II. SUSTAINABILITY BASE: CHANNELING NASA'S EXPERTISE TO CREATE A HIGH-PERFORMANCE BUILDING HERE ON EARTH*

OVERVIEW

Drawing on the same "can-do" spirit that sent men to the moon and unmanned rovers to Mars, NASA has channeled its technical expertise into the design of an innovative new building for its employees at the Ames Research Center in Northern California. Called "Sustainability Base," the building is designed to surpass the LEED Platinum sustainable design certification. Sustainability Base pushes the envelope on environmentally driven design, serving both as functioning office space and as a living laboratory for continuous advancements in intelligent building energy systems. It is one of the federal government's greenest buildings and is designed to produce more electricity than it consumes. Sustainability Base occupies a unique place within the federal government's efforts to lead by example in developing and occupying environmentally advanced buildings.

HUMBLE BEGINNINGS

One of 10 NASA centers throughout the country, the focus of work at Ames Research Center began with research on the aerodynamics of propellers dating back to before World War II. In addition to its continued focus on advanced aeronautics, over the years Ames has developed new areas of expertise including earth sciences, astrobiology, bioengineering, space- and aeronautics-related information technology, and others. Ames is located at Moffett Field in the heart of Silicon Valley, California.

The origins of Sustainability Base can be traced to 2007, when NASA started a "Renovation by Replacement" initiative providing financial support to its centers to replace antiquated buildings and reduce energy intensity by reducing the square footage of facilities. After Ames was selected to receive funding, the center's leadership proposed a fairly traditional design for its replacement facility. Ames Associate Director Dr. Steve Zornetzer had a different vision. He pictured a building that would reflect NASA's technological expertise and its leadership in imagining the future. Under his proposal, NASA would apply the expertise developed in creating livable conditions for spacecraft and astronauts to break new ground with an environmentally sustainable building at Ames. As Zornetzer states, "It was inconceivable to me that in the 21st century, in the heart of Silicon Valley, NASA would be building a building that could have been built 25 years ago. NASA had to build the highest-performing building in the federal government, embed NASA technology inside, and make a statement to the public that NASA was giving back to the people of planet Earth what it had developed for advanced aerospace applications."

The one important catch was that the redesigned building could not cost more than the originally proposed project.

SUSTAINABILITY CHALLENGES[1]

The challenges faced by NASA for its facilities at home involve meeting a growing set of sustainability mandates. Executive Order 13514 requires that all new federal buildings beginning in 2020 be designed to achieve zero net energy.[2] Congressional energy acts have set a goal of using renewables to achieve 7.5 percent of renewable energy by 2013 (Energy Policy Act of 2005)[3] and to reduce energy intensity by 30 percent by 2015 (Energy Independence and Security Act 2007).[4]

Over the decades since it was established in 1958, NASA has repeatedly faced the need to create self-sustaining systems to operate reliably in the harsh environments of space and on extraterrestrial surfaces. As a result, the agency has developed considerable expertise in managing complex systems based on extensive monitoring of dynamic, vital conditions (including energy generation and demand) and maintenance of key systems. No matter the task at hand—safely sustaining an astronaut floating tethered in space, establishing the International Space Station for long-term residence 200 miles above Earth, or powering a rover exploring the hostile surface of Mars—NASA has successfully met the challenges of building instruments and habitats capable

FIGURE 1: Groundlevel View of Sustainability Base

Source: "NASA - Digital Press Kit - NASA Ames Sustainability Base," NASA/ Eric James, last accessed August 28, 2012, http://www.nasa.gov/centers/ames/events/2012/sustainability-base-presskit.html.

of advancing its vision to "reach for new heights and reveal the unknown."

It was that same spirit and commitment to technological advancement that NASA's leadership brought to the design and implementation of Sustainability Base.[5]

The plan for the building centered on four key elements:

- Make maximum use of the existing physical environment through "native to place" design;
- Employ advanced technologies (including renewable energy generation and recycling/reuse) to minimize energy and water consumption and maximize resource efficiencies;
- Install advanced monitoring and adaptive operational systems to achieve sustained building system performance over time; and
- Create a living laboratory for research into advancing sustainability goals.

These elements were fully integrated at the earliest stages of the building's design and construction. The building's core design elements included a complex radial geometry, an innovative steel-frame exoskeleton, and numerous eco-friendly features, such as geothermal wells, natural ventilation, high-performance wastewater treatment, and photovoltaics on the roof. Faced with a tight timeline due to budgetary constraints and the challenges inherent in the building's unique geometry and exoskeleton, the architects and contractors chose to utilize design tools that allowed fast and effective communications among all involved. The design team relied on a Building Information Modeling (BIM) process based on Autodesk Sustainability Solutions, which was integrated with other modeling tools. This facilitated communication across teams and aided in making design decisions in a timely and accurate manner.[6]

For example, in order to maximize the use of natural daylight, the architect modeled local geophysical conditions, including the path of the sun across the sky throughout the seasons of the year. Using Ecotect Analysis software, the building was designed to allow for maximum penetration of sunlight into workspaces. The team also utilized information from the Revit Architecture model, used in the design of the structure, to better understand the cost impacts of its design decisions, particularly the floor-to-ceiling heights and integration of daylight into the design. The extensive use of virtual design tools allowed the project team to complete the drawings and design in nine months, roughly half the time originally estimated for this critical stage of the project.

