow tracking control located at one location within the makeup air unit synchronizes the makeup supply air quantity with the quantity of air exhausted from the spaces and maintains constant global building pressure conditions. Balancing and startup consists of properly setting the makeup airflow tracking controls and calibrating the fume hood exhaust controls.
- Fewer control points and the passive makeup air delivery system combine to simplify the operations and maintenance requirements.
- The system operation is extremely quiet. Because the large quantities of makeup air are delivered through plenums, the system is virtually silent when operating. The silent operation facilitates instruction in the laboratories and classrooms and enhances the learning environment.

One drawback of the KINSC HVAC system has been maintenance costs for the high number of FCUs, particularly the costs of filter change outs. This added maintenance cost is acceptable, however, when compared with the benefits of lower construction costs, quieter laboratories, and more efficient energy use.

An outside air inlet bypass damper on the suction side of the constant volume exhaust air fans maintains constant stack velocity. Most of the 110 fume hoods in the building are VAV fume hoods (a few constant volume hoods are located in the west wing). All the teaching laboratories are designed so that one fume hood can remain active when all the other fume hoods in the laboratory are shut down. This strategy was intended to allow for the continuous operation of only one fume hood per laboratory, to meet the minimum ventilation rate for the laboratory, except for the time periods when students are occupying the laboratories.

Of the considered strategies, the mechanical system design selected for the KINSC was the strategy that had both the lowest first cost and operating costs. The cost of the energy recovery devices in the makeup air-conditioning system nearly doubled the first cost of this equipment, compared to a conventional 100% outside air system. But the increased cost for the energy recovery devices was more than offset by savings resulting from a reduced heating and cooling plant size, the reduced supply-air ductwork, and a simpler control system. These savings reduced the mechanical system construction cost to 10% less than that of comparable facilities built in the region.

Lighting

Suspended, bidirectional fixtures with T-8 fluorescent lamps light the laboratories, classrooms, communal spaces, and corridors. In the laboratories and classrooms, the fixtures are set to supply 85% of the lighting as down lighting and 15% as up lighting, for an 81% fixture efficiency. The fixtures in the communal spaces and corridors are adjusted to provide a 50%–50% distribution of up-to-down lighting, for a fixture efficiency of 94%. Suspended linear fluorescent indirect lighting fixtures with perforated bottoms (97% up and 3% down) illuminate the offices. Fluorescent task lighting is installed in the offices with overhead storage as well as in the library study carrels. Compact fluorescent down lights are used in the circulation areas, offices, and library.

Manual switches control the lighting in the laboratories and classrooms and are wired to permit separate switching of rows of lights. A relay-based lighting control system is used in the circulation areas. This system incorporates time-of-day scheduling, override switches, and/or photocells (outdoor and entry lobby lighting). Wall-mounted occupancy sensors with switch overrides control the office lighting.

Indoor Environmental Quality (IEQ)

The KINSC design delivers good IEQ through the following features:

- The connection with the outdoors is an important design feature of the KINSC. Almost all classrooms, offices, and communal/interactive areas have operable windows, and all stairwells have operable windows and skylights. Students and faculty report that the availability of daylighting and the views to the outdoors from virtually all regularly used spaces in the building make for more comfortable learning and working environments.
- The mechanical system design results in a relatively small amount of air traveling through the FCUs. Less air means less noise.
- No condensation at the FCUs eliminates the possibility of indoor air quality problems associated with the accumulation of condensate in occupied spaces.
- Whenever possible, materials and finishes that emit low levels of volatile organic compounds (VOCs) were used to minimize the introduction of indoor pollutants.
- The simple control strategy of the mechanical and electrical systems in the building ensures that the occupants are comfortable in the spaces.

Materials

Locally quarried stone was used as a building façade material, and regionally quarried slate is used extensively within the building. The precast concrete structural framing was manufactured locally. The concrete masonry units (CMU) and most of the ground-faced block was also locally manufactured. Finally, all slate blackboards and some of the furniture found in the building were reused from other spaces on the Haverford College campus.

Building Metrics

Table 2 summarizes the building's metrics and provides the estimated energy use calculated using the key design parameters. Because the KINSC is not metered separately from other buildings on the Haverford College campus, energy use figures, as reported by measured data or energy utility bills, are not available. The energy consumption of the ventilation system is low compared to other buildings featured in the Labs 21 case study series because of the low fan power requirements. Distributing the air through a network of plenums minimizes the need for ductwork, which significantly reduces system static

Table 2. KINSC Metrics

System	Key Design Parameters	Annual Energy Usage (based on design data)	Annual Energy Use (based on measured data)
Ventilation (sum of wattage of all the supply and the exhaust fans)	Supply = 0.72 W/cfm Exhaust = 0.78 W/cfm Total = 0.75 W/cfm[1] (0.4 cfm/gross ft^2; 0.9 cfm/net ft^2; and 1.2 cfm/net ft^2 of labs)[2]	5.3 kWh/gross ft^2 (11.8 kWh/net ft^2)[3]	Not separately metered
Cooling plant	480 tons 0.64 kW/ton	2.2 kWh/gross ft^2 [4]	Not separately metered
Lighting	1.48 W/net ft^2	2.1kWh/gross ft^2 [5]	Not separately metered
Process/plug	6 W/net ft^2	12.6 kWh/gross ft^2 [6]	Not separately metered
Heating plant	7,000 kBtu	32.5 kBtu/gross ft^2/yr [7]	Not available
Total		22.2 kWh/gross ft^2 /yr (estimated based on design data for electricity only) Total estimated energy use = 108.3 kBtu/gross ft^2/yr	Not available

