CHAPTER 6
GREEN BUILDING CERTIFICATION SYSTEMS AND RESOURCES

6.0 INTRODUCTION

Several green building rating systems are available to guide the design, construction, and operation of high-performance green buildings. The U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design's (LEED) green building rating system is the best known of these systems. The Green Building Initiative (GBI) Green Globes Rating system is an alternative approach that roughly parallels the LEED system in its details. Some of these rating systems are designed specifically for the creation of sustainable schools, and they take into consideration the unique needs of a learning environment. Other rating systems have been developed to guide the design and construction of high-performance commercial or institutional buildings, and they can be easily applied to the design of green educational facilities.

These rating systems illustrate the best practices for development of high-performance school facilities. If an owner desires recognition from a third-party that a school or other building is indeed "green," these rating systems provide for a review of the design and construction process, as well as an award of a designation certifying the achievement level of the building. The LEED rating system awards Certified, Silver, Gold, and Platinum designations, in ascending order of achievement. In a similar fashion, Green Globes provides one to four "Green Globes." Certification requires verification that the specified guidelines were followed and involves the payment of a fee. In this chapter, the major rating systems are introduced, and a case study is provided of the application of LEED to a recent school project in Florida.

6.1 GREEN BUILDING CERTIFICATION SYSTEMS

The green building rating systems applicable to new school construction in Florida are:

1) LEED 2009 for New Construction and Major Renovations
2) LEED 2009 for Schools New Construction and Major Renovations
3) Green Globes for New Construction
4) Florida Green Building Coalition Green Building Commercial Standard

6.1.1 LEED 2009 for New Construction and Major Renovations (LEED-NC 2009)

LEED is actually a suite of rating systems that can be applied to specific building types. LEED for New Construction and Major Renovations 2009 (LEED-NC 2009) was designed to guide new construction and major renovations in the development of high-performance commercial and institutional projects. LEED-NC 2009 may apply to new school buildings; for example, a new administrative building on a middle school campus. The next section describes LEED for Schools 2009 (LEED-S 2009), which applies to the design and construction of buildings containing student instructional spaces. The LEED-NC checklist (http://www.usgbc.org/ShowFile.aspx?DocumentID=5719) provides an outline of the categories and the respective prerequisites and credits that are required to construct a certifiable high-performance green building.

The checklist is divided into seven categories: 1) Sustainable Sites, 2) Water Efficiency, 3) Energy and Atmosphere, 4) Materials and Resources, 5) Indoor Environmental Quality, 6) Innovation and Design, and 7) Regional Priority Credits. In each category, all prerequisites must first be met to receive any points for credits in that category. Points for all categories are totaled and the level of certification is determined as follows: Certified, 40 to 49 points; Silver, 50 to 59 points; Gold, 60 to 79 points; and Platinum, 80 to 110 points. Projects are tracked online and all necessary forms and documentation are submitted electronically. Documentation must be submitted for each of the prerequisites and credits to prove how each was attained. A third-party reviewer assesses the project documentation and determines the certification level. Fees are required for registration and certification, which are based on USGBC membership and building size.

Application:

LEED-NC 2009 is designed for the construction and major renovations of commercial and institutional projects. This type of certification would apply for administrative buildings for schools; however, this certification does not apply to K-12 school buildings containing instructional spaces for students. A checklist and guidelines can be found at http://www.usgbc.org/ShowFile.aspx?DocumentID=5719.

6.1.2 LEED 2009 for Schools New Construction and Major Renovations (LEED-S 2009)

The USGBC developed LEED for Schools 2009 (LEED-S 2009) specifically for the design and construction of educational institutions. LEED-S 2009 has a structure similar to LEED-NC 2009, but takes into consideration the unique features of a teaching and learning environment, for example, the acoustical design. The checklist for LEED-S 2009 is divided into the same seven categories as LEED-NC 2009: 1) Sustainable Sites, 2) Water Efficiency, 3) Energy and

Atmosphere, 4) Materials and Resources, 5) Indoor Environmental Quality, 6) Innovation and Design, and 7) Regional Priority Credits. A few added prerequisites and credits have been added for LEED-S 2009 compared to LEED-NC 2009, which include school specific features, such as joint use of facilities, acoustical performance, mold prevention, and using the school as a teaching tool.

The levels of certification for LEED-S 2009 are the same as for LEED-NC 2009: Certified, 40 to 49 points; Silver, 50 to 59 points; Gold, 60 to 79 points; and Platinum, 80 to 110 points. Projects can be tracked online and all necessary forms and documentation can be submitted electronically. Documentation must be submitted for each of the prerequisites and credits to prove how each was attained. A third-party reviewer assesses the project through documentation and determines the certification level. Fees are required for registration and certification, which are based on USGBC membership and building size.

Application:
LEED-S 2009 is designed solely for the construction of educational institutions, such as K-12 schools, daycares, or higher education buildings. A checklist and guidelines can be found at https://www.usgbc.org/ShowFile.aspx?DocumentID=5721.

6.1.3 Green Globes for New Construction (Green Globes-NC)
Green Globes-NC is an online tool used to help design and build new construction or major renovation projects while minimizing environmental impact and promoting sustainability. Green Globes assesses seven different areas: 1) Energy, 2) Indoor Environment, 3) Site, 4) Resources, 5) Water, 6) Emissions and Effluents, and 7) Project Management. These areas are rated on a 1,000-point scale: the Energy category has the most available points at 360 while Project Management has the least available points at 50. The points received in all categories are totaled and the percentage of 1,000 points is calculated to determine which rating a building can receive. Similar to the LEED process, one Green Globe is awarded for achieving at least 35% of the total points, two Green Globes for 55%, three Green Globes for 70%, and four Green Globes for 85% and higher. Green Globes allows online project tracking, as well as the uploading of documentation necessary to achieve certification. A third-party reviewer assesses the project documentation and determines the certification level. After documentation has been reviewed, an on-site walk-through must be completed. Charges include a third-party assessment fee and an annual per building license fee for using the online tool.

Application:
Green Globes-NC is designed to guide the design and construction for new buildings and major renovations of commercial projects. A checklist and guidelines can be found at http://www.thegbi.org/assets/pdfs/Green-Globes-NC-Pre-3rdParty-Assessment-Checklist-031809.pdf.

6.1.4 Florida Green Building Coalition (FGBC) Green Building Commercial Standard
The Florida Green Building Coalition (FGBC) developed the Green Building Commercial Standard to encourage the sustainable design and construction of small commercial projects. FGBC

supplies a reference guide and a checklist outlining the prerequisites and credits necessary for certification. The checklist is divided into seven categories: 1) Energy, 2) Water, 3) Site, 4) Health, 5) Materials, 6) Disaster Mitigation, and 7) General. Of 100 possible credits, a building must receive at least 50 credits to be considered certified. Certification has only one level. As is the case with other building assessment systems, paperwork documenting how each credit was achieved must be submitted to FGBC. A Project Evaluator is assigned to the project and verifies all documentation and determines if the project has met the minimum of 50 points necessary for certification.

Application:
The FGBC Green Commercial Building Standard was developed to guide the design and construction of commercial occupancy buildings, as listed in the Florida Building Code. A checklist and guidelines can be found at http://floridagreenbuilding.org/files/1/File/Standard_Commercial/Version1/Commercial_v1_Checklist2010.pdf.

6.2 GREEN BUILDING RESOURCES

In addition to green building rating systems, non-certifying resources and guidelines are available. These resources offer recommendations to follow when constructing a high-performance school, but they do not award the building a specific "green" status level. These resources can be considered as manuals for best practices rather than rating systems.

6.2.1 Collaborative for High-Performance Schools, Inc. (CHPS)

Collaborative for High-Performance Schools, Inc. (CHPS) was developed to assist in the design, construction, and operation of high-performance schools. Several states have adopted their own version of CHPS, including California, Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Texas, Vermont, and Washington. CHPS focuses on the following major 10 goals for the construction of green schools: 1) Health and Indoor Air Quality, 2) Thermal Comfort, 3) Visual Comfort, 4) Acoustic Comfort, 5) Security and Safety, 6) Ecosystem Protection, 7) Energy Efficiency, 8) Water Efficiency, 9) Materials Efficiency, and 10) Buildings as a Teaching Tool. These goals are applied across all aspects of the construction project from site planning to HVAC equipment. Because CHPS is merely a guideline, no level of certification needs to be achieved. CHPS is a series of best management practices covering planning, design, operations and maintenance, and commissioning of high-performance schools, as well as guidelines for relocatable classrooms.

Application:

CHPS is developed specifically for educational institutions. A checklist and guidelines can be found at http://www.chps.net/content/038/090124_TX_Scorecard.xls.

6.2.2 New York City Green Schools Guide and Rating System

With the passage of New York City Local Law 86/05, new construction and major renovations, costing more than $2 million, must be eligible for a LEED Certified rating. Several LEED credits are specified that must be met for explicit scenarios. The goal of the program is to reduce energy use and operating costs, provide a healthy environment, and teach environmental responsibility. This system was created using a combination of LEED and CHPS. For a school to be certified, it must receive 28 out of 56 credits in the following categories: 1) Site, 2) Water, 3) Energy, 4) Materials, 5) Indoor Environmental Quality, and 6) Additional. Specific credit forms, certification forms, and a reporting worksheet must be submitted to receive certification.

Application:

The New York City Green Schools Guide and Rating System is designed specifically for educational institutions in New York City. A checklist and guidelines can be found at http://source.nycsca.org/GreenSchools/Samples/DD_sub_IHS259.pdf.

6.3 GREEN SCHOOL CASE STUDY: WATERGRASS ELEMENTARY SCHOOL

6.3.1 Introduction

The Pasco County School Board decided to construct Watergrass Elementary School, a new school in Wesley Chapel, Florida, to promote resource conservation. At the same time, this school was intended to provide a facility that increases overall building efficiency in energy and environmental design. LEED-S version 2.0 was used to guide the design and construction of Watergrass Elementary School. In this version of LEED for Schools, certification had four possible levels: Certified, 29 to 36 points; Silver, 37 to 43 points; Gold, 44 to 57 points; and Platinum, 58 to 79 points. Watergrass Elementary School was completed in 2009 and was awarded a Gold certification by the USGBC.

6.3.2 Watergrass Elementary School Green Building Strategy

Watergrass Elementary School, shown in Figure 6.1, is located in Wesley Chapel, Florida, and was awarded a LEED Gold certification by virtue of applying LEED-S. The facility is comprised of eight buildings totaling 80,000 square feet, with 768 student stations. The school has 10 classroom pods, offices, multipurpose facilities, and facilities for media, art, music, dining, and a kitchen. The project received a total of 46 points out of a maximum of 79 in the six LEED categories: 1) Sustainable Sites, 2) Water Efficiency, 3) Energy and Atmosphere, 4) Materials and Resources, 5) Indoor Environmental Quality, and 6) Innovation and Design Process. The following sections present details on which credits were pursued and the strategies implemented to achieve them.

Figure 6.1 Façade of Watergrass Elementary School in Wesley Chapel, Florida.

Sustainable Sites (SS) Category

The focus of the Sustainable Sites (SS) category is reducing construction impact on a site and the surrounding environment. This category requires meeting two prerequisites: Construction Activity Pollution Prevention (SSp1) and Environmental Site Assessment (SSp2). The project team developed a plan for reducing soil erosion, sedimentation, and dust generation, accomplished by using silt fences along the perimeter of the site and using turbidity barriers where needed. In addition to this plan, an assessment was done to ensure no environmental contaminants were on site. Hiring a company that specializes in land assessments was the easiest way to conform to this requirement.

Watergrass received three of the four available points for Sustainable Sites Credit 4 Alternative Transportation (SSc4), accomplished by incorporating bicycle racks, changing rooms, bike lanes, and preferred parking spaces for low-emitting or fuel-efficient vehicles and car pools into the design. Bicycle lanes, which lead straight to the bicycle rack that holds 108 bikes, were added along the main road. Two showers with changing rooms are available for full-time employees biking to school. Six preferred parking spots were designated for low-emitting or fuel-efficient vehicles, and another six were designated for car or van pools. An area in front of the school was also set aside for carpool/vanpool drop-off.

One of the goals of the Sustainable Sites category is to minimize the building footprint and maintain as much of the natural habitat as possible. Native vegetation was restored on 78.8% of the Watergrass Elementary School site, which allowed for one point for Sustainable Sites Credit 5.1 (SSc5.1), as well as a point for exemplary performance for surpassing the 50% restoration required. Figure 6.2 shows some of the native vegetation at the school, and gives a visual representation of how much of the area was restored. Care was taken in selecting native vegetation, such as sable palms, red maples, bald cypress, and live oaks, for the landscaping. Maximizing the open space around the building is also a priority of site development. Watergrass's dedicated open vegetative space was 705,875 square feet out of a total site area of 977,105 square feet, thus the school easily achieved SSc5.1. and received Sustainable Sites Credit 5.2 (SSc5.2).

Maintaining proper storm water control is another design feature addressed in this project and by the LEED for Schools Storm Water Design credits (SSc6). Because the school was constructed in a community that had been previously designed to handle storm water management, storm water ponds were already in place. Sediment sumps with littoral shelves and yard drains in the grass swales were features that were also added to help with storm water control.

Another issue addressed in the Sustainable Sites category is the problem of Heat Island Effect (SSc7). To help reduce the amount of heat that can radiate from traditional hardscapes, the Watergrass project team decided to use open grid pavers to reduce the heat island effect. The team used a system of honeycomb-shaped cells made of recycled plastic placed on top of a lightly compacted planting base and gravel, which provides structural support for parking while decreasing the heat reflected from the surface.

Figure 6.2 More than 50% of the site for the Watergrass Elementary School was restored with native vegetation (SSc5.1).

Minimizing the light that emanates from a site helps reduce energy costs and allows for better views of the night sky. Light Pollution Reduction (SSc8) focuses on using only the necessary amount of light needed for safety and comfort. The interior lighting for Watergrass was designed so that the power for lighting--with a direct line of sight to openings--is automatically shut off when the building is not in use (between 11 pm and 5 am). Manual overrides or occupancy sensors are used when increased lighting is needed during these hours. For exterior lighting, the actual lighting power density for each building, sidewalk, and parking area was kept below the allowable maximum lighting power density.

The possibility of non-school-related groups being able to use a school's facilities helps integrate green design into a community. The Pasco County School Board made an effort to allow outside groups to use several of its school buildings, including those at Watergrass Elementary School. Such groups as Girl Scouts, Boy Scouts, the Salvation Army, and the Red Cross are able to hold meetings and sponsor events in the school. Table 6.1 summarizes the school's performance in the Sustainable Sites category. The "Yes" represents that a prerequisite has been met, while a number represents the points received for that credit.

Table 6.1 Sustainable Sites: Watergrass Elementary Received 10 out of 16 Possible Points

Credit	Name	10
SSp1	Construction Activity Pollution Prevention	Yes
SSp2	Environmental Site Assessment	Yes
SSc1	Site Selection	0
SSc2	Development Density & Community Connectivity	0
SSc3	Brownfield Redevelopment	0
SSc4.1	Alternative Transportation – Public Transportation	0
SSc4.2	Alternative Transportation – Bicycle Storage and Changing Rooms	1
SSc4.3	Alternative Transportation – Low-Emitting and Fuel-Efficient Vehicles	1
SSc4.4	Alternative Transportation – Parking Capacity	1
SSc5.1	Site Development – Protect or Restore Habitat	1
SSc5.2	Site Development – Maximize Open Space	1
SSc6.1	Storm Water Design – Quantity Control	1
SSc6.2	Storm Water Design – Quality Control	1
SSc7.1	Heat Island Effect – Non-roof	1
SSc7.2	Heat Island Effect – Roof	0
SSc8	Light Pollution Reduction	1
SSc9	Site Master Plan	0
SSc10	Joint Use of Facilities	1

Water Efficiency (WE) Category

To earn credits in the Water Efficiency category, the focus was on the water use reduction in the buildings (WEc3), which was accomplished by using water-efficient fixtures. Dual flush handle valves on toilets were installed (see Figure 6.3), which use 0.5 gallons per flush for liquid waste and 1.6 gallons per flush for solid waste. Aerators for faucets and low-flow showerheads were also installed. The combined features reduced water use by a total of 42%. Table 6.2 shows a summary of the credits the school received in the Water Efficiency category.

Figure 6.3 A dual flush valve was installed in the restrooms for water use reduction.

Table 6.2 Water Efficiency: Watergrass Elementary Received 3 out of 7 Possible Points

Credit	**Name**	**3**
WEc1.1	Water-Efficient Landscaping, Reduce by 50%	0
WEc1.2	Water-Efficient Landscaping, No Potable Use or No Irrigation	0
WEc2	Innovative Wastewater Technologies	0
WEc3	Water Use Reduction	3
WEc4	Process Water Use Reduction	0

Energy and Atmosphere (EA) Category

Energy efficiency was a high priority for the Watergrass project team. The project team used ASHRAE's Advanced Energy and Design Guide (AEDG) for K-12 schools as the primary tool for energy-reduction measures. The use of this guide allowed the team to forgo the option of completing an energy model of the building, resulting in time and money savings on the project. Energy-saving measures were incorporated into the building envelope, the lighting system, and the HVAC system to achieve credit EAc1. The roof structure was designed with two layers of rigid insulation board with the ends staggered to avoid thermal bridging. The HVAC Energy Management System (EMS) maximizes the energy efficiency of the building by also controlling the lighting system. A programmed schedule was created to turn lights off and on at predetermined times, which can also be manually overridden when necessary. All classroom and office lights are fluorescent 28-watt lamps instead of the typical 32-watt lamps. Each classroom also has one exterior wall with 42 sq ft of windows to allow daylighting, while the other walls were painted with a reflective paint color. The exterior windows are operable and shaded on the south, east, and west sides. Shading allows for light penetration while minimizing the heat transfer into the building.

The HVAC system, shown in Figure 6.4, uses air-cooled screw compressor chillers that have a greater efficiency than that required by the Florida Energy Code. Variable air volume (VAV) boxes are used to reduce the need for cooling and reheating air by delivering only the required amount of cool air to a space. Dedicated fresh air coils are used in Wesley Chapel's humid environment to reduce the annual cooling load, which is done by eliminating the need to cool and reheat the air to remove the humidity.

The strategy used for the Green Power credit (EAc6) was to purchase Renewable Energy Certificates (RECs). A contract was entered into to purchase RECs for 70% of the predicted annual electricity consumption over a two-year period. To acquire the point associated with the requirement, the owner must purchase 35% of a building's annual electricity consumption to achieve the credit for LEED; however, doubling the purchase to 70% earned a point for exemplary performance in the Innovation and Design Process category. A summary of the seven credits achieved for the Energy and Atmosphere Category is shown in Table 6.3.

