Deep Energy Savings in a Small Office Building: The Southface Eco Office Demonstration and Research Project

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ABSTRACT

Southface Energy Institute, a 30-year-old non-profit environmental organization in Atlanta, Georgia, has created an 8,000 ft^2 office and training center designed to reduce energy use by 60% and water use by 75% compared to a conventionally designed small office building while maintaining high levels of indoor environmental quality. The building is intended as a showcase to teach a new generation of design professionals that will be needed to address energy, water, and global environmental challenges. By constructing a tight, well-insulated envelope using insulated concrete forms and high performance windows with good orientation, only five small air-to-air heat pumps are needed to condition the building. These efficient heat pumps are further enhanced by evaporative cooling of the condensers using collected rain water. Under-floor supply air is used to condition one zone containing 17 cubicles allowing each occupant to control their own supply vent. Outside air ventilation is decoupled from the heat pumps and incorporates an indirect evaporative cooler, a liquid desiccant dehumidifier, an energy recovery wheel, and carbon dioxide sensors to efficiently deliver outside air in a mixed-humid climate. Daylighting, coupled to a photocell controlled dimmable T5 lighting system with occupancy sensors and extensive use of task lighting, greatly reduces lighting energy use. Purchased energy is further reduced by a 7.1 kW grid-tied photovoltaic array. The building is also extensively instrumented to allow real time evaluation of energy use. Data collected will be shared with researchers interested in understanding and improving the performance of the building's systems.

Introduction

Southface Energy Institute, a non-profit organization in Atlanta, Georgia, was founded in 1978 to promote renewable energy and energy efficiency in homes. Today, with close to 50 employees, Southface's mission has broadened to promoting sustainable homes, workplaces and communities through education, research, advocacy and technical assistance. To house its burgeoning staff and training center needs, Southface has created an 8,000 ft^2 office and training center designed to reduce energy use by 60% and water use by 75% compared to a conventionally designed structure built to ASHRAE 90.1-1999 standards while maintaining high levels of indoor environmental quality. The building, completed in the spring of 2008, is intended as a showcase to train a new generation of design professionals that will be needed to address energy, water, and global environmental challenges. The building is tracking Platinum under the US Green Building Council's LEED green building certification program.

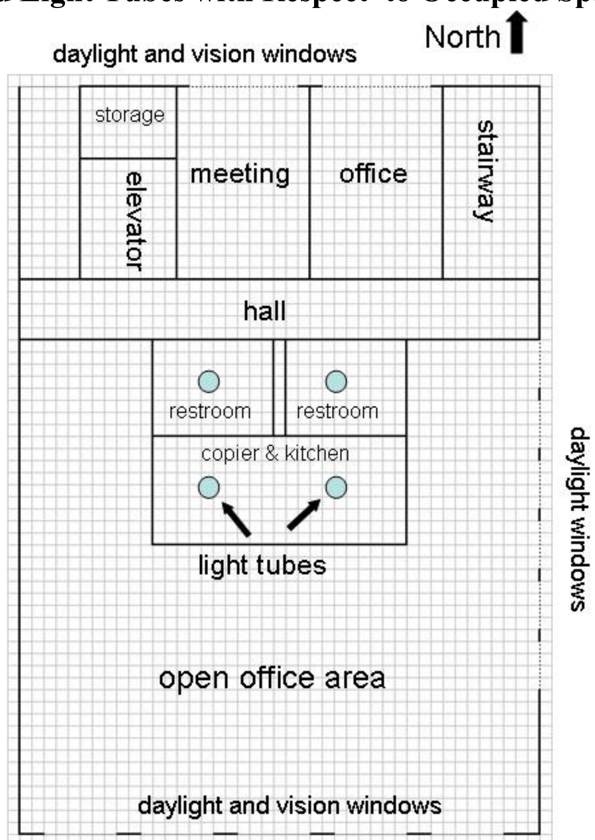
The Eco Office, as the building is called, augments the adjacent 6,500 ft^2 Energy and Environmental Resource Center demonstration house built in 1996. This showcase of state-of-the-art energy-efficient residential technologies has housed Southface's staff since then and spurred on the green home building market in the Southeast as evidenced by the successful EarthCraft House program, a partnership between Southface and the Greater Atlanta Home

