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The Conservation Message of the Rehabilitated Facilities of the International Institute of Tropical Forestry

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Abstract

Over a period of about 20 years, the International Institute of Tropical Forestry (the Institute) and its collaborators developed and implemented a facilities plan that included both new and restored facilities. Among the restored facilities, the historic Headquarters Building received a Leadership in Energy and Environmental Design (LEED) Gold certificate, and was praised by the State Historic Preservation Office for the manner under which the restoration was conducted. It is unusual for historic buildings to acquire this certification. New facilities, both at Institute headquarters and the Sabana Field Research Station, improved the Institute's capacity to fulfill its mission while also enhancing employee safety and comfort during day-to-day activities. The recycling of materials during construction and the performance of facilities in relation to the use of potable and storm water, energy, and materials exemplify the application of the conservation ethic of the Forest Service, and the message it delivers to the public as part of its mission.

Keywords: Sustainable operations, historic building, research facilities, green infrastructure, tropical architecture.

Introduction

On July 18, 2012, Tom Tidwell, Chief of the USDA Forest Service, accompanied by Miguel Muñoz, President of the University of Puerto Rico, opened to the public the rehabilitated headquarters main building (Institute Building) of the International Institute of Tropical Forestry (the Institute) (fig. 1). The day before, Chief Tidwell inaugurated the rehabilitated Sabana Field Research Station (fig. 2).

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Figure 1—USDA Forest Service Chief Tom Tidwell, University of Puerto Rico President Miguel Muñoz, Dr. Frank H. Wadsworth, and International Institute of Tropical Forestry Director Ariel E. Lugo in the lobby of the rehabilitated Institute Building.

Figure 2—Inauguration of the Sabana Field Research Station on July 18, 2012. (Left to right): Director Ariel E. Lugo; Maritza Meléndez, past mayor of Naguabo; Forest Service Chief Tom Tidwell, and Forest Supervisor Pablo Cruz.

On May 22, 2013, past and present employees of the Institute formally opened its green parking lot and green roofs (fig. 3). These activities, which were part of the 75th anniversary celebration of the Institute, can be traced to the beginning of the Institute in 1939, when it was known as the Tropical Forest Experiment Station (see Wadsworth [1995] for a brief history of the Institute's first 50 years). Here we summarize the events that led to the rehabilitation of the Institute Building, present a comprehensive look at all Institute facilities, and discuss how they became part of the conservation message that the Forest Service conveys to the public. All photographs in this report are by María M. Rivera Costa.

Figure 3—Director Ariel E. Lugo and Engineer Juan Vissepó at the opening of the Green Parking Lot and Green Roofs on May 22, 2013. Katie Frerker on a bicycle and an orange 1972 Volkswagon driven by Skip Van Bloem were the first two vehicles to use the green parking lot.

A Word About Facilities

Modern building facilities should be accessible and safe to all users, especially for employees who spend a lot of time in them. Buildings should also be comfortable and functional. In the case of the rehabilitation of the Institute facilities, the notion of accessibility, safety, and comfort was advanced two steps further. First, the facilities at Institute headquarters and Sabana Field Research Station became energy- and water-use efficient. Second, they also became environmentally responsible to their local setting. For the Institute headquarters, the local environmental context included the Río Piedras River Watershed, an urban watershed with a significant flooding problem (Lugo et al. 2013), and the city of San Juan, which has a measurable heat island effect (Murphy et al. 2010, Velázquez Lozada et al. 2006). Therefore, the rehabilitation of facilities at Río Piedras was aimed at addressing mitigation to flooding and heat island issues. Also, because little is known about operational standards for tropical green roofs, the Institute approached the project as a research initiative.

The Institute Building is the signature structure representing the Forest Service in Puerto Rico, thus the Institute logo is a drawing of the building (fig. 4). In 2002, the State Historic Preservation Office (SHPO) determined that the 14,431 ft^2 (1,341 m^2) Institute Building was eligible for inclusion in the National Register of Historic Places. From the beginning, rehabilitation of the building was based on the notion that its reconstruction would demonstrate how facilities can maintain their historical values while also being fully modernized and technologically up-to-date. In fact, the Institute Building was the first building in Puerto Rico to seek Leadership in Energy and Environmental Design (LEED) certification (fig. 5).

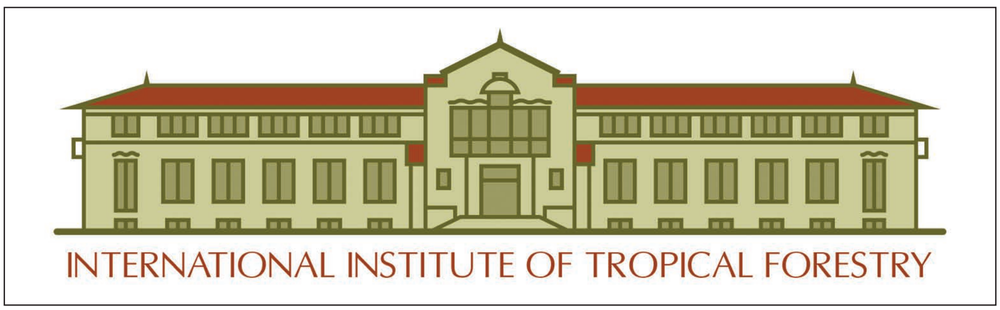

Figure 4—Logo of the International Institute of Tropical Forestry.

Moreover, the Institute is connected to the University of Puerto Rico's Internet 2 Network, illustrating the Forest Service's use of independent servers for data storage and wireless technology. Institute research is at the cutting edge of several scientific fields including climate change, remote sensing, tropical watershed dynamics, and social ecology. The Institute also houses the Frank H. Wadsworth Library, which functions as an electronic library connected nationally and internationally to other libraries and information sources while also maintaining the largest collection of paper copy materials on tropical forestry in the Neotropics.

Figure 5—View of the second-floor corridor of the Institute Building with lighting certified to meet Leadership in Energy and Environmental Design standards.

The Río Piedras Property

Institute Headquarters are located on property leased from the University of Puerto Rico. The property is a 5.09-ac (2.06 ha) hill within the University of Puerto Rico Botanical Gardens and the Agricultural Experiment Station. The site layout before the rehabilitation (fig. 6) included buildings that were to be demolished, retrofitted, or rehabilitated. The elevation at the site ranges from 22 to 31 m above mean sea level. Soils are composed of impermeable expansive clays. The hilltop was leveled to accommodate the building when construction started on the property.

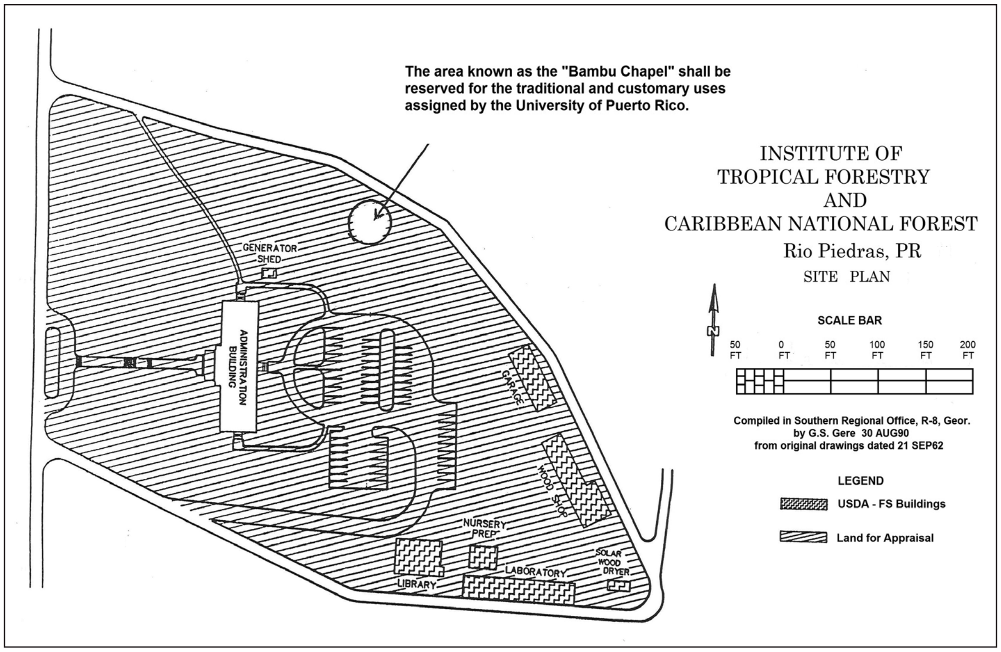

Figure 6—Spatial distribution of building facilities at the headquarters of the International Institute of Tropical Forestry before the buildings were rehabilitated or replaced.

Runoff from the property flowed down hillslopes into the roads of the Botanical Gardens, from which it flowed into storm drains, other Botanical Garden ponds, two unnamed creeks, and then into the Río Piedras River, which collects rainwater from a 49-km^2 watershed within the Municipality of San Juan. The river discharges into San Juan Bay after its confluence with the *Caño Martín Peña*. When the river is in flood stage, it floods the lower portions of the watershed, affecting residential, commercial, and industrial neighborhoods as well as city infrastructure.

Original Design of the Institute's Headquarters Building

William Ellis (W. Ellis) Groben, a Forest Service architect, designed the Institute Building in 1939 (fig. 7). Construction began in 1941 and was completed in 1942. In the tradition of other notable Forest Service professionals, Groben influenced the agency's approach to building design with what was known as the "Groben Dictates." In 1940, he distributed within the agency a report entitled *Architectural Trend of Future Forest Service Buildings*. In that report, he made the point that architectural designs in the agency should "…represent the traditions, ideals, and purposes of the Forest Service (Groben 1940:17)."

Groben advocated adapting the architecture of buildings to their utilitarian purposes and to the environment within which they would be constructed. The architectural environment that Groben was addressing for an agency like the Forest Service, with its nationwide scope of operations, included grasslands, deserts, and

Figure 7—Drawing of the building façade signed by W. Ellis Groben in 1939. The original drawing is in display at the International Institute of Tropical Forestry.

alpine and forested environments. Groben believed in comprehensive planning in anticipation of building design, including the orientation of the building in relation to the sun and prevailing winds, among other principles (fig. 8).