Figure 6.4 A high-energy efficiency HVAC system installed at Watergrass.

Table 6.3 Energy and Atmosphere: Watergrass Elementary Received 7 out of 17 Possible Points

Credit	Name	7
EAp1	Fundamental Commissioning of Building Energy Systems	Yes
EAp2	Minimum Energy Performance	Yes
EAp3	Fundamental Refrigerant Management	Yes
EAc1	Optimize Energy Performance	4
EAc2	On-Site Renewable Energy	0
EAc3	Enhanced Commissioning	1
EAc4	Enhanced Refrigerant Management	1
EAc5	Measurement & Verification	0
EAc6	Green Power	1

Materials and Resources (MR) Category

The Materials and Resources section of the LEED scorecard focuses on reducing waste related to materials and resources used during the construction process. A requirement for this category is designating a space for storing and collecting recyclables (MRp1). The Pasco County School Board had already established that its schools will be responsible for recycling paper products, cardboard, metal/aluminum cans, printer cartridges, plastic bottles, and many other products. As a result, this recycling was not a difficult prerequisite to meet since a standard was already in place for schools built in Pasco County. Watergrass concentrated efforts on reducing the waste that was generated, and using recycled materials, regional materials, and Forest Stewardship Council (FSC) certified wood.

The project team created a Construction Waste Management plan to divert at least 50% of construction waste from landfills (MRc2.1 and MRc2.2). Dumpsters were used to separate concrete, metal, wood, drywall, and asphalt, and they were set up and maintained to ensure no materials were mixed (see Figure 6.5). Records were kept detailing the weight of the materials sent to the recycling facilities and the weight of the waste sent to landfills. Containers for paper and beverage containers were also placed on-site for domestic waste-related construction.

Figure 6.5 Separate dumpsters were used to facilitate the recycling of materials used on the project.

Using regional materials in construction helps reduce both transportation costs and the environmental impact of fuel consumption. To receive points for credit MRc5.1, a minimum of 10% of the total costs of materials must have been locally extracted and manufactured (within 500 miles). Watergrass was able to obtain 53.6% of its total materials regionally. For example, the school purchased asphalt, fill dirt, ready-mix concrete, and soil cement from companies that harvest and manufacture their products within one mile of the project site. These purchases allowed for the award of two points in this category (MRc5.1 and MRc5.2), and a third point in Innovation and Design Process for exemplary performance for exceeding the 20% threshold.

Forest Stewardship Council (FSC) certified wood is wood that is harvested from forests that have been responsibly managed with concern for the environment. Fifty percent of the wood used on a project must be certified to receive a point for credit MRc7. Watergrass purchased materials, such as wood doors and medium density fiberboard (MDF), which were certified by FSC for these credits. The MR credits are summarized in Table 6.4.

Table 6.4 Materials and Resources: Watergrass Elementary Received 7 out of 13 Possible Points

Credit	Name	7
MRp1	Storage and Collection of Recyclables	Yes
MRc1.1	Building Reuse – Maintain 50% of Existing Walls, Floors & Roof	0
MRc1.2	Building Reuse – Maintain 75% of Existing Walls, Floors & Roof	0
MRc1.3	Building Reuse – Maintain 50% of Interior Non-Structural Elements	0
MRc2.1	Construction Waste Management – Divert 50% from Disposal	1
MRc2.2	Construction Waste Management – Divert 75% from Disposal	1
MRc3.1	Materials Reuse – 5%	0
MRc3.2	Materials Reuse – 10%	0
MRc4.1	Recycled Content – 10% (post-consumer + ½ pre-consumer)	1
MRc4.2	Recycled Content – 20% (post-consumer + ½ pre-consumer)	1
MRc5.1	Regional Materials – 10% Extracted, Processed & Manufactured	1
MRc5.2	Regional Materials – 20% Extracted, Processed & Manufactured	1
MRc6	Rapidly Renewable Materials	0
MRc7	Certified Wood	1

Indoor Environmental Quality (IEQ) Category

Enhancing the quality of a building's indoor environment helps improve the comfort and well-being of its occupants. Indoor air quality management plans were developed to ensure that air quality concerns were addressed during construction (EQc3.1) and prior to building occupancy (EQ3.2). During construction, care was taken to protect the HVAC system from construction debris at all times, and the filters were changed prior to occupancy. Low-emitting materials were chosen for adhesives, sealants, paints and coatings, carpets, and substrates (EQc4). Housekeeping practices were employed to minimize dust and/or contaminants (EQc5).

Control of the lighting systems (EQc6.1) and control of the thermal comfort level (EQc6.2) of classrooms are very important for creating an environment conducive to learning. Classroom lighting was designed with core learning lighting, as well as lighting for audiovisual presentations. HVAC sensors were also installed so the temperature could be adjusted as needed. The windows are also operable and provided with blinds to allow additional controllability of temperature and lighting. Thermal comfort was achieved by meeting the ASHRAE comfort standard (EQc7.1). Ensuring that teachers and students are comfortable is important for their well-being and productivity. A survey was performed to verify that the occupants were comfortable and the results suggested they were (EQc7.2). Views to the outdoors in classrooms and offices keep occupants satisfied with their indoor environment while keeping them connected to the natural environment.

Watergrass was able to create views for 90.5% of the indoor spaces and achieve EQc8.2, that is, almost all the classrooms and offices have a view to the outdoors. Because humidity and mold growth can be a problem in the Central Florida climate, the HVAC system was carefully chosen to make sure that humidity levels would be carefully controlled. Dedicated fresh air coils were used not only to help reduce energy usage but also to control humidity and mold (EQc10).

Noise control is also an important factor to consider in schools. Background noise from other classrooms, noise transmission through walls, and structural noise from motors and pumps can all hinder the learning process. To meet the Minimum Acoustical Performance prerequisite (EQp3), the Sound Transmission Class (STC), which is the rating of a sound barrier, must be at least 50 for core learning space walls and 60 for mechanical room walls. The higher the STC, the less sound transmitted through the wall assembly.

Table 6.5 Indoor Environmental Quality: Watergrass Elementary Received 13 out of 20 Possible Points

Credit	**Name**	**13**
EQp1	Minimum Indoor Air Quality Performance	Y
EQp2	Environmental Tobacco Smoke (ETS) Control	Y
EQp3	Minimum Acoustical Performance	Y
EQc1	Outdoor Air Delivery Monitoring	0
EQc2	Increased Ventilation	0
EQc3.1	Construction IAQ Management Plan – During Construction	1
EQc3.2	Construction IAQ Management Plan – Before Occupancy	1
EQc4	Low-Emitting Materials	4
EQc5	Indoor Chemical and Pollutant Source Control	1
EQc6.1	Controllability of Systems – Lighting	1
EQc6.2	Controllability of Systems – Thermal Comfort	1
EQc7.1	Thermal Comfort – Design	1
EQc7.2	Thermal Comfort – Verification	1
EQc8.1	Daylight & Views – Daylight 75% of Spaces	0
EQc8.2	Daylight & Views – Views for 90% of Spaces	1
EQc9	Enhanced Acoustical Performance	0
EQc10	Mold Prevention	1

Innovation and Design (ID) Category

Having a LEED Accredited Professional (LEED-AP) on staff is one of the simplest ways to obtain credit IDc2 in the Innovation and Design Process category. The majority of registered LEED projects receive this point because it is good practice to hire someone with LEED experience and knowledge to decrease the learning curve. Another common way to receive Innovation and Design Process credits is to exceed the requirements of a credit and receive an extra point for exemplary performance. Watergrass earned 4 of the 6 points in this category by concentrating its efforts on maximizing the use of materials with recycled content, (MRc4.1 and MRc4.2), using regional materials (MRc5.1 and MRc5.2), protecting and restoring natural vegetation (SSc5.1), and purchasing green power (EAc6). Table 6.6 specifies the credits for which Watergrass received exemplary performance points.

Credit IDc3 involves using the design and construction of the building to teach others about sustainable construction. By using the school as a teaching tool, green buildings have the potential to have more impact on the community. The project team for Watergrass designed an educational tour or “Environmental Walk” that describes the environmental issues addressed in the LEED certification process. Students are taught about the design of the school and the relationship between the built environment and the natural environment, and they then become the tour guides for the walk. Ten signs are posted to explain the design, construction, and conservation features of the building: 1) Indoor Air Quality, 2) Occupant Well-Being, 3) Recycled Content and Regional Material, 4) Alternative Transportation, 5) Recycling and Waste Management, 6) Water Efficiency, 7) Storm Water Management, 8) Energy Efficiency and Conservation, 9) Eco-System Protection, and 10) Site Development. This credit and the other five credits achieved in Innovation and Design Process are shown in Table 6.6.

Table 6.6 Innovation and Design: Watergrass Elementary Received 6 out of 6 Possible Points

Credit	**Name**	**6**
IDc1.1	Innovation in Design: MRc4 Exemplary Performance	1
IDc1.2	Innovation in Design: SSc5.1 Exemplary Performance	1
IDc1.3	Innovation in Design: MRc5 Exemplary Performance	1
IDc1.4	Innovation in Design: EAc6 Exemplary Performance	1
IDc2	LEED Accredited Professional	1
IDc3	The School as a Teaching Tool	1

6.3.3 Case Study Summary

The achievement of LEED Gold rating is no small achievement, but Watergrass was able to achieve this rating while creating enormous benefits for all involved. Natural resources were conserved, water and energy use were reduced, and a healthy and productive environment was created for the occupants. The LEED-S scorecard was used as a guideline to achieve certification, and the project team went above and beyond the requirements in several categories. The total score, including a summary of the category scores, is shown in Table 6.7. Because of the decisions made by the project team, the occupants and administrators of Watergrass will continue to experience annual energy savings, and therefore monetary savings due to the sustainable design.

Table 6.7 LEED Scorecard: Watergrass Elementary Scored 46 out of 79 Possible Points

LEED Category	Points Earned
Sustainable Sites	10
Water Efficiency	3
Energy & Atmosphere	7
Materials & Resources	7
Indoor Environmental Quality	13
Innovation in Design Process	6
TOTAL	**46**

Certified	Silver	**Gold**	Platinum
29-36 points	37-43 points	**44-57 points**	58-79 points

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GLOSSARY

Acrylic
A transparent or semi-transparent polymer material that exists in liquid or solid form. Acrylic applications include skylight and window sheets, as well as a liquid sealer for a variety of materials.

Admixtures or additives (concrete)
Minor ingredients mixed with concrete to impart particular qualities, such as color, decreased curing time, or improved workability.

Aggregate
Any granular mineral material such as crushed stone, crushed slag, gravel, and sand.

Air-Handling Unit (AHU)
A device used to distribute, filter, heat, cool, ventilate and/or dehumidify air via ducts to spaces in the building.

Allergens
Any substance capable of producing an allergic response.

Alloy
The mixing of two metals to form a third metal with a different set of properties.

Alteration Costs
Costs incurred during the process of significantly upgrading a facility, space,or architectural component, or changing the function of a space. Alteration costs that do not exceed $5,000 are included within the Maintenance Costs category.

Anodizing
An electrolytic process that forms a permanent and often protective coating on the surface of aluminum.

ASHRAE
American Society of Refrigeration and Air Conditioning Engineers, the professional society of mechanical engineers and mechanical contractors in the United States.

ASTM
American Society of Testing and Materials, a widely used and referenced testing and standards organization.

Backing
The layer of a carpet or wall covering that is applied to the surface of a substrate material.

Bitumen
Any of a number of viscous hydrocarbon materials typically used for waterproofing roofs, walls, and foundations. The materials, such as coal tar and asphalt, can be used to: impregnate building paper, can be applieddirectly as a liquid, or laid down in sheets.

Boiler
A device used to heat water for distribution heating to spaces in a building via pumps and pipes.

Capital Costs
Capital Costs are the costs for purchasing high value items such as buildings and are paid from capital funding accounts rather than from agency operating funds.

Carpet
The general designation for fabric used as a floor covering.

Cement
A powder, comprised of aluminum, silica, lime, iron oxide, and magnesia whichis produced in a kiln. Cement is used as the binding ingredient in concrete and mortar.

Cementitious
Any material based on cement or cement-like products, which isinorganic, non-combustible, and hard setting.

Chiller
A machine that includes an evaporator, condenser, expansion valve, and compressor and which contains a refrigerant loop that moves heat from the evaporator to the condenser to provide cooling.

Coil
A heat exchanger that transfers heat between fluids of different temperatures.

Color Rendering Index (CRI)
CRI is a unit of measure that defines how well colors are rendered by different illumination conditions in comparison to a standard (i.e., a thermal radiator or daylight). CRI is calculated on a scale from 1 to 100, where a CRI of 100 would represent that all color samples illuminated by a light source in question would appear to have the same color as those same samples illuminated by a reference source.

Compressor
An electromechanical device that pressurizes a refrigerant in an air-conditioning system or refrigeration system.

Concrete
A mixture of sand, lime, Portland cement, aggregates, and additives. When mixed and allowed to cure (generally for a minimum of 28 days), a hard, structurally useful solid forms. Concrete, whether placed in a foundation, wall, floor, or roof,almost always contains steel reinforcing bars (rebar).

Concrete Masonry Unit (CMU)
A cementitious block that is produced in three basic types: hollow units, hollow blocks, or larger solid units. The most common nominal dimensions for a CMU are 8" x 8" x 16".

Condenser
The element that removes heat from the refrigerant in an HVAC system and transfers it to another medium, typically the outside air or a condenser water loop.

Cooling Tower
A device located outdoors that removes heat from the condenser water of an HVAC system and transfers it to the outside air. The cooling tower is usually a relatively large structure with an array of beads for breaking water into small droplets and a fan to circulate air through the water.

Construction Costs
Also referred to as *First Costs,* these are the total cost of the materials and systems that comprise the building and its sitework, including the labor required for the construction process.

Contaminants
Unwanted constituents in air, water, or soil that may be associated with adverse physical health reactions.

Cubic Feet per Minute (CFM or cfm)
The volumetric flow of air through a duct or space measured in English units of volume per unit time.

Decoupled System
A decoupled system separates the cooling system from the ventilation system. This approachallows the temperature of the circulating air to be controlled independently from the conditioning of fresh air, which is accomplished by a different system.

Demand Charges
Some electrical utilities charge higher electrical fees tomajor consumers, such as commercial buildings or schools, for power that is used during periods of high demand, usually in the afternoon.

Diffuser
An air distribution outlet or grille designed to direct airflow into desired patterns.

Duct
A device used to distribute cooling, heating, ventilation, or exhaust air between locations in buildings.

Durability
The capacity of a material, product, component, assembly, or construction to remain serviceable, as intended, with prudent maintenance during the designed service life under anticipated internal and external environments.

Efficacy
The ratio of lumens per square foot to lighting power per square foot or the number of lumens per watt of energy characteristic of a given lighting technology.

Efficiency
The power output of a device divided by the power input.

Elasticity
The ability of a material to return to its original shape after deformation by stretching, compression, or torsion.

Emission
A measure of the quantity of a chemical released into the air from a specific source.

Emissions
Releases of gases or airborne contaminants from any process or material. Liquid emissions are commonly referred to as *effluents*.

Energy Inflation Rate
Compounding rate associated with the price escalation of energy over time.

Envelope
The various layers of materials, both finish and substrate, used for the enclosure of interior space and the protection of that space from the external environment.

Epoxy
A class of synthetic resins used for high-performance adhesives, paints, and protective coatings. Epoxy adhesives and paints can be a single material or a two-part material that is mixed immediately before use. The ingredients are hazardous and should be handled only by those trained on using epoxy.

Evaporator
The heat exchanger in an HVAC system that removes heat from air or water to provide cooling.

Exhaust
The indoor air that is removed from a building.

Exterior Insulated Finish System (EIFS)
Exterior Insulated Finishing System (EIFS) is an exterior cladding system that consists of several layers of separate materials. These layers are typically made of a rigid, insulating polymer board over which is applied a reinforcing polymer/glass fiber mesh. This fiber meshthen receives a thin layer of cementitious and polymer-based surfacing material (stucco).

Fan
A device used to force air through ducts to deliver cooling or heating to a location in a building. Fans are typically part of an air-handling unit (AHU). They may also be used to remove exhaust air from locations in buildings, such as toilet rooms or kitchens.

Fan Coil Unit (FCU)
A device to heat, cool and/or filter air in a building. The fan coil unit does not provide fresh ventilation air.

Fiberglass
A type of manufactured mineral fiber made from spun glass.

Filter
A device used to clean air by removing particulates from air as it flows through an air-handling system.

Footcandle
One lumen per square foot of lighting level.

Formaldehyde (HCHO)
A pungent and irritating gas used in the manufacturing of many adhesives and plastics or as a preservative.

Furnace
A device that heats air for distribution to spaces in a building, usually via ductwork.

Glass Block
Unit masonry made out of glass with the property of being able to transmit light.

Glass Fiber
Glass that has been extruded (stretched) while molten to make fine fibers for insulation, nonflammable fabrics, or reinforced plastics. Glass fibers are irritating to the skin and are dangerous if they are inhaled.

Grille
The component of a return air system through which air exits as it leaves a space.

Grout
A cementitious material used to fill the joints between tiles. Grout contains acrylic or epoxy adhesives for greater durability.

Heat Strips
Electrical resistance heating elements used in air distribution systems to heat air.

HVAC
Heating, Ventilating, and Air Conditioning (see "Mechanical Systems").

Indoor Air Quality (IAQ)
The characteristics of the indoor air of a building, including the gaseous composition, air temperature, humidity, air movement, and airborne contaminants.

Indoor Environmental Quality (IEQ)
The overall quality of an interior space that includes air quality, ventilation, thermal comfort, lighting quality, noise, vibration, and odors.

Inflation Rate
The rise in the general price level for goods and services.

Joint compound
A wet filler material used to join materials of the same type to create a uniform surface, such as gypsum filler.

Life Cycle Cost (LCC)
The total discounted cost of owning, operating, maintaining, and disposing of a building or building system over a specified time frame.

Linoleum
A durable and resilient flooring material madeof natural ingredients that include linseed oil, cork, limestone, wood flour, and tree resins.

Linseed oil
Nontoxic oil from the seed of the flax plant.Linseed oil is used in paints, varnishes, linoleum, and synthetic resins.

Maintenance Costs
Costs incurred as the result of repair, annual maintenance contracts, and salaries of maintenance staff. (Note: "Maintenance and repair," as defined by the Chapter 1013 of the Florida Statutes, means: "… the upkeep of educational and ancillary plants, including, but not limited to, roof or roofing replacement short of complete replacement of membrane or structure; repainting of interior or exterior surfaces; resurfacing of floors; repair or replacement of glass; repair of hardware, furniture, equipment, electrical fixtures, and plumbing fixtures; and repair or resurfacing of parking lots, roads, and walkways. The term "maintenance and repair" does not include custodial or groundskeeping functions, or renovation except for the replacement of equipment with new equipment meeting current code requirements, provided that the replacement item neither places increased demand upon utilities services or structural supports, nor adversely affects the safety function of life systems.")

