Cost Implications of LEED Silver Certification for New House Residence Hall at Carnegie Mellon University

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Executive Summary

The objective of this study was to determine, with the greatest possible accuracy, how the design and construction cost and yearly energy cost of the Carnegie Mellon New House residence hall were affected by the decision to pursue LEED (Leadership in Energy and Environmental Design) Silver certification for the building. Construction of New House residence hall was completed in August 2003. The U.S. Green Building Council certified New House as LEED Silver in October 2003. New House is the first LEED certified university residence hall in the U.S.

The project assessed the difference between costs associated with design, construction, and operation of New House compared to what those costs would have been if conventional Carnegie Mellon approaches had been employed in design, construction and operation. To acquire the information needed for comparison of design, cost, and operation procedures, interviews were conducted with the Carnegie Mellon project managers, the external architects responsible for the design, and the external contractors responsible for the construction of New House. In addition, energy modeling was performed to assess the energy use characteristics of New House relative to several alternative building designs.

Design and construction of New House to achieve LEED Silver certification cost approximately $129,700 to $347,118 more than if the university's conventional design and construction approaches had been employed. This amounts to a premium of only 1% to 2.8% of the total project cost for both hard and soft first costs, including design, construction, and documentation.

New House was found to be either substantially more efficient or slightly less efficient than a "typical" Carnegie Mellon building, depending on how the typical building is defined. The energy use of New House was calculated to be 20.3% to 24.2% less than a non-LEED Carnegie Mellon residence hall with the same layout if the building does not incorporate a heat recovery system. This amounts to an estimated annual energy savings of $44 to $4,378, including the increased cost of purchasing renewable wind power for 50% of the building's electricity. If it is assumed that a typical non-LEED Carnegie Mellon building would have incorporated a heat recovery system, then New House is estimated to use approximately 6% to 12% more energy, an annual extra cost of $8,410 to $12,744, as a LEED Silver certified building. This additional energy use is due to the increased heating and cooling loads and ventilation fan electricity required to provide 100% fresh outdoor air to every student room in the building. These energy savings numbers do not take into account the possible energy savings provided by the measurement and verification equipment or the commissioning and re-commissioning efforts, which can save energy by helping to identify operational or equipment inefficiencies.

Because Carnegie Mellon already had high standards for its buildings before the University committed to LEED Silver certification for all new projects, the additional first costs required to achieve LEED Silver certification in New House were relatively small and the energy efficiency of the building is at least comparable if not substantially greater than a typical Carnegie Mellon building. While the design features implemented to achieve LEED Silver certification in New House resulted in a modestly higher project cost, the additional first costs yielded a wide range of benefits including improved quality of life for building occupants though reductions in indoor air pollution and access to exterior views, and in lower environmental impacts through use of local manufacturers, selection of recycled or recyclable materials, use of sustainably harvested wood products, and reduction of fossil fuel use through energy efficiency measures and renewable energy use. Perhaps an even more important benefit of LEED Silver certification for New House is the example it provides of how Carnegie Mellon is looking towards the future as a leader in environmental education, technology and stewardship.

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1.0 Introduction

As part of Carnegie Mellon's Green Practices effort, the university has committed to LEED (Leadership in Energy and Environmental Design) Silver certification for all newly constructed buildings on campus. LEED is a green building rating system developed by the U.S. Green Building Council which helps to promote environmentally sustainable building practices (USGBC, 2004). It is widely assumed that constructing a LEED certified building involves more design effort and cost than a conventional building. This CIT Honors Research Project tested the aforementioned hypothesis through investigation of the design and construction efforts, costs, and benefits associated with the university's first LEED Certified building, New House residence hall. This report provides details of the findings and results of this research.

2.0 Methodology

In order to determine the additional first cost associated with making New House a LEED Silver building it was first necessary to understand what aspects of the building were different than typical Carnegie Mellon building practices. This was accomplished by examining the LEED submittal documents for the project, meeting with the Project Manager, Architect, HVAC Engineer, General Contractor and subcontractors, and through discussions with Carnegie Mellon engineers, architects and other facilities personnel. Key personnel involved with the project and interviewed for this study are listed in Table 1.1. Through these discussions a list was developed of ways in which New House residence hall was different than if it had been designed and constructed with the typical approaches employed heretofore at Carnegie Mellon.

For each aspect of New House that was different, the party responsible for that aspect of the building, which included engineers, architects, and subcontractors, was contacted for information regarding any additional cost for that building feature. In cases where an exact extra cost could not be given a cost range was provided. Therefore, the additional first costs for the project are reported in a range. Once the additional first costs were established, the energy use and annual energy costs of New House were compared to the energy usage of several possible alternative non-LEED Carnegie Mellon residence hall designs by way of a computer energy model of the buildings. The energy model used was DOE2 (LBNL, 2004), which enables simulation of the energy use performance of a building whose characteristics are specified by the user.

Table 2.1: Key Personnel Involved with Design and Construction of New House Residence Hall at Carnegie Mellon University

Name	Title	Affiliation	Contact
Peg Hart	Project Manager	FMS[1], Carnegie Mellon	412-268-5567
Natalie Gentile	Architect	BCJ[2], Pittsburgh, PA	412-765-3890 x111
Michael Wychers	Architect	BCJ[2], Pittsburgh, PA	mwychers@bcj.com
John Stewart	Mechanical Eng.	H.F. Lenz, Johnstown, PA	814-269-9300 x392
Alan Hopperstead	Project Manager, General Contractor	Rycon Construction, Pittsburgh, PA	412-392-2525 x112
John Sabatos	Operations Manager, General Contractor	Rycon Construction, Pittsburgh, PA	412-392-2525
Vince Sakraida	Commissioning Authority	LLI Technologies, Pittsburgh, PA	412-338-4913
Rohini Brahme	Energy Modeler	CBPD[3], Carnegie Mellon	rohini@cmu.edu
Steve Guenther	Commissioning Authority	FMS[1], Carnegie Mellon	Guenther-Steve@aramark.com
Brad Hochberg	Energy Manager	FMS[1], Carnegie Mellon	
Ed Banichowski	Carpentry Subcontractor	Allegheny Millwork	724-873-8700
Brian Bartholomew	Roofing Subcontractor	Bruin Roofing	412-778-8848
Jim Bennett	HVAC Subcontractor	James E. Huckestein	412-781-5750
Scott Kirkham	Landscaping Subcontractor	JML Landscaping	412-767-4994
Dennis Ball	Painting Subcontractor	Patrino's Painting	412-854-2700
Phil Rendulic	Flooring Subcontractor	Wright Contract Interiors	412-471-2700
Michael Coelho	Door Supplier	A.G. Mauro	412-782-6600
Matt Campise	Controls Subcontractor	Pittsburgh Automatrix	724-327-2334
Jeff Picard	Interior Subcontractor	Linkrist Construction	412-278-2784

[1] FMS: Facilities Management Services

[2] BCJ: Bohlin Cywinski Jackson

[3] CBPD: Center for Building Performance and Diagnostics

3.0 Overview of LEED Features

The following sections describe the requirements for meeting each LEED credit and what was done in New House to achieve each credit. These sections also tell which of the building's LEED features were different than typical Carnegie Mellon building practice and what the normal alternative would be. All LEED credit requirements were taken from the U.S. Green Building Council's LEED Green Building Rating System for New Construction and Major Renovations

Version 2.1, November 2002. This document is available online at http://www.usgbc.org/Docs/LEEDdocs/LEED_RS_v2-1.pdf. The LEED features implemented in New House are described in the LEED documentation submitted to the U.S. Green Building Council by Carnegie Mellon (CMU, 2003).

3.1 Sustainable Sites

3.1.1 Prerequisite 1: Erosion and Sedimentation Control

Requirements

Develop a site sediment and erosion control plan that follows either the best practices guidelines outlined in the EPA's Storm Water Management for Construction Activities or the local sedimentation control codes, whichever is more stringent.

New House Implementation

During the construction of New House, measures were taken to reduce the amount of erosion from the site in order to keep from polluting the surrounding area and storm sewers. Silt fences were installed around the site and filters were installed at storm sewer inlets in order to prevent exposed soil from washing away from the site during rain. The amount of exposed soil was decreased by planting temporary and permanent seeds, and using mulch to help control and stabilize the soil. Pittsburgh building code requires erosion control on construction projects, so these measures would have been taken even if LEED had not been a goal.

3.1.2 Credit 1: Site Selection

Requirements

Select a building site that is not considered prime farmland (defined by the American Farmland Trust), is not lower than 5 feet above the 100-year flood line (defined by FEMA), and is more than 100 feet from any wetland (defined by 40 CFR or local or state rules). Also, new construction must not take place on land that is home to threatened or endangered species, and must not be built on public parkland unless parkland of equal or greater value is traded to the public landowner.

New House Implementation

The site for New House fulfills the above requirements and was selected before the decision to seek LEED certification. Since any site on Carnegie Mellon's campus would fulfill this requirement, there was no difficulty obtaining this credit.

3.1.3 Credit 4: Alternative Transportation

3.1.3.1 Public Transportation Access

Requirements

Locate the building within ½ mile of a subway, light rail or commuter rail station, or within ¼ mile of two or more bus routes.

New House Implementation

Since Forbes Avenue, located approximately 75 yards from New House, is one of Pittsburgh's major bus lines this requirement was easily met.

3.1.3.2 Bicycle Storage and Changing Rooms

Requirements

Provide bicycle storage and shower / changing facilities to accommodate at least 5% of the building's regular occupants.

New House Implementation

This credit is aimed mostly at commercial buildings where showering and changing facilities are often not available for employees who wish to use bicycles to commute. When such facilities are available, the number of employees who chose to commute by bicycle may increase. In a typical office building, meeting this point usually requires careful planning of storage areas and changing facilities that are located near to the employee entrances, which can complicate the design of the building. In New House, however, the point was relatively easy to achieve. Because the building is residential, it already contains showering and changing facilities for all of the building occupants. Beyond that, all that was required was to install a bicycle rack indoors in the basement of the facility that would provide covered bicycle storage for 5% of the building's residents. New House actually provides covered bicycle storage for over 15% of the residents. While this did decrease the amount of space available for student storage (the room would have been used to store students' belongings over the summer) it did not result in extra capital cost.

3.1.4 Credit 7: Landscape and Exterior Design to Reduce Heat Islands

Heat islands are caused when dark colored, non-reflective surfaces absorb heat from the sun and then radiate it to the surrounding area. Heat islands can cause the temperature in urban areas to be more than 10 degrees Fahrenheit more than the temperature in nearby undeveloped areas. This temperature rise not only makes urban areas less comfortable, but also increases air conditioning cost and energy use and disturbs local wildlife and ecosystems. Un-shaded asphalt or concrete sidewalks, streets and parking lots are major contributors to heat islands. Another major cause of heat islands is dark-colored roofs. Most buildings with low-sloped roofs use a layer of black EPDM (ethylene propylene diene monomer) rubber which is then covered with stones and tar to protect it from damage. Roofs made in this fashion are dark in color and have low reflectance, causing a great deal of heat gain.

3.1.4.1 Credit 7.1: Non-Roof

<u>Requirements</u>

Use light colored / high albedo (reflectance greater than 0.3) materials or provide shading (within 5 years) for 30% of the sites non-roof impervious surfaces, place 50% of the parking space underground, or use an open-grid pavement system with a net imperviousness of less than 50% for 50% of the parking space.

<u>New House Implementation</u>

Two major steps were taken to reduce heat islands from the paved pathways around New House. First, many of the sidewalks and pathways around the building were paved with light-colored brick paving (with a reflectance of 0.35). Second, trees were placed to provide shading for some of the areas paved with concrete. In total, 40% of the non-roof paved areas around New House are either highly reflective or shaded.