To our knowledge, the Institute Building was the only tropical building that Groben designed, but the structure obviously reflects his architectural vocabulary. The shape of the main portal, the use of tiles on the roof, and the display and design of windows are recurrent themes in Groben's work. All these elements are also present in his designs throughout the Nation. A prime example is Groben's design for the Pagosa Springs Ranger Station on Colorado's San Juan National Forest (Grosvenor 1999:24). These characteristics that Groben incorporated into the design of the Institute Building are all relevant to the rehabilitation of facilities that we undertook, and today they still have an effect on the beauty and function of the building.

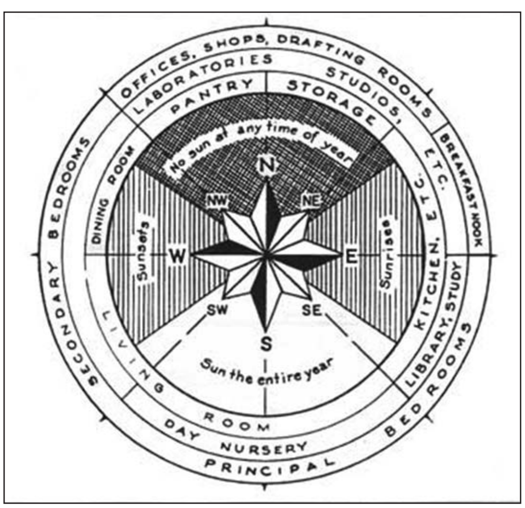

Figure 8—W. Ellis Groben's diagram on building orientation (Grosvenor 1999).

Planning for Building Rehabilitation

All units of the Forest Service develop facilities plans, and the Institute is no exception. During the 1980s, when the Institute was part of the Southern Forest Experiment Station, engineer Tom Chappell visited Puerto Rico to develop a long-term facilities master plan for the Institute. His work was included in *Integrated Facilities Master Plan for Research, State and Private Forestry, and the National Forest System in Puerto Rico*, published by the Southern Region of the Forest Service in October 1991. At the time, Institute Director Ariel Lugo was skeptical of the exercise, as he could not visualize implementing such a comprehensive plan within the length of his incumbency at the Institute. The plan included numerous new facilities for the Institute's headquarters (fig. 9) and for the Sabana Field Research Station located in the Luquillo Experimental Forest, also known as the El Yunque National Forest. As it turned out, in 1990, the U.S. Congress passed a farm bill that authorized the International Institute of Tropical Forestry to become an independent unit of the Forest Service. The Institute was able to hire its own engineer, Juan Vissepó. Over the next 20 years, Vissepó implemented the full plan, making the Institute one of only two units in the agency to actually complete a facilities master plan.

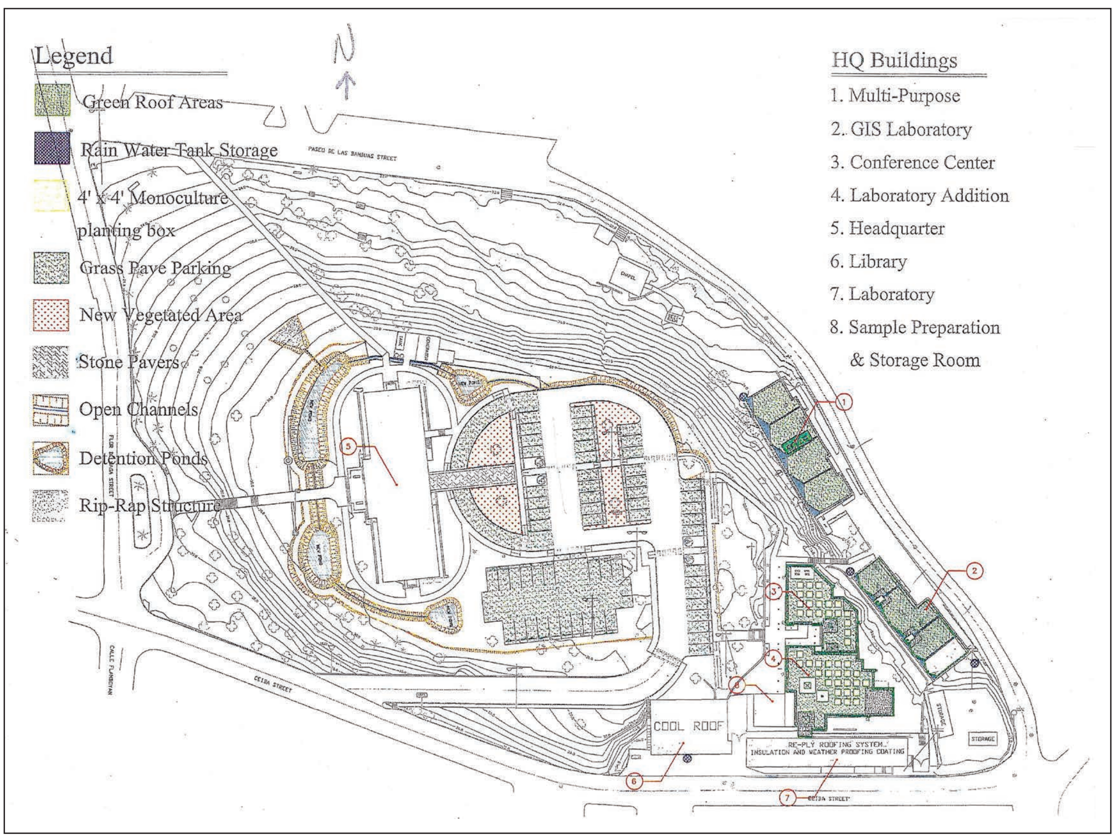

Figure 9—Spatial distribution of current building facilities, green parking lot, and green roofs at the headquarters of the International Institute of Tropical Forestry.

Vissepó had the ability to anticipate the required future improvements to facilities, visualize their applications to the Institute, then get the funding necessary to construct them. Taking advantage of accessibility and safety regulations required by the Americans with Disabilities Act of 1990, and proposing small and low-cost projects, were part of Juan's formula to attract construction funding to the Institute. The projects were then discussed with Institute employees, who suggested additions or modifications that went beyond the accessibility and safety perspectives. In so doing, the final product of the rehabilitation of facilities was superior to that initially conceived based only on regulatory concepts. Vissepó also established long-lasting collaborations with other professionals who became critical partners in the rehabilitation of Institute facilities at Headquarters and the Sabana Field Research Station.

These Forest Service and private-sector partners included Southern Region regional architect Maurice Hoelting; Jerry Carson, initially the Southern Research Station engineer and later the Research and Development engineer in the Washington Office; architect Jeannette Rullán, principal of RMA Architects, P.S.C.;[2] and Southern Research Station Engineer Mark McDonough. Southern Region Regional Facilities Engineer Peter LaShoto and Building Systems Engineer Jack Vithayapun supported these principal collaborators. LaShoto advised on issues dealing with the LEED program, and Vithayapun designed the Fresh-Air Air Conditioning system.

Several Forest Service contracting officers and Institute administrative staff supported the architects and engineers who worked on the design and supervision of the rehabilitation of all Institute facilities. These included Southern Region contracting officers Marcia O'Connor, Christy Smith, and Cassandra Carey; Forest Products Laboratory contracting officer Mike Belovsky; and Pacific Northwest Region contracting specialist Dan Mayer. Within the Institute, a support administration team was established. It included contracting specialist Amelia Dávila, purchasing agent Yolanda Padilla, budget officer Rosa Avila, receptionist Maricarmen Parrilla, and in the later stages of the project, Institute administrative officer Adolfo Menéndez. The Institute also had three other engineers working on construction projects: Marivel Cano, who focused on the Sabana Field Research Station construction; Celso Ruiz, an engineering trainee; and Guillermo Aponte, a Southern Region civil engineer assigned to the El Yunque National Forest.

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[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

This group of superb professionals, working in different combinations over the past 20 years, designed and built a new Chemistry Laboratory (completed in October 2001), a multipurpose building with a modern gymnasium for employees (completed in April 2005), a Technology Transfer Conference Center[3] (completed in September 2003), and a Geographic Information Systems (GIS) and Remote Sensing Laboratory, which was inaugurated by Forest Service Associate Chief Sally Collins on August 26, 2004. Also, an old parking and cafeteria building was renovated to become the Institute's Frank H. Wadsworth Library, which was inaugurated on May 29, 1996, by Forest Service Chief Jack Ward Thomas. This library was renovated in 2011 to make it more energy efficient.

Notably, until 2002, we had no comprehensive plans for rehabilitating the Institute Building. Although the notion of improving access to the Institute Building and expanding building facilities in Río Piedras had been included in the 1991 integrated facilities master plan of the Southern Region, the idea of rehabilitating the building was one that developed slowly and serendipitously. For example, in the 1990s some of the roof tiles of the Institute Building fell off the western façade right in front of the main door of the building. This forced us to close access to the building through that door, and until 2012, no one used that door (fig. 10). All foot traffic to the building was through the eastern door facing the parking lot.

[3] We have proposed that this building be named after José Marrero, the first Puerto Rican scientist at the Institute.

Figure 10—The eastern main entrance door of the Institute building was closed to all foot traffic for many years. In this 2012 photo, the old flagpoles that initiated the discussion about building restoration lay on the ground and the new poles have been erected.

Workforce reductions meant the loss of the Institute's capacity to raise and lower each day the U.S. and Puerto Rican flags that flew in front of the Institute Building. Carlos Domínguez Cristóbal, a historian and Institute employee, highlighted the issue of proper treatment of the flags, noting that the United States Flag Code required that flags left up overnight must be illuminated. Lugo asked Juan Vissepó to address the problem; Vissepó suggested that a solution for illuminating the flags be implemented while the building was being repainted. Soon we found that to paint the building we had to remove the old lead paint, which required a special removal procedure. Also, because the building was more than 50 years old, additional permits were required, one for removing and disposing of lead paint, another for painting a historic building, and a third from the University of Puerto Rico, on whose property the building stood. Construction permits from the Commonwealth were also required. Moreover, the SHPO required an "as found" study in compliance with the National Historic Preservation Act Section 106, before they would consider our permit application for painting the building. Jeannette Rullán was hired to develop the historical analysis and submit to SHPO for Section 106 compliance for both the Institute Building and the Sabana Field Research Station, where we also intended to rehabilitate a historic building and expand facilities.