Builders Association. Likewise, the Eco Office is intended as a technological classroom and networking hub that will help transform the market for commercial green building. This paper focuses on the building design and the heating, cooling, ventilation, and lighting strategies employed to maximize comfort while minimizing energy use.

Building Design and Shell

In 2003 Southface commissioned Lord, Aeck and Sargent Architecture to design the Eco Office, a four million dollar project where half of the value is in donated products and labor. The building houses 20 employees and contains a 1500 ft^2 classroom. Principles of integrated design were used that included a well-insulated shell, high performance daylighting and vision glass, an efficient lighting system, and mass floors and walls to utilize passive heating and cooling. Normally occupied spaces were placed adjacent to the north and south facing exterior walls and few windows were placed on the east and west exposures (see Figure 1).

Figure 1. Third Floor Layout Showing Placement of Windows and Light Tubes with Respect to Occupied Space



Charrettes played an important part in the design of the Eco Office. A team of Southface employees was formed in 2000 to create a vision for a new building. The team envisioned a building that would address solutions to local water, energy, and air quality issues and build an indoor environment that nourishes its workforce. Southface held a public charrette at the 2002 Greenprints Conference in Atlanta. Charrette participants were asked to brainstorm innovative design strategies that pushed the envelope of current regional building design. Based on ideas developed at this charrette, a request for proposals (RFP) was issued to architects a short time later. Three short-listed firms all participated in a design competition at the 2004 Greenprints Conference to flesh out details of a more realistic final design.

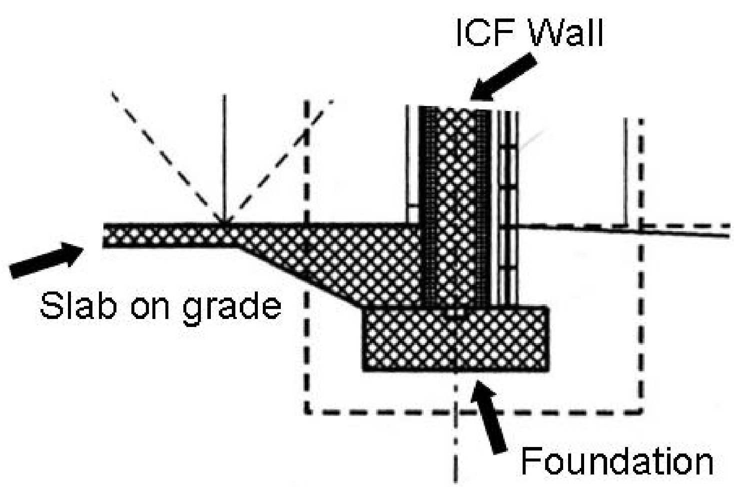
A consortium of five contractors was selected for the project. The Eco Office project introduced many of the contractors and subcontractors to LEED buildings and to green building methods in general. The complete project team is listed in Appendix A. Using a consortium of prime contractors as well as depending on large amounts of donated labor and material, posed organizational and logistical problems. The completion date was delayed a year or more as a result. Choosing a single contractor and not relying on heavily donations would, in retrospect, have been preferable.