Mastic
Refers to many synthetic caulking materials and adhesives used for floors and laying tile.

Mechanical Systems
Air-conditioning units, heating devices, air handlers, ventilation systems, distribution systems, and control devices, that provide thermal comfort through modification of the temperature, humidity and/or air quality in the occupied spaces of schools.

Metal Lath
A base material to which plaster or stucco is applied.

Mildew
A superficial covering of organic surfaces caused by fungi formed under damp conditions.

Mold
A fungal infestation that causes disintegration of a substance.

Mortar
A mixture of cement, plaster, or lime with water and sand, used to bond units of stone or ceramic tiles, or for use as a grout for these materials.

Net Present Value
The time-equivalent value of past, present, and future cash flows, at the beginning of the base year of a Life Cycle Cost (LCC) analysis.

Off-gassing (or out-gassing)
The release of gases or vapors from solid materials after the manufacturing process is complete. It is a form of evaporation or slow chemical change, whichproduces indoor air pollution for prolonged periods after installation of the material.

Operating and Maintenance (O & M) Costs
Non-investment costs related to the use of a building or building system, including energy and water costs.

Operational Costs
Costs incurred during the normal functioning of the facility or building component, including regular custodial care. These costs consist of energy expenditures and the cost of maintaining materials.

Padding
Any type of material placed under a carpet to provide a softer walking surface. It also can provide acoustical benefits and a longer carpet wear life.

Permeability
The ability of a material to transmit water vapor.

Pollutant
A contaminant that is known to cause illness.

Polymer
A naturally occurring or synthetic compound consisting of large molecules made up of a linked series of repeated simple monomers.

Portland Cement
A gray-colored powder that serves as the binder in concrete, mortar, and stucco.

Pump
A device used to distribute liquids, such as chilledwater, condenser water, or glycol, through pipes for heating or cooling in a building.

Qualitative Issues
Issues such as environmental concerns and architectural preference, which are not possible to quantify with a precise and consistent cost figure.

Relative Humidity (RH)
A measure of the moisture content of air compared to the maximum amount of moisture that the air could carry at that temperature. Relative humidity is expressed as a percentage with 100% indicating air that is fully saturated with moisture. Relative humidity is an important factor in comfort and air quality.

Remodeling
Changing existing facilities by rearrangement of spaces and their use, including, for example, the conversion of two classrooms to a science laboratory or the conversion of a closed plan arrangement to an open plan configuration.

Renovation
Rejuvenating or upgrading existing facilities by installation or replacement of materials and equipment. Renovation includes: interior or exterior reconditioning of facilities and spaces; new air-conditioning, heating, or ventilation equipment; upgraded fire alarm systems; emergency lighting; new electrical systems; and complete roofing or roof replacement.

Replacement Costs
Replacement Costs incurred in the facility's life to maintain the original function of the facility or item. An example would be the cost of replacing chillers with a service life of 20 years during a facility's 50-year lifetime.

Resilient Flooring
Floor coverings such as rubber, vinyl, and linoleum that have elastic properties.

Resins
Resin is a non-volatile or semi-solid organic material, obtained as gum from certain trees or manufactured synthetically, whichtends to flow when subjectedto heat or stress. Resins are soluble in most organic solvents but not in water. Resins are used as the film-forming component of paints and varnishes and in making plastics or adhesives. Artificial resins used in the manufacture of plastics and synthetic finishes are usually petroleum-based polymers.

Return Air
Air that is extracted from the space and returned to the air handler to be mixed with fresh air, cooled and/or heated, and sent back to the space (as supply air).

Rock Wool or Mineral Wool
Insulating material spun from heated slag (waste) from metal smelting, which is similar to glass. The fiber is irritating to the skin and hazardous if inhaled.

Salvage Value
The estimated value of any building or building system removed or replaced during the LCC study period or remaining at the end of the LCC study period.

Sealant
Any material used to prevent the passage of liquid or gas through a joint or opening.

Service Life
The projected life (in years) of an existing structure, structural component, or system under normal loading and environmental conditions before replacement or major rehabilitation is required.

Solvent
A liquid used to dissolve a solid (such as paint resin) so that it is brushable. A solvent is usually volatile and evaporates from the paint film after application.

Stainless Steel
Steel alloyed with chromium to make it rust-resistant and stain-resistant.

Stains
Pigments suspended in oils, water, or other agents used as part of a finishing process in painting.

Subfloor
The structural floor under the finished floor.

Substrates
A material that provides a surface on which an adhesive is spread for any purpose, such as laminating or coating.

Superstructure
Primary structure of a building that transfers dead and live loads down to the ground.

Supply Air
Air that is supplied to the space to offset cooling or heating loads from the building envelope, equipment, and people.

Terrazzo Flooring
Marble or granite chips embedded in a binder that may be cementitious, non-cementitious (epoxy, polyester, or resin) or a combination of both. Terrazzo flooring can be used with divider strips of brass, zinc, or plastic.

Thermostat
A device that senses the temperature of aspace and actuates various devices such as air handlers, mixing boxes, or fan-coil units to supply cooling or heating as needed.

Toxic
Characteristic of a substance that can cause adverse physical health reactions or harm to living organisms.

Urethane
A family of resins, usually called polyurethane, used in insulating and upholstery foams, paints, and varnishes. Because this family of resinscontains a cyanide group in its chemical structure, most will release deadly cyanide gasses if exposed to fire. At room temperature, they are relatively non-toxic.

VAV Box
A device used to control the air flow to a space that requires cooling. As more cooling is needed, the box allows more air (at a constant temperature) to pass. As less cooling is

needed,less air of the same temperature is allowed to pass into the space, reducing the amount of cooling provided.

Ventilation
Fresh air provided for occupied spaces of buildings to dilute airborne contaminants and gases that are released into the air from people, equipment, and building materials. ASHRAE Standard 62.1-2007 sets ventilation rates for various types of building spaces.

Volatile Organic Compounds (VOCs)
Gases with organic structures that are emitted from materials made from polymers or containing solvents or plasticizers. Many VOCs are irritants and some are toxic. In building interiors, VOCs are generated by building products, cleaning materials, solvents, and furnishings. VOCs are typically carbon alkanes, chlorinated hydrocarbons, alcohols, and aldehydes and affect the air quality of buildings.

Wood Veneer
A thin sheet of high-grade wood formed by cutting a thin strip from a larger section of the wood. The veneer is applied to thicker wood or paper to make plywood and decorative wood-surfaced panels for furniture and doors.

Appendix A
Life Cycle Cost

Superstructure

Columns	Unit	First Cost	LCC	O&M
Cast-in-Place Reinforced Concrete	LF	$ 53.75	$ 53.75	0.00%
Precast Reinforced Concrete	LF	$ 63.23	$ 63.23	0.00%
Concrete Block Column	LF	$ 50.59	$ 50.59	0.00%
Steel Column, W-Shape	LF	$ 30.35	$ 30.35	0.00%
Round HSS	LF	$ 41.10	$ 41.10	0.00%
Square HSS	LF	$ 35.84	$ 35.84	0.00%

Beams	Unit	First Cost	LCC	O&M
Cast-in-Place Concrete	LF	$ 105.39	$ 105.39	0.00%
Reinforced Masonry Beams	LF	$ 64.96	$ 64.96	0.00%
Precast Concrete	LF	$ 152.15	$ 152.15	0.00%
Steel W-Shape	LF	$ 33.20	$ 33.20	0.00%

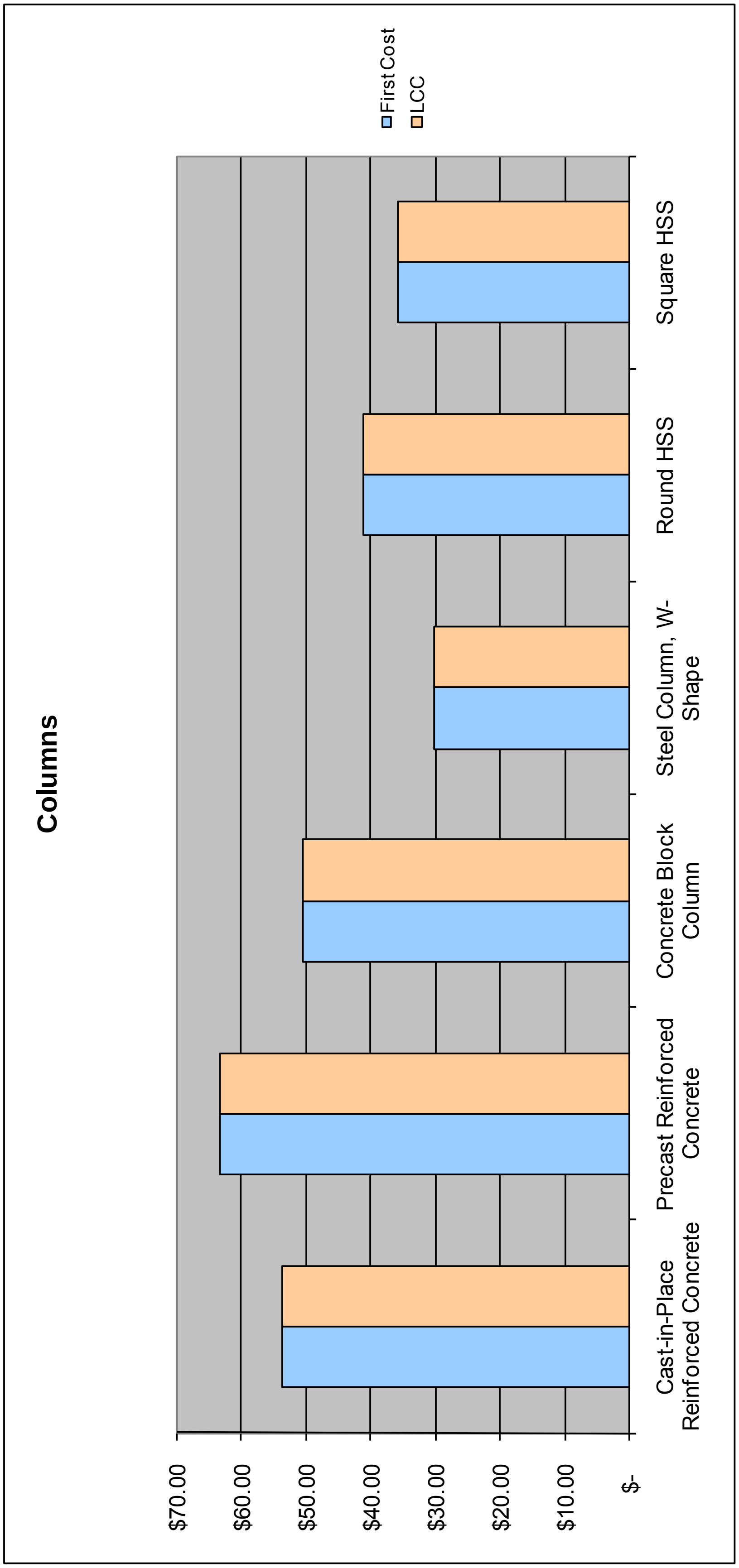
Floors 30'-40' span	Unit	First Cost	LCC	O&M
Steel Deck 1-1/2" Deep + 4” Thick Concrete	SF	$ 10.23	$ 10.23	0.00%
Cast-in-Place Flat Concrete Plate, 4” Thick	SF	$ 13.26	$ 13.26	0.00%
Precast Plank with Concrete Topping	SF	$ 11.79	$ 11.79	0.00%

Floors over 40'-60' span	Unit	First Cost	LCC	O&M
Steel Deck + 4” Thick Concrete Cast On Site + Open Web Steel Joist + Steel	SF	$ 16.60	$ 16.60	0.00%
Precast Double Tees Floor Members with Topping	SF	$ 11.79	$ 11.79	0.00%

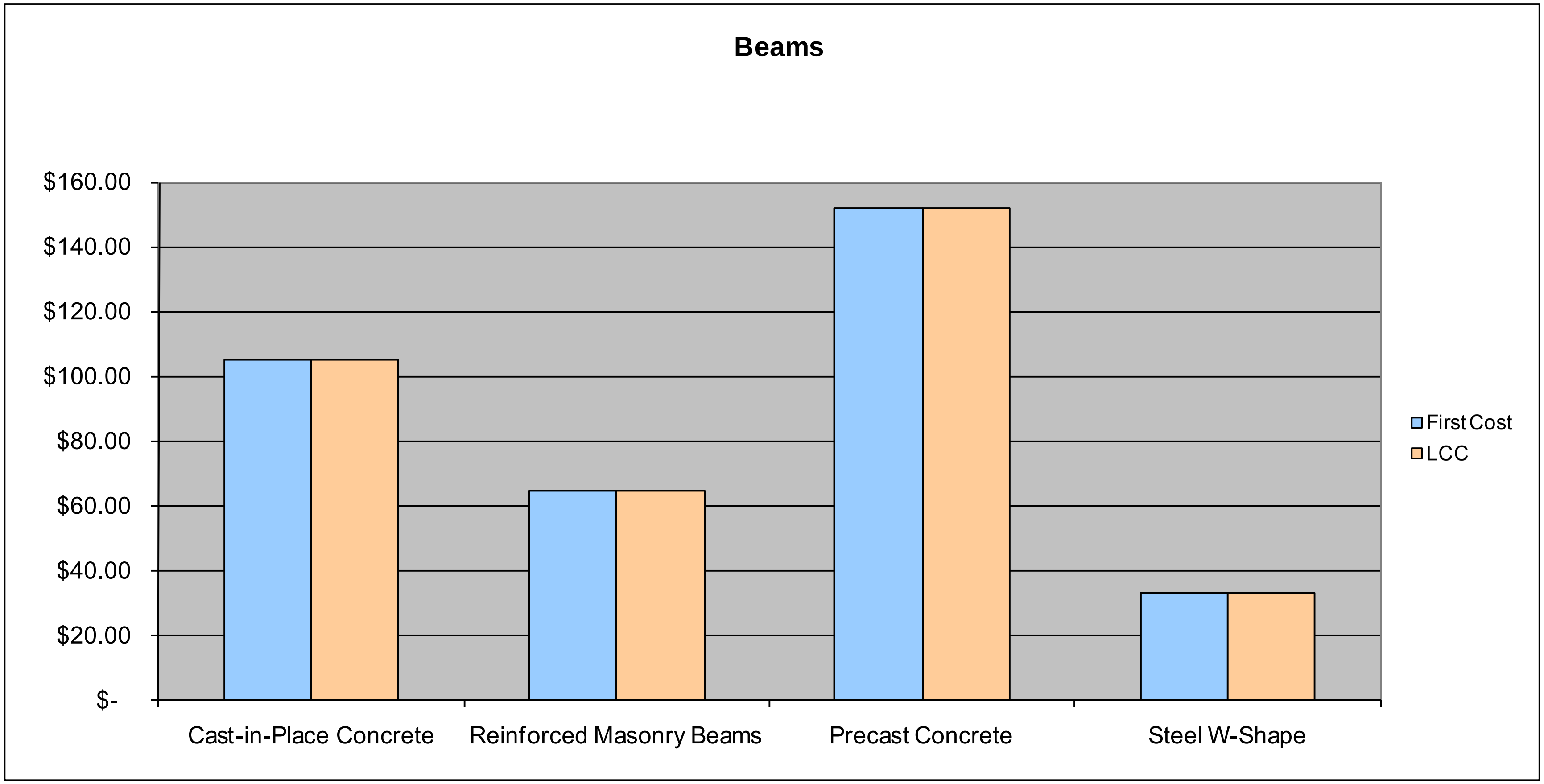
Roofs 30'-40' span	Unit	First Cost	LCC	O&M
Steel Deck 1-1/2" Deep + Open Web Steel	SF	$ 3.95	$ 3.95	0.00%
Cast-in-Place Flat Concrete Plate, 4” Thick	SF	$ 12.20	$ 12.20	0.00%
Precast Double Tee	SF	$ 9.45	$ 9.45	0.00%
Steel Purlins + Steel Beams	SF	$ 33.61	$ 33.61	0.00%
Light Gauge Steel Trusses	SF	$ 8.50	$ 8.50	0.00%

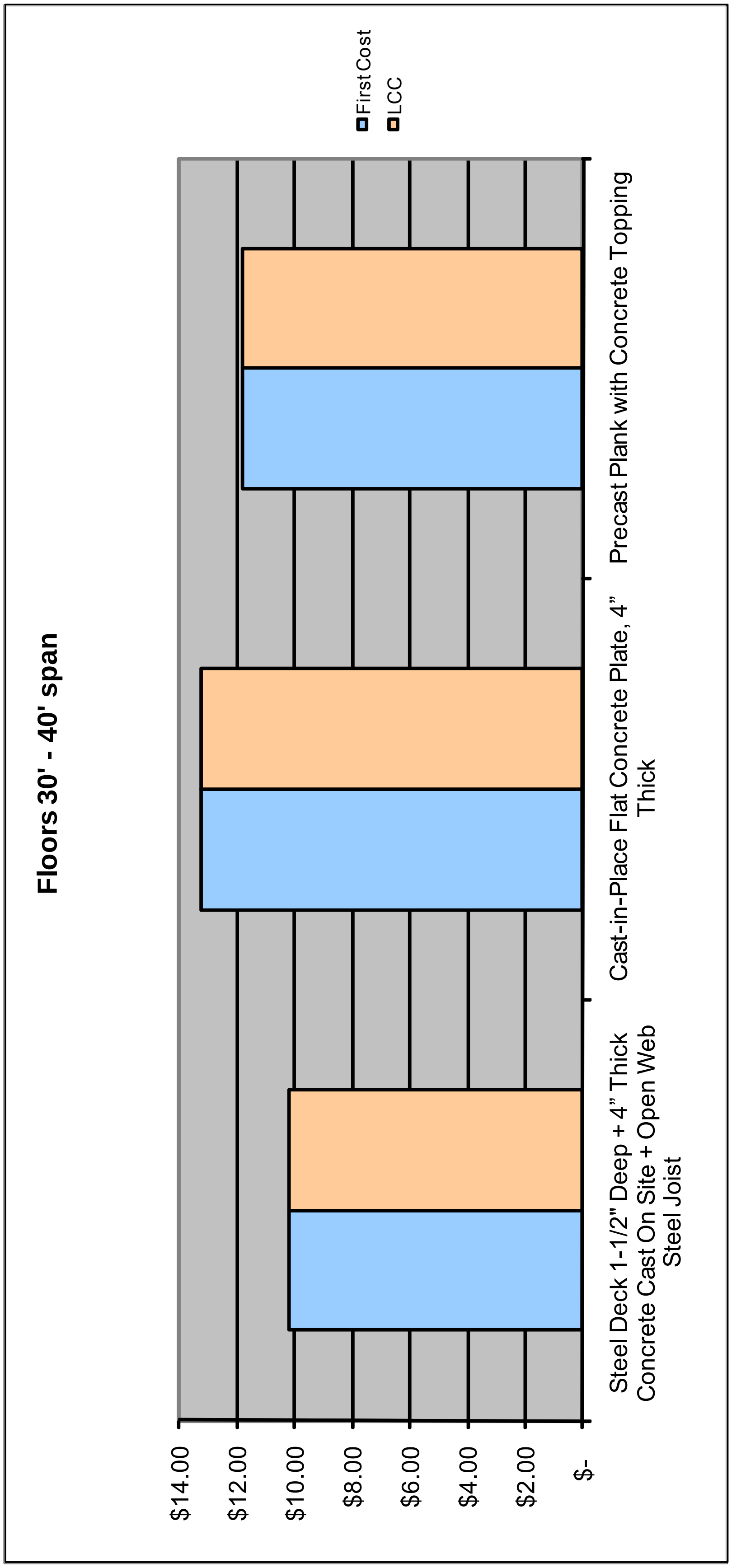
Roofs over 40'-60' span	Unit	First Cost	LCC	O&M
Steel Deck 1-1/2" Deep + Open Web Steel Joist	SF	$ 7.71	$ 7.71	0.00%
Precast Double Tee	SF	$ 9.75	$ 9.75	0.00%
Light Gauge Steel Trusses	SF	$ 10.00	$ 10.00	0.00%