In the case of New House, the decision to install the brick pavers was actually made based on their aesthetic appearance and Housing Services' desire to improve the home-like decor of their buildings. The pavers were selected before their albedo value was known. This highlights that making a building "green" need not compromise its aesthetics. In order to improve the shading around the building, the trees used in the landscaping were larger than trees that are normally installed, which resulted in a slight increase in landscaping costs over typical practices.

3.1.4.2 Credit 7.2: Roof

Requirements

Use Energy Star compliant high reflectance and high emissivity roofing for at least 75% of the roof surface, or install a vegetated "green" roof over at least 50% of the roof area.

New House Implementation

The roof of New House is an Energy Star compliant GenFlex white PVC roof which is bonded using a water-based adhesive. This roofing material has a solar reflectance of 82.2% and covers 98.43% of the total roof surface. While there is an increase in material and labor costs over an EPDM roof, there is also the potential for energy savings since the roof provides more insulation and absorbs less heat, thus reducing the building's heating and cooling loads.

3.2 Water Efficiency Credit 1.1 – 1.2: Water Efficient Landscaping

Requirements

Credit 1.1: Reduce the potable water used in irrigation by 50% over conventional means.

Credit 1.2: Use no potable water for irrigation or do not install a permanent irrigation system.

New House Implementation

This credit was met by selecting native trees and shrubs that are drought-tolerant and so made a permanent irrigation system unnecessary. A lawn mixture was selected that performs well in a variety of climates. The Marshall Ash and Serviceberry trees planted throughout the site are not only drought resistant but also stand up well to freezing and exposure to rock salt in the winter months. Native Sandcherry, Euonymus and Cotoneaster shrubs were also planted in mulch beds around the building.

Carnegie Mellon chose not to install a permanent irrigation system for the New House lawns. While many campus lawns do not have permanent irrigation systems, there are areas where irrigation is used to maintain the lawns during the summer months. Because the lawn area is not that large, it is likely that the lawn would have been irrigated through the use of movable sprinklers and hoses rather than a permanent system; the plant and grass choices should make even this level of irrigation unnecessary.

3.3 Energy and Atmosphere

3.3.1 Prerequisite 1: Fundamental Building Systems Commissioning

Requirements

Implement a commissioning plan with a third party commissioning agent (anyone not part of the design team) that includes: review of design intent, incorporating commissioning requirements into construction documents, verifying installation, functional performance, training and operations documents, compiling a commissioning report.

New House Implementation

LLI Technologies was hired as the commissioning authority for the fundamental commissioning of New House. They were responsible for ensuring that the correct equipment was purchased and that it was installed correctly. LLI also reviewed the startup procedures for all equipment and ensured that all sensors were calibrated properly. Finally, they compiled a commissioning report for the project.

This level of fundamental systems commissioning was evolving as a campus standard before the New House project. Commissioning had been performed on some recently completed, non-LEED construction projects. Therefore, it is difficult to say if this fundamental systems commissioning would have been performed for New House if LEED certification had not been a goal.

3.3.2 Prerequisite 2: Minimum Energy Performance

Requirements

Design the building to meet or exceed the ASHRAE/IESNA Standard 90.1-1999 energy code or the local energy code, whichever is more stringent. This code defines acceptable insulation values, lighting power use, and equipment performance and operations.

New House Implementation

Designing to meet this ASHRAE/IESNA standard is typical practice for most construction projects. New House would have been designed to achieve this standard regardless of LEED certification.

3.3.3 Prerequisite 3: CFC Reduction in HVAC&R Equipment

Requirements:

Use HVAC&R systems that use no CFC-based refrigerants.

New House Implementation

This is another area where technology has caught up to environmental concerns. CFCs, which contribute to ozone depletion, have been slowly phased out of everything from HVAC systems to hair spray bottles during recent years. Today all new HVAC systems use refrigerants that are free from CFCs, so this prerequisite is easily met.

3.3.4 Credit 1.1 – 1.2: Optimize Energy Performance

Requirements

Achieve increased energy efficiency beyond that required by ASHRAE/IESNA 90.1-1999. Documenting the energy optimization is achieved through computer simulation comparing the designed building to the Energy Cost Budget building described in the referenced standard. One point is achieved by demonstrating an increased efficiency of 15%, an extra point is awarded for every subsequent 5% increase in efficiency (20% = 2 points, 25% = 3 points, etc.).

New House Implementation

By incorporating high efficiency HVAC equipment, using compact florescent, low-wattage lighting fixtures and installing high performance windows, New House was designed to use an estimated 33% less energy than a similar building that simply meets the ASHRAE/IESNA standard. This energy savings was calculated using a computer simulation.

Energy modeling for New House was performed by Carnegie Mellon's Center for Building Performance and Diagnostics. A computer model of the building, including its interior and exterior construction and orientation, equipment type and size, and lighting level was created using a program called DOE2.1(LBNL, 2004). Once the building features were defined in the model, the computer then used a "weather file" for the Pittsburgh region that gives approximate hourly temperature, humidity, and sunlight levels for an entire year to simulate how much energy the building will use over the course of one year. The LEED documentation required running two simulations: one of New House as it was designed the other of an ASHRAE defined energy budget building with the same layout and dimensions. The energy modeling revealed that New House achieved a 33% energy savings (by cost) compared to the ASHRAE budget building.

The energy models used are described in further detail in section 4.1.1. During the course of this research project, other energy models were also performed to give an idea how New House's energy performance would have been different if LEED certification had not been a goal.

3.3.5 Credit 3: Additional Commissioning

Requirements

In addition to the fundamental systems commissioning cited above, a commissioning authority must review the design of the building before construction documents are started. Once construction documents are complete, the commissioning authority must review the construction documents and the contract submittals that pertain to the systems being commissioned. Finally, a manual for re-commissioning is required and a contract to review the operations and maintenance of the building systems with the building staff.

New House Implementation

The additional commissioning procedures were performed by a member of Carnegie Mellon Facilities Management Services who was not involved in the design of New House. He worked with the project team as well as LLI (the other commissioning authority) to ensure that the building systems were designed and constructed to meet the established needs and requirements, and then created a manual to guide any re-commissioning efforts. This work was done specifically to achieve this LEED credit, so the additional level of commissioning would not have been performed on a "typical" Carnegie Mellon building.

3.3.6 Credit 5: Measurement and Verification

Requirements

Install metering equipment to monitor lighting systems, motor loads, variable frequency drives, chiller efficiency, cooling loads, air and water economizer and heat recovery cycles, ventilation air volume and static pressures, boiler efficiency, building energy systems and equipment, and water risers and irrigation systems. Develop a Measurement and Verification plan for collecting and processing information from the above meters.

New House Implementation

A system was installed in New House to continuously monitor the building's energy use. Submeters were set up to monitor fan coil power, lighting power (on each floor), plug loads (on each floor), HVAC equipment, total building power consumption, domestic water use, chiller power and efficiency, constant and variable speed HVAC motors, and the building's cooling and heating loads. In addition to being monitored by the existing campus building automation system, much of this metering information is available to the campus community through a website.

While the sub-metering installed in New House is above and beyond what would normally be installed in a Carnegie Mellon building, it provides many benefits beyond gaining a LEED credit. First, the information from the meters can be used to identify problems in the building's mechanical systems that might otherwise go unnoticed (a problem that does not render a piece of equipment inoperable, but decreases its efficiency might be very difficult to detect without metering). Sub-metering can also help to verify the performance of various energy saving measures to determine which techniques are the most beneficial. It has also been suggested that the metering information be used to promote energy efficient practices among building residents (for example, contests between floors of the building to see who can use the least electricity). Finally, the information can be used in green building research on campus.

3.3.7 Credit 6: Green Power

Requirements:

50% of the building's electricity must be purchased from a renewable energy source (meeting the Center for Resource Solutions Green-e product certification requirements) for at least two years.

New House Implementation

Prior to the construction of New House, Carnegie Mellon entered into a 5-year contract to purchase renewable energy from Community Wind Energy Inc. The university annually purchases 5,805 Mega-Watt hours of wind generated electricity, which amounts to about 6% of the university's total energy use. In order to fulfill this LEED Credit requirement, the university specified that about 50% of the electricity used in New House will come from this wind energy, amounting to about 6% of the total wind energy purchased by Carnegie Mellon.

3.4 Materials and Resources

3.4.1 Prerequisite 1: Storage and Collection of Recyclables

Requirements:

Provide an area for the collection, separation and storage of recyclables (paper, glass, plastics and metals).

New House Implementation

Every floor of New House is equipped with a designated recycling room which has storage bins for residents to separate paper, glass, plastic, metal and cardboard for recycling. As part of its Green Practices effort, Carnegie Mellon places recycling containers in all of its buildings. The centralized recycling rooms in New House extend this effort by making it easy and convenient for students to locate bins for every type of recyclable material.

3.4.2 Credit 2.1 – 2.2: Construction Waste Management

Requirements

Implement a construction waste management plan and salvage or recycle at least 50% (by weight) for credit 2.1 or 75% for credit 2.2 of the construction, demolition and land clearing waste.

New House Implementation

Two major steps were taken to recycle and salvage construction, demolition and land clearing wastes generated during the construction of New House.

During the site clearing and demolition phase, the Noralco Corporation was contracted to remove and salvage top soil, trees, existing concrete and asphalt paving and an existing stone wall. The top soil was stored on campus and used later in the project for landscaping. All existing trees on the site were ground up and used for mulch around Carnegie Mellon's campus. The asphalt and concrete paving was crushed and used as a temporary roadbed for another construction project. The existing stone wall was torn down and the stones were reused by a Noralco employee as a retaining wall on his personal property.

Empire Environmental was contracted to remove the construction waste from the site and sort out recyclable or salvageable materials at their facility. A major advantage of this was that all construction waste could be collected into one dumpster on-site. This was important because the

New House site is in a dense area, so space for sorting and storing salvageable or recyclable materials was not available.

Once the dumpsters were taken off-site, Empire Environmental separated salvageable and recyclable materials according to seven categories: reusable wood, non-reusable non-treated wood, scrap metal, plaster and drywall, brick and block, concrete, and cardboard. Nails and other metals were removed from any reusable pieces of wood which was then set aside for donation to other building projects. Any wood which was non-reusable (due to size or damage) and non-treated was ground into mulch and used on-site or donated to local residents. Scrap metals were sorted and sold to scrap metal companies for reuse. All plaster and drywall was donated to area farmers for use in their fields. Brick and block were separated and cleaned and made available for reuse in other projects. All concrete waste was taken to Collier Stone to be reground and reused. Cardboard waste was bound and sold for reuse or recycling. Any material that did not fall into one of the above categories was then hauled to a landfill.

Both Noraclo and Empire Environmental kept detailed records of the amount of waste material that was salvaged, reused or recycled as well as the amount of waste that was land-filled. In the end, of the 851 tons of total construction, demolition and land clearing waste, only 23 tons was taken to the landfill; 97.3% of the waste generated during the construction of New House was salvaged, reused or recycled.

3.4.3 Credit 4.1 – 4.2: Recycled Content

Requirements

Of the total building materials cost, show that the total value of all post-consumer content plus 50% of all post-industrial recycled content is at least 5% for Credit 4.1 or 10% for Credit 4.2. Post-industrial recycled materials are those which are byproducts of industrial processes or manufacturing methods, or materials that are salvaged from manufacturing processes, which were never manufactured into consumer goods. Recycled content value is calculated by multiplying the total cost of the material by the recycled content percentage.

New House Implementation

The total value of the post-consumer plus half of the post-industrial recycled content in New House was $245,875, which is nearly 12% of the total materials cost for the project. The following table shows the products that contain recycled material and the percentages of post-consumer and post-industrial material.