Exterior Walls and Foundation

The walls of the entire three-story structure are constructed using insulated concrete forms (ICF) made by Polysteel. The ICFs are made with an inner and outer layer of 2.5” of expanded polystyrene treated with borate to protect against insects. The cavity between the foam is filled with 8” of concrete to form a mass wall insulated to a continuous R-22. (See Figure 2.) ICF walls provide a low air infiltration rate and eliminate the thermal bridging associated with conventional stud construction. Mass walls in climates without large daily swings in temperature help to shift the summer peak cooling load from the walls to later in the day, thus helping to reduce the building’s total peak summer electrical demand. The ICF walls also insulate the edge of the foundation slab. (See Figure 3.) The underside of the slab is uninsulated as under-slab insulation tends to hurt cooling performance more than it helps heating performance in the Atlanta climate.

Figure 2. ICFs Being Filled with Concrete

Figure 3. ICF Wall/Slab Detail Showing ICF Wall Insulating Slab Edge



Windows

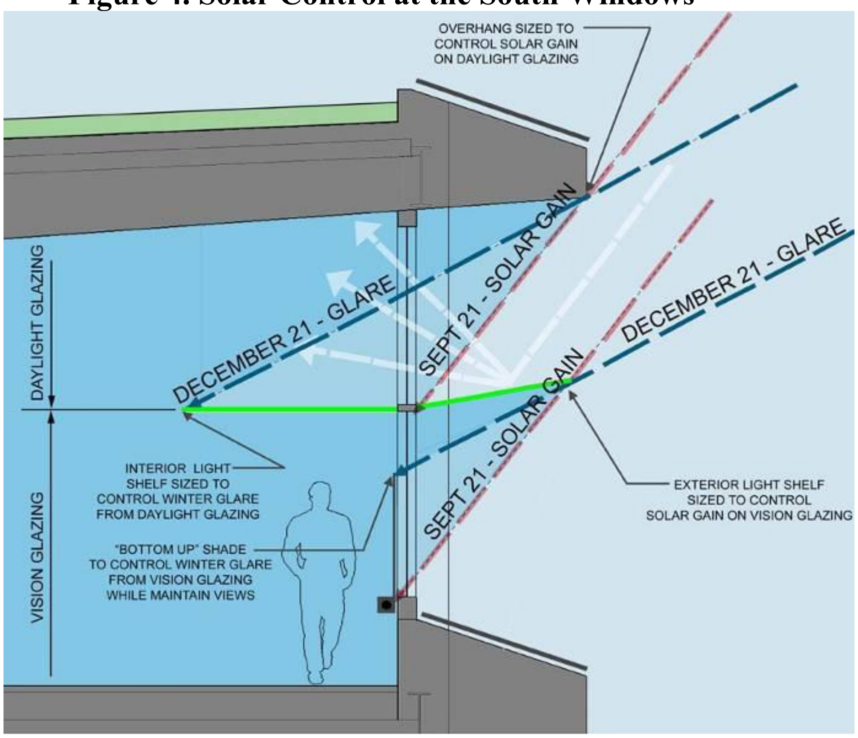
Approximately 12.5% of the building's wall area is windows and 94% of the window area is located on the north and south exposures. Monarch brand wood-framed windows are used throughout. Windows located high up on walls intended for daylighting have somewhat higher visible transmittance than lower vision windows. Table 1 contains the performance characteristics of the windows. Higher performing windows would have been preferred but the choice of donated windows was limited.

Table 1. Complete Assembly Window Characteristics

Window Type	U-value	Solar Heat Gain (shgc)	Visible Transmittance	Operation
Daylight	0.43	0.31	0.55	fixed
Vision	0.41	0.28	0.48	operable

Exterior window overhangs prevent direct solar heat gain during summer afternoons but allow for heat gain in the winter. (See Figure 4). Light shelves and motorized Nysan shading devices prevent direct sunlight from reaching occupants and creating glare during both the winter and summer. Operable windows are used for all vision glazing. There is considerable debate whether operable windows will save energy or actually increase annual energy use. The ability to open windows is an employee amenity but if the dedicated outdoor air system discussed below works as designed, building occupants may rarely be inclined to open a window. Administrative policy is used to make sure windows are closed during cooling and heating periods.