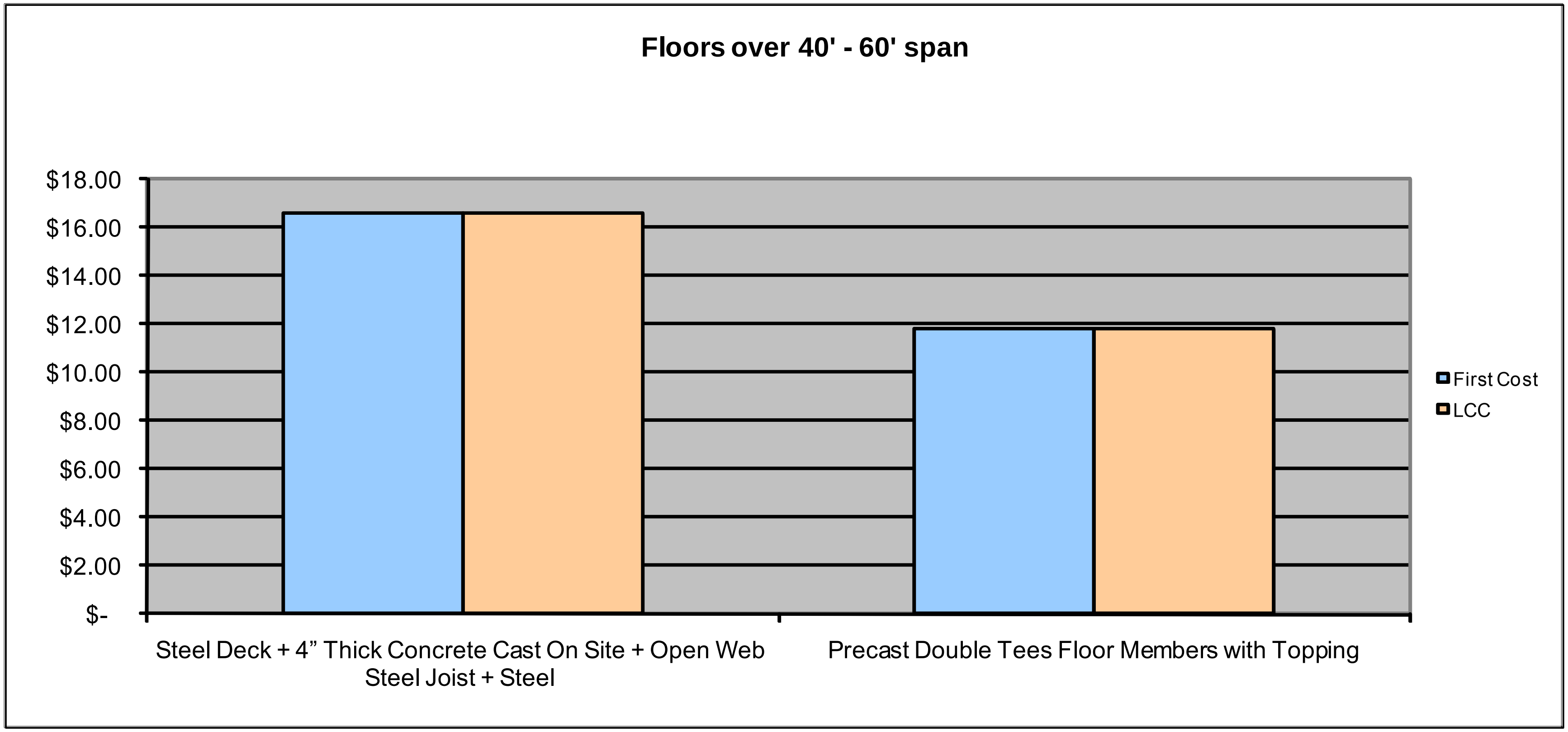
Roofs over 60'-100' span	Unit	First Cost	LCC	O&M
Steel Deck 1-1/2" Deep + Open Web Steel Joist	SF	$ 13.07	$ 13.07	0.00%
Precast Double Tee	SF	$ 12.03	$ 12.03	0.00%
Light Gauge Steel Trusses	SF	$ 12.00	$ 12.00	0.00%

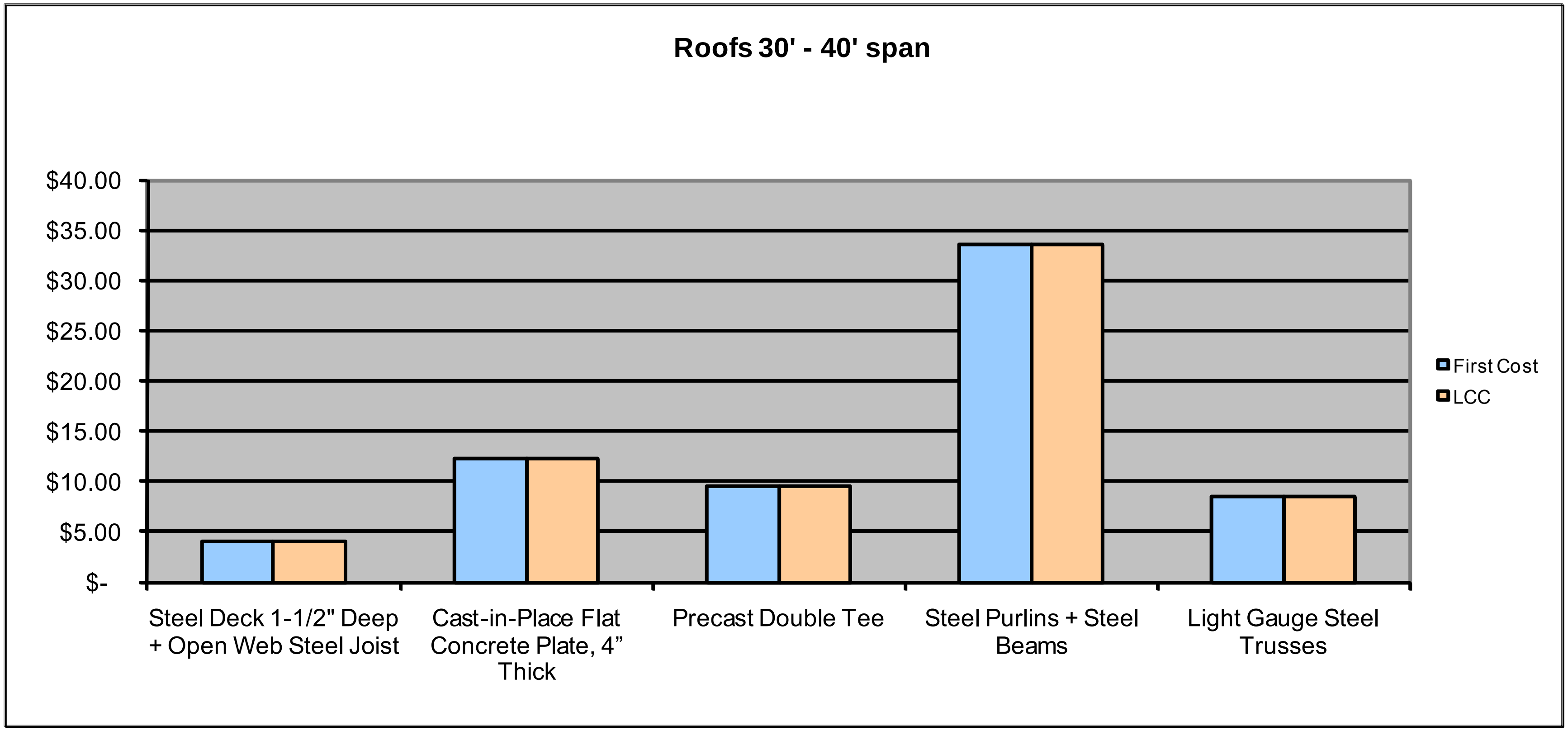


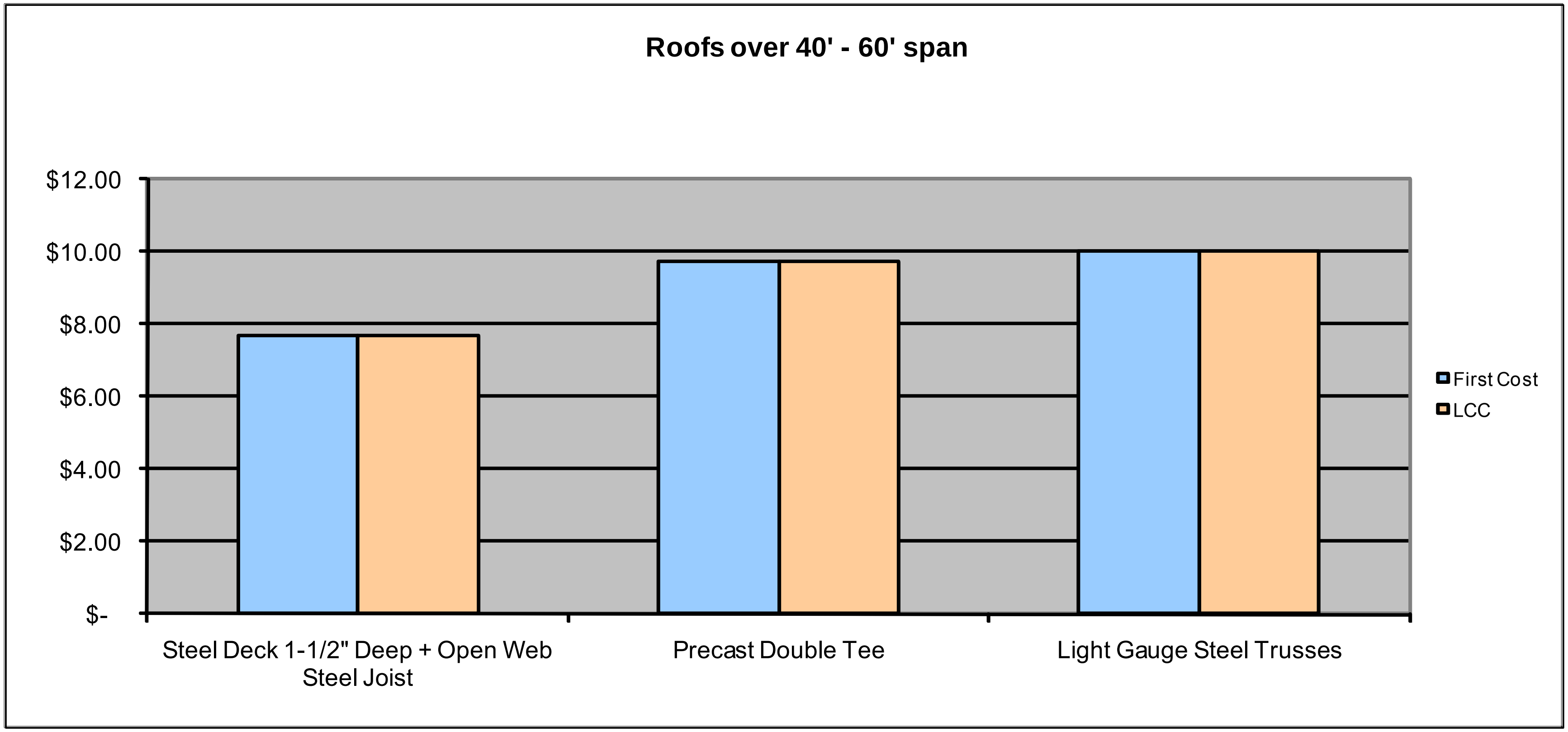
Columns
$70.00
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$-
Cast-in-Place Reinforced Concrete
Precast Reinforced Concrete
Concrete Block Column
Steel Column, W-Shape
Round HSS
Square HSS
First Cost
LCC

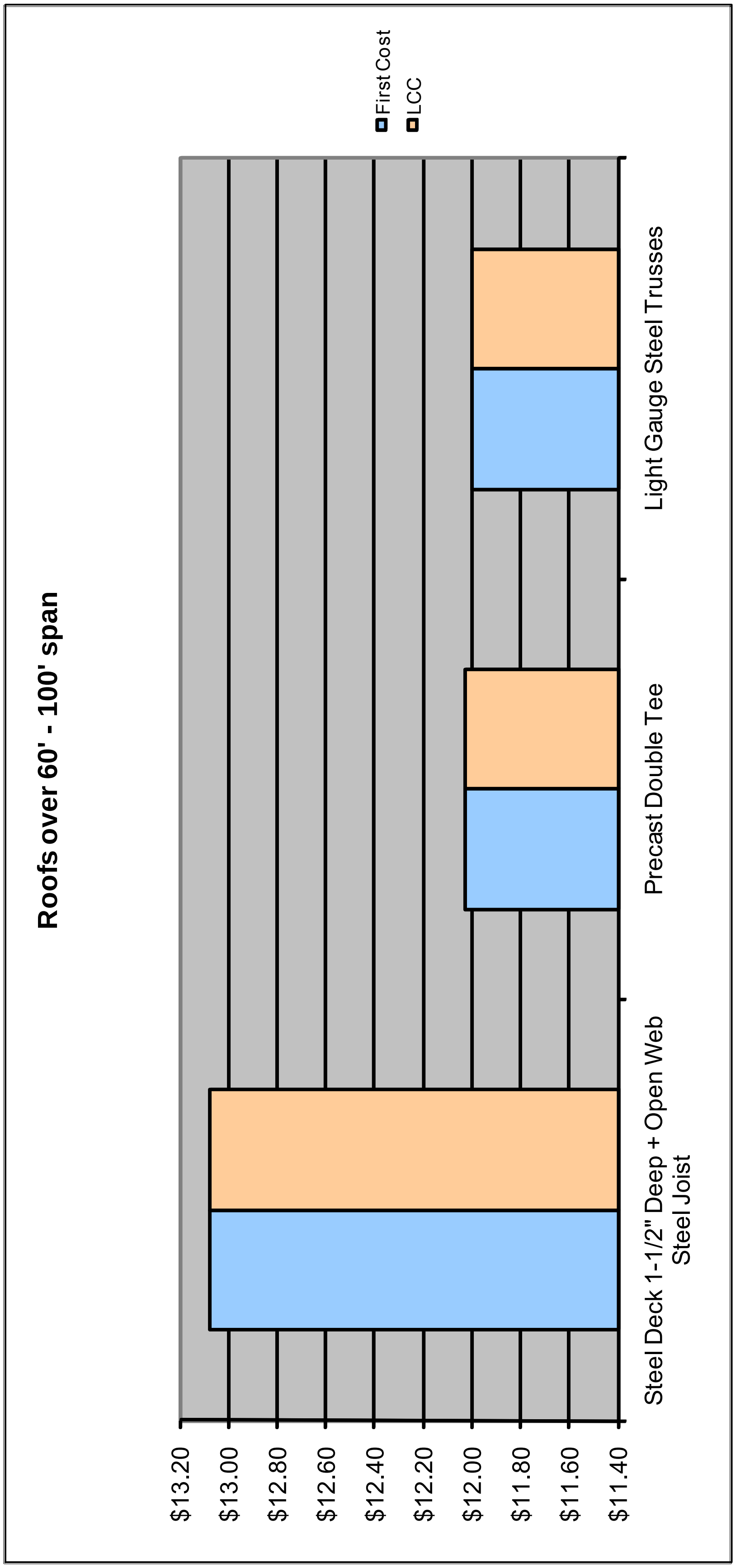

Beams
$160.00
$140.00
$120.00
$100.00
$80.00
$60.00
$40.00
$20.00
$-
Cast-in-Place Concrete
Reinforced Masonry Beams
Precast Concrete
Steel W-Shape
First Cost
LCC


Floors 30' - 40' span
$14.00
$12.00
$10.00
$8.00
$6.00
$4.00
$2.00
$-
Steel Deck 1-1/2" Deep + 4" Thick Concrete Cast On Site + Open Web Steel Joist
Cast-in-Place Flat Concrete Plate, 4" Thick
Precast Plank with Concrete Topping
First Cost
LCC


Floors over 40' - 60' span
$18.00
$16.00
$14.00
$12.00
$10.00
$8.00
$6.00
$4.00
$2.00
$-
Steel Deck + 4” Thick Concrete Cast On Site + Open Web Steel Joist + Steel
Precast Double Tees Floor Members with Topping
First Cost
LCC


Roofs 30' - 40' span
$40.00
$35.00
$30.00
$25.00
$20.00
$15.00
$10.00
$5.00
$-
Steel Deck 1-1/2" Deep + Open Web Steel Joist
Cast-in-Place Flat Concrete Plate, 4” Thick
Precast Double Tee
Steel Purlins + Steel Beams
Light Gauge Steel Trusses
First Cost
LCC


Roofs over 40' - 60' span
$12.00
$10.00
$8.00
$6.00
$4.00
$2.00
$-
Steel Deck 1-1/2" Deep + Open Web Steel Joist
Precast Double Tee
Light Gauge Steel Trusses
First Cost
LCC