The resulting $26 million, 50,000-square-foot, two-story building houses 220 office workers, including scientists, managers, mission support personnel, and financial specialists. The extensive floor-to-ceiling windows and open spaces fully embrace the natural daylight. With reduced demand for artificial illumination and the application of high-efficiency radiant heating/cooling systems, the building site produces more electricity than it uses. And it is well on its way to reducing potable water consumption by up to 90 percent compared to a traditional building of the same size. Sustainability Base is not only energy efficient, but resource efficient as well.

NATIVE-TO-PLACE DESIGN

A critical starting point in the design of a resource-efficient building is to make maximum use of the existing environment in ways that minimize energy requirements. Up to 50 percent of the energy savings in a building can be achieved through native-to-place design. In the design of Sustainability Base, the positioning of the building

itself, the use of natural light and air, and key features of the building's design all were developed with the goal of reducing energy needs and maximizing natural light and ventilation, while enhancing the comfort of its occupants.

Sustainability Base is located on the San Francisco Peninsula in Silicon Valley, where the semi-arid, Mediterranean-like climate results in temperate days most of the year. The key challenge for the building's designers was keeping the building comfortable in an area generally characterized by a temperate climate but also subject to an occasional hot summer day.

In pursuing native-to-place design solutions, Sustainability Base takes these climatic factors into consideration. The positioning of the building with a narrow western face maximizes shading and limits solar heating during the long summer days. To further reduce heat load and late afternoon glare in the summer, the sides most exposed to the sun have horizontal aluminum grills on the exterior that act to deflect sun exposure away from the interior of the building.

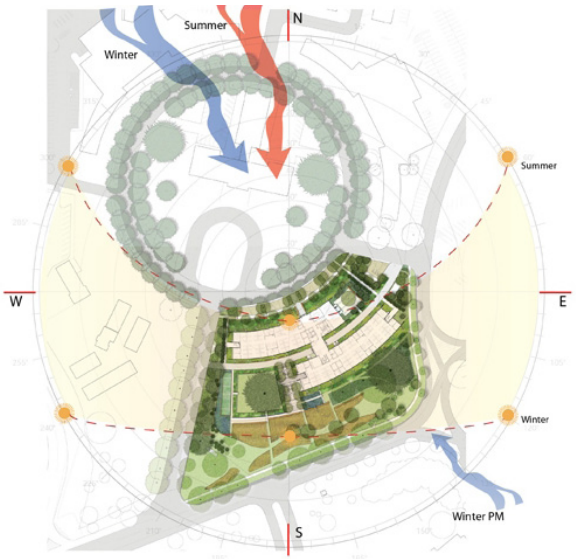
In addition, the base of the building is narrower than comparable buildings. This made it easier to design the building without interior columns, allowing for freer penetration of natural light and circulation of air. The floor-to-ceiling banks of windows are double-paned and argon-filled, with Solarban 70XL glaze permitting sunlight penetration while minimizing heat load and glare.

Windows accessible to the occupants on each floor can be manually opened and closed. Other windows throughout the building are operated automatically depending on external weather conditions. For example, the automated windows are set to open when the outside temperature reaches 70°F. With increased natural ventilation from the open windows, the rooftop air handling system automatically shuts off until outside temperatures rise above 83°F, when the windows close.

Window shades are also operated automatically to reduce solar heat loads. A series of three radiometers on the roof provide data to the software program that incorporates programmed solar tracking to determine when the shades should be open or closed.

To take advantage of the cool nighttime temperatures, which are typically 20°F lower than daytime readings year-round, rooftop air handlers perform nighttime air flushing. Some of this refreshed cool air is then retained in underfloor plenums and circulated into the building during the day for ventilation.

FIGURE 2: Sustainability Base Through the Seasons



Source: "NASA Sustainability Base," William McDonough + Partners, last accessed August 28, 2012, http://www.mcdonoughpartners.com/projects/view/nasa_sustainability_base.

The building's design further embraces the temperate climate by offering wireless access surrounding the building and landscaped outdoor work areas for employees. To minimize water use, the landscaping relies extensively on drought-tolerant, native plants with low water requirements. The landscaping also utilizes bioswales (gently sloped vegetation) in its design, maximizing the retention of rainwater. Additional irrigation is provided with water remediated from nearby groundwater contamination sites, further reducing the requirement for use of primary potable water sources.