Table 3.1: Post-consumer and Post-industrial Recycled Content Materials used in New House

Product name	% Post-consumer	% Post-industrial
caisson concrete	0%	4%
structural concrete	0%	4%
reinforcing steel	100%	0%
structural steel	90%	0%
misc. metals	100%	0%
roofing	0%	10%
metal wall panels	25%	75%
drywall	0%	98%
metal studs	25%	0%
ceiling tile	0%	33%
insulation	0%	25%
carpet	0%	60%
steel doors and frames	25%	0%
masonry wall ties (steel)	50%	0%

The caisson and structural concrete in New House was made with cement containing 18% fly ash, a byproduct created in the combustion of coal. Concrete containing fly ash has slightly different properties than that made using normal cement, and as a result is sometimes more difficult to work with, which is why the fly ash was used only in the caisson and structural concrete and not in the concrete floors. In the case of New House, the most difficult part of using fly ash concrete was locating a vendor.

Generally, finding steel and other metal products that contained recycled content was not difficult. Most metal manufacturing processes include some recycled material. Similarly, ceiling tiles and drywall commonly contain recycled material, and most carpet manufacturers use recycled carpet fibers to some degree.

3.4.4 Credit 5: Local / Regional Materials

LEED offers two credits for using local and regional materials, one for local manufacture and one for local extraction. The intent of these credits is to minimize energy used in transporting building materials and to encourage the growth of local economies.

3.4.4.1 Credit 5.1: Locally Manufactured

Requirements

Use building materials that are manufactured within a 500 mile radius for at least 20% (by cost) of the total building materials. A product is considered to be manufactured in the location of its final assembly.

New House Implementation

Because Pittsburgh is situated in an industrial region, finding manufacturers within 500 miles of the New House site was not difficult. The vendor selection for the project would most likely not have been different if LEED had not been a goal. The following table shows the locally manufactured materials and the distance between the manufacturing site and the New House project site.

Table 3.2: Locally Manufactured Materials used in New House

Product Name	**Manufacturing Distance (miles)**
Concrete	5
Reinforcing steel	222
Pre-cast Concrete	111
Concrete Masonry Units	6
Brick	172
Structural Steel	15
Misc. Metals	10
Window Wall	16
Drywall	297
VCT	120
Roofing	25
Door Frames	10
Metal Studs	50
Ceiling Tile	200
Insulation	325

3.4.4.2 Credit 5.2: Locally Extracted

Requirements

Of the regionally manufactured materials, ensure that at least 50% (by cost) are harvested, extracted or recovered within 500 miles.

New House Implementation

Of the above locally manufactured materials, the concrete, pre-cast concrete, concrete masonry units and brick were also extracted within 500 miles of the New House site.

3.4.5 Credit 7: Certified Wood

Requirements

Use wood that has passed the Forest Stewardship Council (FSC) certification for sustainably harvested building material for at least 50% (by cost) of the total wood used in the project.

New House Implementation

Since New House is primarily a concrete structure there is little wood used in the building except for finishing purposes, including window sills, some wood flooring, trim pieces, and display cases. The majority of the wood costs for the project come from the wood doors that are used for the student rooms and bathrooms as well as some other common areas. For these doors, the project team selected Marshfield Environmental Class doors supplied by A G Mauro. At least 70% of the volume of wood used in these doors comes from forests certified by SmartWood as being sustainably managed according to FSC standards. The value of certified wood in these doors alone makes up over 53% of the total cost of all wood products used in the construction of New House. Since this is enough to meet the credit requirements the doors are the only certified wood source that was recorded in the LEED documentation. However, other FSC certified wood was used in the project, including window framing, door jams and kitchen cabinetry.

3.5 Indoor Environmental Quality

3.5.1 Prerequisite 1: Minimum Indoor Air Quality Performance

Requirements:

Design to meet the ASHRAE standard for acceptable indoor air quality (ASHRAE 62-1999), which specifies ventilation rates and the design of ventilation systems that prevent air contamination.

New House Implementation

Meeting this prerequisite required one of the most dramatic changes to the design of New House. This is because while Pittsburgh building code says that having operable windows in dorm rooms provides enough ventilation, the ASHRAE standard requires that any natural ventilation must be designed into the building, and must provide a certain ventilation rate. Since designing such a natural ventilation system for individual dorm rooms was not possible, New House had to be equipped with a forced air ventilation system that provides 30 cubic feet per minute of fresh outdoor air to each dorm room. This required installing a larger air handling unit on the roof of the building that would provide fresh air not only to the corridors and bathrooms, as is typical practice, but also to the individual student rooms. Extra ducting was also required to circulate the air through the rooms.

While it was suggested that Carnegie Mellon might have chosen to meet this ASHRAE standard regardless, in the New House's case the final decision was determined primarily by the goal of LEED certification. By providing fresh air to each student dormitory room, the ventilation system ensures that New House residents are not exposed to pollutants collected in stagnant indoor air. Studies of "Green" office buildings have shown that such improvements to indoor air quality can substantially reduce illness and thus increase productivity (information and studies on the benefits of improved indoor air quality is available from the Lawrence Berkeley National Laboratories Environmental Energy Technology Division, Indoor Environment Department http://eetd.lbl.gov/IED/). While it is difficult to quantify the benefits that this credit brings to the university, the goal is to improve the health and quality of life for Carnegie Mellon residents.

For the common spaces, designing to the ASHRAE standard is common practice at Carnegie Mellon and would have been done in New House. Also, as mentioned previously, the required ventilation rates for bathrooms and other spaces would have been met regardless of the LEED goal.

3.5.2 Prerequisite 2: Environmental Tobacco Smoke Control

Requirements

Ensure that building occupants are not exposed to any environmental tobacco smoke by prohibiting smoking in the building or designing smoking rooms that are vented directly to the outdoors.

New House Implementation

This credit was met by declaring New House to be a non-smoking building. Furthermore, designated outdoor smoking areas near the building are located away from the building air intakes, entrances, and operable windows.

3.5.3 Credit 1: Carbon Dioxide (CO_2) Monitoring

Requirements

Install a permanent CO_2 monitoring system that measures the amount of carbon dioxide in the building and outdoors and controls the ventilation system to ensure that the indoor CO_2 level is never higher than 530 parts per million over the outdoor level.

New House Implementation

Carbon dioxide sensors are installed on the three air handling units (AHUs) that serve the common spaces on the first floor of New House. These sensors detect the amount of CO_2 in the return air ducts. An external sensor located on the roof of the building detects the amount of CO_2 in the outside air. These CO_2 readings are reported to the building's DDC system, which controls the AHUs. The system is configured to keep the indoor CO_2 level at no more than 450 parts per million over the ambient outdoor CO_2 level. If CO_2 levels greater than 450 parts per million over ambient are detected, the fresh air intake of the AHUs in increased, reducing the indoor CO_2 level. The AHU that serves the student rooms, rest rooms, and corridors is a 100% outdoor air unit with a heat recovery system, so CO_2 sensors are not required to regulate its fresh air intake.

For AHUs of the size used in New House, CO_2 monitors are not typical, and so there was an initial cost over normal building practices. However, the use of CO_2 sensors not only ensures high indoor air quality, but also can result in energy savings. In a typical building, AHUs are set to mix a certain percentage of outdoor air with the air that is re-circulated through the building. At times when the indoor CO_2 level is low, the AHUs may take in more outdoor air than needed. If the AHUs are not equipped with heat recovery systems (which are also not typical for small systems) this can result in increased air conditioning or heating loads since the outdoor air must be cooled or heated to the temperature of the indoor air.

3.5.4 Credit 2: Increase Ventilation Effectiveness

Requirements

Design a ventilation system that results in an air change effectiveness of at least 0.9 (determined by ASHRAE 129-1997), or demonstrate that natural ventilation flows cover at least 90% of the room or zone area.

New House Implementation

This credit deals with the design and placement of air supply and return grates. Improperly placed ventilation ducts and grates can result in a "short circuit" of air flow, where fresh air coming into the room travels directly to the return air duct and thus does not circulate through the room. Designing to meet this ASHRAE standard does not require significant effort and is typical practice in most buildings.

3.5.5 Credit 3: Construction Indoor Air Quality Management Plan

3.5.5.1 Credit 3.1: During Construction

Requirements

Follow the SMACNA (Sheet Metal and Air Conditioning National Contractors Association) Indoor Air Quality (IAQ) guidelines for buildings under construction, protect stored on-site materials from moisture damage, and replace all HVAC filters prior to occupancy.

New House Implementation

Construction IAQ Management of New House involved several measures to ensure that the air quality of the building would not be compromised. To prevent the HVAC system from accumulating dust and other contaminants that would then be circulated through the building, extra filter bays were installed in the air handling units and return diffusers and air ducts were covered with filters during the construction. At the end of the construction phase, the AHU filters were replaced and the diffuser covers removed. While this resulted in extra cost, the measures ensured that the building's residents were not exposed to particles or chemicals created during the building's construction. The AHUs were run on 100% outside air during any painting or interior work that involved dust or VOCs. The use of low VOC paints, adhesives, carpets and particle board helped to further prevent poor indoor air quality during the construction phase.

3.5.5.2 Credit 3.2: Before Occupancy

Requirements

Perform a two-week flush-out of the building after construction is complete and before occupancy by running the ventilation system at 100% outside air, or conduct an indoor air quality testing procedure (EPA Protocol for Environmental Requirements, Baseline IAQ and Materials, for the Research Triangle Park Campus, Section 01445).

New House Implementation

Construction on New House was finished during the summer of 2003, more than two weeks before any students were scheduled to move into the building. This allowed time to perform a two-week flush-out of the building between the end of construction and the first occupancy. This flush-out, which simply involved running all AHUs on 100% fresh outside air, was one final step to ensure that particulate and chemical pollutants generated during the construction of the building were removed before the residents moved in.

3.5.6 Credit 4: Low Emitting Materials

3.5.6.1 Credit 4.1: Adhesives and Sealants

Requirements

Use adhesives that meet the VOC (Volatile Organic Compound) limits established in South Coast Air Quality Management District Rule #1168 and sealants that meet Bay Area Air Quality Management District Reg. 8, Rule 51.

New House Implementation

In order to gain LEED certification all adhesives and sealants used are below the VOC limits established in the above standard. Table 2.3 lists each adhesive and sealant used and its VOC content.

Table 3.3: VOC Content of Adhesives and Sealants used in New House

Product description	VOC content
Carpet adhesive	0 g/L
Carpet seam sealer	0 g/L
Rubber base adhesive	98 g/L
VCT adhesive	49 g/L
Concrete sealer #1	0 g/L
Concrete sealer #2	0 g/L

3.5.6.2 Credit 4.2: Paints and Coatings

Requirements

All paints and coatings must meet Green Seal requirements for VOC and chemical component limits.

New House Implementation

Interior paints and coatings can be a major source of indoor air pollution, as anyone who has ever painted with traditional paints in a closed room can attest. To combat this, the interior of New House is finished with low or zero VOC paints and textures. In order to meet Green Seal requirements, flat interior paints must have a VOC level lower than 50 grams per liter and Gloss or Semi-gloss paints must have fewer than 150 grams per liter. The flat finish paint in New House is Harmony paint from Sherwin-Williams, which contains zero VOCs, and the semi-gloss and egg-shell paints contained 85 and 142 g/L respectively. The Block filler used on the concrete block walls in the building is also low in VOCs, and the ceiling texture contains zero VOCs. Currently low VOC paints do come at a premium, but as the popularity and availability of these finishes increases this premium will likely shrink.

3.5.6.3 Credit 4.3: Carpet

Requirements

Carpet must pass the Carpet and Rug Institute Green Label Indoor Air Quality Test Program.