Roofs over 60' - 100' span
First Cost
LCC
$13.20
$13.00
$12.80
$12.60
$12.40
$12.20
$12.00
$11.80
$11.60
$11.40
Steel Deck 1-1/2" Deep + Open Web Steel Joist
Precast Double Tee
Light Gauge Steel Trusses

Exterior Materials

Exterior Walls	Unit	First Cost	LCC	O&M
Cast-in-Place Reinforced Concrete Wall System	SF	$ 8.69	$ 18.49	1.00%
Precast Reinforced Concrete	SF	$ 7.90	$ 16.81	1.00%
Structural Precast Panels	SF	$ 14.22	$ 30.26	1.00%
Precast Panelized Wall System	SF	$ 19.75	$ 122.37	1.00%
Lightweight Precast Aerated Concrete Wall Panel System	SF	$ 10.27	$ 21.85	1.00%
Tilt-Up Slab	SF	$ 8.45	$ 17.99	1.00%
Curtain Wall System	SF	$ 56.13	$ 182.76	2.00%
Concrete Masonry Unit (CMU)	SF	$ 6.90	$ 8.46	0.20%
Double Wythe CMU	SF	$ 7.98	$ 25.98	2.00%
Lightweight Aerated Concrete Block	SF	$ 10.27	$ 68.19	5.00%
Double Wythe Brick Wall	SF	$ 30.97	$ 205.62	5.00%
Single Wythe Exterior Brick Facing over CMU	SF	$ 14.30	$ 94.94	5.00%
Single Wythe Brick Facing over Steel Studs	SF	$ 19.15	$ 127.15	5.00%
Single Wythe Brick Facing on Fully Reinforced Concrete Wall Panel	SF	$ 14.30	$ 94.94	5.00%

Exterior Wall Coverings	Unit	First Cost	LCC	O&M
Paint	SF	$ 0.27	$ 17.61	50.00%
Stucco	SF	$ 1.66	$ 17.76	5.00%
Exterior Insulated Finishing System (EIFS)	SF	$ 15.41	$ 164.96	5.00%
Copper: Flat-Seam Field Formed Wall System	SF	$ 12.09	$ 38.78	0.35%
Zinc-Copper Alloy: Flat-Seam Field Formed Wall System	SF	$ 15.80	$ 60.45	0.50%
Stainless Steel: Flat-Seam Field Formed Wall System	SF	$ 9.95	$ 34.72	0.20%
High-Performance Coated Metal Panel Wall System	SF	$ 16.99	$ 94.90	0.46%

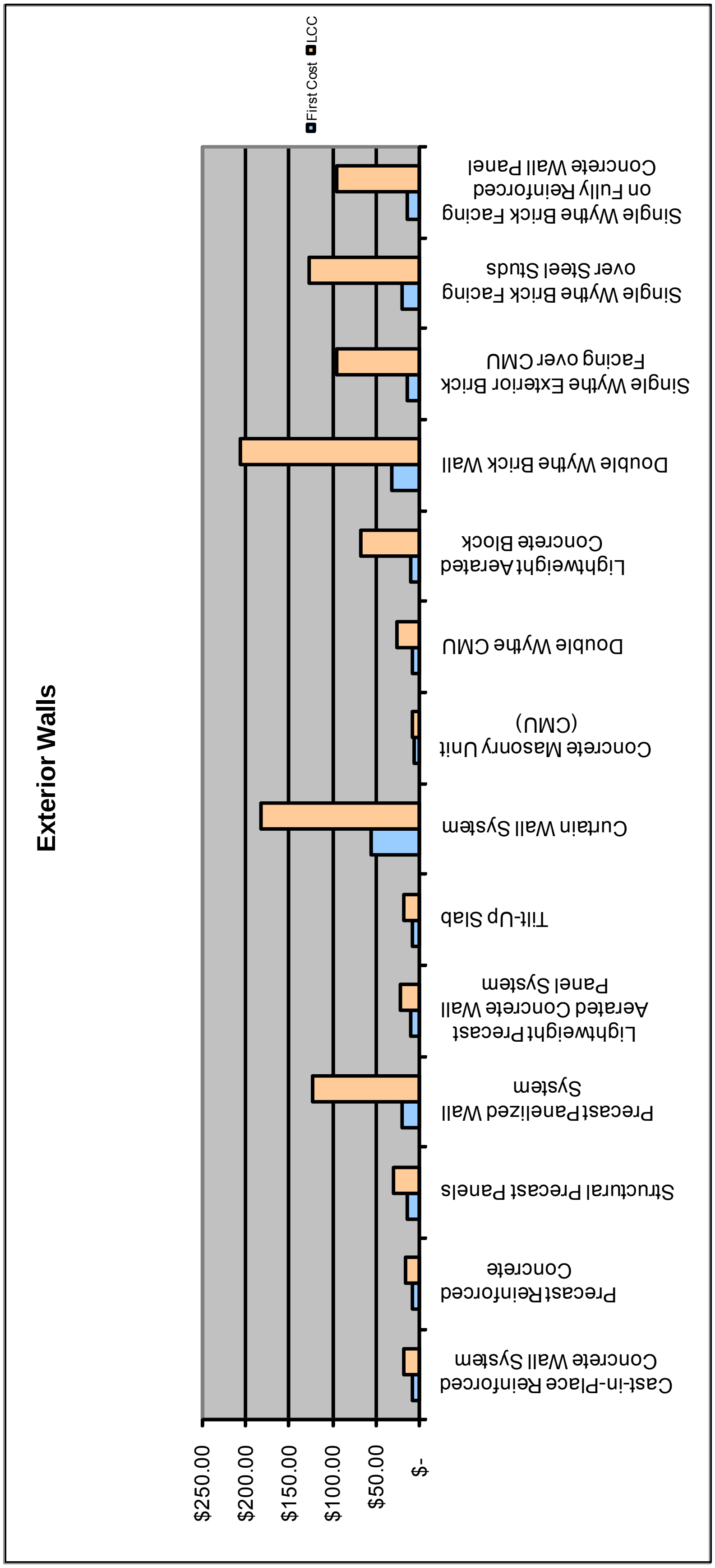
Pitched and Curved Roof Systems	Unit	First Cost	LCC	O&M
Steel, Flat Profile, 1-3/4" Standing Seam, 10" Wide, Zn/Al	SF	$ 4.71	$ 25.98	2.00%
Copper, Standing Seam, 20 oz., 150lb/square	SF	$ 12.40	$ 26.39	1.00%
Zinc-Copper Alloy, Standing Seam, 0.32" Thick	SF	$ 15.80	$ 24.71	0.50%
Asphalt Shingles, Class C, 300-385 lb/square, 5 bundles/square	SF	$ 2.35	$ 65.04	20.00%
Concrete Tiles	SF	$ 3.39	$ 36.27	5.00%
Metal Tiles	SF	$ 8.63	$ 47.60	2.00%

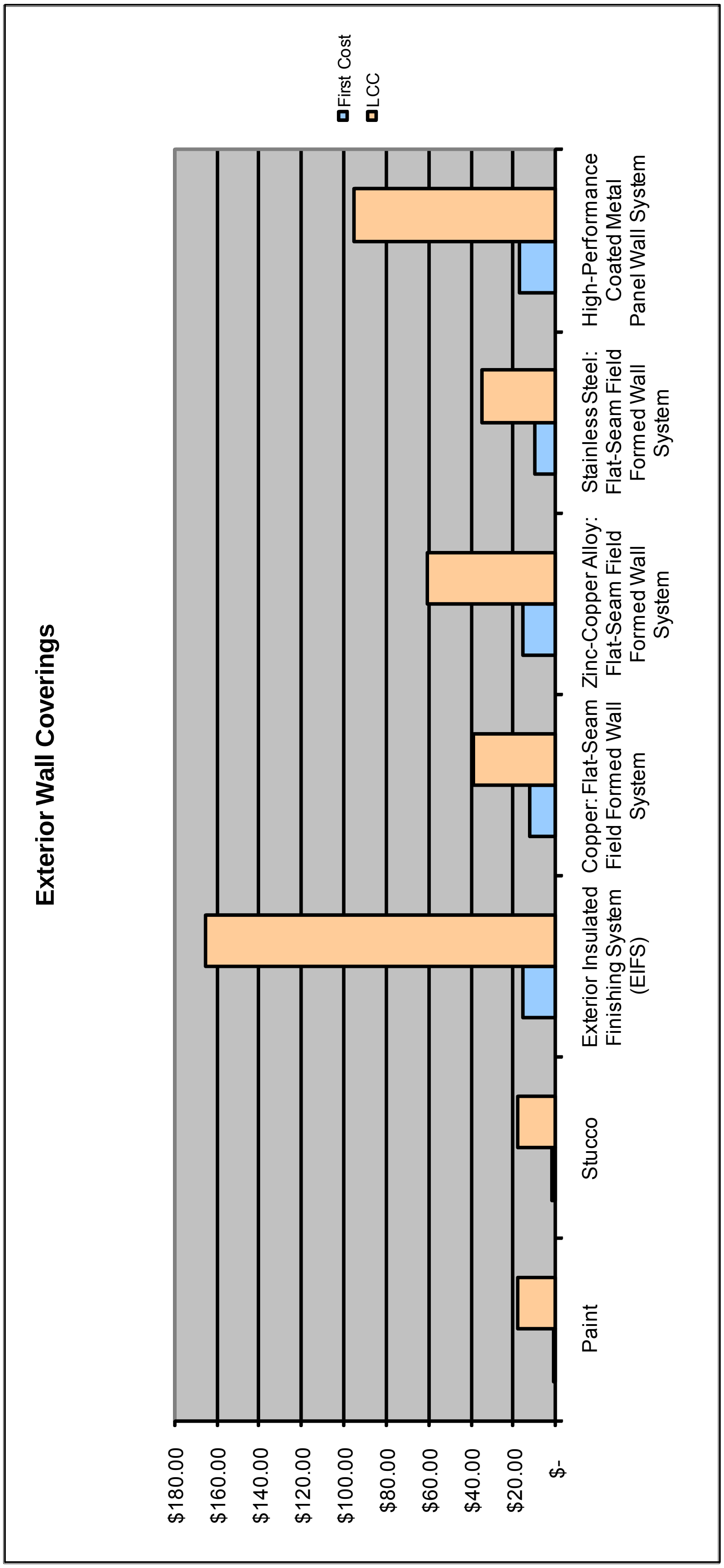
Low Slope Roof Systems	Unit	First Cost	LCC	O&M
Built-Up Roofing, 4 plies #15 Asphalt Felt	SF	$ 2.34	$ 57.73	15.00%
SBS Modified Bitumen, Hot Mopped	SF	$ 2.26	$ 55.78	15.00%
Coal-Tar Pitch	SF	$ 2.52	$ 22.45	1.00%
Polyurethane Spray-Foam (SPF)	SF	$ 1.29	$ 11.47	1.00%
SBS Modified Bitumen, Cold Applied	SF	$ 1.19	$ 10.58	1.00%
Ethylene Propylene Diene Monomer (EPDM), Single-Ply, 45 mil, Loose-Laid and Ballasted	SF	$ 1.45	$ 41.75	20.00%
EPDM, Single-Ply, 45 mil, Fully Adhered, No Ballast	SF	$ 2.10	$ 60.36	20.00%
TPO, Single-Ply, 45 mil, Fully Adhered, No Ballast	SF	$ 1.76	$ 50.43	20.00%
PVC Single-Ply, Reinforced 50 mil, Fully Adhered, No Ballast	SF	$ 1.84	$ 46.80	18.00%
Ketone Ethylene Ester (KEE) Membrane, Mechanically Attached	SF	$ 1.02	$ 25.52	20.00%

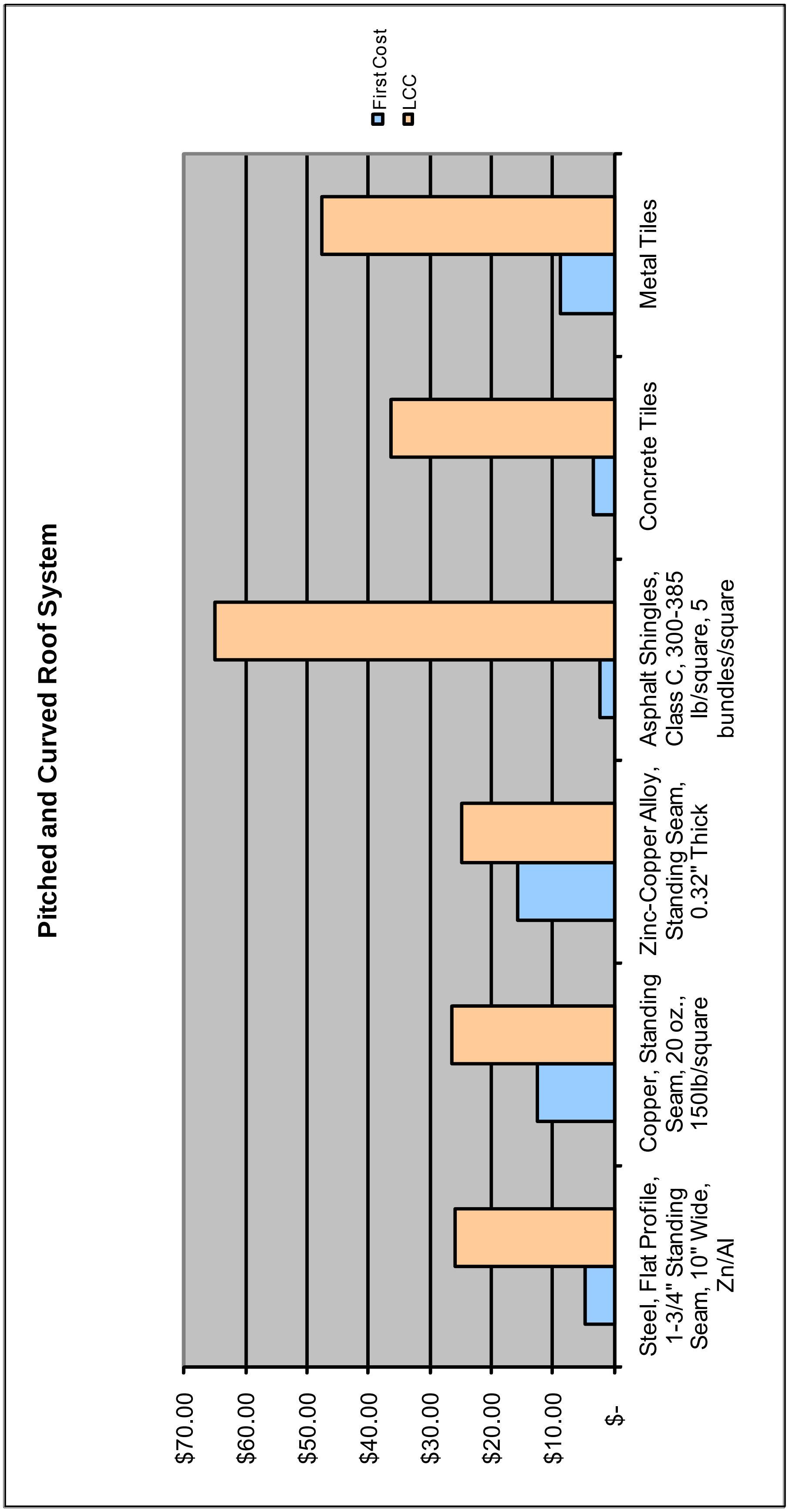
Windows	Unit	First Cost	LCC	O&M
Aluminum Frame	LF	$ 3.40	$ 27.91	5.00%
Aluminum Frame, Thermally Broken	LF	$ 3.74	$ 30.70	5.00%
Vinyl (PVC) Frame	LF	$ 3.68	$ 49.64	7.00%

Doors	Unit	First Cost	LCC	O&M
Glazed Entry, Aluminum Frame	EA	$ 707.23	$ 5,705.30	5.00%
Glazed Entry, Aluminum Frame, Thermally Broken	EA	$ 707.23	$ 5,705.30	5.00%
Hollow Metal, Painted	EA	$ 309.52	$ 2,755.31	5.00%
Roll-Up Overhead Service	EA	$ 2,179.83	$ 7,749.78	1.00%

Glazing	Unit	First Cost	LCC	O&M
Float Glass (1/4") with Low Emissivity Coating	SF	$ 10.99	$ 72.94	5.00%
Float Glass (1/4"), Tinted	SF	$ 12.26	$ 81.40	5.00%
Tempered Float Glass (1/4"), Clear	SF	$ 12.33	$ 81.87	5.00%
Tempered Float Glass (1/4"), Tinted	SF	$ 15.32	$ 101.72	5.00%
Laminated Float Glass, Clear	SF	$ 17.94	$ 119.12	5.00%
Laminated Float Glass, Tinted	SF	$ 22.25	$ 147.71	5.00%
Double Glazed	SF	$ 37.89	$ 79.33	5.00%
Double Glazed, Tinted	SF	$ 32.82	$ 217.92	5.00%
Triple Glazed	SF	$ 60.67	$ 402.84	5.00%
Triple Glazed, Tinted	SF	$ 87.96	$ 584.02	5.00%
Polycarbonate	SF	$ 16.27	$ 34.07	5.00%


Exterior Walls
First Cost
LCC
$250.00
$200.00
$150.00
$100.00
$50.00
$-
Cast-in-Place Reinforced Concrete Wall System
Precast Reinforced Concrete
Structural Precast Panels
Precast Panelized Wall System
Lightweight Precast Aerated Concrete Wall Panel System
Tilt-Up Slab
Curtain Wall System
Concrete Masonry Unit (CMU)
Double Wythe CMU
Lightweight Aerated Concrete Block
Double Wythe Brick Wall
Single Wythe Exterior Brick Facing over CMU
Single Wythe Brick Facing over Steel Studs
Single Wythe Brick Facing on Fully Reinforced Concrete Wall Panel


Exterior Wall Coverings
$180.00
$160.00
$140.00
$120.00
$100.00
$80.00
$60.00
$40.00
$20.00
$-
Paint
Stucco
Exterior Insulated Finishing System (EIFS)
Copper: Flat-Seam Field Formed Wall System
Zinc-Copper Alloy: Flat-Seam Field Formed Wall System
Stainless Steel: Flat-Seam Field Formed Wall System
High-Performance Coated Metal Panel Wall System
First Cost
LCC