1. W/cfm for the supply/exhaust air handlers represents the fan brake horsepower (bhp). Supply: (115 bhp × 746 W/bhp)/119,300 cfm = 0.72 W/cfm. Exhaust: (85.9 bhp × 746 W/bhp/81,380 cfm = 0.78 W/cfm. Total: [(115 bhp + 85.9 bhp) × 746 W/bhp]/(119,300 cfm + 81,380 cfm) = 0.75 W/cfm.
2. 81,380 cfm (total cfm based on exhaust)/90,253 net ft^2 = 0.902 cfm/net ft^2; 81,380 cfm/185,423 gross ft^2 = 0.439 cfm/gross ft^2; 81,380 cfm/65,477 net ft^2 of labs = 1.243 cfm/net ft^2 of labs.
3. 0.75 W/cfm × 0.4 cfm/gross ft^2 × 8,760 h × 2/1,000 = 5.3 kWh/gross ft^2 (0.75 × 0.9 × 8,760 × 2/1000 = 11.8 kWh/net ft^2). The equations were multiplied by 2 to account for supply and exhaust.
4. 0.64 kW/ton × 480 tons × 1,350 h/185,423 gross ft^2 = 2.2 kWh/gross ft^2 (assumes cooling runs 15% of the hours in a year).
5. 0.72 W/gross ft^2 (weighted average) × 2,860 h/1,000 = 2.1 kWh/gross ft^2 (1.48 W/net ft^2 × 2,860 h/1,000 = 4.2 W/gross ft^2). (Assumes lights are on 55 h/week).
6. 3 W/gross ft^2 (weighted average) × 0.80 × 5,256 h/1,000 = 12.6 kWh/gross ft^2 (6 W/net ft^2 × 0.49 = 3 W/gross ft^2). (Assumes that 80% of all equipment is operating 60% of the hours in a year).
7. 7,000 kBtu x 860 h/185,423 gross ft^2 = 32.5 kBtu/gross ft^2/yr (assumes that the heating plant full load equivallent annual operating hours is 860 h).

pressure. Less fan power is then needed to distribute the air. The calculated energy use is 22.2 kWh/gross ft^2/yr.

Summary

The strong rapport between the design team and Steering Committee was a key factor in the success of the KINSC project. The building design evolved through an iterative process consisting of continuous communication between the design team and the Steering Committee. The design schedule set at the beginning of the project was not adversely affected by the extensively iterative nature of the design phase. The final design balanced the program interdisciplinary requirements, quality of construction and finishes, and budget (final project cost of \$230/ft^2). Finally, the design team and Steering Committee felt that they successfully created a building that assimilates well into the Haverford campus and constructed a facility that can be used and enjoyed by all, not just the scientists it houses.

The project construction cost was less than originally anticipated, primarily because distributing makeup air through plenums minimized the amount of ductwork in the building. In addition, the energy recovery system reduced the amount of heating and mechanical cooling needed to meet building loads, which resulted in decreased heating and chiller capacity requirements. Designers chose not to install ceiling finishes in most of the building as a strategy to give the building a taller, more open feeling, and for additional cost savings.

Other innovative features of the KINSC include locating fume-hood-intensive laboratories on the top floor just under the mechanical room (to accommodate the large number of fume hoods as efficiently as possible), installing FCUs so that each unit serves only one laboratory (to avoid cross contamination between laboratories), and the practice of turning the chillers off and draining and shutting down the cooling towers during the winter months.

Acknowledgments

This case study would not have been possible without the contributions of Norman Ricker of Haverford College; Jim Patz and Earl Purdue of Ayers/Saint/Gross Architects; and Philip Bartholomew of CUH2A. Sheila J. Hayter, P.E., of the National Renewable Energy Laboratory (NREL) authored this case study. Also from NREL, Nancy Carlisle, A.I.A., and Otto Van Geet, P.E., contributed helpful comments and peer reviews. René Howard and Susan Sczepanski provided editing and graphic design.

For More Information

On the Marian E. Koshland Integrated Natural Science Center:

Client
Norman Ricker
Haverford College
370 Lancaster Avenue
Haverford, PA 19041-1392
610-896-1100
nricker@haverford.edu

Architect
Adam Gross, F.A.I.A.
James M. Patz, A.I.A.
Earl Purdue, A.I.A.
Ayers/Saint/Gross Architects
1040 Hull Street, Suite 100
Baltimore, MD 21230
410-347-8500
jpatz@asg-architects.com
epurdue@asg-architects.com

Engineer
Philip Bartholomew, P.E.
CUH2A
CN-5380
Princeton, NJ 08543-5380
609-844-1212
pbartholomew@cuh2a.com

On Laboratories for the 21st Century:

Dan Amon, P.E.
U.S. Environmental Protection Agency
1200 Pennsylvania Ave., N.W. (3204R)
Washington, DC 20460
202-564-7509
amon.dan@epa.gov

Will Lintner, P.E.
U.S. Department of Energy
Federal Energy Management Program
1000 Independence Ave., S.W.
Washington, DC 20585
202-586-3120
william.lintner@ee.doe.gov

Sheila Hayter, P.E.
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
303-384-7519
sheila_hayter@nrel.gov

Laboratories for the 21st Century
U.S. Environmental Protection Agency
Office of Administration and Resources Management
www.labs21century.gov

In partnership with the
U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable
www.eere.energy.gov

Prepared at the
National Renewable Energy Laboratory
A DOE national laboratory

DOE/GO-102005-2105
June 2005

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 20% postconsumer waste