New House Implementation

As concerns for indoor air quality have increased the availability of low VOC products has increased, and their cost has decreased. Carpeting, which in the past was often a source of significant VOC off-gassing, is no exception. Today, most carpeting manufacturers have embraced the Carpet and Rug Institute's Green Label program and design the majority of their carpeting to pass the Indoor Air Quality Test Program.

3.5.6.4 Credit 4.4: Composite Wood

Requirements

Use composite wood or agrifiber products that contain zero added urea-formaldehyde resin.

New House Implementation

All of the composite wood used in New House was Medex medium-density fiberboard from Sierra Pine. Medex contains no added urea-formaldehyde and is often used in hospitals where indoor air contamination is a major concern. In addition, Medex is manufactured from 100% recycled wood fibers. The only composite wood used in New House was for kitchen cabinetry and counter tops.

3.5.7 Credit 5: Indoor Chemical and Pollutant Source Control

Requirements

Install permanent entry way grates and mats to prevent dirt and other particles from entering the building, design rooms for high chemical use activities that are exhausted directly out of the building, and provide drains for disposal of liquid waste in areas where chemicals and water are mixed.

New House Implementation

To ensure that any indoor pollutant sources do not compromise the air quality within New House, the building's restrooms and janitors' closets are exhausted directly to the outdoors and have a negative pressure when compared to other spaces. This ensures that any air pollutants from these areas will not be re-circulated to other spaces in the building. The janitors' closets are also sealed with floor-to-ceiling partitions to prevent air leakage to other areas of the building. Sealed and separately exhausted janitors' closets are fairly common and would have been used even if LEED was not a goal.

A permanent entryway walk-off grate / mat system was also installed at the main entrance to prevent outdoor chemicals and dirt from being tracked into the building. This system not only helps to improve indoor environmental quality, but also helps to reduce cleaning cost, and thus is often installed in typical buildings.

3.5.8 Credit 6.1: Controllability of Systems, Perimeter

Requirements

Provide at least one operable window and one lighting control zone per 200 square feet for all occupied areas within 15 feet of an exterior wall.

New House Implementation

This credit was easily met because most of the spaces that are within 15 feet of the exterior walls are student dormitory rooms which each have their own light switch and operable windows.

3.5.9 Credit 7: Thermal Comfort

3.5.9.1 Comply with ASHRAE 55-1992

Requirements

Comply with ASHRAE Standard 55-1992, which dictates thermal comfort standards including appropriate humidity and temperature ranges.

New House Implementation

The temperature control range for the systems in New House is 70 – 78 degrees F, and the humidity control range is 30% to 60% relative humidity, both of which meet the ASHRAE guidelines. While designing temperature ranges to meet the standard is common, meeting the humidity range requirement necessitated purchasing AHUs with humidifiers which is not common practice for residence halls.

3.5.9.2 Permanent Monitoring System

Requirements

Install a system which monitors the temperature and humidity which allows operators to control the performance of the building humidifiers and dehumidifiers.

New House Implementation

Permanent monitoring of HVAC equipment is a standard practice at Carnegie Mellon. Sensors and equipment instrumentation feed information into a computerized Building Automation System, which allows Facilities Management Services to monitor the performance of the buildings HVAC systems. Because humidifiers were used in the AHUs, the only unusual aspect of the monitoring system in New House was the installation of humidity sensors to monitor the performance of the humidifiers.

3.5.10 Credit 8.2: Daylight and Views, Views for 90% of Spaces

Requirements

90% of all regularly occupied spaces must have direct views to exterior windows.

New House Implementation

New House was designed with many windows which provide exterior views for common spaces and student rooms. Every common space (excluding spaces such as the rest rooms, utility closets, and basement storage areas which are not regularly occupied) and each student room has at least one window or glass door that allows occupants to see outside. In total, over 97% of the regularly occupied space in New House has a direct line of site to the outside.

3.6 Innovation and Design Process, Credit 2: LEED Accredited Professional

Requirements

At least one principle member of the project team must have completed the LEED Accredited Professional exam, which tests knowledge of green design principles and practices and familiarity with the LEED system. This credit is given to encourage industry professionals to learn about green design and the LEED system to spread green building practices throughout the industry.

New House Implementation

The LEED Accredited Professional for New House was John Stewart, the lead Mechanical Engineer for the project. He had worked with Carnegie Mellon on a number of projects before the University committed to LEED Certification for all new construction and before New House was designed.

4.0 First-Cost Analysis of LEED Features

The primary goal of this research project was to determine if making New House a LEED Certified building resulted in extra first costs over typical Carnegie Mellon building practice. After determining how the building was different than a typical Carnegie Mellon building, as explained in the previous sections, the next step was to determine the cost differential for each aspect of the building that was designed or constructed differently in order to gain LEED Silver certification. These cost differences were determined primarily though conversations with the architect, project manager, mechanical engineer, general contractor and sub-contractors for the project (see Table 1.1). If an exact value could not be determined a low and high estimate were given. Table 4.1 shows the extra first cost associated with gaining each LEED credit, taking into account these estimates.

Table 4.1: Extra First Cost Associated with each LEED Credit

for New House Residence Hall

LEED Credit	Extra Cost	
	Low	High
SS Prereq. 1: Erosion and Sedimentation Control	$0	$0
SS Credit 1: Site Selection	$0	$0
SS Credit 4.1: Public Transportation Access	$0	$0
SS Credit 4.2: Bicycle Storage and Changing Rooms	$0	$0
SS Credit 7.1: Heat Island Reduction, Non-roof	$4,120	$4,120
SS Credit 7.2: Heat Island Reduction, Roof	$6,750	$13,500
WE Credit 1.1-1.2: Water Efficient Landscaping	$0	$0
EA Prereq. 1: Fundamental Building Systems Commissioning	$0	$50,000
EA Prereq. 2: Minimum Energy Performance	$0	$0
EA Prereq. 3: CFC Reduction in HVAC&R Equipment	$0	$0
EA Credit 1.1-1.2: Optimize Energy Performance	$0	$23,000
EA Credit 3: Additional Commissioning	$5,827	$15,000
EA Credit 5: Measurement and Verification	$16,000	$17,000
EA Credit 6: Green Power	$0	$0
MR Prereq. 1: Storage and Collection of Recyclables	$0	$0
MR Credit 2.1-2.2: Construction Waste Management	$0	$0
MR Credit 4.1-4.2: Recycled Content	$0	$0
MR Credit 5.1-5.2: Local/Regional Materials	$0	$0
MR Credit 7: Certified Wood*	$4,060	$19,817
IEQ Prereq. 1: Minimum IAQ Performance	$25,000	$100,000
IEQ Prereq. 2: Environmental Tobacco Smoke Control	$0	$0
IEQ Credit 1: CO_2 Monitoring	$1,500	$1,500
IEQ Credit 2: Increased Ventilation Effectiveness	$0	$0
IEQ Credit 3.1: IAQ Management, During Construction	$21,520	$21,520
IEQ Credit 3.2: IAQ Management, Before Occupancy	$0	$0
IEQ Credit 4.1: Low Emitting Adhesives and Sealants	$355	$355
IEQ Credit 4.2: Low Emitting Paints	$4,190	$4,190
IEQ Credit 4.3: Low Emitting Carpet	$0	$0
IEQ Credit 4.4: Low Emitting Composite Wood*	$4,060	$4,816
IEQ Credit 5: Indoor Chemical and Pollutant Source Control	$0	$0
IEQ Credit 6.1: Controllability of Systems, Perimeter	$0	$0
IEQ Credit 7.1: Comply with ASHRAE 55-1992	$9,500	$9,500
IEQ Credit 7.2: Thermal Comfort, Permanent Monitoring	$0	$0
IEQ Credit 8.2: Views for 90% of Spaces	$0	$0
ID Credit 2: LEED Accredited Professional	$0	$0
Cost of Compiling LEED Documentation	$25,000	$61,000
Cost of LEED Registration and Certification	$1,800	$1,800
Total Extra Cost	**$129,744**	**$347,118**

* Cost estimate derived from Allegheny Millwork extra contract cost, see Section 3.4.5 for explanation.

As Table 4.1 shows, the additional first cost, including design and construction costs, for making New House a LEED Silver building was found to be between $129,744 and $347,118. The total project cost of New House, including design and construction costs, was $12,550,000, so the premium for making New House a green building was 1% to 2.8%. The project cost premium of 1% to 2.8% is consistent with the premium costs quantified for other LEED projects in the U.S. (Kats et al., 2003). The following sections describe the sources and calculations used to obtain the extra cost figures for each LEED credit and the LEED documentation costs.

4.1 Sustainable Sites Credits Extra Cost Calculations

In total, gaining the five Sustainable Sites credits awarded to New House required an additional spending of between $10,870 and $17,620. While Sustainable Sites credits amounted to 14% of the total number of credits received, the extra cost for these credits is only 6% - 9% of the LEED premium.

4.1.1: Prerequisite 1: Erosion and Sedimentation Control

As mentioned in Section 3.1.1, Pittsburgh building code requires erosion and sedimentation control measures similar to those referenced in the LEED standard. Because the erosion and sedimentation control measures would have been similar for New House even if LEED had not been a goal, no additional spending was required to meet this prerequisite (Bohlin Cywinski Jackson, 2003).

4.1.2: Credit 1: Site Selection

Since the site of New House was chosen before the decision to seek LEED certification, there was no additional cost for this credit (Bohlin Cywinski Jackson, 2003).

4.1.3: Credit 4.1 – 4.2: Alternative Transportation

The public transportation access credit resulted from Carnegie Mellon's proximity to Forbes Avenue and the many bus routes that travel on it. Since no extra shower facilities were required to meet the bicycle storage and changing facilities credit, there was no cost above a non-LEED building (Bohlin Cywinski Jackson, 2003).

4.1.4: Credit 7: Landscape and Exterior Design to Reduce Heat Islands

The only aspects of the New House site that would have been different if LEED had not been a goal were the design of the exterior landscaping and roof in order to reduce heat islands. Gaining these two credits required additional cost as described below.

4.1.4.1 Credit 7.1: Non-roof

The extra cost for reducing heat islands in the area surrounding New House came from purchasing trees for shading that were larger than trees normally purchased for landscaping. Table 4.2 shows each of the larger trees purchased and the cost associated with specifying the larger trees as reported by JML Landscaping, the landscaping subcontractor for New House.

Table 4.2: Size and Extra Cost of Shading Trees used on the New House Site

Tree Type	# Used	Caliper Specified	Normal Caliper	Extra Cost per Tree	Total Extra Cost
Ash	8	3”	1.5” – 2”	$200	$1,600
Marshal Ash	8	3”	1.5” – 2”	$200	$1,600
Serviceberry	36	1.75”	1.25” – 1.5”	$20	$720
Honey Locus	1	3”	1.5” – 2”	$200	$200

The total extra cost for gaining the non-roof heat island reduction credit was $4,120 (Kirkham, 2004).

4.1.4.2 Credit 7.2: Roof

The white PVC roof used to reduce the heat island effect in New House cost between $0.50 and $1.00 per square foot, including materials and labor, over a black EPDM roof according to Bruin Roofing, the roofing subcontractor for the project (Bartholomew, 2004). The roof has a surface area of 13,500 square feet, so the total extra cost of the PVC roof is between $6,750 and $13,500.

4.2 Water Efficiency Credits Extra Cost Calculations

The two water efficiency credits, 1.1 and 1.2: Water Efficient Landscaping, were both awarded because there was no permanent irrigation system installed on the grounds around New House. Permanent irrigation was not necessary because the trees, shrubs, and grasses selected for the building’s landscaping were either native to the Pittsburgh region or compatible with the region’s climate. Because Pittsburgh does not have a particularly harsh climate, such as might be found in the desert southwest for example, finding plants that could flourish in the region without irrigation was not difficult. Because the plant choices would have likely been the same if LEED had not been a goal, there is no additional cost for the water efficiency credits (Bohlin Cywinski Jackson, 2003).