Pitched and Curved Roof System
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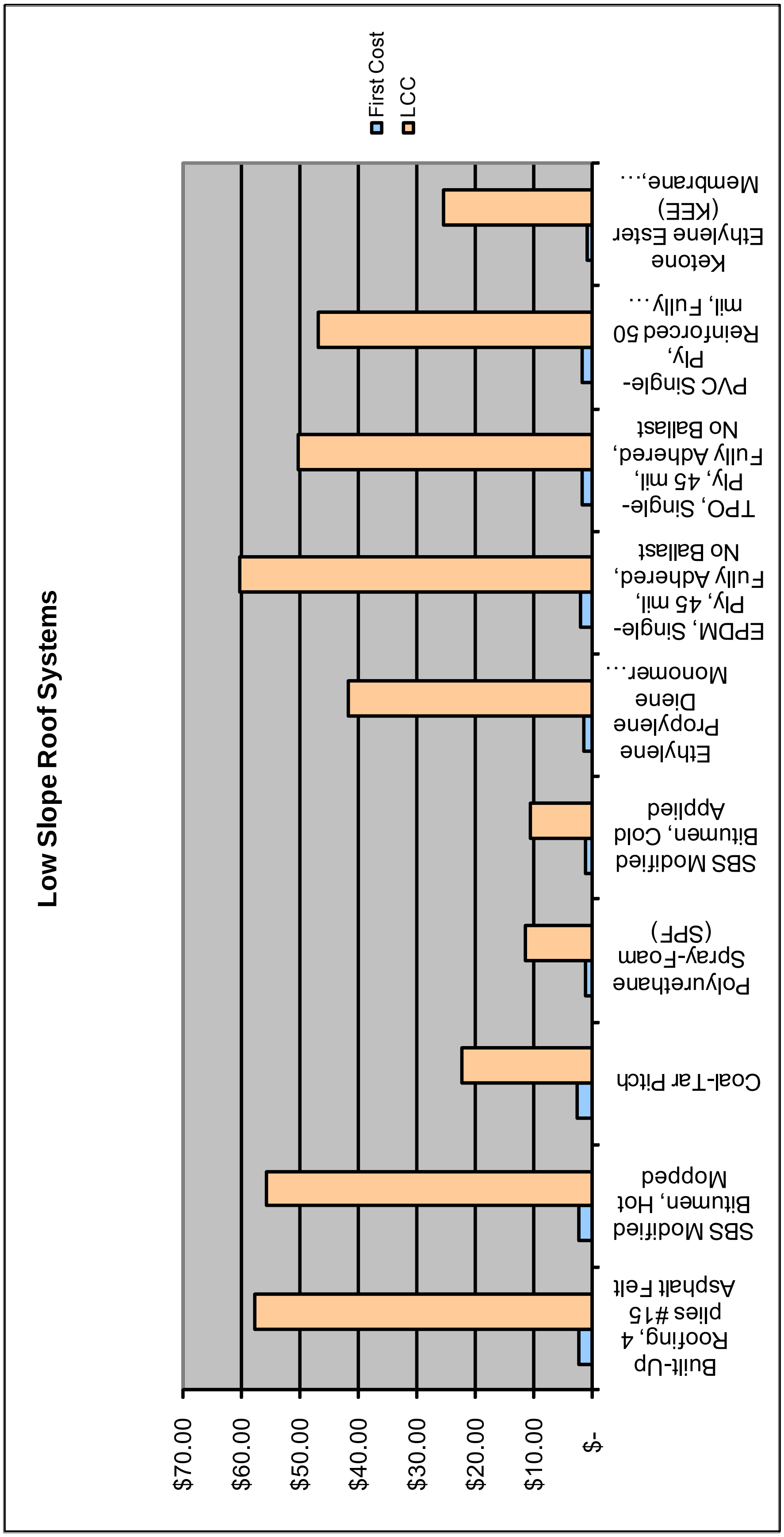
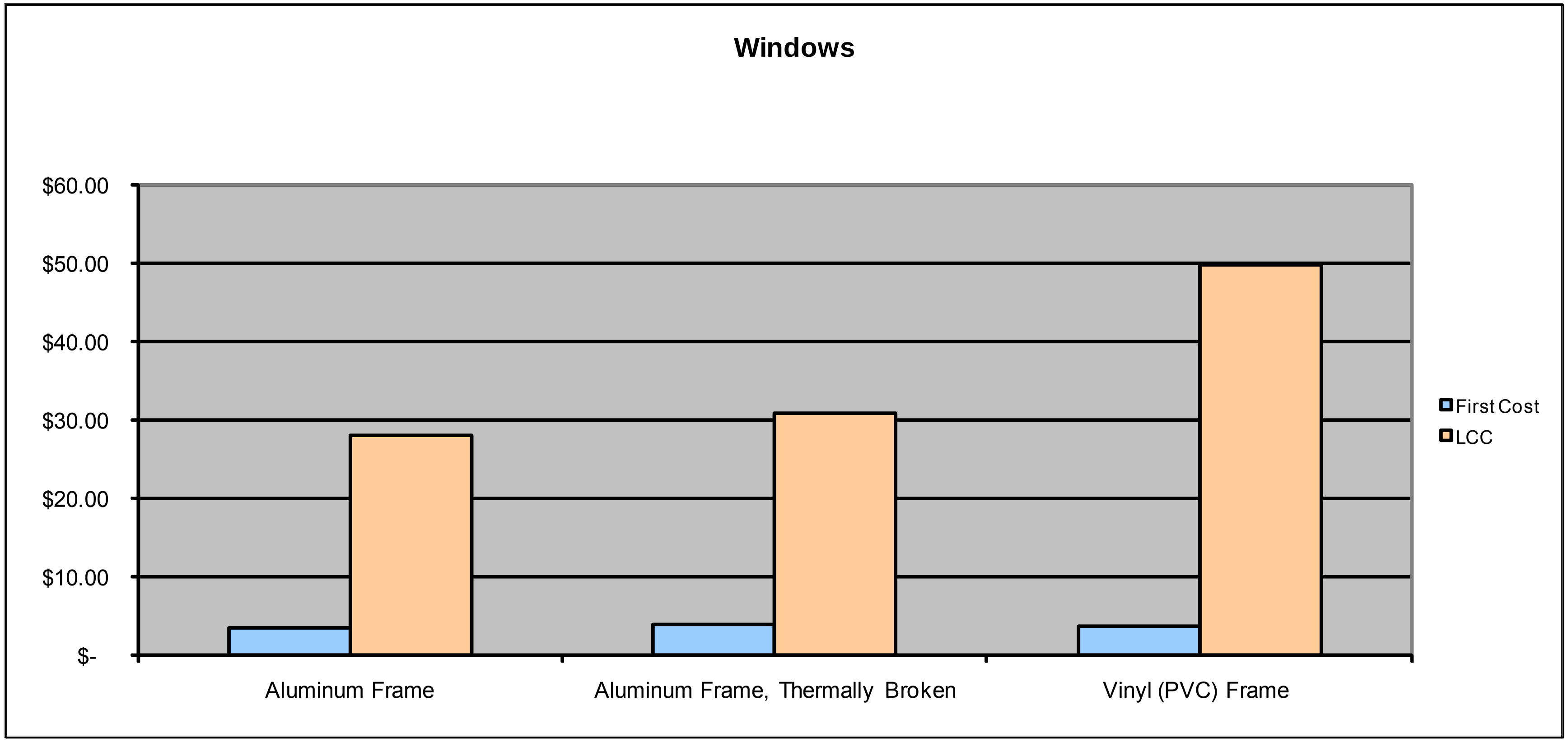
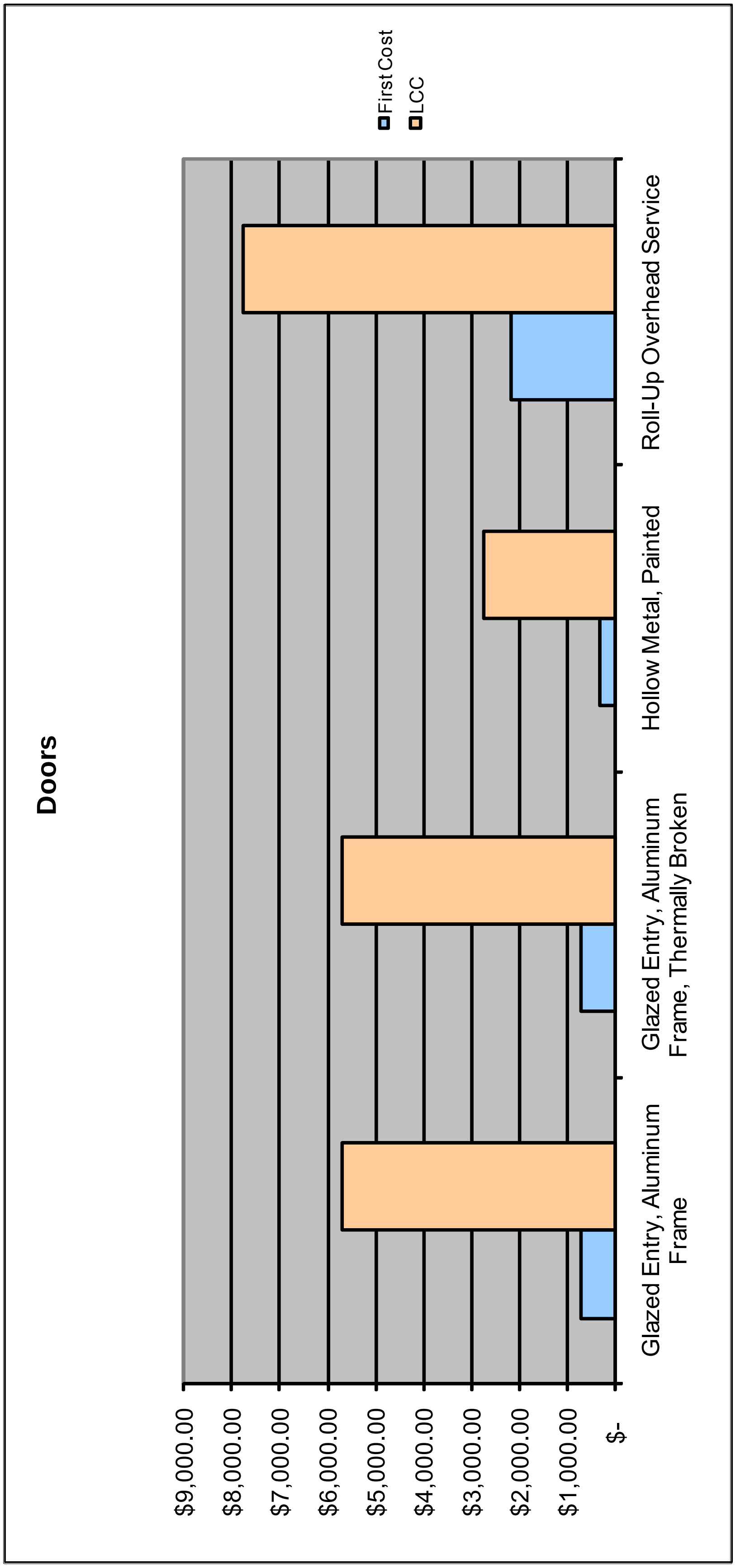
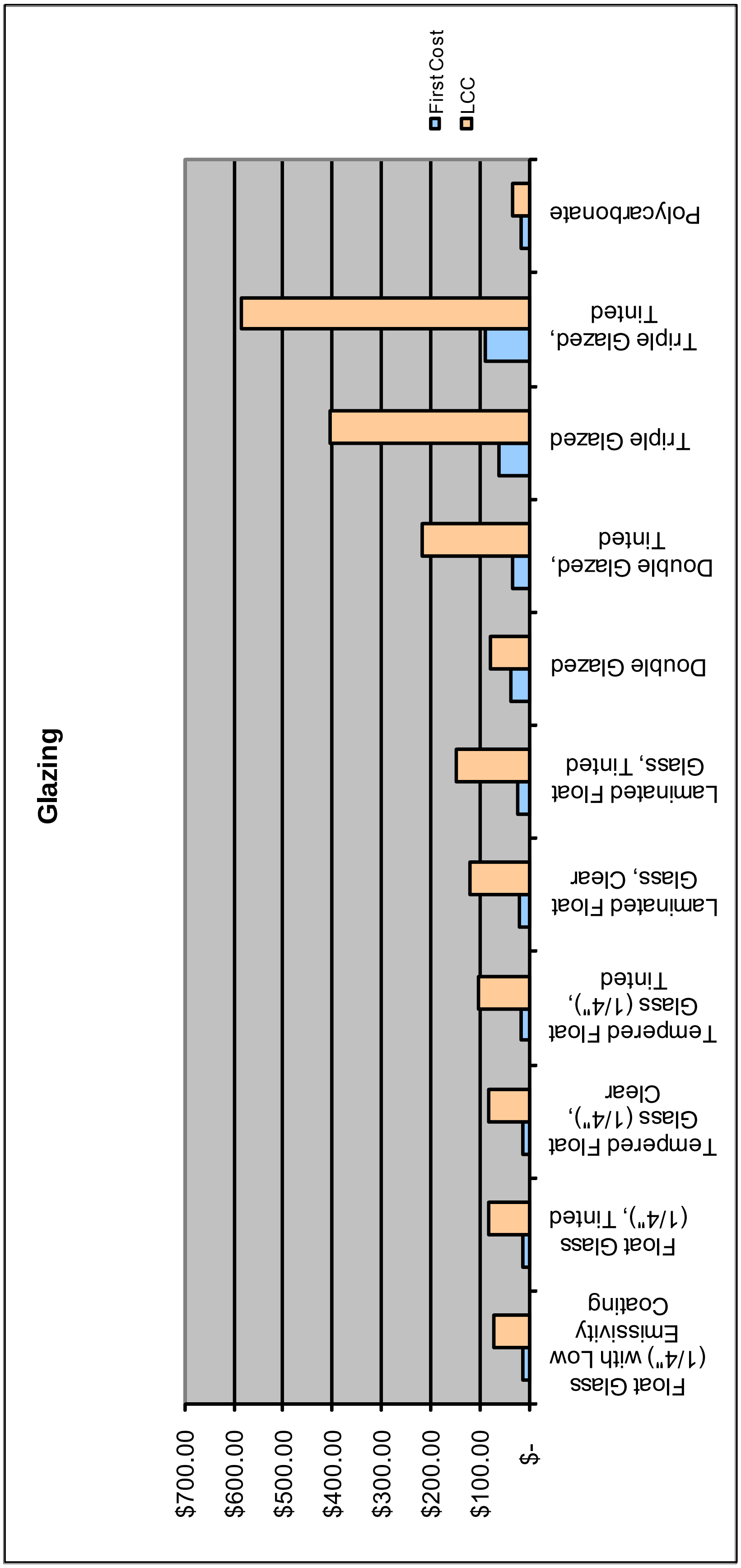
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$-
Steel, Flat Profile, 1-3/4" Standing Seam, 10" Wide, Zn/Al
Copper, Standing Seam, 20 oz., 150lb/square
Zinc-Copper Alloy, Standing Seam, 0.32" Thick
Asphalt Shingles, Class C, 300-385 lb/square, 5 bundles/square
Concrete Tiles
Metal Tiles
First Cost
LCC


Low Slope Roof Systems
First Cost
LCC
$70.00
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$-
Built-Up Roofing, 4 plies #15 Asphalt Felt
SBS Modified Bitumen, Hot Mopped
Coal-Tar Pitch
Polyurethane Spray-Foam (SPF)
SBS Modified Bitumen, Cold Applied
Ethylene Propylene Diene Monomer...
EPDM, Single-Ply, 45 mil, Fully Adhered, No Ballast
TPO, Single-Ply, 45 mil, Fully Adhered, No Ballast
PVC Single-Ply, Reinforced 50 mil, Fully...
Ketone Ethylene Ester (KEE) Membrane,...


Windows
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$-
Aluminum Frame
Aluminum Frame, Thermally Broken
Vinyl (PVC) Frame
First Cost
LCC


Doors
First Cost
LCC
$9,000.00
$8,000.00
$7,000.00
$6,000.00
$5,000.00
$4,000.00
$3,000.00
$2,000.00
$1,000.00
$-
Glazed Entry, Aluminum Frame
Glazed Entry, Aluminum Frame, Thermally Broken
Hollow Metal, Painted
Roll-Up Overhead Service


Glazing
First Cost
LCC
$700.00
$600.00
$500.00
$400.00
$300.00
$200.00
$100.00
$-
Float Glass (1/4") with Low Emissivity Coating
Float Glass (1/4"), Tinted
Tempered Float Glass (1/4"), Clear
Tempered Float Glass (1/4"), Tinted
Laminated Float Glass, Clear
Laminated Float Glass, Tinted
Double Glazed
Double Glazed, Tinted
Triple Glazed
Triple Glazed, Tinted
Polycarbonate

Interior Surface and Substrate Materials

Interior Floor Surfaces	Unit	First Cost	LCC	O&M
Vinyl Composition Tile (VCT)	SF	$ 2.26	$ 236.72	86.00%
Vinyl Sheet	SF	$ 3.24	$ 244.37	60.00%
Linoleum	SF	$ 7.11	$ 233.79	27.00%
Rubber Flooring	SF	$ 8.37	$ 291.27	23.00%
Ceramic Tile	SF	$ 11.55	$ 24.58	1.00%
Quarry Tile	SF	$ 10.59	$ 53.67	2.00%
Carpet	SF	$ 5.70	$ 170.70	18.00%
Cork	SF	$ 5.42	$ 324.52	36.00%
Exposed Concrete	SF	$ 1.25	$ 108.25	76.00%
Terrazzo	SF	$ 11.22	$ 112.45	8.00%
Wood Plank	SF	$ 14.71	$ 433.92	24.00%
Wood Laminate	SF	$ 18.96	$ 203.02	5.00%
Bamboo Flooring	SF	$ 20.89	$ 444.26	17.00%
Resinous Flooring	SF	$ 11.22	$ 112.45	8.00%

Interior Partitions	Unit	First Cost	LCC	O&M
Gypsum Wallboard	LF	$ 23.23	$ 494.77	12.00%
Very High-Impact (VHI) Wall Board	LF	$ 53.72	$ 538.42	2.00%
Fiberboard Panels	LF	$ 25.60	$ 343.16	5.00%
Green Board	LF	$ 24.65	$ 330.45	5.00%
Blue Board and Veneer Plaster	LF	$ 24.96	$ 334.68	5.00%
Metal Lath and Plaster	LF	$ 51.19	$ 548.16	5.00%
Precast Concrete Panels	LF	$ 28.44	$ 44.48	0.50%
Concrete Masonry Units (CMU)	LF	$ 71.57	$ 111.94	0.50%
Glass Block	LF	$ 280.45	$ 296.27	0.05%
Demountable Partition	LF	$ 42.85	$ 1,229.83	10.00%

Interior Wall Finishes	Unit	First Cost	LCC	O&M
Waterborne Paint	SF	$ 0.68	$ 19.96	5.00%
Epoxy Paint	SF	$ 5.74	$ 112.86	2.00%
Acoustical Panels	SF	$ 13.22	$ 193.55	10.00%
Ceramic Tile	SF	$ 7.54	$ 16.04	1.00%
Vinyl Wall Coverings	SF	$ 2.69	$ 430.43	12.00%
Wallpaper	SF	$ 2.53	$ 95.37	18.00%
Fiberglass Reinforced Panel (FRP)	SF	$ 2.72	$ 8.79	2.00%