Figure 4. Solar Control at the South Windows



Roof

The roof consists of a 6” concrete deck covered with 3” of extruded polystyrene foam with an R-value of 15 and assembly u-value of 0.056 Btu/hr-ft^2-F. About 2/3 of the roof is vegetated with various types of drought resistant plants growing in 4” of engineered lightweight soil. The rest of the roof is covered with a patio that will be an amenity for the staff and guests. The patio is protected from the sun and rain by a large photovoltaic canopy that will be discussed below. Design constraints allowed for a roof with a u-value only slightly better than a 90.1-1999 code compliant roof.

Heating, Ventilating, and Air Conditioning Systems

In Atlanta’s humid climate, dehumidification is a major component of the cooling load. Conventional mechanical equipment is designed to handle both the sensible and latent cooling loads of the outside ventilation air and the building’s sensible and latent loads. Mismatched loads and capacities often lead to inefficient operation of these systems. The Eco Office HVAC system cools and dehumidifies outside air independently from the rest of the building’s load allowing for more efficient operation.

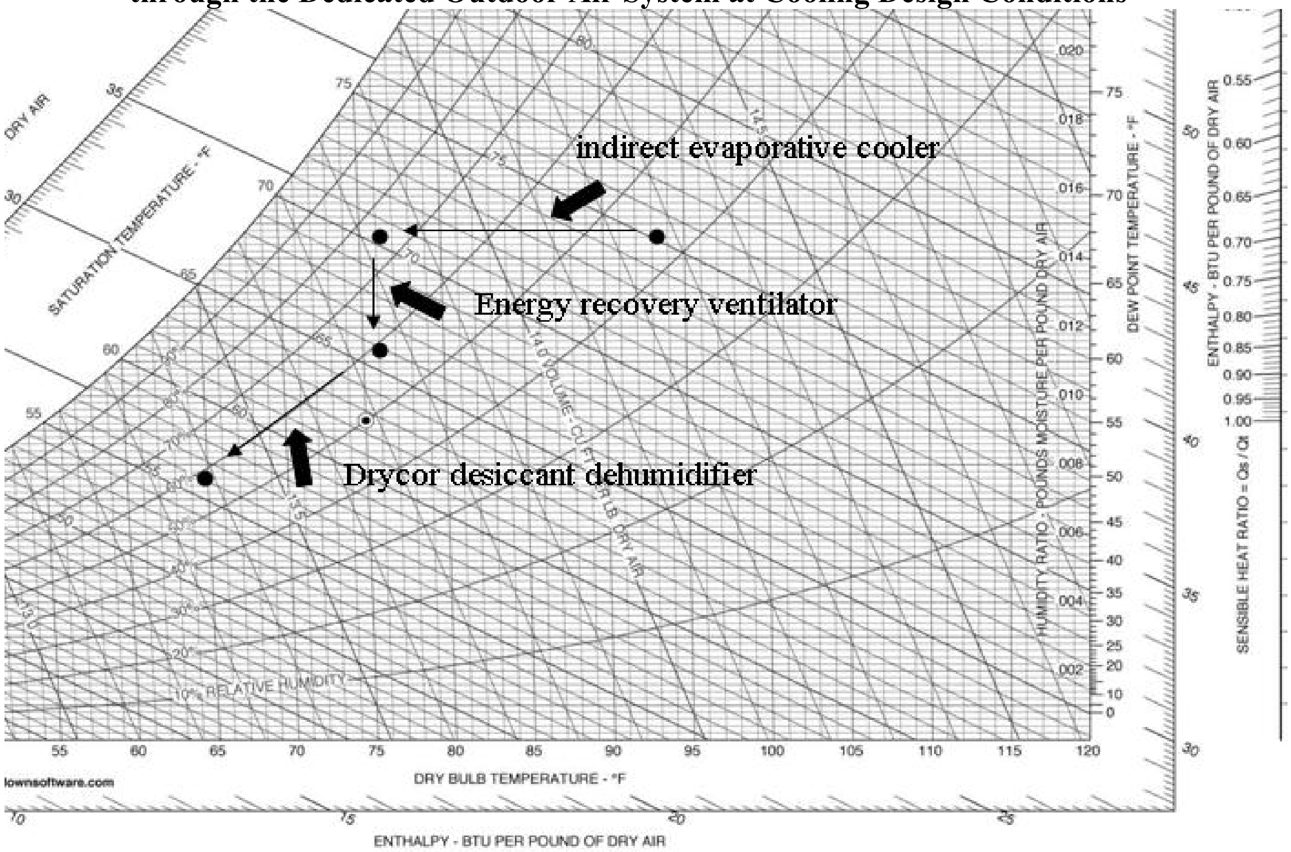
Dedicated Outside Air System

The 1500 Cubic feet per minute (cfm) Dedicated Outdoor Air System (DOAS) designed by McKenney’s consists of three pieces of equipment working in series during the cooling season. The first is a Coolerado Series R600 indirect evaporative cooler that cools down the outside air to near its wet bulb temperature without adding moisture to the process air stream. It does this by evaporating water into a separate working air stream and uses it to cool down the process air stream. By continually allowing some of the cooled process air stream to mix with the working air stream, the wet bulb temperature of the working air stream is reduced and further evaporation chills the air stream’s dry bulb to near the original wet bulb temperature. At ambient design conditions of 93F DB and 75F WB, the air will be cooled 17 degrees by the Coolerado unit. The unit’s peak water usage is 8 gallons per hour. Water is supplied from a large rainwater cistern.