4.3 Energy and Atmosphere Credits Extra Cost Calculations

Energy and atmosphere credits resulted in an extra first cost of between $16,000 and $90,000. The large range is the result of uncertainty about whether or not fundamental systems commissioning would have been performed if LEED had not been a goal, as explained further in Section 4.3.1. It is interesting to note that most of the extra costs for gaining the energy and atmosphere credits did not come from the actual energy saving measures and equipment (such as low-E coated windows, high efficiency HVAC systems, and low-wattage lighting) but rather from commissioning, energy modeling, and measurement and verification equipment. This is due largely to the fact that Carnegie Mellon buildings are typically very efficient, and so many of the actual energy saving measures would have been implemented regardless of the LEED goal.

4.3.1 Prerequisite 1: Fundamental Building Systems Commissioning

As mentioned previously, whether or not fundamental commissioning of the New House systems would have been done if LEED had not been a goal is debatable. While commissioning is not currently a typical industry practice, and most Carnegie Mellon buildings have not had systems commissioning performed, the construction project completed most recently before New House, an addition to Doherty Hall, did undergo fundamental commissioning similar to that of New House. Because of this, some people believe that commissioning was evolving as a campus standard even before the university's decision to seek LEED certification for all new construction projects. The low and high extra cost estimates, then, are $0 and $50,000 respectively. The low estimate assumes that fundamental systems commissioning was evolving as a campus standard, and so would have been performed for New House even if LEED had not been a goal. The high estimate assumes that commissioning was performed for the purpose of achieving this LEED prerequisite; the extra cost of $50,000 was the contract cost for LLI Technologies, the commissioning authority for the project (Hart, 2004).

4.3.2 Prerequisite 2: Minimum Energy Performance

Designing building's to meet the requirements of ASHRAE Standard 90.1-1999 is a typical industry and Carnegie Mellon practice. New House would have met and likely far exceeded the minimum energy performance required to achieve this prerequisite even if LEED had not been a goal, therefore there is no additional cost for this prerequisite (Hart, 2003).

4.3.3 Prerequisite 3: CFC Reduction in HVAC&R Equipment

The use of CFC based refrigerants has been phased out of modern heating, ventilation, air conditioning and refrigeration equipment as alternative refrigerants which cause less ozone depletion have been developed. The CFC-free HVAC equipment would have been installed in New House even if LEED had not been a goal so there was no extra cost associated with this prerequisite (Bohlin Cywinski Jackson, 2003).

4.3.4 Credit 1.1-1.2: Optimize Energy Performance

As mentioned previously, the majority of the energy saving measures implemented in New House would likely have been implemented regardless of the decision to seek LEED certification. The decision to use compact fluorescent lighting fixtures, which results in substantial energy savings over traditional florescent or incandescent lighting, was based primarily on the aesthetics and durability of this type of lighting, so the choices would likely have been the same if LEED were not a goal. The high performance windows that were selected for the project by Carnegie Mellon Housing Services would also likely have been chosen even in a non-LEED project because of their aesthetic value and potential for energy cost savings (Michaels, 2004). Similarly, the choice to use air handling units and fan coil units for heating and air conditioning, as opposed to the less efficient packaged terminal air conditioners specified in the ASHRAE budget building (ASHRAE, 2000), the reference case for LEED energy evaluations, was based on the type of building and the availability of campus-wide steam for heating.

It is unclear whether the desiccant heat recovery system, which provides major heating and cooling energy savings in New House, would have been installed if LEED had not been a goal for the project. While the heat recovery system would have been suggested regardless, the system might have been eliminated for cost-saving purposes if the energy savings it provides had not been necessary in accomplishing the LEED goal. Also, if a smaller ventilation system had been used, which did not serve the student rooms (see section 3.5.1), the energy savings from the heat recovery would have been less substantial, making it more likely that the system would have been eliminated (Stewart, 2004b). If the heat recovery system had not been incorporated, it would have resulted in a savings of approximately $15,000 including the installation of the heat wheels and additional ducting (Stewart, 2003). The low and high estimates for the extra cost of the heat recovery system, then, are $0 if one assumes that the system would have been installed regardless of LEED, and $15,000 if it would have been omitted if not for the LEED goal.

There were also additional first costs associated with calculating and documenting the energy efficiency of New House. The energy modeling required to demonstrate the building's efficiency for this LEED credit required a great deal of time and effort to set up the building and system parameters and analyze the output data. Because the energy modeling for New House was performed by the Carnegie Mellon Center for Building Performance and Diagnostics, the university did not actually have to pay for the work, so the low estimate for the extra cost of this credit is $0. If the energy modeling had been contracted to an outside consultant, or if the Center for Building Performance and Diagnostic had charged Housing Services for their work, it is estimated that the extra cost associated with the energy modeling would have been around $8,000 (Brahme, 2003).

The total cost above typical Carnegie Mellon building practice for this credit is between $0 and $23,000.

4.3.5 Credit 3: Additional Commissioning

Similar to the energy modeling, the additional commissioning for the New House project was performed in-house by a member of Carnegie Mellon Facilities Management Services. Records from Facilities Management Services report that he spent a total of 67 hours on the project, for a cost of $5,827. If the additional commissioning had been contracted out to a third party, it would likely have cost close to $15,000, so this is used as a high estimate for the cost above typical building practice (Guenther, 2004).

4.3.6 Credit 5: Measurement and Verification

Achieving the measurement and verification credit required installing sub-metering devices that were above and beyond what would have been installed in New House had LEED certification not been a goal. The major extra cost for this credit came from the extensive electricity sub-metering (separate sub-meters for lights and plug loads on each floor as well as equipment sub-meters and whole-building sub-meters). A representative from Pittsburgh Automatrix, the controls sub-contractor responsible for the measurement and verification systems, estimated that the cost above normal Carnegie Mellon sub-metering standards was between $13,000 and $14,000 for the electricity metering (Campise, 2004a). A water main sub-meter was also installed in New House, which is not typical practice. This added approximately $3,000 to the cost of the project (Campise, 2004a). The other measurement and verification equipment, the chilled water and steam temperature and flow meters, are typical practice in Carnegie Mellon building projects (Campise, 2004b). One area of interest regarding the measurement and verification equipment is that the cost of installing the sub-meters during the construction of the project was much less than it would cost to install them as a retro-fit in a completed building because the wires for the sub-meters can be installed at the same time as other electrical wiring (Campise, 2004a). Accordingly, if there is any speculation that sub-metering of a building will be desirable at some point in the future, it is most cost efficient to have the metering equipment installed during the construction.

4.3.7 Credit 6: Green Power

Because Carnegie Mellon had already established a contract to purchase wind energy before New House was constructed, there was no additional first cost associated with gaining this LEED credit. However, it is important to consider the long-term energy cost associated with purchasing renewable energy for 50% of the building's electricity. Based on the energy simulation performed by the Center for Building Performance and Diagnostics, the total electricity use per year for New House is 2465.6 MBTU, or 722,400 Kilowatt-hours. If 50% of this electricity is provided by wind energy, which has a premium of 1.4 cents per kilowatt-hour over typical Pittsburgh electricity costs (Hochberg, 2004), the total yearly additional energy cost for meeting the Green Power credit is about $5,050.

4.4 Materials and Resources Credits Extra Cost Calculations

4.4.1 Prerequisite 1: Storage and Collection of Recyclables

Because placing recycling containers in residence halls and other campus buildings is common practice at Carnegie Mellon, no additional spending was required to meet this prerequisite (Bohlin Cywinski Jackson 2003)

4.4.2 Credit 2.1-2.2: Construction Waste Management

According to the information provided in the LEED documentation, which was later confirmed by a representative from Rycon Construction (REF?), the general contractor for the project, the price charged (per dumpster pulled) by Empire Environmental for their recycling service, $325 per dumpster, is similar to prices charged by haulers that take the dumpsters straight to a landfill. Empire is able to maintain this competitive price because they resell the recyclable material to other projects or industries. Also, because the site debris, handled by the Noralco Corporation, consisted of easily recyclable materials, there was no increase in cost for gaining these LEED credits.

4.4.3 Credit 4.1-4.2: Recycled Content

Surprisingly, it was determined that meeting the LEED requirements for recycled content did not result in additional cost to the project. Using recycled metals in metal manufacturing processes has become standard practice; most metal building materials contain recycled materials, so there was no additional cost for obtaining recycled metal products. The fly-ash concrete, while fairly new and unconventional, does not cost more than typical concrete mixes, since the fly-ash is an industrial waste byproduct (Sabatos, 2004b). While the PVC roofing did cost more than a traditional roof, the roof was selected in order to meet Sustainable Sites Credit 7.2, so the additional cost for the roof was not a result of its recycled content. The drywall, ceiling tiles, and insulation, all of which contained recycled content, did not cost more than typical materials according to Linkrist Construction, the sub-contractor responsible for interior work in New House (Picard, 2004). According to a representative from Wright Contract Interiors, even the 60% recycled content carpeting is becoming standard practice and does not require additional spending (Rendulic, 2004).

4.4.4 Credit 5.1-5.2: Local / Regional Materials

Because the choice of material suppliers would have been similar in a comparable non-LEED building, there was no additional cost associated with purchasing locally manufactured or extracted materials for the New House project (Bohlin Cywinski Jackson, 2003).

4.4.5 Credit 7: Certified Wood

While using certified wood typically results in significant extra cost, due to the relatively small number of certified forests and the documentation required to verify that a product is made from certified wood, as the result of an accounting error the use of certified wood in New House resulted in relatively little additional cost. Due to an error in accounting, the A.G. Mauro Company did not charge Carnegie Mellon for the extra cost associated with supplying certified wood doors. Carnegie Mellon was charged $48,000 for the 212 wood doors used in New House, when the cost would have been approximately $63,000 had it not been for the accounting glitch (Coelho, 2004). Therefore, the low estimate of $0 extra cost reflects how much cost the Certified Wood doors actually added to the New House project cost, the high estimate of $15,000 reflects what the extra costs would have been had Carnegie Mellon been charged the correct price for the doors.

An exact extra cost for the other certified wood used in the project could not be calculated. This is because Allegheny Millwork, the subcontractor responsible for window trim, kitchen cabinetry, and other woodwork in New House, could only give an estimated total contract premium that they charge for LEED certified projects. Because the work performed by Allegheny Millwork impacts multiple credits (Materials and Resources Credit 7, Certified Wood and Indoor Environmental Quality Credit 4.4 Low Emitting Composite Wood), the total extra cost bid into their contract for LEED compliant work was divided evenly between the two credits.

Allegheny Millwork reported charging a premium of between 10% and 12% for contracts which require meeting LEED certification standards (Banichowski, 2004). Their total contract cost for New House was $90,000. Assuming this contract cost is 10% to 12% higher than it would have been had LEED Certification not been a goal, their contract for a typical building would have been $80,357 to $81,818. This amounts to an additional cost of $8,182 to $9,633. Again, because it is unknown what percentage of this total contract premium went towards meeting the Certified Wood or the Low-Emitting Composite Wood credit, it was assumed that each credit amounted to 50% of the total extra contract cost. Thus, the estimated additional cost for the certified wood used in New House other than the doors was $4,060 to $4,816.5.