At some point through the maze of permit applications and approvals, Juan Vissepó suggested that full restoration of the Institute Building include fixing the roof tiles (fig. 11) and making the building energy efficient as well as fully accessible, which it was not at the time. He surmised that it would be best to do one comprehensive study with all possible restoration scenarios for SHPO. Such a level of work required more studies and greater professional involvement in the design. The Institute identified and contracted Jeannette Rullán as the overall planner of the Institute Building restoration project. Richa Wilson, an architect in the Washington Office of the Forest Service, was instrumental in verifying the historical analysis of Rullán's firm, RMA Architects, P.S.C., for both the Institute Building and the Sabana Field Research Station. We also agreed to seek a silver LEED certification status for the Institute Building.

In 2002, RMA Architects, P.S.C. prepared and submitted documentation of the Institute Building to SHPO to evaluate. The report findings indicate that the Institute Building was the only building in the headquarters complex that had maintained its structural and architectural integrity. The building embodied distinctive characteristics of the Spanish Revival architectural style, is historically significant for its association with the Institute's first presence in the island, and represents significant scientific contributions that the Institute has made. In 2002, SHPO determined that the 14,431 ft^2 (1,341 m^2) Institute Building was eligible for inclusion in the National Register of Historic Places.

Figure 11—Restoration of the roof tiles of the Institute building. Notice also the new windows.

In 2004, SHPO staff approved the rehabilitation project, stating that they were "very pleased to receive and review projects that follow the Secretary of the Interior's Standards for Rehabilitation, through repairing; which makes possible and efficient contemporary use while preserving those portions and features of the property which are significant to its historic, architectural and cultural values. This undertaking is a good example of such practice." In January 2005, the Institute registered the project with the United States Green Building Council (USGBC), becoming the first LEED project registered in the Caribbean.

In 2007, a flagpole light beacon that moves with the flag position and lights only the flag was installed to reduce light reflection into space and comply with regulations. This work required the original flagpole to be replaced by a flagpole that would accept the light beacon. Further, by July 2007, the building's hazardous material removal was completed and painting of the building commenced.

Engineer Vissepó also suggested that we make the parking lot more water-retentive and the roofs more energy efficient. This required the development of a rainwater harvesting system, control of storm water at the site, and installation of green roofs for energy efficiency. A conceptual design for site water management was laid out using RMA Architects, P.S.C., proposed site improvements with the assistance of landscape architect Linda Barfield. Gregory L. Morris was hired through RMA Architects, P.S.C., to prepare a hydrologic and hydraulic study to manage all rainwater within the site. This was a major challenge owing to the low permeability of the clayey soil. We did not know what the source of funding for these projects would be, but when it became available, we wanted to be ready to proceed expeditiously by having everything planned and ready for contracting.

In 2008, the American Recovery and Reconstruction Act was enacted by the U.S. Congress, and the Institute entered proposals for a diversity of projects, including the rehabilitation of the Institute Building (fig. 12), headquarters green roofs (fig. 13), green parking lot (fig. 14), and the rehabilitation and construction of a new dormitory (fig. 15) and research laboratory at the Sabana Field Research Station (fig. 16). The Institute received funding for what turned out to be the largest construction program under the 2008 Act among all Forest Service research stations. This funding set us on the road to implementing all the plans envisioned for the Institute.

In 2009, the Institute hired RMA Architects, P.S.C. to prepare plans for an experimental greening project that included green roofs, site storm water management, and rainwater harvesting. Technical information on green roofs in the Caribbean was not available, thus the project was designed as a research project to obtain empirical knowledge that will be benefit the public and the scientific community. Engineer Juan Vissepó obtained additional funds from the Research and Development branch of the Forest Service to purchase and install sensors to gather empirical data from the green roofs. Green roof specialist David L. Aponte Dones, president of Puerto Rico Green Design, Inc., was instrumental in the design and construction of the green roofs, and Jorge Torres Scandali designed the rainwater harvesting system. Also contributing to these projects were Nick Smith of ZinCo

Figure 12—Rehabilitation of the Institute building.

Figure 13—Preparation of the green roof of the Geographic Information System and Remote Sensing Laboratory for planting of green vegetative material.

Figure 14—Groundwork in progress at the green parking lot.

Figure 15—New dormitory facility in the Sabana Field Research Station after construction.

Figure 16—Rehabilitation and construction of the research laboratory and parking lot at the Sabana Field Research Station.

USA, Firestone Waterproofing Products, and Peter Philippi of Rooflite. Pedro Cortés & Associates, a civil engineering firm, prepared the construction documents for the site improvements defined in the hydrological study prepared by the office of Greg Morris. Pedro Cortés worked with Tatiana Proctor from Greg Morris' office to fine tune the proposed work that included green parking, grading, and the storm water collection and detention system that was reflected in the revised hydrological study issued in 2010.

Juan Vissepó and Architect Maurice Hoelting were instrumental in coordinating and updating the project plans and specifications with new technology, and searching for alternatives to lower costs of the rehabilitation project. They worked with Southern Region building systems engineer Jack Vithayapun, to redesign the air conditioning system, because this represented a large part of the overall project costs. The air-conditioning redesign is energy efficient, lowering energy costs, and by dehumidifying fresh air to 50 percent humidity, has improved the comfort of all employees and visitors. In addition, the design scheme of return airflow allows for unconditioned spaces to feel conditioned, achieving total comfort throughout the building.

Green Roof Features

Green roofs covering 12,600 ft^2 (1,171 m^2) were installed in four headquarters buildings: the GIS and Remote Sensing Laboratory, the new addition to the Chemistry Laboratory (fig. 17), the Technology Transfer Conference Center, and the Multipurpose Building (fig. 18). Before construction of green roofs, all buildings in the Institute had cool roofs with the exception of the old chemistry laboratory and Institute Building. Thus, green roofs were installed over cool roofs (fig. 19). The roofs of the GIS and Remote Sensing and Chemistry Laboratories were subdivided into seven separate green roof sections and one cool roof section. For cools roofs, a white ethylene propylene diene monomer (EPDM) membrane was used to insulate the roof and increase reflectivity. On green roofs, black-colored EPDM membranes were installed over the cool roofs. These membranes have a 90 mil thickness (2.29 mm). Green Roofs were designed and maintained following the standards set by the National Roofing Contractor Association, American Standard Testing Materials (green roofs for healthy cities), and the German FLL-guidelines for planning, execution, and upkeep of green roof sites. The project included a moisture retention/protective layer over the cool roof, a drainage system, a filter sheet, growing medium and plant materials, a rainwater harvesting system, monitoring, and maintenance.

Figure 17—Green roofs of the Technology Transfer Conference Center.

Figure 18—Green roofs of the Geographic Information System and Remote Sensing Laboratory.

Figure 19—Layering of materials over cool roofs in preparation for the green roof of the Geographic Information System and Remote Sensing Laboratory.

The moisture retention/protective layer protected the waterproofing of the roof. The layer consisted of material made of recycled non-rotting fibers for water- and nutrient-retention as well as providing protection . This layer was 0.2 in (5 mm) thick, weighed 0.1 lb/in^2 (470 g/m^2), had a water-retention capacity of about 0.12 gal/ft^2 (5 L/m^2), and was bitumen-resistant and biologically and chemically neutral. The drainage system provided adequate drainage and water retention to ensure plant survivability. The material of this system was made of recycled polyethylene, with water-retaining troughs and openings for ventilation and evaporation. The drainage system also contained a drainage canal system on the underside. The system is bitumen-resistant and resists compression to more than 24.7 lb/in^2 or 170 kN/m^2 (1.73 kg/cm^2). The water-retention capacity is approximately 0.1 gal/ft^2 (4 L/m^2), height is about 1.6 in (40 mm), and weight is about 0.5 lb/ft^2 (2.2 kg/m^2).

A filter sheet provides separation between the underlayment green roof system and the growing medium (soil). This material is made of non-rotting thermal consolidated polypropylene. When there is a water column of 4 in (10 cm), the water flow rate is about 228 gal/min/ft^2 (155 L/m^{2}s). The apparent opening size is d90% (110 µm) with a weight of about 0.02 lb/ft^2 (100 g/m^2). Lightweight soil (Rooflite A) was used as a growing medium. This is a mixture of lightweight inorganic material and organic matter. Rooflite A is designed to reduce compaction rates, provide hydraulic conductivity, and provide a balance between water and air for ensuring plant establishment. Plant selection involved 22 species; about 16,000 plant plugs were installed. Soil depths varied throughout the roofs so that we could test the effects of soil volume on roof performance. The depths included 2, 3, 4, 5, 6, 8, and 10 inches (5.1, 7.6, 10.2, 12.7, 15.2, and 20.3 cm, respectively). A protective boundary of pumice rock imported from Mexico was used as protective boundary material.

The rainwater harvesting system consisted of a drainage system, pumps, and cisterns (fig. 20). The drainage conveys all roof rainwater to two 2,400-gallon or two 1,000-gallon (9,085 or 3,785 L, respectively) cisterns (size depends on the roof area drained) located on the side of buildings. The total water storage capacity of the four cisterns is 6,800 gallons. When full, the overflow of the cisterns flows into surrounding green strips. Cisterns are outfitted so that water can be used for gardening and all-purpose cleaning at the Institute. Also, a ¾-hp electrical pump can return water from the cisterns to the roof when a humidity sensor in the soil indicates a water shortage for plants growing on the green roof. Maintenance involves weeding, upkeep of equipment, and overall roof functioning. The monitoring system is described below.

Figure 20—The roof rainwater collecting system in back of the Frank H. Wadsworth Library. Shown are the drainage pipes from the roof to the blue cistern, pump used to return water to the roof during draught conditions, and blue cistern where water is stored.

Green Parking Lot Features

The Forest Service objective in this project was to demonstrate that storm water could be managed on site even with the worst soil conditions. Further, the project was to showcase design strategies that could reduce the heat island effect and light pollution.