The cooled outdoor air is then passed through a Greenheck Energy Recover Ventilator model ERV-361S which utilizes the building’s exhaust air stream to remove moisture and, depending upon operating conditions, heat from the incoming stream. Lastly, the incoming air stream passes through a DryCor liquid desiccant system that dehumidifies and cools the air even further during peak summer conditions. The DryCor system uses an internal heat pump to regenerate the liquid lithium chloride desiccant and simultaneously cool the air stream. (Unfortunately, the DryCor system is no longer manufactured.)

The DOAS produces about 8 tons of cooling during peak summer conditions at a predicted cost one half of conventional conditioning. The psychometric conditions of the outdoor air as it passes through the DOAS in the cooling season are shown in Figure 5. An economizer cycle is not used as there are few times when cooling is needed in Atlanta that outside temperature and humidity conditions allow for this. However, since the DOAS acts independently of the heat pumps, it is likely that the DOAS will provide all cooling needed during cool and humid ambient conditions.

Figure 5. Psychometric Chart of Outdoor Air Passing through the Dedicated Outdoor Air System at Cooling Design Conditions



Control of the DOAS is critical to its energy efficiency. Water to the evaporative cooler is shut off when dry bulb temperatures approach wet bulb temperatures as is often the case in Atlanta during summer mornings. During the heating season, only the ERV is used to condition the incoming ventilation air and the water supply to the evaporative cooler is shut off. To further reduce the cost of conditioning ventilation air, demand controlled ventilation using CO_2 sensors throttles back the incoming air if less than the design capacity of people are in the building. An innovative Kouba people counter is also installed at the entrance to the large classroom that will help anticipate ventilation needs in the classroom before the CO_2 levels rise.

During unoccupied periods of the week, a small 200 cfm RenewAire EV200 energy recovery ventilator transfers heat and moisture from the exhaust air that is required to keep the compost toilet unit under a small negative pressure allowing the larger DOAS to be shut down.