4.5 Indoor Environmental Quality Credits Extra Cost Calculations

4.5.1 Prerequisite 1: Minimum Indoor Air Quality Performance

Meeting this prerequisite required more additional first cost than any other single LEED feature. The extra cost of the larger air handling unit and extra ducting required to supply fresh outside ventilation air to the student rooms was estimated by the project HVAC Engineer to be roughly $25,000 (Stewart, 2003). Project Manager for New House, Peg Hart, reported that an estimate of the extra cost for meeting this credit was reported to be $100,000 (Bohlin Cywinski Jackson, 2003). These two estimates provide the low and high extra cost values associated with this prerequisite.

4.5.2 Prerequisite 2: Environmental Tobacco Smoke Control

Because this prerequisite was achieved by establishing a non-smoking policy for New House, there was no additional cost.

4.5.3 Credit 1: Carbon Dioxide Monitoring

Installing carbon dioxide monitors in the return ducts for the air handling units serving the common spaces on the first floor, as well as the meter which measures outdoor ambient carbon dioxide levels, resulted in additional cost since they would not have normally been installed on systems the size of those in New House. The four return duct CO_2 monitors cost around $300 per meter, including installation, for a total of $1,200. The outdoor CO_2 monitor also cost around $300 (Campise, 2004a). The total extra cost associated with this credit, then, was approximately $1,500.

4.5.4 Credit 2: Increased Ventilation Effectiveness

Because designing to the ASHRAE ventilation effectiveness standard referenced in this credit is conventional building practice, there was no additional cost associated with gaining this LEED credit in New House.

4.5.5 Credit 3: Construction Indoor Air Quality Management Plan

4.5.5.1 Credit 3.1: During Construction

Replacing the filters in the building air handling units and placing filters over every diffuser required substantial labor and material costs that would not have been necessary if LEED had not been a goal. A representative from James E. Huckestein, the subcontractor responsible for Construction IAQ Management in New House, estimated that the total cost for the filters used was around $8,000, and that the total labor for covering and uncovering the diffusers and replacing the air handling unit filters was around 208 hours at a cost of $65 per hour (Bennett, 2004). This equates to a total cost of $21,520 above normal building practice to obtain this LEED credit.

4.5.5.2 Credit 3.1: Before Occupancy

Because New House was completed during the summer, when no students would be occupying the building anyway, Carnegie Mellon was able to perform the two-week flush-out of the building required to meet this credit without any additional cost. If the timing had not been as favorable, the school might have had to pay for temporary housing for the building residents in order to meet this credit requirement (Bohlin Cywinski Jackson, 2003).

4.5.6 Credit 4: Low Emitting Materials

4.5.6.1 Credit 4.1: Adhesives and Sealants

Specifying adhesives and sealants that meet the VOC limits required to achieve this credit did not result in significant extra costs. The low-VOC carpet adhesives used cost roughly $2 per 4-gallon pail more than traditional carpet adhesives. Each 4-gallon pail can cover approximately 40 square yards (Rendulic, 2004). Since New House contains approximately 7100 square yards of carpeting, the total additional cost for using low-VOC carpet adhesives was approximately $355. The water-based low-VOC concrete sealants used in New House are fairly common, and would have likely been used in a typical building (Sabatos, 2004b).

4.5.6.2 Credit 4.2: Paints

Representatives from Patrino's Painting, the painting subcontractor for New House, estimate that low-VOC paints currently cost approximately 20% more than traditional paints. Since a painting contract cost is typically 75% labor cost and 25% materials cost, the total LEED premium on a painting contract for using low-VOC paints is approximately 5% (Ball, 2004). Patrino's contract cost for New House was $88,000, so assuming this contract included a 5% premium for low-VOC paints, the contract for using traditional paints in New House would have been roughly $83,810. The premium for using low-VOC paints in New House, then, was approximately $4,190.

4.5.6.3 Credit 4.3: Carpet

All new carpeting is required to pass the Carpet and Rug Institute's Green Label Indoor Air Quality Tests according to a representative from Wright Contract Interiors, the subcontractor responsible for the carpeting used in New House (Rendulic, 2004). Because low-VOC carpet is standard, there was no additional cost associated with this credit.

4.5.6.4 Credit 4.4: Composite Wood

The kitchen cabinets, the only items in which composite wood was used in New House, were constructed by Allegheny Millwork. The extra cost associated with using composite wood having no added urea formaldehyde is estimated as being 50% of their total LEED contract premium (see Section 4.4.5). The premium for using composite wood with no added urea-formaldehyde in New House was between $4,060.00 and $4,816.50.

4.5.7 Credit 6.1: Controllability of Systems, Perimeter

Because each student room would have been equipped with lighting controls and operable windows regardless of the decision to seek LEED Certification, there was no extra cost associated with gaining this credit in New House.

4.5.8 Credit 7: Thermal Comfort

4.5.8.1 Credit 7.1: Comply with ASHRAE 55-1992

While the temperature set-points dictated by the referenced ASHRAE standard are common practice, meeting the humidity control requirement did result in an additional cost over typical building practice. In order to maintain appropriate humidity levels in New House, a humidifier was installed on the air handling unit serving the student rooms and corridors. This humidifier was built into the air handling unit, so an exact cost for the unit is difficult to determine. The mechanical engineer for the New House project estimated that the system would have cost around $8,000 less if no humidifier had been installed in order to achieve this credit (Stewart, 2004).

4.5.8.2 Credit 7.2: Permanent Monitoring System

Permanent monitoring of HVAC equipment is standard practice at Carnegie Mellon (Bohlin Cywinski Jackson, 2003). However, because New House would not have had a humidifier had LEED not been a goal, the cost of the humidity sensors can be considered above and beyond the typical permanent monitoring costs. The humidity sensors for New House resulted in an extra $1,500 (Campise, 2004a).

4.5.9 Credit 8.2: Daylight and Views, Views for 90% of Spaces

Since the building envelope and floor plans for New House, including the placement of windows, were developed before the decision to seek LEED Certification, there was no additional cost associated with this credit (Hart, 2004).

4.6 Innovation and Design Credits Extra Cost Calculations

As stated in Section 3.6, the LEED Accredited Professional for the New House project was John Stewart, the project mechanical (HVAC) engineer. Because Mr. Stewart has worked with

Carnegie Mellon on a number of projects, and would likely have been the HVAC engineer for New House even if LEED had not been a goal, there was no additional cost associated with this credit.

4.7 LEED Documentation and Certification Extra Cost Calculations

Compiling the LEED submittal documentation for New House was a major source of additional labor cost. The LEED submittal was handled primarily by the project architect, who charged Carnegie Mellon an additional $25,000 for the work. By the architect's estimate, this was only approximately half of the cost of doing the certification. The architect accepted the lower payment because they had never compiled a LEED submittal before, so the project also provided them with experience in the process. The high end estimate of $50,000 reflects what the architect's service would have cost at full rate (Bohlin Cywinski Jackson, 2003). These figures include the documentation work performed by the HVAC engineer (Stewart, 2003).

Members of the project team from Rycon Construction, the general contractor for New House, also contributed to compiling the LEED submittal. Rycon, however, did not add an additional fee to their contract for work relating specifically to the documentation, so there was no additional cost to Carnegie Mellon for their work on the LEED submittal. By their estimates, Rycon incurred an additional $11,000 in administrative costs relating to the LEED documentation (Sabatos, 2004a). This amount is added to the high extra cost estimate for the project, since in the future the general contractor would likely include these fees in their contract proposal.

Some pages and sections of the LEED submittal for New House were compiled by members of the Carnegie Mellon community, mostly from Facilities Management Services. Records of the amount of time spent internally on the LEED documentation do not exist, and because the work was distributed between different members it was not possible to achieve any reliable estimate of the extra cost incurred by Carnegie Mellon internally for this work.

Finally, any project certified under the LEED system must pay a registration / certification fee of $1,800 to the U.S. Green Building Council to cover the administrative costs involved with reviewing the LEED submittal.

5.0 Energy Modeling

The energy savings estimates documented in Energy and Atmosphere Credit 1 were made using the DOE2.1 building energy simulation program (LBNL, 2004). For application of the model, building features are defined in an input file, including floor plans, wall and roof construction, material properties, window placement, mechanical system specifications, lighting power use, and schedules for both occupancy and equipment. A weather file is also defined which provides hourly temperature, humidity and sunlight levels for a period of one year. Given these inputs, the DOE2.1 program performs a simulation that calculates the energy used in the building every hour for the year, and delivers summarized reports of the energy used for different purposes.

To gain LEED credits for optimized energy performance, New House was compared to an Energy Cost Budget Building, defined by ASHRAE/IESNA Standard 90.1-1999, that has the same floor plan. This simulation for New House, performed by the Carnegie Mellon Center for Building Performance and Diagnostics, calculated a 33% improvement in efficiency compared to the ASHRAE budget building. This information, while valuable for comparing and quantifying the energy efficiency of different buildings (comparing the effectiveness of the energy saving measures used in New House to those used in another green building) it is not particularly useful in determining the energy savings for Carnegie Mellon because a new residence hall would have been more energy efficient than the ASHRAE budget building even if LEED had not been a goal. In order to determine any energy savings or costs associated with making New House a LEED Silver Certified building, this research project included modifying the model to approximate how a typical Carnegie Mellon residence hall would likely have been constructed, and performing another energy simulation based on this new model. Further comparison was also done to estimate the impact that various energy saving measures have on the overall energy use in the building. The following sections describe these different building models and compare their estimated energy performance. The DOE2.1 input and output files and the spreadsheets used for the post-processing are available online through the Carnegie Mellon Green Practices website, http://www.cmu.edu/greenpractices/; descriptions of the available documents are included in Appendix A.

5.1 Description of Energy Models

The energy modeling for New House actually involved two separate processes: creating and running the DOE2.1 simulations and then post-processing the hourly data from the model. This second step was necessary because DOE2.1 does not have the capability to simulate the desiccant heat recovery system that is installed on the main AHU that serves the student rooms and upstairs corridors and bathrooms. Therefore, the only way to get an accurate estimate of the energy used for heating and cooling in New House was to calculate the energy saved using the heat recovery wheels by comparing the enthalpy of the supply and return air flows in the main AHU and then subtracting that savings from the energy use reported by DOE2.1. Because it is possible that some sort of heat recovery system would have been installed even if the main AHU was smaller and served only the student rooms, it was necessary to perform post-processing work on the energy model output created during this research project as well. A description of the post-processing technique used for this research is given in Section 5.1.2.

5.1.1 Description of DOE2.1 Building Inputs

Table 5.1, taken from the LEED submittal for the project, shows the differences between the New House energy model and the ASHRAE Budget Building energy model.

All of the energy models created for this research project were adapted from the model of New House. The following sections describe the changes made to the New House model for each of the energy-related design alternatives considered, named Building A, B, C and D.

5.1.1.1 Building A Energy Model

Building A is the same as the New House model, except that the main air handling unit no longer provides fresh air to the dormitory rooms, providing instead only the amount of air to the social areas, study area and corridors that is required to properly ventilate the restrooms. The airflow of the AHU is reduced accordingly: the supply airflow rate from 11850 CFM to 7830 CFM, and the return airflow rate from 10150 CFM to 7830 CFM. Note that in New House, the differential between the supply and return airflow rates is due to the fact that the dormitory rooms are positively pressurized. Because they no longer receive forced ventilation air and thus do not need this pressure differential the supply and return rates for the Building A model are the same.

5.1.1.2 Building B Energy Model

The model for Building B is the same as the model for Building A (with no forced ventilation to the dorm rooms) except that Building B does not have the highly reflective roof, but rather the same roof construction as the ASHRAE Budget Building. This affects not only the reflectivity, but also the thermal resistance of the roof. Building B most accurately represents how New House would have been designed if LEED Certification had not been a goal.