ADVANCED ENERGY TECHNOLOGIES

To achieve its goal of producing more electricity than it consumes, Sustainability Base relies extensively on a range of advanced clean energy technologies that reduce its demand for electricity from the grid. Among the cornerstone technologies is a geothermal system providing radiant heating and cooling. Using an extensive network of more than 100 interconnected wells drilled to an average depth of 140 feet, the system circulates water through a closed-loop piping system in the ground. The system draws on the thermal inertia at this depth and maintains the recirculated water at 57°F regardless of outdoor temperatures.

On-site heat exchangers modify the temperature of the circulating water, either increasing or decreasing it to warm or cool the building. Instead of traditional temperature-controlled forced-air circulation, Sustainability Base is cooled through radiant ceiling chilling panels and warmed through wall-mounted radiators. Occupants of the building have noted the absence of the noise and drafts associated with forced-air systems and have observed that the indoor air feels more refreshing and less dry. NASA estimates that the combined system of geothermal wells, water pumps and heat exchangers is designed to be up to 70 percent more energy efficient than traditional methods used in commercial buildings.

For on-site electricity generation, Sustainability Base relies on energy from solar photovoltaic (PV) panels and an emerging fuel cell technology. The solar PV installation includes 432 SunPower E-19 panels that have an estimated conversion efficiency of 19 percent and that can produce 87 kilowatts (kW) of electricity at peak generation. At maximum output, the electricity produced from these solar panels should exceed the building's instantaneous demand. Averaged over the year, the electricity from the solar panels should generate up to 30 percent of the facility's total needs.

Sustainability Base also utilizes a state-of-the-art fuel cell that converts natural gas into electricity through a chemical reaction rather than traditional combustion. This device, the Bloom Energy Server ES-5700 (aka BloomBox) from Bloom Energy, is rated to produce 200 kW (max.) of electricity. The fuel cell can achieve up to 55-percent efficiency and reduce greenhouse gas emissions by 40 percent compared to conventional combustion. The BloomBox installed at Sustainability Base is the first installation of the second-generation model of this emerging technology.

The PV installation was financed using a Utility Energy Service Contract (UESC) with Pacific Gas and Electric. Under this agreement, the utility provided the upfront capital required for the purchase and installation of the solar panels. NASA will repay the initial capital cost over time, based on prorated utility charges that it would have paid without the UESC-provided improvements. When the investment is paid in full, the improvements and subsequent energy savings remain with NASA.

When electricity production exceeds Sustainability Base's demand, both the solar panels and BloomBox move the excess electricity to the grid, and this net contribution is metered.

Sustainability Base also reduces energy consumption through technologies aimed at lowering the electricity usage of its occupants' plug-in equipment. Plug-load demand represents approximately 30 percent of total building electricity use. The building includes such energy efficiency technologies as LED lights, laptops (where possible) that use less power than desktops, and some plug-load monitoring to automate power savings. Several technologies related to plug-load management are being analyzed in pilot studies in Sustainability Base. Early results from simple "rule-based" automation of power-up/power-off strategies indicate that they can achieve savings of 30-50 percent for identified devices.

WATER REDUCTION TECHNOLOGIES

Drawing on technology developed for space travel, Sustainability Base utilizes a grey-water recycling system. It consists of a water purification system that was initially developed for use on the International Space Station and that uses both forward- and reverse-osmosis. The recycled grey water replaces potable water for flushing toilets and urinals. The system installed at Sustainability Base will serve as a scaled-up, long-term test before it is deployed in future extraterrestrial applications. To facilitate reusing wastewater, the building was designed with a dual piping system that allows for segregation of grey water and potable water. These technologies combine with low-flow fixtures to keep water requirements to a minimum; potable water consumption is reduced on the order of 60 percent. Additional reductions in water requirements are achieved through drought-tolerant plants and landscaping that captures rainwater while reducing runoff. Together, these measures were designed with the goal of reducing potable water requirements by up to 90 percent compared to a conventional building design.

OPERATIONAL PARAMETERS

Optimal design and innovative energy-saving technologies are the cornerstones of all high-performance buildings, but by themselves are not sufficient to ensure that the buildings can actually achieve energy-saving goals. Studies have shown that initial energy savings are diminished over time as buildings age and building performance systems deteriorate.

Integrated building control systems are designed to monitor the performance of key systems and to ensure optimal set points and proper operations and maintenance. These systems have become standard in modern

buildings and typically focus on the performance and upkeep of the lighting and heating/cooling/ventilation systems.