The 3,951-m^2 parking lot was designed as a hydrological system that detains without producing runoff all rainwater produced by a 1-inch (25.4 mm) over 24-hour rainfall event. The parking lot was designed not to experience runoff for 89 percent of the rainy days of the year. The design exceeded the requirements of Commonwealth Planning Board Regulation number 3, which requires that post-development runoff not exceed pre-development runoff. Table 1 shows the peak discharge at downstream limits of the parking lot. The occurrence of discharge at the downstream limits of the project does not mean discharge outside our property, because after the point of discharge from the parking lot system, there is a sloped vegetated lawn of the Institute through which runoff water passes. This last swale also filters and evaporates water before its eventual runoff outside the property. Moreover, the design called for ½ inch (12.7 mm) of rainfall to be trapped and treated each day by the system. This level of rainfall is the threshold beyond which runoff occurs within the system. The trapped water is treated water that because it produces no runoff or sediments, and results in high-water quality. That level of trapping and 100 percent treatment occurs all days except for 5 percent of the rainy days of the year when events with the largest precipitation occur.

Table 1—Peak discharge of the parking lot hydraulic system at the downstream limits of the system

	Peak discharge		
Condition	**2-year**	**25-year**	**100-year**
		Cubic feet per second	
Before the project	2.2	4.9	6.5
After construction	1.6	3.2	5.6
Percentage of reduction	27	35	14

The components of the Green Parking Lot system (see fig. 9) include green areas for parking, two vegetated swales, concrete sidewalks and traffic lanes, open water canals, four detention ponds (fig. 21), and a gravel dissipater bed (fig. 22). This bed is located in the outlet of the system above the last vegetated slope, and helps reduce erosion and allows infiltration of any excess rainwater. Concrete surfaces of traffic lanes and sidewalks of the parking lot produce runoff and are more reflective of light than the original blacktop, thus reducing the heat island effect. The green

Figure 21—Construction of the concrete sidewalks, open water canals, and detention pond in front of the Institute Building. The system outlet is the concrete box on the far right. The muddiness of the water is due to construction work. The marble cube in the center is a calibrated monument for the Geographic Position System Coordinates of this location. The official name for this cube is 100 Year Commemorative Monument and High Accuracy Geodetic Control Mark.

Figure 22—Outlet for the hydrologic system of the Green Parking Lot. Rocks dissipate the energy of outflowing waters before they flow downslope through the lawn, which acts as a green swale that absorbs and evaporates water.

areas and vegetated swales function to absorb sunlight and infiltrate rainwater, thus contributing to reducing the Heat Island effect, and runoff from the parking lot.

The Green Parking lot runoff system is designed to channel all runoff waters to collection canals in the periphery of the parking lot and direct those waters to interconnected detention ponds. Concrete walls prevent water from sloping outside the property. Green Parking lot runoff waters can only flow through the canal system to the detention ponds and then to the dissipater bed, and from there, to the swale in front of the building. The detention ponds, when filled, spill over a structure that connects to the dissipater bed and swale on the front slope of the property. The detention ponds also receive runoff from the roof and immediate surroundings of the Institute Building. Surfaces receiving fast flows into the ponds and outside the system towards the sloped swale are rock-lined to reduce erosion.

To reduce light pollution, existing parking lot light fixtures were modified to be full cutoff. New security lighting is also full cutoff, and the flag beacon light directs light downward to illuminate only the flags.

Green Wall

On July 5, 2011 Mary Jeane Sánchez, head of the Institute's Chemistry Laboratory, proposed the construction of a green wall between the Chemistry Laboratory and the Technology Transfer Conference Center (fig. 23). The wall was designed and installed by Flower Box of Puerto Rico in August 2011. The system consists of a substrate constructed of recycled materials and an automatic watering system. The initial objective was to spell the Institute initials (IITF) with plants (bromeliads and ferns), but this objective was discarded owing to the anticipated high maintenance

Figure 23—The green wall between the Chemistry Laboratory and the Technology Transfer Conference Center was installed on July 2011. Contrast (a) the initial planting with (b) current state of this wall (b).

cost of controlling plant succession (ferns displacing the bromeliads). We settled for a lower maintenance option, which allowed ferns to grow. This resulted on a beautiful vertical fern bank along with other plants that occupied less space on the wall. This was the Institute's first effort to use vegetation on building surfaces to reduce indoor air temperature and for aesthetics.

Recycling

The rehabilitation of the Institute Building used 98 percent of all structural elements and 78 percent of the non-structural elements of the building. However, the 22 percent of the internal elements removed was donated, reused, or recycled in such a way as to minimize the involvement of Institute personnel. Thus, the recycling strategy used both at the Río Piedras and Sabana construction sites lowered demolition and insurance costs as well as hauling and landfill charges (fig. 24). To our knowledge, this is the first time the initiative to donate materials as a method to reduce waste hauled and disposed in the landfill was executed. Nevertheless, it proved to be economically beneficial to both the agency and the benefiting entities.

Figure 24—Woodshop building in the Sabana Field Research Station during the demolition and recycling process.

The following examples illustrate the recycling effort (table 2). Wood was re-used for construction purposes; some electrical wires were re-used in the building; aluminum windows were recycled through a commercial program; the acoustic ceilings were donated; lamps were donated, reused, or recycled; air conditioning units were donated; the earth excavated during the construction of the elevator shaft

Table 2—Materials donated or recycled as part of the rehabilitation of the Headquarters Main Building and the Sabana Field Research Station of the International Institute of Tropical Forestry

Material donated or recycled	Receiving organization
Furniture and acoustic ceilings	Abraham Lincoln School—Corozal
Furniture and A/C wall units	Manuel López Cepero School—Río Piedras
Acoustic ceilings, A/C wall units, and furniture	Emergency Management—Río Grande
Furniture, A/C wall units, glass doors	UPR—General Services
Acoustic ceilings and aluminum poles	Rafaela Ybarra Home—Río Piedras
Acoustic ceilings	Community Initiative—San Juan
A/C wall unit	Community Initiative—Juncos
Vertical curtains, doors, wall fans	Recycling—Las Piedras Municipality
A/C wall unit, lamps, ceiling fan, furniture	Las Piedras Municipality
Furniture	Benito Medina School—Las Piedras
Flagpoles	Luquillo Treatment Center
Supplies	Las Piedras Municipality
Sabana laboratory furniture	Mata de Plátano School
Sabana woodshop	Villa del Sol Cooperative—Toa Baja
Electronic equipment	Recycled with Ecologic—Quebradillas
Aluminum windows	Recycled with Borinquen Metal—Santurce

A/C = air conditioning.

was reused as fill in the construction; the concrete removed before excavating the elevator shaft was ground and reused by the family of Luis Álvarez Ruiz; and the old flagpoles were donated to the *Centro de Diagnóstico y Tratamiento* in Luquillo. The University of Puerto Rico received air conditioners, furniture, and the central air conditioning unit. The Abraham Lincoln School of Corozal received furniture and acoustic ceilings. The Office of Emergency Management of the Municipality of Río Grande received air conditioners, ceilings, wooden doors, doorframes, glass doors, and curtains.

A notable example of recycling was the relocation of the Woodshop Building in the Sabana Field Research Station, a wooden structure used for decades by the El Yunque National Forest and Institute. After Institute employees held their 2010 holiday party in that structure; the whole building was moved by a community cooperative to Toa Baja, Puerto Rico, where it would serve as a community center for the Villa del Sol community.

The recycling of construction materials was conducted through the Institute's recycling program, led by Maribelís Santiago Márquez, an Institute chemist. For more than a decade, the Institute has recycled paper, ink cartridges, cardboard, aluminum, batteries, telephone directories, cell phones, eye glasses, fluorescent lights, motor oil, electronic equipment, vegetable matter for organic composts, hazardous wastes, and toys for distribution to children during the Three Kings day celebration. Institute employees, in collaboration with the University of Puerto Rico and other government and non-government institutions, conduct the Institute recycling program.

We conducted a special ceremony to dispose of old flags of the United States and of Puerto Rico. To do so, we followed flag etiquette as stipulated in the United States Flag Code and Puerto Rico's State Department's Regulation 5282 of August 3, 1995. Etiquette requires a solemn, dignified, and private ceremony to dispose of flags, and we used the burial method. This was done in front of the Frank H. Wadsworth Library (figs. 25a and b).

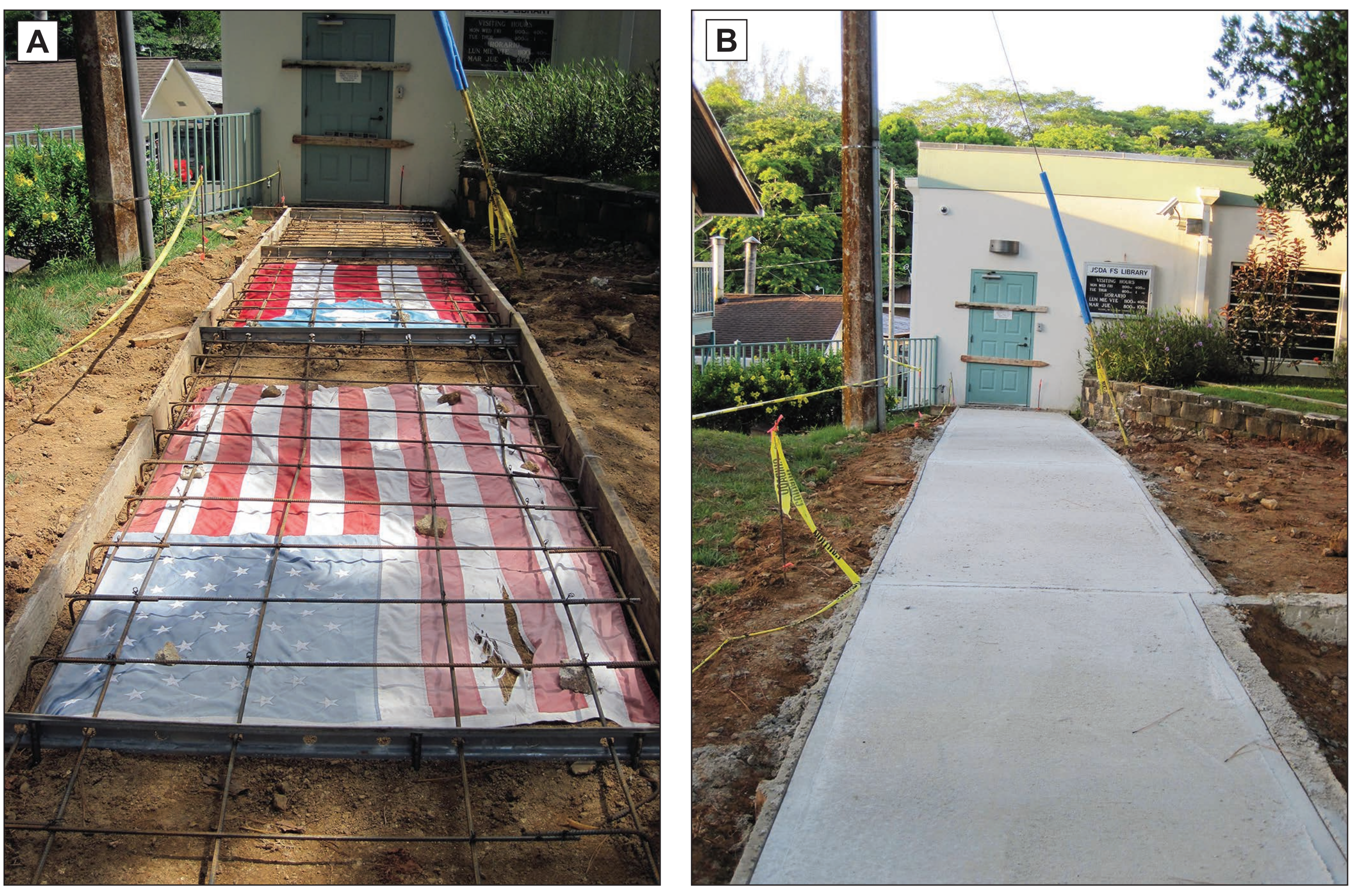

Figure 25—Burial of the flags of the United States of America and the Commonwealth of Puerto Rico in a path leading to the Frank H. Wadsworth Library during (a) and after (b) the process.