Table 5.1: Differences between New House and ASHRAE Budget Building Energy Models

Category	New House	ASHRAE Budget Bldg.
External Wall		
Roof	24.6 R-Value	15 R-Value
Basement Wall	10 R-Value	
Glass / Curtain Wall	U = 0.51, SC = 0.44	U = 0.67, SC = 0.45/0.57
Lighting	0.3 W/sqft – Dorms 2.29 W/sqft – 1st floor office 1.02 W/sqft – Dining/Kitchen 0.38 W/sqft – Mid staircase, floors 2-5 1.17 W/sqft – Reading room 1.08 W/sqft – Lounge/Rec. room 0.75 W/sqft – End staircases 0.19 W/sqft – Mid staircase, 1st floor 0.72 W/sqft – Entrance 1.17 W/sqft – 1st floor corridor 0.98 W/sqft – Other corridors 0.93 W/sqft - Basement	1.5 W/sqft
Roof Reflectance	0.45	0.3
HVAC System	AHU with energy recovery wheel supplying outside air to the dorms, social area, study area	
	Fan coil units for dorms, social area, study area	Packaged terminal air-conditioning (PTAC) for dorms, social area, study area with outside air CFM same as that provided by AHU with energy recovery wheel
	AHU for reading room	PTAC for reading room
	AHU for TV lounge + rec. room	PTAC for TV lounge + rec. room
	AHU for dining room + kitchen	PTAC for dining room + kitchen

5.1.1.3 Building C Energy Model

Building C was set up to investigate energy savings resulting from the use of the Low-E coated windows that were selected for New House when compared to the ASHRAE Budget Building's standard windows. This model is the same as that of Building B except that the ASHRAE windows (U=0.67, SC=.045/.057) are used instead of the windows that were used in New House (U=.051, SC=.044). While the choice of windows in New House was not greatly influenced by the decision to do LEED, this model was created simply to see what impact the Low-E coated windows have on energy use.

5.1.1.4 Building D Energy Model

Building D is the same as Building C except that the lighting wattage per square foot was changed to the ASHRAE standard of 1.5 W/sqft as opposed to the low-wattage lighting power used in the New House model. Again, New House would have most likely had the same lighting fixtures and bulbs installed if LEED had not been a goal, so this model is purely for the sake of testing the impact of low-wattage lighting on energy use.

5.1.2 Description of Heat Recovery System Calculations

In the LEED documentation for New House the total energy savings from the heat recovery system was calculated to be 1904.3 MBTU per year: 1804.7 MBTU savings for space heating, 23.8 MBTU for space cooling, 6.1 MBTU for heat rejection equipment, and 69.7 MBTU for pumps. Unfortunately, documentation of how these savings were calculated does not exist in any complete form. The only documentation that could be located was a preliminary spreadsheet used to calculate the space heating and space cooling savings. This spreadsheet showed the general method used to calculate the heating and cooling savings, but the final calculated values for heating and cooling savings do not match those reported in the LEED documentation.

Because of the lack of documentation, it was necessary to start essentially from the beginning and redo the heat recovery energy savings calculations for this research project, using the available spreadsheet as a guide.

A method for calculating the energy savings gained from an air-to-air heat recovery system is outlined in the ASHRAE Systems and Equipment Handbook (ASHRAE, 2000). This method involves finding a theoretical maximum heat transfer and then multiplying that value times the efficiency of the heat recovery system. The equation used to calculate the maximum possible energy transfer between the two air streams is:

$$q_{max} = 60*\rho*Q(h_1 - h_2) \tag{5.1}$$

Where q_{max} is the maximum possible heat recovered (in BTU per hour), ρ is the density of the airstreams, Q is the airflow rate in cubic feet per minute, and h_1 and h_2 are the enthalpies of the hot and cold airstreams. The airflow rate Q for the main AHU is reported by DOE2.1 as a constant 12324 CFM. It is impractical to attempt to calculate the exact density ρ for the airstreams because the density of moist air depends on the humidity level and the temperature, each of which change for every hour that the simulation runs. Using a table to calculate the density for every hour for the year would be extremely time consuming. Therefore, we assume a constant value of 0.075 lb/ft^3, which is an average value for moist air at atmospheric pressure.

DOE2.1 does not report the enthalpy of the supply or return airstreams for a given system, so the values of h1 and h2 must be calculated from the air temperature and humidity (which are reported by DOE2.1). The specific enthalpy of moist air is defined as:

$$h = h_a + w*h_w \tag{5.2}$$

Where h is the specific enthalpy of moist air, h_a is the specific enthalpy of dry air, w is the humidity level and h_w is the specific enthalpy of water vapor. The values for h_a and h_w can be calculated from the temperature of the moist airstreams reported by DOE2.1 using the following equations:

$$h_a = T*c_{pa} \tag{5.3}$$

$$h_w = T*c_{pw} + h_{we} \tag{5.4}$$

For the above equations, T is the temperature of the air reported by DOE2.1 in degrees Fahrenheit. The specific heat of air c_{pa} is assumed to be a constant 0.24 BTU/lbm-^oF, and the specific heat of water vapor c_{pw} is assumed to be a constant 0.444 BTU/lbm-^oF. The evaporation heat of water h_{wa} is assumed to be a constant 1061 BTU/lbm. Given the above equations, the final equation used to calculate the enthalpy of the air was:

$$h = T*0.24 + w(1061 + 0.444*T) \tag{5.5}$$

The values of T and w for the incoming outdoor air are taken from the hourly report delivered by DOE2.1. For the return exhaust air, the temperature and humidity are assumed to be constant at the optimal temperature and humidity level set-points. The optimum temperature and humidity levels for New House’s HVAC system are 75 degrees Fahrenheit and 0.009 lb water / lb dry air, respectively. The enthalpy of the exhaust air stream through the heat recovery system is also constant.

Using Equations 5.1and 5.5, the maximum theoretical heat transfer between the incoming outdoor and exhaust airstreams was calculated. This maximum value was then multiplied by the effectiveness of the heat recovery system, which is supplied by the manufacturer. The heat recovery system used in New House has an effectiveness of 78%, so the heat recovered is:

$$q_{rec} = 0.78*q_{max} \qquad (5.6)$$

The above equations were used to calculate the total heat recovered for every hour for the entire year. This value was then compared to the values for heating and cooling energy in the main AHU reported by DOE2.1. Since these heating and cooling energy use values represent the amount of energy that would go into heating or cooling the incoming outdoor air *without the heat recovery system*, the actual energy input needed to heat or cool the incoming outdoor air is the difference between the value reported by DOE2.1 and the calculated q_{rec}. In other words, during the heating season, the actual energy used by the heating coils in the main AHU is the difference between the reported heating energy input (from DOE2.1) and the calculated heat recovery. If the heat recovered is greater than the reported heating energy input, then the heating coils in the main AHU are not needed at all, and the actual heating energy use is zero. The same idea applies to cooling season where energy is transferred from the incoming hot air to the cool exhaust air.

The energy savings, then, are the difference between the energy use reported by DOE2.1 and the calculated actual energy use. It is worth noting that according to the above calculation, the heating coils in the main AHU are *never* necessary as long as the heat recovery system is working. All of the heating energy needed for the zones served by this unit is used by the fan-coil units in those spaces.

This method for calculating the energy savings from the heat recovery system for the New House model yields results similar to those reported in the LEED documentation for the building. The heating savings calculated are slightly less than those reported in the LEED documentation (56.9 MBTU/year), and the cooling savings are slightly higher (325.5). Because documentation does not exist for the original calculations, the source of these discrepancies is unknown. The report submitted for LEED documentation also shows energy savings in the pumps and heat rejection equipment in the building. Methods for calculating this energy savings could not be determined and no documentation exists, so any energy savings in the heat rejection equipment or pumps was ignored in the models created for this project.

5.2 Energy Use for Each Model

The following table shows the simulated yearly energy use (in MBTU) for each of the building models as reported by DOE2.1. This table does not take into account the heat recovery system.

Table 5.2: Energy Usage Reported by DOE2.1 (MBTU)

	New House	Bldg A	Bldg B	Bldg C	Bldg D	ASHRAE
Area Lights	928.4	928.4	928.4	928.4	1747.2	1931.6
Misc Equipment	889.3	889.3	889.3	889.3	889.3	889.3
Space Heat	2344.2	1662.8	1686.5	1737.4	1577.5	2054.5
Space Cool	508.7	516.0	518.7	510.4	686.5	652.2
Heat Reject	129.2	139.4	139.6	136.3	180.5	0.0
Pumps & Misc	137.3	109.0	109.9	111.6	119.3	31.9
Vent Fans	861.8	611.8	612.5	613.5	630.1	533.3
Total	**5798.9**	**4856.7**	**4884.9**	**4926.9**	**5830.4**	**6092.8**

As one would expect, the space heating energy for the New House model is larger than for Buildings A-D because of the increased outside air flow. This also accounts for the increased energy used by the ventilation fans.

Table 5.3 reflects the energy use after taking into account the energy savings from a heat recovery system. Note that the ASHRAE building is eliminated from the calculations since the budget building does not have a heat recovery system.

Table 5.3: Energy Usage after Heat Recovery System Calculations (MBTU)

	New House (LEED report)	New House (new calc)	Bldg A	Bldg B	Bldg C	Bldg D
Area Lights	928.4	928.4	928.4	928.4	928.4	1747.2
Misc Equipment	889.3	889.3	889.3	889.3	889.3	889.3
Space Heat	539.5	596.4	508.5	532.2	583.1	423.22
Space Cool	484.9	159.4	276.3	279.0	270.7	446.82
Heat Reject	123.2	129.2	139.4	139.6	136.3	180.5
Pumps & Misc	67.6	137.3	109.0	109.9	111.6	119.3
Vent Fans	861.5	861.8	611.8	612.1	613.5	630.1
Total	**3894.4**	**3701.8**	**3462.7**	**3490.5**	**3532.9**	**4436.4**

Figure 5.1 presents the yearly energy usage values for each building. The bars to the left of the ASHRAE budge building are for the energy use reported by DOE2.1, the bars to the right are the energy use after the calculated energy savings due to heat recovery.