Conventional Heat Pumps

Five Carrier Infinity air-to-air dual capacity heat pumps provide heating and cooling for the building. These models feature R-410A refrigerant, ECM fan motors, and SEER values between 15 and 16.2 and HSPF values between 8.5 and 9.1. The combined nominal cooling capacity of these units is 16 tons. The outdoor units for the heat pumps are located on the roof adjacent to the vegetated roof, taking advantage of some cooling provided by the vegetation. To further cool the condensing units in the summer, an EcoMesh spray system is employed. (see

Figure 6.) This system mists harvested rainwater to evaporatively cool the ambient air entering the condensers, increasing the capacity and efficiency of the heat pumps. Depending on the dry bulb temperature and humidity, the condenser air can be cooled by 10 to 15 degrees F by this system.

Figure 6. Eco Mesh on Outdoor Units of Heat Pumps and a Light Tube Poking through Vegetated Roof

Air Distribution

As a demonstration of integrated mechanical planning, the mechanical room was placed in the middle of the building on the 2nd of 3 floors to allow efficient air distribution throughout the building. The open office area on the 3rd floor features a raised floor that acts as a distribution plenum. Each of the 17 cubicles in this area has a Johnson Controls Personal Environmental Module that allows temperature and air flow to be controlled at each desk. The classroom on the 1st floor features overhead air distribution using a resource efficient, washable FabricAir fabric duct.

Lighting and Daylighting

Large north and south facing windows and task lighting will provide much of the lighting for the building during the day. Daylight penetrates deep into the office area and class room below from windows that extend to the high ceilings in both areas. Light colored ceilings and walls further contribute to daylight dispersal in the rooms. High output T5 suspended fluorescent fixtures supplied by Lithonia Lighting provide the majority of the small overhead lighting requirements in the building. These fixtures contain dimming ballasts that are controlled using photocells so that they are automatically dimmed or shut off when sufficient daylight is available. Approximately 80% of the normally occupied space has sufficient daylight for most of the day that overhead lighting is not needed. In addition, occupancy sensors are installed that turn off the lights when no one is present regardless of light levels. Occupants can override these controls using wall switches. A Synergy Lighting Controls unit controls all lighting in the building and at a predetermined interval will sweep all the lights to return them to default settings.

Additional daylighting is provided to an interior break room and two restrooms on the 3rd floor using four Solatube 14" light tubes shown in Figure 1. The offices and classroom have lighting power densities between 1.0 and 1.3 watts/ft^2. The average lighting power density for the entire building is about 0.91 watts/ft^2. ASHRAE 90.1-1999 sets a limit of 1.3 watt/ft^2 for average lighting power densities of offices. ASHRAE 90.1-2004 has a limit of 1.0 watt/ft^2 for this building.

Other Building Features

A salvaged 6.4 kW BP photovoltaic array located on the roof provides shade for a roof-top patio below it (Figure 7). In addition, three glazing-integrated Open Energy photovoltaic panels provide 690w of peak power. This glazing has a visible transmittance of 18% and is located in an enclosed stairway, or nexus, joining the Eco Office and Resource Center. Both PV systems are grid tied and are part of a 17.4 cent/kWh green power buy-back program from Georgia Power. The estimated 9,000 kWh annual output of these PV arrays will provide 10% to 15% of the Eco Office's total energy requirements.

Figure 7. Photovoltaic Canopy as Seen from Front of Building

Domestic hot water is provided to a break room sink using a Chronomite Laboratories Instant-Flow model SR-30 electric tankless water heater. Hot water is not provided in the restrooms. An Energy Star qualified Whirlpool refrigerator and dishwasher is also located in a break room. All computers in the building are either laptops or use a LCD monitor. By administrative policy all computers are manually shut down at the end of each work day and the last person to leave is responsible to see that this is done.