Sustainability Base currently uses a state-of-the-art building control system, but over time NASA aims to develop a more integrated, adaptive system. This Integrated Intelligent Building Control System would take extensive real-time measurements of light, humidity and temperature, and combine these with online weather predictions and the calendars of occupants. It would also integrate the automation algorithms of existing building system elements (lighting, shades, windows). The operation of windows and shades, for example, would interact and mutually inform alterations to cooling and heating controls to provide for maximum comfort at minimum energy consumption. Data mining and fault-checking rules would be incorporated into the system for early identification of operational instabilities and maintenance requirements.

NASA intends to work with its own experts and with outside partners from industry and universities in developing this intelligent system over time.

LIVING LABORATORY

Continued efforts to develop the Integrated Intelligent Building Control System are one example of how Sustainability Base serves as a living laboratory for research and testing of advanced systems. NASA Ames Research Center is reaching out to public- and private-sector researchers interested in advancing sustainability goals and utilizing aspects of this building as a test bed. For example:

- NASA is working under an interagency agreement to conduct joint research with DOE's Lawrence Berkeley National Laboratory's Energy Efficient Building Systems Regional Innovation Cluster.
- A partnership with a private company, Integrated Building Solutions, produced the energy dashboard that greets visitors to the facility, displaying real-time energy generation and demand and other real-time data.
- Sustainability Base is experimenting with plug load management instruments from Enmetric Systems, with the company also providing consultation on the project.
- Partnership agreements have recently been concluded with Autodesk and Verdigris Technologies, for projects investigating Building Information Modeling for high-performance facilities and plug-load management, respectively.

Additional partnerships are under development and reflect a key feature of NASA Ames' mindset and history: its focus on entrepreneurship and advancing forward-looking technological solutions.

BARRIERS AND CHALLENGES FACED BY SUSTAINABILITY BASE

The lessons learned from NASA's experience with this building underscore the important role that technological advances can play in meeting the growing challenges of becoming a more sustainable society. NASA's experience with this building also provides additional examples of the practical applications from the technologies NASA has developed for its mission to explore outer space.

Pushing the design envelope for a high-performance building has not been without its problems. Just as NASA has occasionally encountered challenges in space, so has Sustainability Base faced start-up issues on Earth. The initial shakedown period has required significant interaction with, and fine-tuning of, the hydronic heating/cooling system to optimize function and flush out finely milled installation debris. During installation of the geothermal field, the installers unexpectedly discovered artesian wells at the depth initially planned for the drilling locations, necessitating a revision to shallower depths and more holes to compensate.

Setting aside start-up issues, the building is meeting its goals of providing more quality office space in a more sustainable manner for the employees at Ames. Most importantly, there is a genuine continued commitment to using the building and NASA's technological expertise to look outside the box to find solutions for advancing sustainability. If innovations developed for Sustainability Base find their way into widely disseminated products and practices, then this cutting-edge habitat will truly have made an impact far beyond its Earth-based footprint.

NEXT STEPS/TRANSFERABILITY

By bringing the skills and creativity it has applied to the challenges of exploring space, advancing aeronautics, and studying Earth systems to the design of its newest office building, NASA has once again demonstrated its willingness to be a leader in developing problem-solving technologies. Sustainability Base stands out as an example of a high-performance federal building that breaks new ground in utilizing advanced energy-saving technologies and ”native-to-place” design. As a living laboratory for further advancing sustainability objectives, this building is expected to continue to be a model for other buildings and a source for innovative solutions to improving the way we design, build and occupy buildings.

NOTES

* The Center for Climate and Energy Solutions wants to express our appreciation to several NASA Ames employees who contributed their insights during the preparation of this case study, including Rosalind Grymes and Krisstina Wilmoth, and Aniruddha Deodhar from Autodesk.

1 "NASA Sustainability Base," NASA, last accessed August 28, 2012, http://www.nasa.gov/externalflash/sustainability-base. Much of the following information was drawn from this website.

2 U.S. National Archives and Records Administration, "Executive Order 13514--Federal Leadership in Environmental, Energy, and Economic Performance," Federal Register 74, no. 52117 (October 2009), http://www.gpo.gov/fdsys/pkg/FR-2009-10-08/html/E9-24518.htm.

3 Energy Policy Act of 2005, Pub. L. No. 109-58, http://www.gpo.gov/fdsys/pkg/PLAW-109publ58/html/PLAW-109publ58.htm.

4 Energy Independence and Security Act 2007, Pub. L. No. 110-140, http://www.gpo.gov/fdsys/pkg/PLAW-110publ140/html/PLAW-110publ140.htm.

5 NASA Ames selected William McDonough + Partners (WM+P) as design architect and AECOM as architect of record for the project. Swinerton Builders served as general contractors.

6 "NASA Sustainability Base," Autodesk, Inc., last modified July 28, 2010, http://usa.autodesk.com/adsk/servlet/pc/item?siteID=123112&id=16881672.