The Long Wait

Construction of all facilities took almost 6 years. A significant delay was caused by many factors, among them funding, contracting, contractor's performance, and procurement of windows (fig. 26).

The SHPO had authorized the Institute to replace the wood windows with a more lasting material as long as the original historical design and proportions were kept. As a requirement for LEED certification, windows have to comply with the Handbook of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE 90.1) and be National Fenestration Rating Council (NFRC) certified. There were no manufacturers in Puerto Rico, nationwide, or in Europe that could provide an NFRC-certified window with the historical proportions and original design of the Institute Building. Jeannette Rullán, through the USGBC Caribbean Chapter, coordinated a seminar at which all window and door manufactures in the island were invited to learn about the new codes and how to request NFRC certification for their products. This effort did not succeed because Green Building practices were still mostly unknown or considered costly and unnecessary.

Paul Lambert, principal of Storm King Windows & Doors Inc., agreed to custom-build a window for the Institute. Because their window sections could not achieve the original window proportions, Lambert traveled several times to Europe

Figure 26—Construction in progress at the Institute building.

to find parts that could be assembled to achieve the required proportions. Storm King Windows & Doors Inc. did not have the capacity to draft shop drawings, so RMA Architects provided the necessary support. This was a long journey of trial-and-error until the final design was achieved. Storm King Windows & Doors Inc., using reinforced PVC with aluminum jalousies to simulate the original window design, built exterior windows and doors in Ciales, Puerto Rico. The windows are NFRC-certified and highly energy efficient (fig. 27). The frames are metal-covered with PVC and they reduce the transfer of heat from the outside through the frame. The windows have a double glass pane, with the space between the glasses filled with argon gas, which further reduces heat transfer through the windowpanes.

Figure 27—Installation of new windows at the Institute building.

Headquarter employees spent 5 years in temporary quarters that included rented trailers (fig. 28), and moved to the restored building on April 23, 2012. The green roofs were also delayed because the initial contractor was unable to follow specifications and went bankrupt. Construction of the green parking lot was also a challenge and took longer than expected. Employees and visitors were able to park vehicles on the green parking lot 13 months after returning to the rehabilitated Institute Building.

Figure 28—Rented trailers in the parking lot were used as temporary offices for 5 years.

The Sabana Property

The Sabana property covers 1.29 acres (0.51 ha) at the eastern-most location within the El Yunque National/Luquillo Experimental Forest. The property has a long history of use by the Forest Service. At one time the Civilian Conservation Corps conducted training there. Later it was the location for processing logs used at a nearby sawmill. The Sabana property also housed a district office and district ranger home; both buildings were constructed in 1938 and qualify as historic buildings. The construction of signs for the National Forest was performed here in a wooden wood shop building. In or about 1995, the Forest supervisor transferred the use of the property to the Institute, a move that supported the use of the site for offices of scientists in the wildlife and fungal ecology and taxonomy fields. This transfer coincided with the expansion of facilities in the Catalina sector of the national forest. At the time, the old ranger house was used as a dormitory facility, while the old district office was used for offices of field technicians working mostly in the Institute's Bisley Experimental Watershed program.

At the Sabana Field Research Station, we renovated the historic building that was originally designed as the residence for the district ranger and more recently had been used as a dormitory. A new dormitory for sleeping up to 20 people was added to the Field Research Station, as was a new laboratory and sample processing facility (fig. 29).

Figure 29—Completed dormitory (right) and scientists offices (left) at the Sabana Field Research Station.

Success at Last: Look What We Have Done!

The Institute Building

The Institute Building was redesigned for employee comfort, health, safety, and accessibility (fig. 30). Key objective of the rehabilitation were to recover the historic finishes and space design and to limit the use of new materials. The building interior is designed to assure that employees have sufficient space for accomplishing their tasks, and it also provides for public spaces as well as employee lounges. A room is dedicated to the Institute's research files, and the basement, used earlier as a print shop, office space (Ariel Lugo had his office there in 1963), and meeting room is now used for multiple purposes, as needed. All walls and false ceilings were stripped to change roof height from 8 ft to 13 ft (2.44 to 3.96 m), and the original concrete surfaces of the building were exposed. Existing walls were furred with insulation and gypsum board to conceal electrical and communications infrastructure and to insulate walls from outside heat or adjacent spaces. The gypsum board also resists mold, and provides a healthy environment for employees and visitors. The original stairs on the north side of the building had been covered to extend the use of office space. During the rehabilitation, the area was uncovered, the stairs demolished, and windows and new stairs constructed to comply with construction codes that stipulate a means of egress. An energy-efficient elevator was incorporated into the original structure to connect all three floors in compliance with accessibly requirements. During construction, a portal originally intended as a reception area was discovered in the first floor, which led us to relocate the receptionist to that space. Building infrastructure is organized above the hallways and suspended from the ceiling, from where it is distributed to individual office spaces.

Figure 30—Completed main façade of the Institute building. The hand rails mark that passage of the drainage canals that originate in the Green Parking Lot.

The light environment was carefully planned. Natural light enters the building through windows and exterior doors (fig. 31). Office doors have glass panels to allow natural light to illuminate hallways. All light fixtures are energy efficient and are programmable for an output consistent with the light intensity needed for employees to work safely. Most lights are turned on or off by motion detectors. To avoid light pollution, the location and height of interior light fixtures was planned to prevent light from exiting through the windows to the outdoors.

The building was heavily insulated in the attic and exterior walls and hermetically closed by the new window design. Biobased insulation was installed under the roof slab to reach an R-value of 30 as required by energy codes. A vapor barrier was installed on the inside of exterior walls and covered with insulation with an R-value of 13 and gypsum board. Windows and doors have double glass (compliant with ASHRAE 90.1 SHGC = 0.25) that significantly reduces the transfer of heat loads to the inside of the building. During the day, windows are much hotter on the outside than the inside. Insulation of the attic and exterior walls, combined with the highly efficient windows and doors, resulted in a high-performance building envelope. The improvements to the building exterior reduced heat loads by 20 to 25 percent and by an additional 10 percent by reducing air conditioner use. The high-performance building envelope significantly reduced the need to air condition spaces thus reducing significantly total energy use.

Figure 31—Natural light entering the Institute building through exterior doors.

The building operates with all doors and windows closed. However, in the event of a power and emergency generator failure (the Institute has three emergency generators for powering its headquarters facilities), all windows and exterior doors of the Institute Building open and allow natural cross breezes to flow through the facility. When this happens, the building functions with natural light and wind, as originally designed by Groben.

Individual air-conditioning units are installed in each office to allow users to control room temperature. A centralized fresh air system supplies dehumidified air to conditioned spaces to improve indoor air quality, occupant comfort, and well-being. Fresh air is dehumidified to 50 percent relative humidity for air conditioning to work at a higher temperature to reduce energy consumption. Cold air inside those offices that use the air conditioner contribute to keeping the hallways cool because cold air leaks to hallways through doorways. Offices and hallways are under positive air pressure, and exhaust fans located at the restrooms (negative pressure) pull the air in hallways and blow it through the attic to outside the building. Ceiling fans in all offices and hallways circulate air and help ventilate all building spaces.

In terms of water use, toilets consuming 0.8 gallons (3.0 L) per flush urinals consuming 0.125 gallons (0.5 L) per flush , and automatic lavatory faucets consuming 0.5 gallons per minute (1.9 L/min) replaced the original units. These higher efficiency units resulted in significant potable water savings and reduction of sanitary water disposal. Sanitary water discharge was reduced by 59.5 percent to 23,266 gal/yr (6,147 L/yr), and potable water use was reduced by 67.3 percent to 30,070 gal/yr (7,945 L/yr). A system that does not harm the ozone layer replaced the gas system for fire control. The Institute also has two emergency potable water tanks with a combined capacity of 3,000 gal (11,356 L).

All products used during construction contained little or no volatile organic compound products (VOC) to ensure that indoor air quality was protected. Further, all actions taken with ceilings, walls, ventilation, illumination, type of painting, and building maintenance virtually eliminated the possibility of “sick building syndrome” from occurring in the building. The day-to-day building maintenance that we are using is called “green cleaning” because it avoids products that might cause allergies or negative effects to employees or the visiting public. For example, the products used for cleaning are all low-VOC products; some are non-acidic; multipurpose and glass cleaners are non-ammoniated; other products are no fragrance and odorless, as are the paints used in the building. Windows are cleaned with a dry cloth, thus avoiding the use of any liquid that might affect employees. Moreover, the products that we used during reconstruction leave no residues with which future generations might have to contend, as we had to do with the lead paint or asbestos panels.