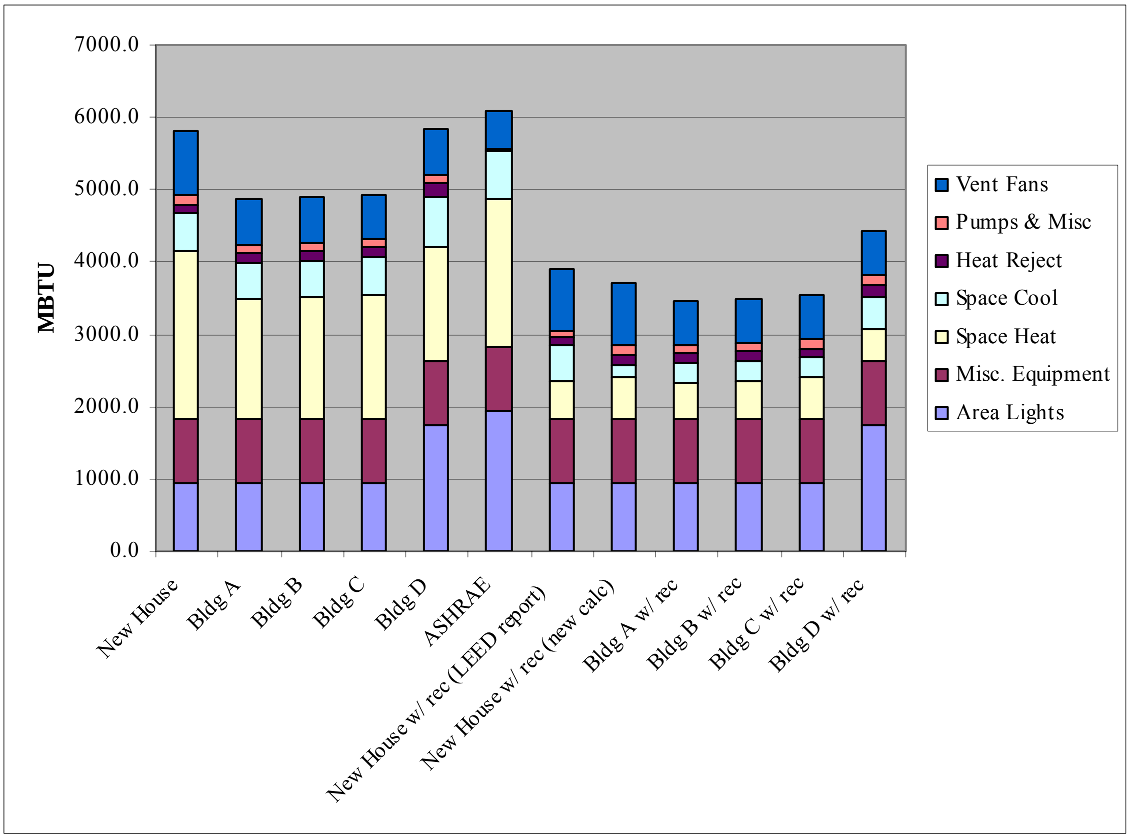

Figure 5.1: Building Model Energy Use by Category

Figure 5.1 reveals that the energy savings (or extra energy use) of New House when compared to a similar non-LEED Carnegie Mellon residence hall are greatly influenced by whether or not a heat recovery system would have been installed in a typical building. If it is assumed that the heat recovery system would have been eliminated had LEED not been a goal (as represented in the third column of Figure 5.1: Building B), then the energy modeling predicts that New House is 20.3% or 24.2% more efficient than a similar non-LEED Carnegie Mellon building when compared to the New House energy use reported in the LEED documentation or the energy use calculated during this project, respectively.

If, however, we assume that the heat recovery system would have been included regardless of the LEED goal, then the energy modeling predicts that New House is slightly less efficient than a typical Carnegie Mellon building would have been. When compared to the Building B with energy recovery model (the tenth column in Figure 5.1), New House uses 6% or 12% more energy per year depending on whether it is compared to the New House energy use calculated during this project or that reported in the LEED documentation respectively.

These numbers, however, do not reflect a fully accurate picture of the difference in energy use between New House and a typical Carnegie Mellon building due to a limitation in the energy modeling program. While the program is able to account for fresh air coming into the building through the ventilation system, it does not account for outdoor air that enters when students open their room windows. This is significant in the case of New House because it is likely that if the student rooms were not provided with fresh air through the ventilation system it would result in the students opening their windows more often because the air in the dorm rooms would feel stagnant. This direct outside air would require increased energy use in the fan-coil units which provide heat for the student rooms that is not reflected in the energy modeling (Stewart 2004b). Considering that New House spends much of the year being heated (thanks to the Pittsburgh climate), it is easy to imagine that cold winter air entering the building through windows opened to avoid hot, stagnant air could result in a major increase in heating loads. Quantifying this additional energy use would require energy modeling expertise and time beyond the scope of this project, but would be an interesting area for future work.

Along with this energy use comparison information, the energy modeling also provided information on which of the energy saving measures implemented in New House resulted in the greatest gains in efficiency. Comparing the first column of in the figure to the seventh and eighth columns (New House without the heat recovery system compared to New House with the heat recovery system) demonstrates the large impact that the heat recovery system on main air handling unit had on the building's energy use.

Examining columns eight, nine and ten reveals the energy savings resulting from the highly reflective and insulated roof and the use of windows with low-emissivity coatings. The white PVC roof resulted in an approximate energy savings of 28 MBTU/year, or around 0.8%, compared to a building with a traditional black EPDM roof. The use of Low-E coated glass windows provided additional savings of roughly 42 MBTU/year, around 1.2%, when compared to the windows specified for the ASHRAE budget building.

The energy modeling also revealed the importance of the low-wattage compact florescent lighting fixtures in reducing energy costs. While the heat gain from the higher wattage light fixtures would reduce heating loads in the building (compare columns 10 and 11 in Figure 5.1), the additional energy needed to run the lights and the extra energy required to cool the building during the summer far outweigh the reduction in heating load.

5.3 Energy Cost Implications

From the energy modeling results it is possible to determine the additional yearly energy costs associated with making New House a LEED Silver building. According to the LEED documentation, the electricity cost is $18.50 per MBTU, and the cost for the district steam used for space heating is $7.23 per MBTU.

For the Building B model, which represents a non-LEED Carnegie Mellon residence hall with the same physical layout as New House and excluding any heat recovery system, the estimated annual electricity cost is $56,588 and the annual steam cost is $12,193, for a total annual energy cost of $68,781.

For the Building B with heat recovery model, which represents a "typical" Carnegie Mellon building having the same physical layout as New House and including a heat recovery system, the calculated annual electricity cost is $52,145 and the annual steam cost is $3,847, for a total estimated yearly energy cost of $55,993.

For New House as designed, the annual electricity cost is calculated as $55,059 and the steam cost is $4,294, for a total annual energy cost estimate of $59,353. In the LEED documentation, the New House as designed energy use is reported as follows: the electricity cost is $59,786 annually and the steam cost is $3,900, for a total annual cost of $63,687. If one also takes into account the additional estimated $5,050 additional electricity cost associated with purchasing wind generated energy for half of New House's electricity use (see Section 4.3.7 for explanation of this additional cost), the total yearly energy costs for New House can be estimated at between $64,403 and $68,737.

Therefore, when compared to a similar non-LEED Carnegie Mellon building without a heat recovery system, New House has an estimated annual energy savings of $44 to $4,378. This seems low for the relatively large percentage total energy savings because the non-LEED building uses more steam and less electricity than New House and the cost per MBTU of steam is less than half of the cost per MBTU of electricity, and also takes into account the increase in electricity cost due to the use of renewable energy. If it is assumed that a typical Carnegie Mellon residence hall would have had a heat recovery system, then the energy modeling predicts an annual energy cost premium of $8,410 to $12,744 for the larger ventilation system and improved indoor air quality in the dormitory rooms.

Again, however, these figures reflect only the changes in energy use that could be modeled, and do not include the possible increase in heating and cooling energy resulting from increased direct outside air infiltration through open windows in dorm rooms with stagnant air. In addition, the measurement and verification equipment has the potential to generate long-term energy savings by helping building personnel to identify operating and equipment problems that might otherwise go unnoticed. If a heating unit or chiller were to be damaged, for example, so that it was running at less than peak efficiency but continued to function, the increase in its energy use would be recorded and thus the problem could be identified and fixed. If there were no system of measurement installed, such a problem might go unnoticed for some time and result in significant excess energy cost. Similarly, the systems commissioning and additional commissioning have the potential to save long-term energy costs by identifying operating problems and inefficiencies (Stewart 2004b). Because New House has only been operating for a year it is impossible to speculate how much these saving may amount to over the life of the building. In future years, a study of all equipment and operating problems identified by the measurement and verification system and the commissioning and re-commissioning of the building would be a valuable piece of the Green Building cost puzzle.

6.0 Summary and Conclusions

In total, making New House a LEED Silver certified dormitory resulted in an extra first cost of between $129,744 and $347,118 when compared to a similar non-LEED Carnegie Mellon residence hall. The additional cost represents a premium of 1% to 2.8% of the total project cost, including design and construction, consistent with the premium costs quantified for other LEED projects in the U.S. The largest increases in first cost came from the increased size of the forced air ventilation system equipment ($25,000 - $100,000), labor spent compiling the LEED submittal documentation ($25,000 - $61,000), and commissioning costs ($5,827 - $65,000). While the design features implemented to achieve LEED Silver certification in New House resulted in a modestly higher project cost, the additional first costs yielded a wide range of benefits including improved quality of life for building occupants though reductions in indoor air pollution and access to exterior views, and in lower environmental impacts through use of local manufacturers, selection of recycled or recyclable materials, use of sustainably harvested wood products, and reduction of fossil fuel use through energy efficiency measures and renewable energy use.

New House is 20.3% to 24.2% more energy efficient than a similar non-LEED Carnegie Mellon residence hall that does not incorporate a heat recovery system on its main AHU. This equates to an estimated annual energy savings of $44 to $4,378. If it is compared to a similar non-LEED Carnegie Mellon building that is equipped with a heat recovery system, New House is estimated to use 6% to 12% more energy, for an annual energy cost premium of $8,410 to $12,744. These cost savings or premiums do not take into account the possible increase in heating and cooling energy due to increased direct outdoor airflow through open windows that might result from the removal of the forced air ventilation into the student rooms. It also does not include savings realized by catching operational inefficiencies though the use of measurement and verification systems and commissioning efforts. Any increased energy costs are a result of the LEED requirement for increased fresh outdoor air supply to the student rooms, which results in greater cooling and heating loads and ventilation fan electricity use, and the purchasing of green power generated by wind energy.

Examination of the areas of greatest additional first cost leads to a number of insightful conclusions. First, because the forced air ventilation system which provides fresh air to the student dorms was such a large contributor to additional first costs, in future green projects the cost of meeting the LEED ventilation requirements might be lessened through the use of natural ventilation methods. Secondly, the large extra costs associated with compiling the LEED submittals suggests that if a method could be developed to streamline the documentation process, it could result in significantly smaller labor costs. As LEED certification becomes more widespread and more industry professionals are familiar with the submittal documentation process, the time required to compile the documentation will also likely decrease.

For the annual energy savings, one way in which New House could have been made more energy efficient would have been to change the exterior wall construction to allow for more insulation. The envelope of the building, including wall construction and window placement, was actually designed before the decision to seek LEED certification had been made. The Project Manager for

New House, Peg Hart, suggested that one way the building might have been designed differently if the LEED goal had been in place from the beginning of the project is that rather than having the exterior walls be the load-bearing walls, the interior walls, between the dormitory rooms, might have been designed as the main structural elements. If the building had been designed as such, it would have allowed additional insulation to be added to the exterior walls, which could potentially have lowered the heating and cooling loads and allowed for smaller HVAC equipment.

7.0 References

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Appendix A: Energy Modeling Input, Output and Calculation Files

The following files associated with the DOE2 energy modeling performed in conjunction with this study are available at the Carnegie Mellon Green Practices web site, where this report is also posted: http://www.cmu.edu/greenpractices

ASHRAE.inp – DOE2.1 building input file for ASHRAE energy cost budget building
ASHRAE.OUT – DOE2.1 output file for ASHRAE energy cost budget building

New_House.inp – DOE2.1 building input file for New House as designed
New_House.OUT – DOE2.1 output file for New House as designed
New_House Calculation Sheet.xls – Calculation spreadsheet for New House heat recovery system

BLDG_A.inp – DOE2.1 building input file for Building A model
BLDG_A.OUT – DOE2.1 output file for Building A model
BLDG_A Calculation Sheet.xls – Calculation spreadsheet for Building A heat recovery system

BLDG_B.inp – DOE2.1 building input file for Building B model
BLDG_B.OUT – DOE2.1 output file for Building B model
BLDG_B Calculation Sheet.xls – Calculation spreadsheet for Building B heat recovery system

BLDG_C.inp – DOE2.1 building input file for Building C model
BLDG_C.OUT – DOE2.1 output file for Building C model
BLDG_C Calculation Sheet.xls – Calculation spreadsheet for Building C heat recovery system

BLDG_D.inp – DOE2.1 building input file for Building D model
BLDG_D.OUT – DOE2.1 output file for Building D model
BLDG_D Calculation Sheet.xls – Calculation spreadsheet for Building D heat recovery system