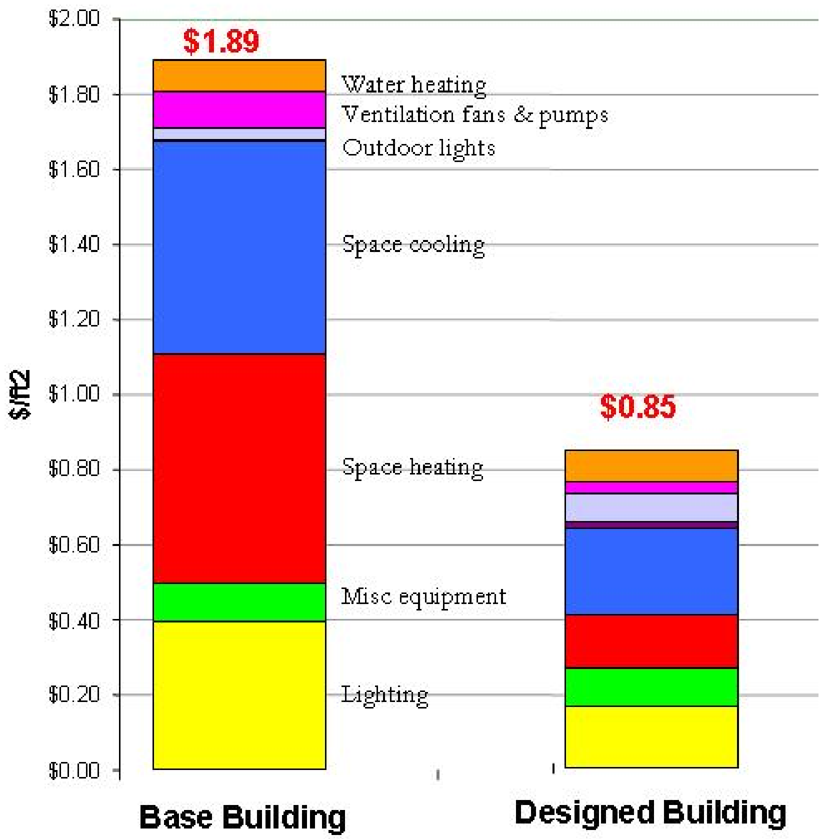
A Kone EcoSpace Low-Rise Elevator is installed. This elevator requires no mechanical room, does not require hydraulic oil, and uses about 1/3 the energy of a conventional elevator. The hoisting motor, a permanent-magnet synchronous motor (PMSM), is attached to the guide rail in the elevator shaft and uses a set of belts and pulleys to control the elevator.

A 15,000-gallon buried Atlantis Matrix cistern will collect rainwater from the site and provide water for irrigation, while a 1,750-gallon rooftop cistern will collect water from the PV array to be utilized for sewage conveyance, the indirect evaporative cooler and condenser spray system. Sloan motion sensor activated timed flow faucets, waterless urinals, CaromaUSA dual-flush toilets and a Clivus Multrum foam flush toilet and compost system serving the employee restrooms will greatly reduce water usage.

Simulation Results and Instrumentation

Energy simulations performed by Lord, Aeck, and Sargent using eQuest version 3.55 showed that a building built to the ASHRAE 90.1-1999 energy code would have a total annual energy cost of $1.89 per square foot. The Eco Office model predicted an annual energy cost of $0.85 per square foot and a site energy use intensity of 24 kBtu/ft^2 per year, or about a 55% reduction, before the photovoltaic output is considered. With onsite generation factored in, annual energy costs are projected to be 60% below the 90.1-1999 base building. Figure 8 shows a graph of these results by end-use. The building is projected to have an Energy Star rating of 95. The average building of this type, corresponding to an Energy Star score of 50, has a site energy use of 53 kBtu/ft^2 per year.

Figure 8. Predicted Energy Operating Costs for Base Building and Eco Office



Documenting and communicating the effectiveness of energy and water conserving design strategies and products of the Eco Office is a major goal of Southface. Energy and water use and weather data will be collected and made available for researchers. In addition, a real time interpretive kiosk and web display system developed by Lucid Design Group will collect and display energy and water use and renewable energy production information that will make the Eco Office's environmental performance visible and understandable to the public. A list of data to be collected is given in Appendix B.