The building original design was an “E” shaped building, but only the existing rectangular building shape was built. Therefore, the entrance located on the east side of the building that provides access from the parking lacked any protection from the weather in the original building design. The building façade was restored to its original design, with the exception of a canopy cover over the eastern main door to the parking lot (fig. 32a). Employees and visitors heavily used this backdoor entrance/exit to the building because it provided access to the parking lot and other facilities within the complex. Over the years a rainfall cover was added to this entrance. We elected to retain this feature but had to design it in a way that would be obvious to users that this was an add-on. This action follows the restoration guidelines suggested by architect Camillo Boito, who focused attention on the restoration of ancient buildings. Some users of the Institute Building criticize this feature of the rehabilitation because they object to the aesthetics of the structure (fig. 32b).

Figure 32—The Institute building had an entrance portal on the west end facing the parking lot (a), which was not part of the original building design. We retained the function of this portal with the installation of a new structure (b), which has not been painted as designed, owing to budget limitations.

Green Parking Lot

At first, a casual look at the green parking lot can lead the observer to confuse it with a normal lawn. Although the parking lot has room for 62 vehicles, all parking spots except four dedicated to accessible parking have a green grass cover. Accessible parking spots have a concrete surface. Below the green grass cover, the parking lot has three layers of materials. At a depth of about 1 foot (31 cm), the base of the parking lot is the compacted sub-grade soil. Over this sub-grade soil are between 6 and 12 inches (15 and 31 cm) of compacted sandy gravel. Over this compacted sandy gravel layer is a network of black plastic rings filled with clean concrete sand (fig. 33). The rings have a dimension of 50 × 50 × 2.5 cm. A hydro growth mix was applied below these rings. Two grass species were used to bind the surface and provide the green cover (fig. 34). These layers of solid material provide the rigid surface required to support automobiles and function to maximize the infiltration of water during heavy downpours. The parking lot is sloped towards detention ponds and canals that collect and detain runoff waters.

In time, maintenance of the Green Parking Lot could not maintain the grass green because of several factors including shading, slow growth, and heavy rains that eroded and washed out the upper surface of the parking lot, exposing the plastic cylinders in many places. The system continued to function hydrologically but it was no longer green.

Figure 33—The Green Parking Lot has several layers of materials. Black plastic rings seen on the sidewalk were added to these layers to provide strength to the system.

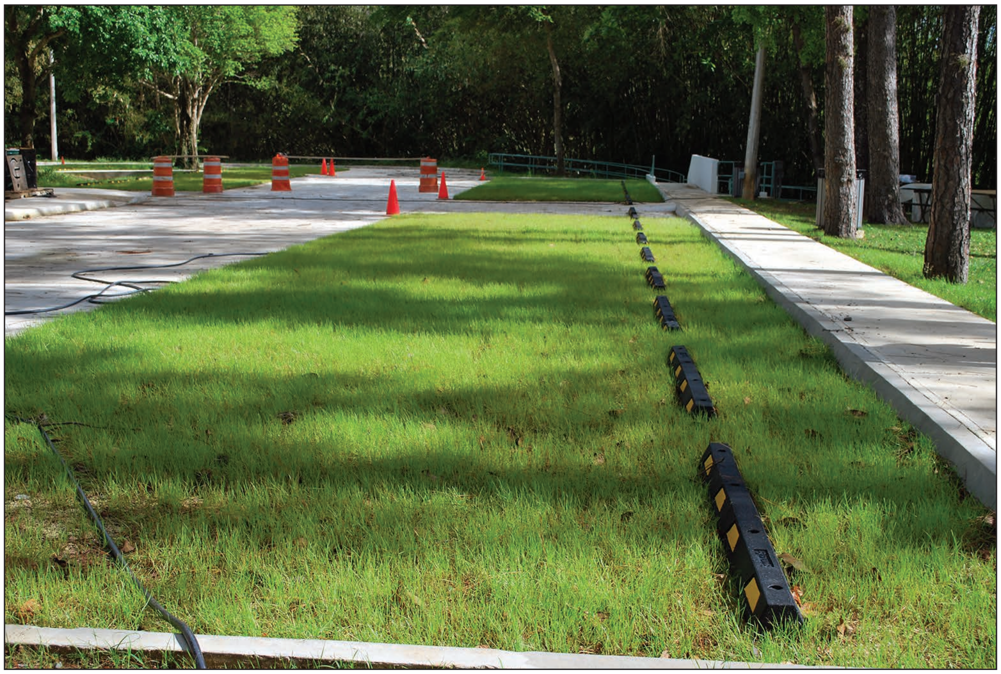

Figure 34—Two grass species were used to provide the green cover of the Green Parking Lot.

Landscape

With the construction of ponds and green parking lots, the landscape around the building changed. Historically, the Institute Building surroundings were vegetation-free following construction. A traditional lawn landscape quickly followed, then trees were planted. Because Institute research was heavily oriented toward tropical silviculture, the trees that were initially planted reflected this research, and included pines (*Pinus caribaea*), mahogany (*Swietenia macrophylla*), eucalyptus (*Eucalyptus deglupta*), hibiscus (*Hibiscus elatus*) and other similar tree species useful for timber production through plantation forestry. Over time, as these trees matured and died they were replaced with native tree species such as royal palms (*Roystonea borinquena*), moca (*Andira inermis*), ucar (*Bucida buceras*), ausubo (*Manilkara bidentata*), algarrobo (*Hymenaea courbaril*), maricao (*Byrsonima spicata*), and others. A notable ausubo is a specimen planted by Jose Marrero some 60 years ago, and which now is a large tree on the northern side of the property. An inventory in 1997 yielded 63 tree species and 242 trees within the property (table 3). Two of the trees are Commonwealth champions in the American Forests Champion Tree Register. They are a tall *Eucalyptus deglupta* (fig. 35) and a large diameter *Pterocarpus indicus* (fig. 36). Today, employees are empowered to plant native tree species in the understory of mature pine and eucalyptus trees, with the idea that the landscaping will become more reflective of the native plants of the subtropical moist life zone where the Institute is located.

Table 3—Tree species found on the grounds of the International Institute of Tropical Forestry headquarters

Species	Common name	Origin
Acacia mangium	mangium, sabah salwood	NA
Albizia procera	Albizia, white siris	NA
Alstonia macrophylla	alstonia	I; Hawaii and lower 48 states
Andira inermis	moca, cabbage angelin	N
Araucaria bidwillii	bunya-bunya	I; Australia
Araucaria columnaris	Araucaria, candelabro, columnar pine, New Caledonia pine	NA
Bambusa longispiculata	bambu, longispiculata	I
Bambusa textilis	bambu, textilis	I
Bambusa tulda	bambu, tulda	I
Bambusa tuldoides	bambu, tuldoides	I
Bauhinia multinervia	bauhinia blanca, baujinia	NA
Bombacopsis quinata	pochote	I
Bucida buceras	ucar, oxhorn bucida	N
Byrsonima spicata	maricao, doncella	N
Calophyllum inophyllum	maría grande, kamani, Alexandrian laurel (Hawaii), beauty-leaf	NA
Cariniana legalis	cariniana	I
Catalpa longissima	roble dominicano, Haiti catalpa	I
Cecropia obtusifolia	cecropia exótica	I
Cecropia schreberiana	yagrumo hembra, trumpet tree	N
Ceiba pentandra	ceiba, cotton-silk tree	I
Chrysalidocarpus lutescens	palma areca, golden-fruited palm	I
Cinnamomun camphora	canela, camphorwood	I
Clitoria fairchildiana	clitoria	NA
Cordia alliodora	capa prieto, spanish elm	N
Cordia laevigata	cereza	N
Cyathea arborea	helecho gigante, giant tree fern	N
Delonix regia	flamboyan, flamboyant tree	NA
Dialium guianensis	dialium	NA
Eucalyptus deglupta	deglupta	I
Ficus americana	jaguey	EN
Flindersia australe	flindersia	I
Hibiscus elatus	majó, mahoe	NA

Table 3—Tree species found on the grounds of the International Institute of Tropical Forestry headquarters (continued)

Species	Common name	Origin
Hibiscus pernambucensis	majahua	NA
Hymenaea courbaril	algaroba	N
Inga laurina	guama, Sweet pea	N
Khaya senegalensis	caoba	NA
Leucaena leucocephala	leucaena, giant leucaena	NA
Maesopsis eminii	musizi	NA
Manilkara bidentata	ausubo, bulletwood	N
Peltophorum pterocarpum	flamboyan amarillo, yellow flamboyant	NA
Pimenta racemosa	malagueta, bay-rum tree	N
Pinus caribaea	pino hondureño, Honduras pine	NA
Piper aduncum	higuillo, Piper	N
Pterocarpus indicus forma echinatus	terocarpus, prickly narra	I
Pterocarpus indicus forma indicus	terocarpus, smooth narra	I
Pterocarpus macrocarpus	terocarpus, Burma padauk	NA
Ptychosperma macarthurii	palma de Macarthur, Macarthur palm	I
Roystonea borinquena	palma real, Puerto Rican royal palm	EN
Schefflera morototoni	yagrumo macho	N
Spathodea campanulata	tulipan africano, African tulip tree	NA
Swietenia macrophylla × mahagoni	caoba hibrida, hybrid mahogany	NA
Swietenia mahagoni	caoba dominicana, small leaf mahogany	NA
Tabebuia heterophylla	roble	N
Tabaebuia rosea	roble de Venezuela	I
Tabebuia donnell-smithii	primavera	N
Tecoma stans	ginger thomas	N
Terminalia ivorensis	idigbo	NA
Terminalia oblonga	smooth bark terminalia	NA
Thespesia grandiflora	maga	EN
Toona ciliata	cedro de Himalaya, burma toon	I
Trema micranthum	trema	N
Triplaris cumingiana	triplaria	NA
Xanthostemon chrysanthus	yellow stamon, golden penda	I

Note: this information corresponds to an inventory in 1997 by International Institute of Tropical Forestry employees María Rivera, Janet Rivera, and Juan Ramírez. Sources for species information were Molina and Alemañy (1997) and Little et al. (1974). The species origin codes are: N = native, E = endemic, I = introduced, and NA = naturalized.

Figure 35—The *Eucalyptus deglupta* (eucalipto) tree growing on the Institute grounds was recorded as a Champion Tree, mostly for its height.