Interior Ceilings	Unit	First Cost	LCC	O&M
Painted Cement Plaster	SF	$ 6.92	$ 40.22	3.00%
Standard Drywall	SF	$ 4.16	$ 47.58	8.00%
Blue Board and Veneer Plaster	SF	$ 5.39	$ 61.70	8.00%
Suspended Metal Grid System	SF	$ 1.45	$ 40.16	20.00%
Mineral Wool Acoustical Tiles	SF	$ 3.48	$ 77.78	12.00%
Fiberglass Acoustical Tiles	SF	$ 4.61	$ 90.02	8.00%
Cellulose Fiber Acoustical Tiles	SF	$ 1.58	$ 38.92	14.00%
Moisture-Resistant Mylar Tiles	SF	$ 2.48	$ 83.80	12.00%
Painted Metal Deck and Steel Frame	SF	$ 12.06	$ 52.85	3.00%

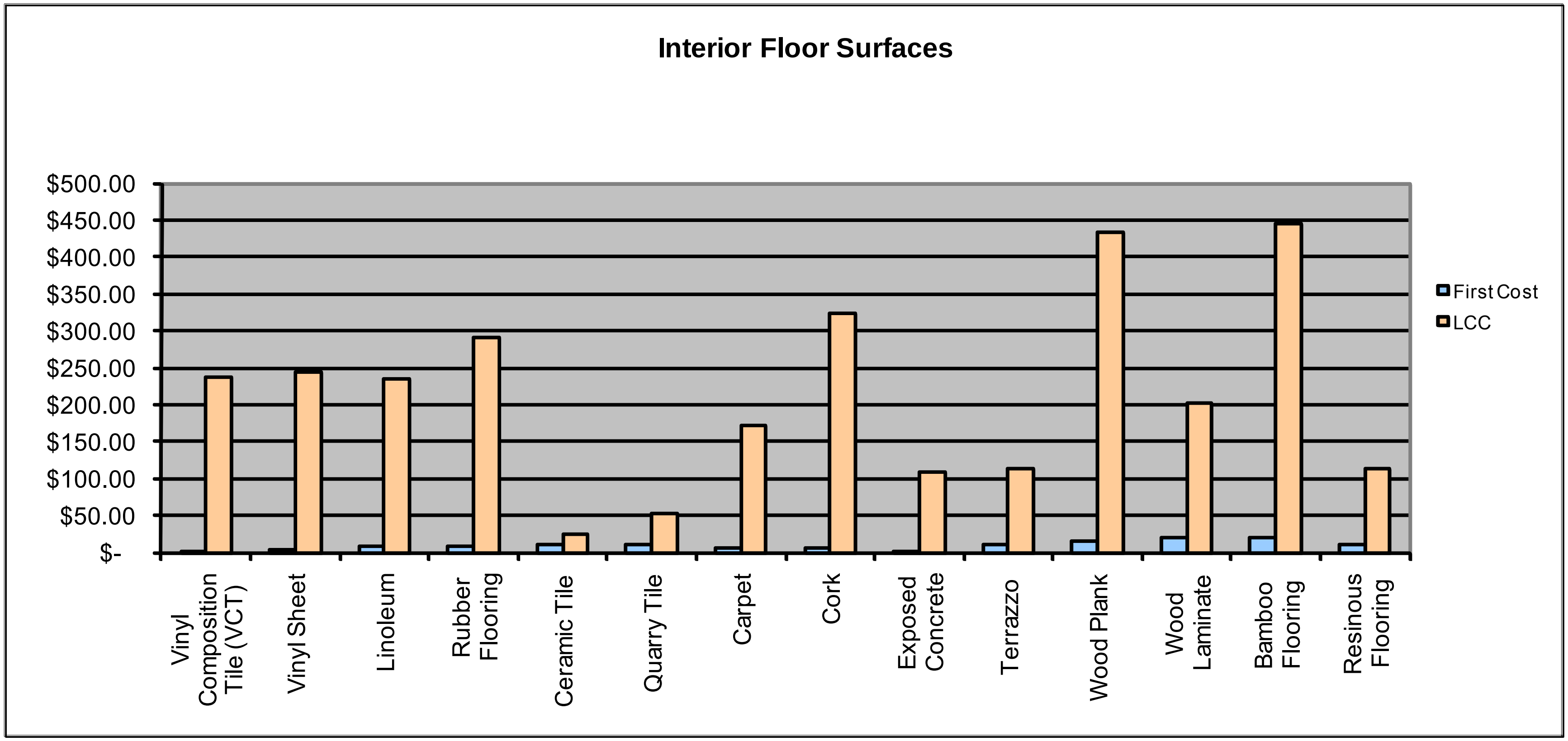
Interior Door Assemblies	Unit	First Cost	LCC	O&M
Steel Door	EA	$ 521.40	$ 7,582.06	10.00%
Hollow Core Wood Door	EA	$ 134.40	$ 1,893.95	8.00%
Solid Core Wood Door	EA	$ 173.60	$ 2,446.35	8.00%
Aluminum Door	EA	$ 932.04	$ 12,775.45	10.00%
Fiberglass Door	EA	$ 463.68	$ 2,558.57	2.00%

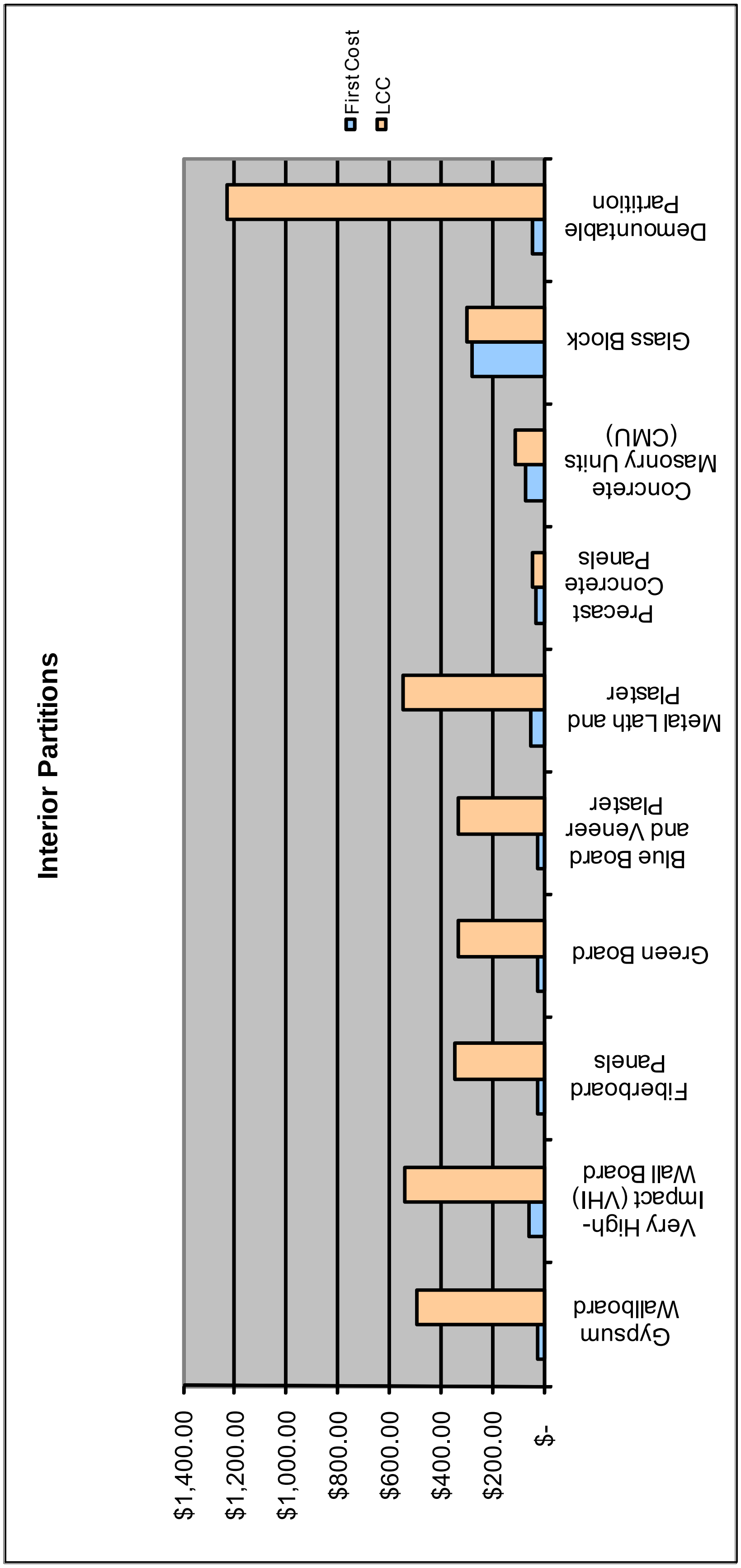
Interior Window Assemblies	Unit	First Cost	LCC	O&M
Aluminum Frame Window	SF	$ 45.28	$ 365.30	5.00%
Steel Frame Window	SF	$ 44.87	$ 298.22	3.00%
Vinyl Frame Window	SF	$ 44.24	$ 692.91	7.00%

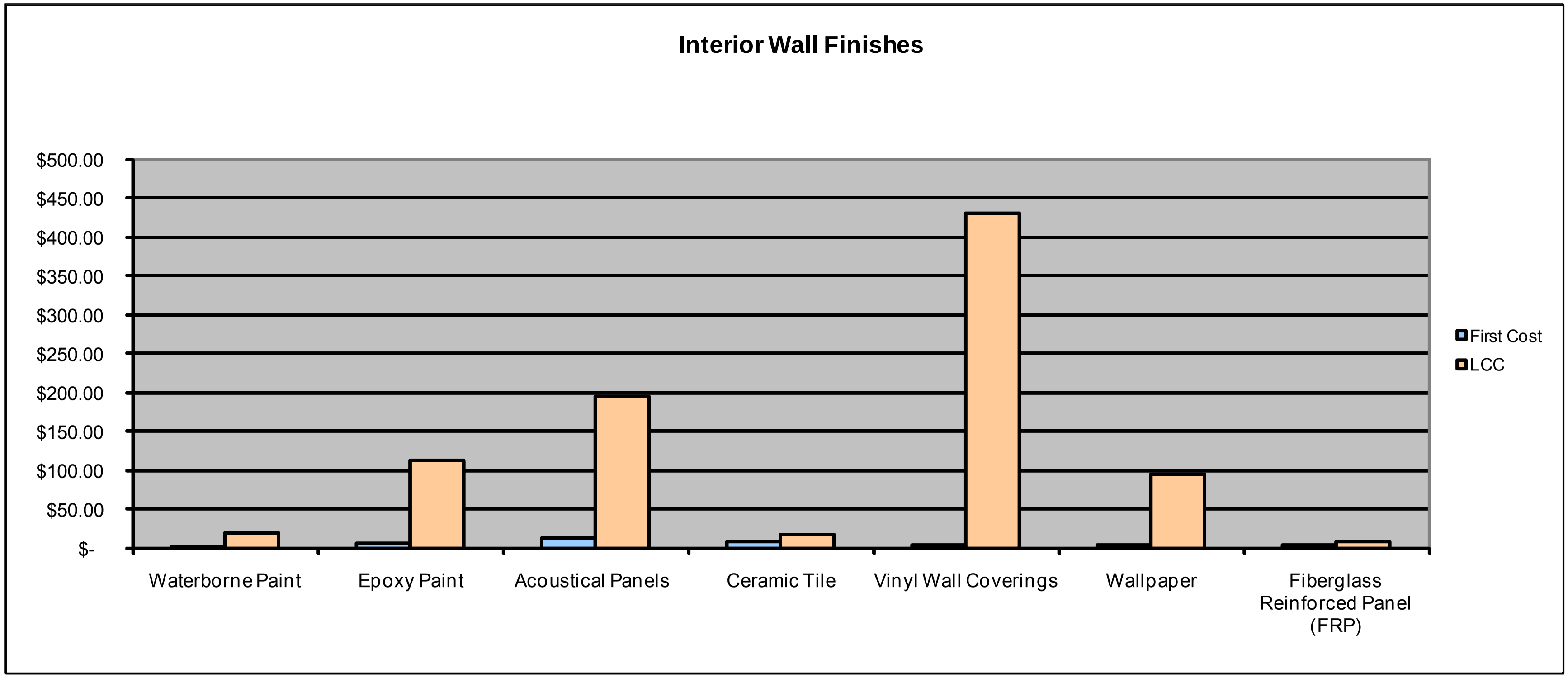
Interior Specialty Items: Wall Bases	Unit	First Cost	LCC	O&M
Vinyl	LF	$ 2.43	$ 46.34	10.00%
Ceramic Tile	LF	$ 13.51	$ 58.70	0.50%
Quarry Tile	LF	$ 14.22	$ 42.54	0.50%
Terrazzo	LF	$ 34.76	$ 348.43	8.00%
Wood	LF	$ 5.53	$ 106.99	15.00%
Rubber	LF	$ 2.43	$ 51.83	12.00%
Resinous Base	LF	$ 34.76	$ 348.43	8.00%

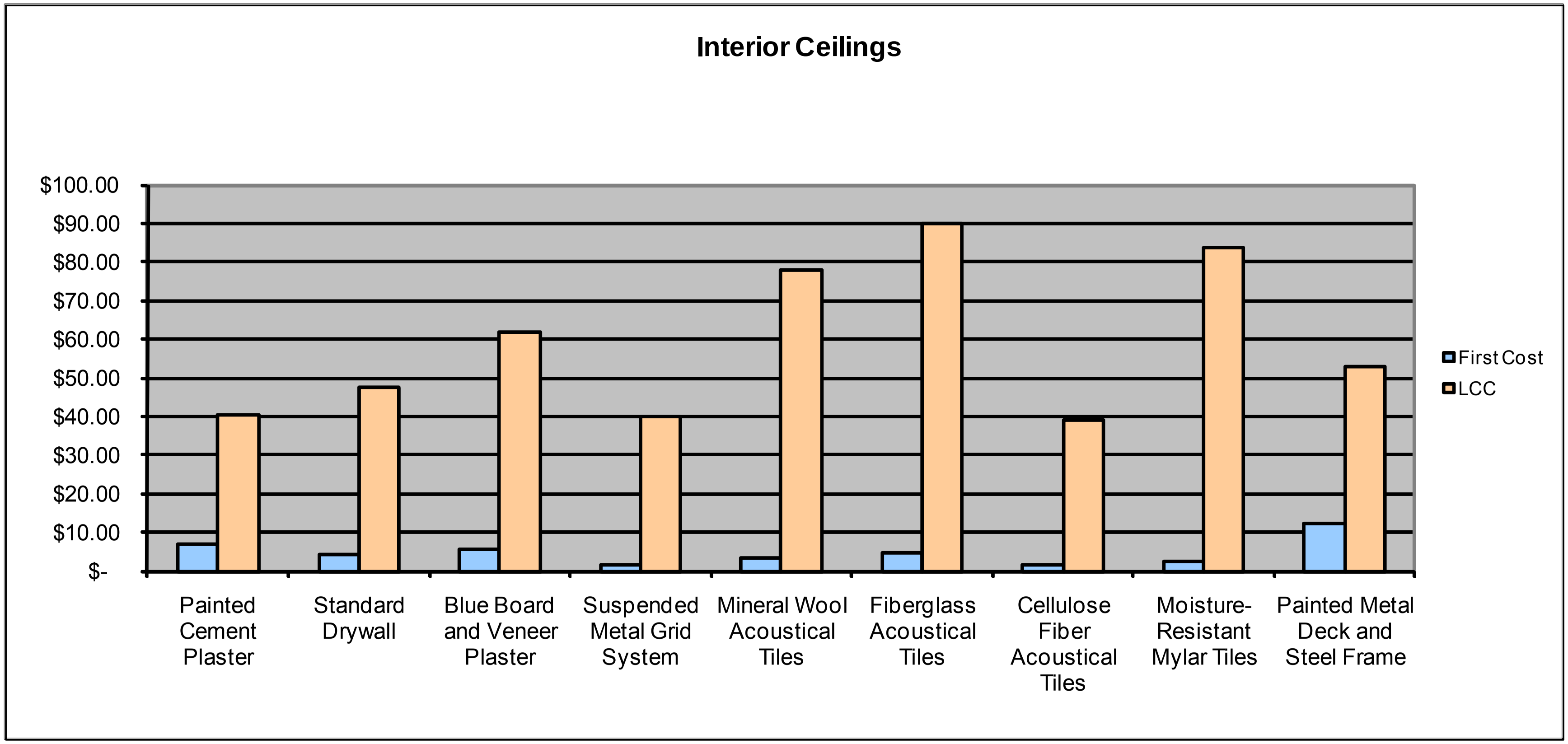
Interior Specialty Items: Millwork - Built-in Cabinetry	Unit	First Cost	LCC	O&M
Plywood	LF	$ 260.70	$ 2,907.00	3.00%
Medium Density Fiberboard (MDF)	LF	$ 260.70	$ 4,204.81	5.00%
Particle Board	LF	$ 221.20	$ 7,032.65	15.00%
Melamine board	LF	$ 205.40	$ 6,530.32	15.00%