Conclusion

Southface has created a small office and training facility intended as a showcase to teach a new generation of design professionals that will be needed to address energy, water, and global environmental challenges. Transforming the market starts with educating building owners and tenants, developers, architects, contractors, and code officials on the benefits of green building practices. The Eco Office will be a real, easily accessible example of what can be done and will help professionals in the building field visualize what they can do. There is no one solution to building an energy and water efficient building that creates a good environment for its occupants. By heavily instrumenting the Eco Office, Southface hopes not only to make efficiency real to the general public, but also evaluate performance of the installed energy and water systems to help propel the continual improvement of building and HVAC design.

References

[ASHRAE] American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. 1999. "ASHRAE/IESNA Standard 90.1-1999 Energy Standard for Buildings Except Low-Rise Residential Buildings." Atlanta, Georgia

[ASHRAE] American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. 2004. "ASHRAE/IESNA Standard 90.1-2004 Energy Standard for Buildings Except Low-Rise Residential Buildings." Atlanta, Georgia

Appendix A

Southface Eco Office Project Team

Architect: Lord, Aeck & Sargent
Structural: KSi/ Structural Engineers
Design MEP: KEEN Engineering (Stantec)
Civil: Eberly & Associates, Inc.
Landscape: ECOS Environmental Design
Daylighting: RMI/ENSAR Built Environment
Audio/Visual: Waveguide Consulting, Inc.
Commissioning: Working Buildings, LLC
Design-Build:
- Mechanical: McKenney's Mechanical Contractors
- Electrical: Dynalectric Georgia

Contractor's Consortium: Eco Office Contractors:
- DPR Construction, Inc.
- Hardin Construction Co.
- Holder Construction Co.
- Skanska USA Building, Inc.
- The Winter Construction Co.
- with assistance by R. J. Griffin & Co.

Appendix B

Eco Office Building Performance Monitoring

Energy Production

- BP Canopy Photovoltaic System
  - DC Power (W) derived
  - AC Power (W) w/ current transducer & watt node
  - PV Panel Temp. (def. F) w/ thermocouple
- Glazing-Integrated Photovoltaic System
  - DC Power (W) derived
  - AC Power (W) w/ current transducer & watt node

Energy Consumption

- Main Panel
  - Total building import (kWh)
  - Total building export (kWh)
- HVAC Sub Panel
  - Total sub panel energy use (kWh)
  - Energy use of each piece of mech. equip. (kWh)
- Interior Lighting Sub Panel (kWh)
- Exterior Lighting Sub Panel (kWh)
- Elevator Sub Panel (kWh)
- Plug Loads Sub Panel (kWh)
- Water Heating Sub Panel (kWh)
- Misc. Sub Panel (kWh)

Water Usage

- Total building potable water use (gal)
- HVAC water use (gal)
- Domestic water use (gal)
- Harvested rainwater use (gal)
- Potable makeup water to rooftop cistern (gal)
- Composting toilet water use (gal)
- Rainwater use for HVAC (gal)
- Rainwater use for irrigation (gal)

Water Capture

- Rainwater harvested from PV canopy (gal)
- Volume of rooftop cistern (gal)
- Volume of site cistern (gal)

ICF Temperature Profile

- Thermocouple sensors (deg F) at 4 points thru ICF wall at N,S & E elevations at ea. floor level

Green Roof

- Soil moisture (%)
- Temp. above green roof (deg F)
- Temp. under green roof (deg F)
- Temp. above nexus Energy Star roof (deg F)

Weather Conditions

- Horizontal light energy (W/m^2), pyranometer
- Vertical light energy (W/m^2), pyranometer
- Wind speed & direction (MPH, deg), anemometer
- Outside air temp (deg F)
- Dew point (deg F)
- Relative humidity (%), derived
- Rainfall (in/ft^2), tip bucket