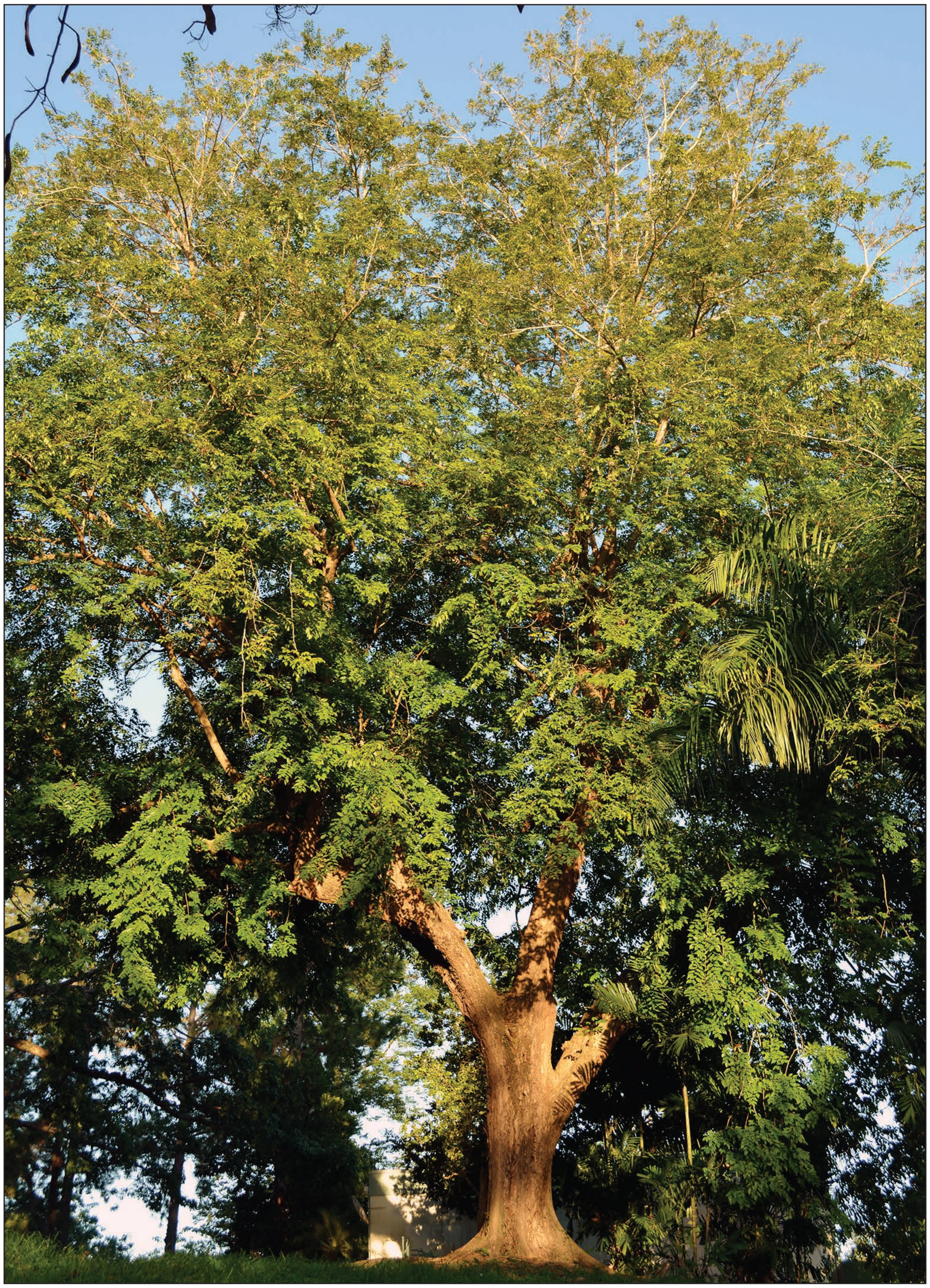

Figure 36—The *Pterocarpus* indicus tree growing on the Institute grounds was recorded as a Champion Tree, mostly for its diameter.

Cool and Green Roofs

All building roofs in the Institute Headquarters complex were initially converted to cool roofs, with the exception of the Institute Building, which has a tiled roof, and the original Chemistry Laboratory building. For the Institute Building restoration, the attic of this building was heavily insulated. Cool roofs are treated roofs with a white surface that reflects solar energy, thus keeping roof temperature lower than normal roofs and reducing the Heat Island effect. We converted 1171 m^2 of its cool roof area to green roofs. Initially, twenty-two plant species were planted on these roofs. Plants were arrayed in monoculture blocks and periodically weeded for a year. The original plant material was procured from Mexico. Some species were grown from seed, while others were planted as seedlings. Growth has been rapid and many species flower copiously, creating a beautiful multicolor carpet over the roofs (fig. 37). Many insects and birds now visit or live in the green roofs. Seeds from surrounding trees, particularly *Spathodea campanulata*, eucalyptus, *Leucaena leucocephala*, and *Cecropia schreberiana*, germinate abundantly on roofs and their seedlings are removed during maintenance.

Figure 37—Green Roofs can be beautiful.

Sabana Field Research Station

We constructed a new dormitory that sleeps 20 people and includes all the ancillary facilities needed to support this level of housing and fieldwork. A new sample preparation laboratory was constructed as well, so that soil, plant, and water samples can be sorted, dried, ground, or filtered in Sabana prior to sending them for analysis to the chemistry laboratory in Río Piedras. A laboratory for processing water samples was also improved. The construction at Sabana also included a new generator to provide electricity in case of power failures as well as improved systems for dealing with water sanitation. The parking lot was improved, as were the landscaping and electronic communications.

New Research

We soon realized that the green parking lot and roofs offered a new research opportunity for the Institute. The tropics lack standards for green roof establishment and operation, including the recommended soil depth and composition, suitable plant species, and evaluation of the effectiveness of the green roof itself. Therefore, we included a monitoring scheme in the roof contract so that we could track its effectiveness in three areas: the balances of energy, water, and nutrients. To accomplish this we located two Campbell Scientific weather stations on the roofs to monitor air temperature and humidity, wind speed, energy incidence, and rainfall (fig. 38). Hydrological and temperature sensors were also placed on the soil surface, inside the soil volume, and on the surface of the roof. These measurements were made on cool and green roofs. A hydrological sensor was also placed on the detention ponds just before the drain to the swale on the front of the Institute Building. The Institute has also operated since 2002 a climate station just below the outflow of the detention ponds (fig. 39).

The monitoring program design included 2 precipitation gages; 13 temperature probes; 7 humidity sensors, 1 each for wind speed and direction; 3 radiometers; and 1 heat flux sensor. All these sensors and the weather stations (80 sensors in total) are connected to the two Campbell data logger programmed to read each sensor. Data are transmitted to the Campbell Company website, from which it is periodically retrieved and stored in an Institute server. Real-time data can be displayed to the public on a plasma screen.

The sensor system measures seven parameters, which allow us to describe the conditions under which plants grow. These conditions include air and soil temperature, air and soil humidity, the energy differential between the atmosphere and the surface of the roofs, and the energy and water balance of the system.

For nutrients, we expect to sample all waters (rainwater, soil water, roof runoff water, and parking lot runoff water) and take them to our chemistry laboratory. There we will analyze for anions (fluoride, chloride, sulphate, bromide, nitrate, and phosphate), cations (lithium, sodium, amonium, potassium, magnesium, and calcium), pH, dissolved organic matter, and conductivity. With these data we will categorize water quality, and when coupled to the water balance, we can estimate a nutrient balance for both the cool and green systems.

Figure 38—One of two Campbell weather stations on the green roofs. These stations monitor air temperature and humidity, wind speed, energy incidence, and rainfall.

Figure 39—Climatological data sensors (temperature and rainfall) are part of a climate station operated by the Institute in front of the Institute building.

The plantings are arrayed so that we can investigate the effectiveness of individual plant species as well as plots where we allow natural processes of species dispersal, establishment, and growth to determine plant cover. The only exception to allowing natural dispersal processes to occur is that we remove the tree seedlings that germinate on the roofs.

Some Results

A fundamental question about the rehabilitation of our facilities involves their effectiveness in reducing the Institute's electricity and water consumption. Our preliminary analysis shows a significant reduction in electric consumption in the Frank H. Wadsworth Library when the first year of operations after the rehabilitation are compared with the last year of operations prior to the rehabilitation (fig. 40). On average, the monthly electric consumption was 55 percent of the corresponding monthly consumption before the restoration. These reductions in energy and water consumption are attributed to the many conservation features of the rehabilitation (see below), of which reduced air conditioning use looms as the most significant one. However, in spite of reduced energy use by air conditioning, the rehabilitated buildings offer improved comfort to employees and visitors.

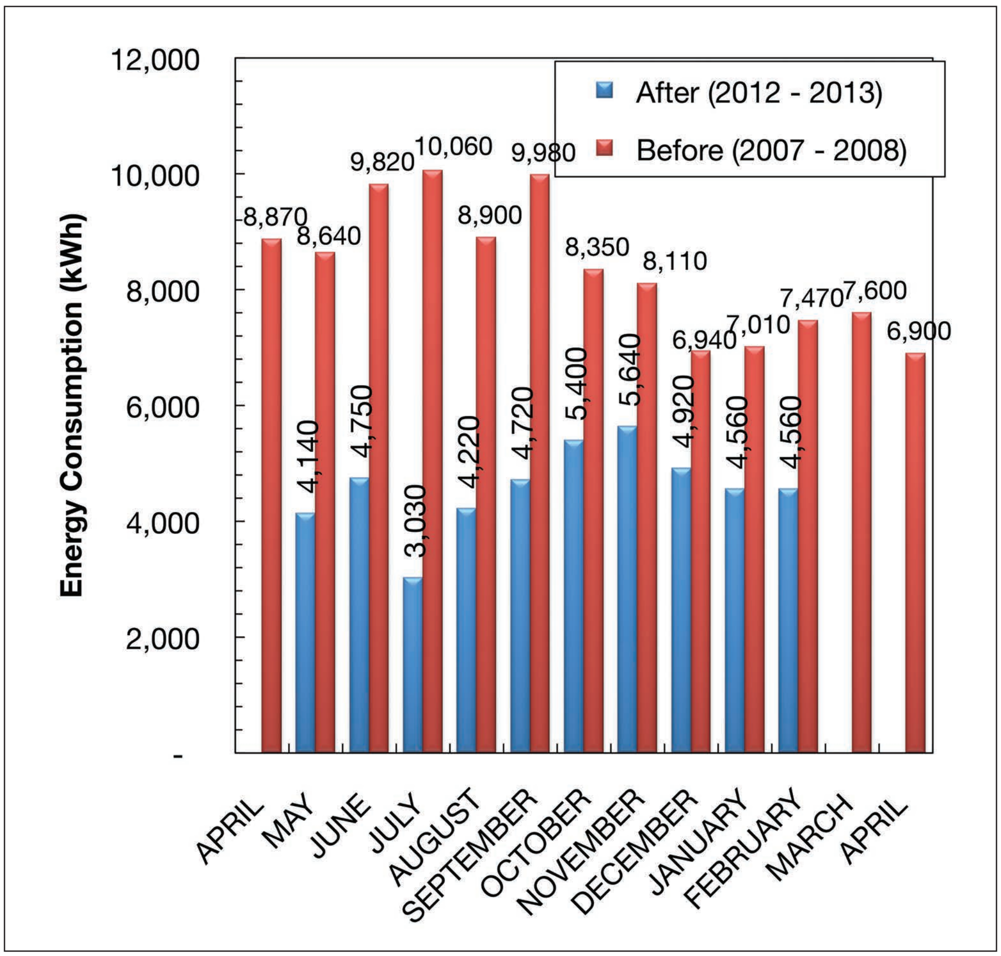

Figure 40—Monthly rate of energy consumption by the Frank H. Wadsworth Library the last year it was operated before restoration and the first year after restoration.

Water conservation:

- 0.5 gal/min (1.9 L/min) lavatory faucets turn on/off automatically.
- 0.8 gal/min (3.0 L/min) low flow water closets.
- Rainwater harvesting—roof water runoff is recycled and reused.
- Detention ponds, open channels, vegetated swales, concrete channel, and green parking system by invisible structure that maximize infiltration reducing contaminants and reduce runoff quantity.

Energy efficiency:

- Renewable energy Green-e Certificate for 121,800 KwH or 70 percent of expected consumption.
- Lights turn on/off automatically.
- Natural light is maximized.
- Light bulbs are energy efficient.
- Roofs and parking lot reduce heat return to the atmosphere.
- Building wall insulation and energy efficient windows optimize the use of the fresh air System.
- Independent control of air conditioning units on each office allows for their use only as needed.
- Reduced dependence on air conditioning.
- Fresh-air and exhaust-air system maintains fresh air in the offices and controls humidity. The fresh air system makes it possible for hallway and lobby areas to remain cool and comfortable, without the need for additional air conditioning units.

Roof temperature is always below air temperature during the day and higher than air temperature during the night (fig. 41). This is true even if the roof temperature is measured in shallow soil. As soil depth increases, the diurnal temperature variation is less variable, with small increases during the daytime. During the hotter times of the day, the roof temperature is almost 10 °F cooler than air temperature. At nighttime, the roofs can be 10 °F warmer than the air. The differences in temperature between the green roof and air temperature translate to a reduced load on internal building temperature control, thus in energy savings.

We have observed that runoff from our property no longer floods the streets of the Botanical Garden as it did before the construction of the parking lot water detention system. During heavy downpours we have observed runoff leaving our property but not causing floods, as the amount of runoff is handled by the storm

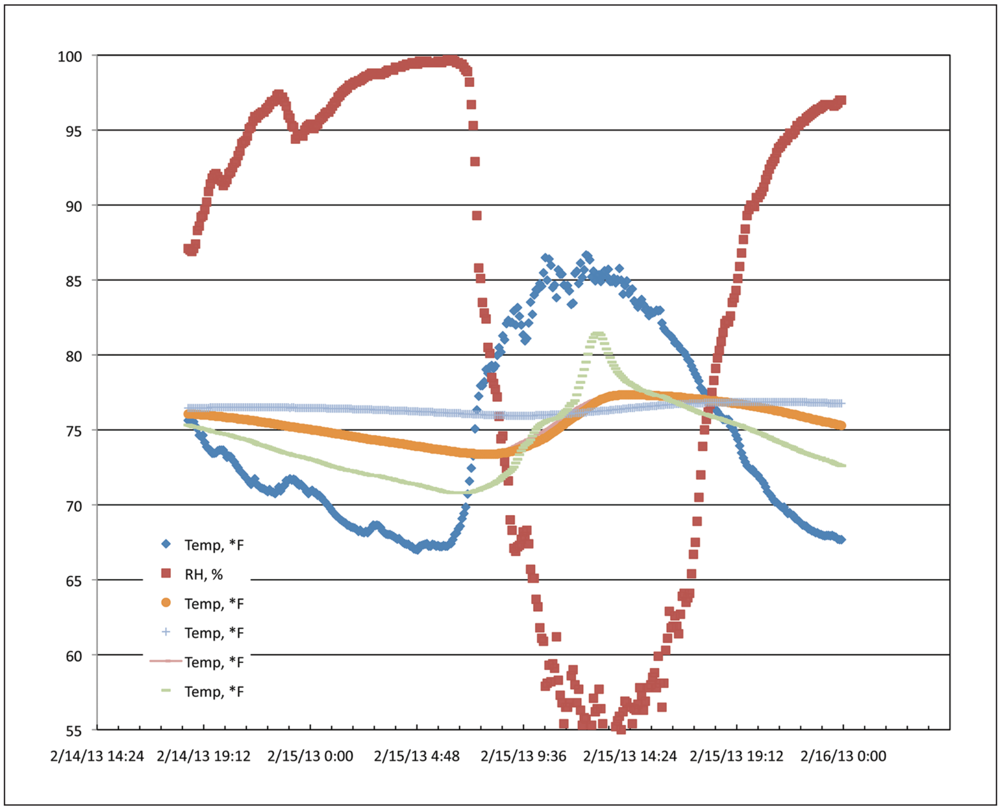

Figure 41—Diurnal of temperature and humidity of air, soil, and roof surface of green and cool roofs of headquarters buildings of the International Institute of Tropical Forestry. Red line = the relative humidity of the air; blue line = air temperature; the other lines are soil temperatures on the roofs.

drain system. The maximum rainfall intensity through that period has been more than 250 mm over two weeks (fig. 42). On several occasions, the system has drained water into the swale outside the dissipater bed, saturated the swale, and produced limited runoff (but not flooding) into the Botanical Gardens.

The roof cisterns will overflow during rainy periods, particularly if the stored water has not been used, allowing the cistern to be almost full at the beginning of rainfall events.

The Conservation Message of Institute Facilities

As humans seek solutions to their many environmental problems, certain conservation actions will be needed regardless of the environmental problem being addressed. These have to do with the conservation of such vital resources as space, water, energy, and materials. All these resources are globally limited in quantity and all are required to support human activity. Any approach used to define future relationships between humans and ecological systems will require that these resources be used as optimally as possible.

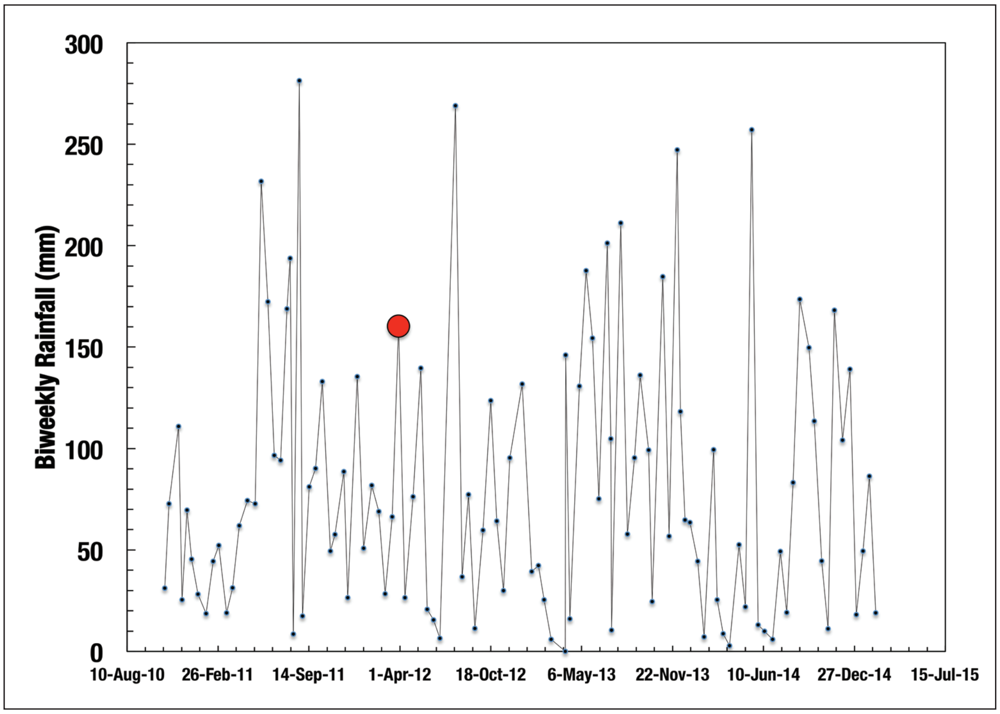

Figure 42—Rainfall record from a station in front of the headquarters main building (illustration by Grizelle González). The red dot points to the time when the runoff management system of the green parking lots became operational.

The rehabilitation of Institute facilities addressed the optimal use of these four vital and limiting elements. We have demonstrated that an organization can make a conservation statement in the way it designs, constructs, and manages building facilities and programs. Facilities can exert a mitigating effect on the problems of water and energy conservation, urban flooding, environmental change, recycling of materials, reduction of water pollution, and Heat Island effects. Our efforts were rewarded with a gold LEEDS certification, which is unusual for a historic building. We invite the public to visit us and see how the design, construction, and management of our facilities have contributed to the conservation of resources and mitigation of fundamental environmental problems in Río Piedras, San Juan, and Sabana, Puerto Rico. We realize that more can be done at our site, but we celebrate what has been done so far, which can be summarized as follows.

Our facilities:

- Are safe and healthy from an employee and visitor point of view
- Conserve energy and water
- Contribute to the management of runoff in Río Piedras, a city besieged by flooding downstream from us. Managing surface runoff also benefits neighbors and the community at large

- Reduce heat re-radiation to the atmosphere, thus helping reduce the Heat Island effect over San Juan
- Optimize the use of space
- Recycle water, nutrients, and materials
- Serve as a research and demonstration location to learn and further improve resource use-efficiency in urban landscapes
- Are cost effective to taxpayers.

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