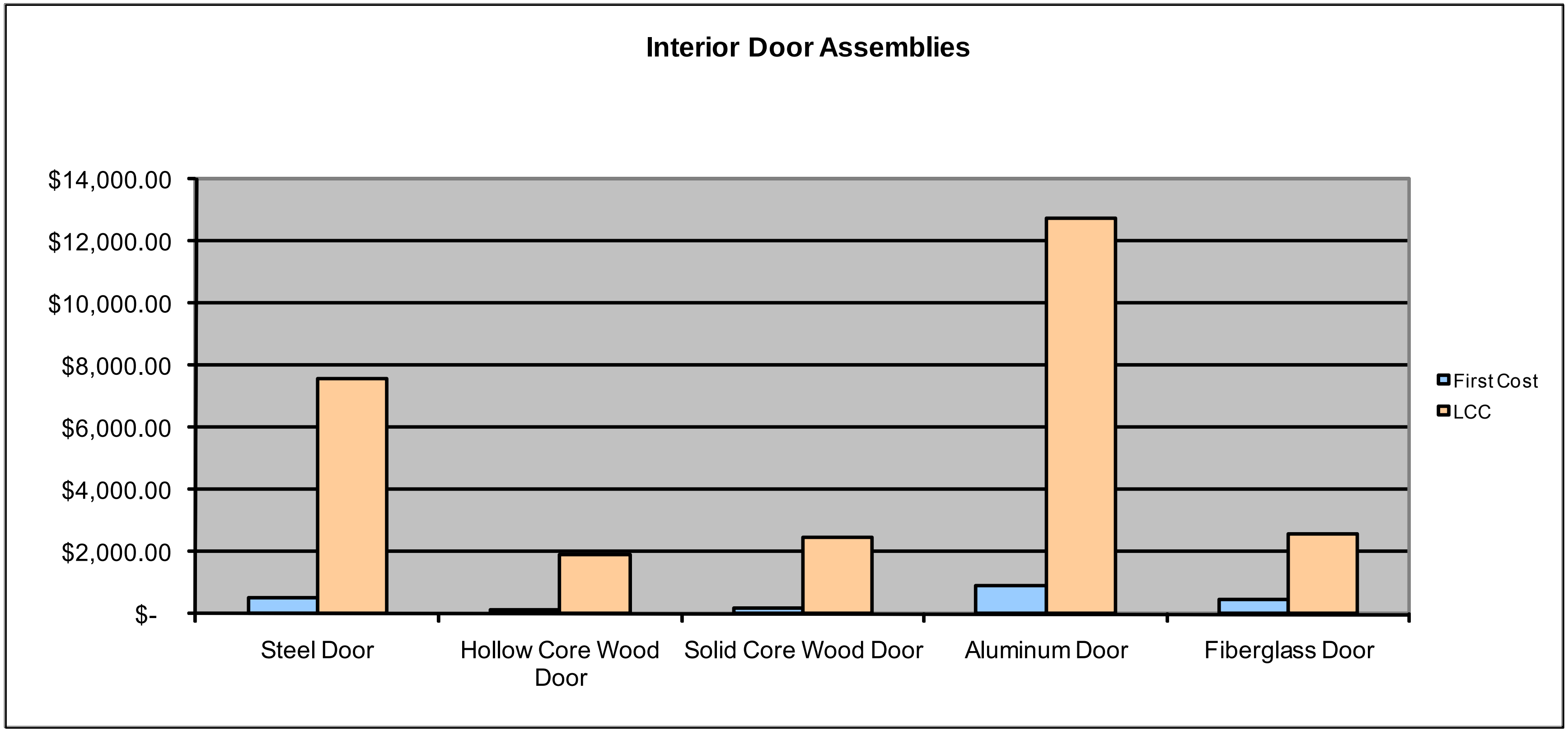
Interior Specialty Items: Countertops	Unit	First Cost	LCC	O&M
Granite	LF	$ 161.16	$ 252.05	0.50%
Chemical-Resistant Solid Surfacing	LF	$ 118.50	$ 467.11	1.00%
Linoleum Over Plywood	LF	$ 33.18	$ 674.48	12.00%
Plastic Laminate Over Plywood	LF	$ 91.64	$ 1,745.42	10.00%
Stainless Steel	LF	$ 172.22	$ 366.48	1.00%
Quartz	LF	$ 136.99	$ 214.24	0.50%

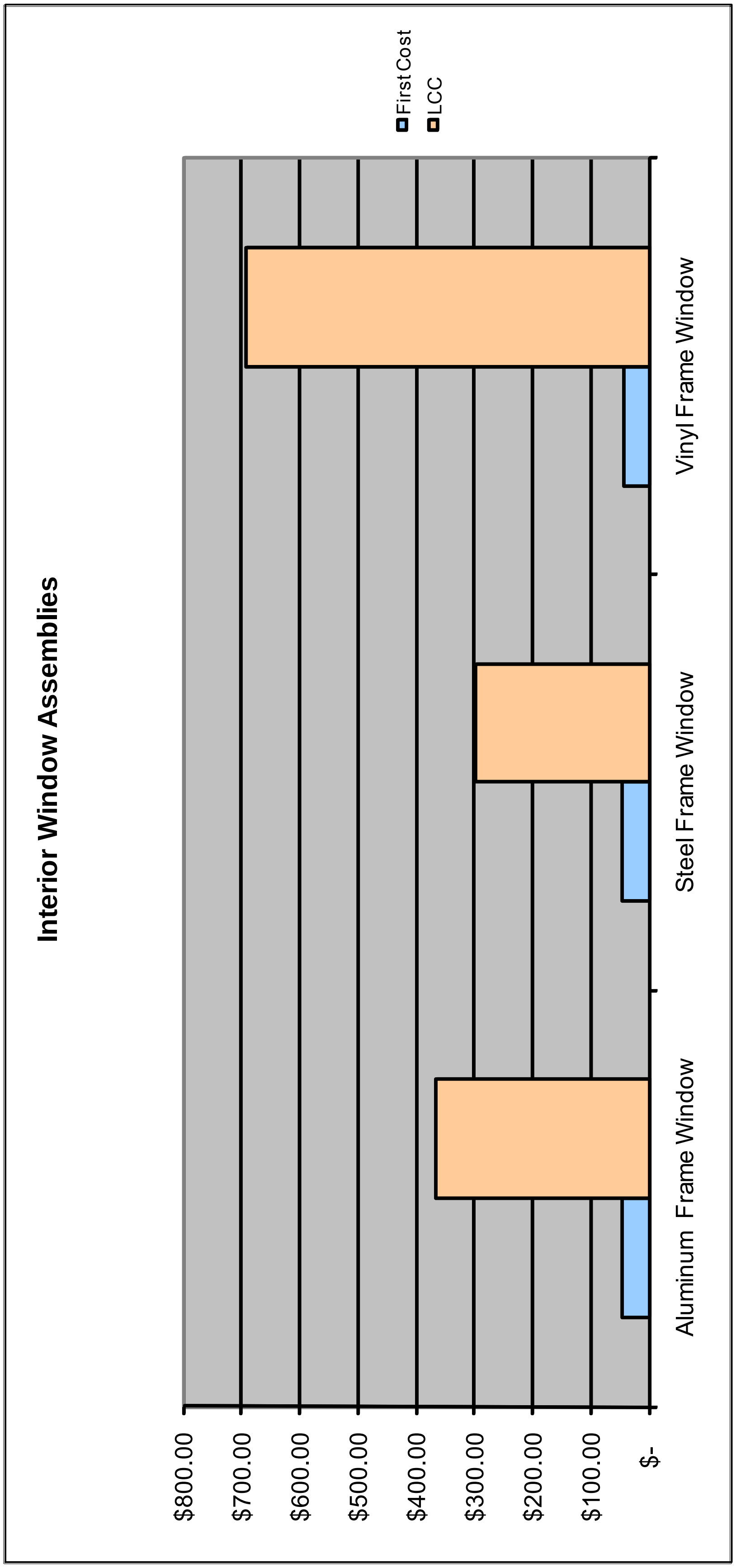

Interior Floor Surfaces
$500.00
$450.00
$400.00
$350.00
$300.00
$250.00
$200.00
$150.00
$100.00
$50.00
$-
Vinyl Composition Tile (VCT)
Vinyl Sheet
Linoleum
Rubber Flooring
Ceramic Tile
Quarry Tile
Carpet
Cork
Exposed Concrete
Terrazzo
Wood Plank
Wood Laminate
Bamboo Flooring
Resinous Flooring
First Cost
LCC


Interior Partitions
$1,400.00
$1,200.00
$1,000.00
$800.00
$600.00
$400.00
$200.00
$-
Gypsum Wallboard
Very High-Impact (VHI) Wall Board
Fiberboard Panels
Green Board
Blue Board and Veneer Plaster
Metal Lath and Plaster
Precast Concrete Panels
Concrete Masonry Units (CMU)
Glass Block
Demountable Partition
First Cost
LCC


Interior Wall Finishes
$500.00
$450.00
$400.00
$350.00
$300.00
$250.00
$200.00
$150.00
$100.00
$50.00
$-
Waterborne Paint
Epoxy Paint
Acoustical Panels
Ceramic Tile
Vinyl Wall Coverings
Wallpaper
Fiberglass Reinforced Panel (FRP)
First Cost
LCC

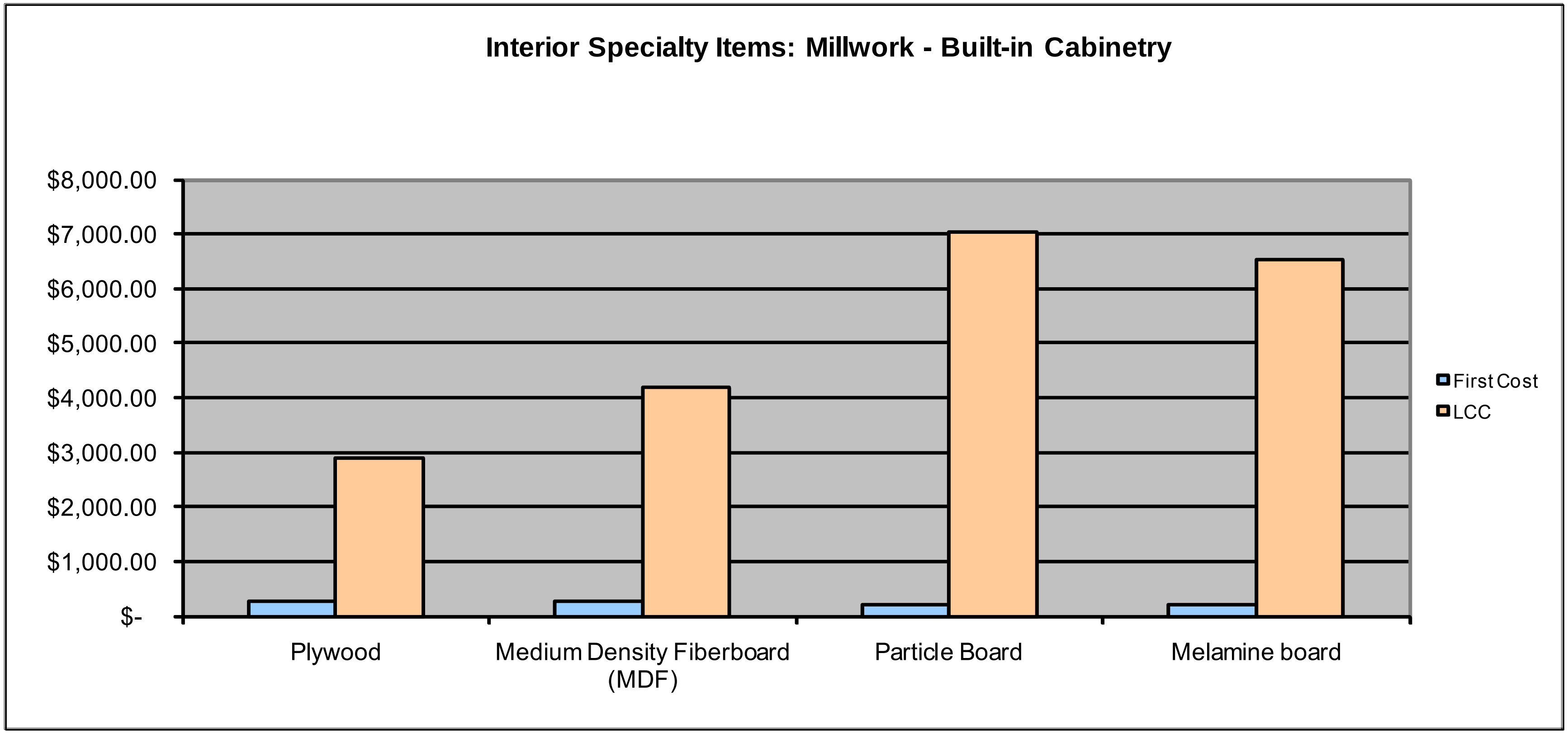

Interior Ceilings
$100.00
$90.00
$80.00
$70.00
$60.00
$50.00
$40.00
$30.00
$20.00
$10.00
$-
Painted Cement Plaster
Standard Drywall
Blue Board and Veneer Plaster
Suspended Metal Grid System
Mineral Wool Acoustical Tiles
Fiberglass Acoustical Tiles
Cellulose Fiber Acoustical Tiles
Moisture-Resistant Mylar Tiles
Painted Metal Deck and Steel Frame
First Cost
LCC


Interior Door Assemblies
$14,000.00
$12,000.00
$10,000.00
$8,000.00
$6,000.00
$4,000.00
$2,000.00
$-
Steel Door
Hollow Core Wood Door
Solid Core Wood Door
Aluminum Door
Fiberglass Door
First Cost
LCC



Interior Window Assemblies
$800.00
$700.00
$600.00
$500.00
$400.00
$300.00
$200.00
$100.00
$-
Aluminum Frame Window
Steel Frame Window
Vinyl Frame Window
First Cost
LCC

Interior Specialty Items: Wall Bases



Interior Specialty Items: Millwork - Built-in Cabinetry
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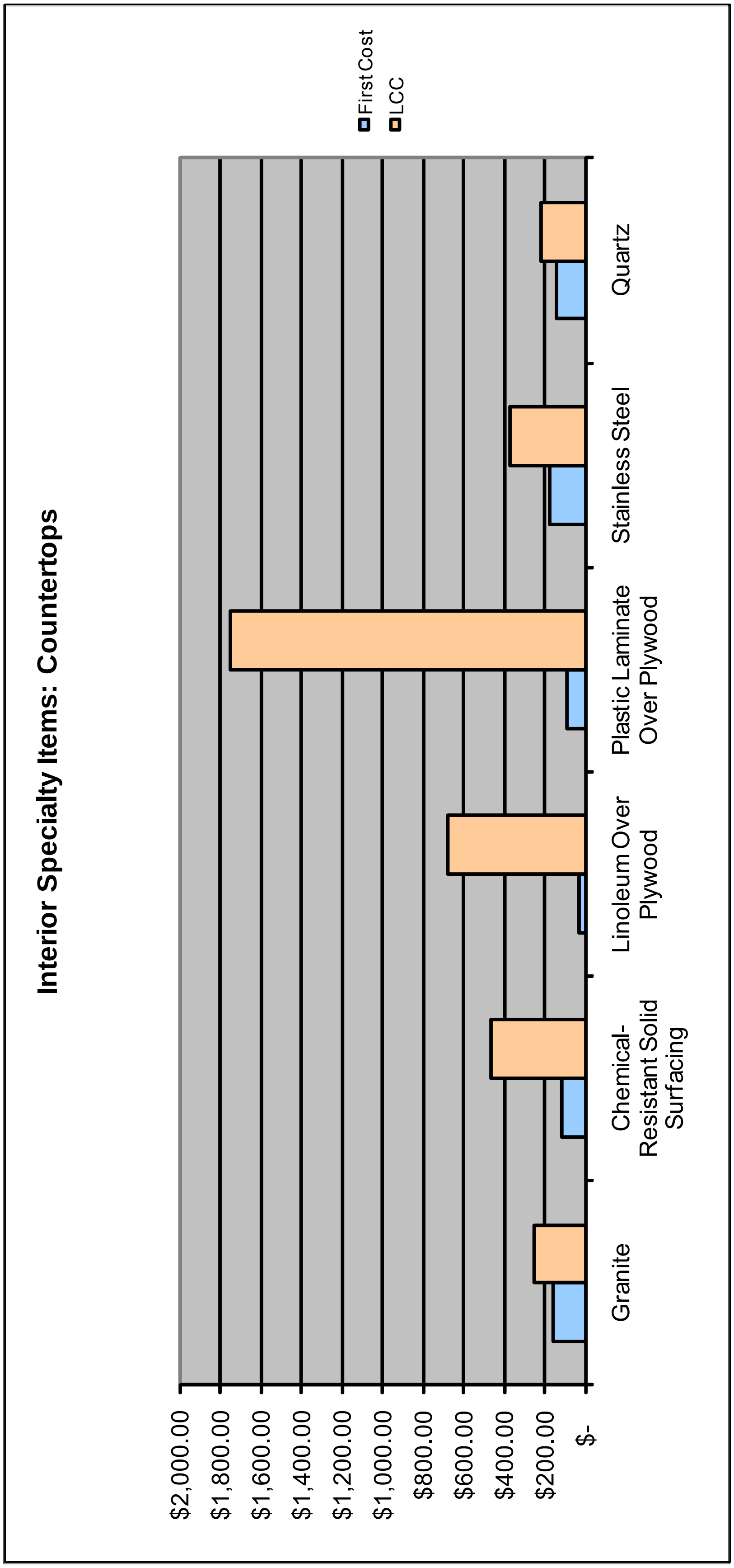
$7,000.00
$6,000.00
$5,000.00
$4,000.00
$3,000.00
$2,000.00
$1,000.00
$-
Plywood
Medium Density Fiberboard (MDF)
Particle Board
Melamine board
First Cost
LCC


Interior Specialty Items: Countertops
$2,000.00
$1,800.00
$1,600.00
$1,400.00
$1,200.00
$1,000.00
$800.00
$600.00
$400.00
$200.00
$-
Granite
Chemical-Resistant Solid Surfacing
Linoleum Over Plywood
Plastic Laminate Over Plywood
Stainless Steel
Quartz
First Cost
LCC

APPENDIX B
LIFE CYCLE ANALYSIS (LCA)

B.1 INTRODUCTION

Life cycle analysis or assessment (LCA) is an environmental impact assessment framework. LCA is defined as a four-phase process consisting of goal definition and scoping, which defines the objectives of the study and determines the analysis boundary; inventory analysis; impact analysis; and improvement analysis, which is an evaluation of the environmental loads identified in the previous stages in order to determine modifications to the product or process that will reduce environmental impact. Within an LCA framework, environmental assessment methods differ primarily in how the inventory analysis is performed and in how the impacts are evaluated.

B.2 NOTES AND ASSUMPTIONS

The LCA rankings in tables in Chapters 1 and 2 are largely based on data from the Athena LCA calculator as implemented for the Green Globes building assessment method. The life cycle of each material, system, or element is evaluated and an inventory of relevant emissions or resource use is tabulated. These are categorized into five areas: primary energy use, global warming potential, weighted resource use, an air pollution index, and a water pollution index. In this case, the inventory values have been allocated on a square foot basis.

Primary energy is an aggregation of the non-renewable energy consumed in producing the material or system from raw material stage to the manufacturer's gate. In this case, primary energy is similar to the more commonly used term embodied energy. Global warming potential (GWP) is calculated by applying the Intergovernmental Panel on Climate Change (IPCC) 100 year equivalence factors to the various global warming gases in the life cycle inventory in order to calculate the equivalent pounds of carbon dioxide emitted by the material or system. Resource use is weighted by the relative impact of resource extraction in terms of area, intensity, ecological sensitivity, and recovery time. The air pollution and water pollution indices are based on the critical volume method developed by Muller-Wenk in 1978. The critical volume of air or water is defined as the sum of the ratio of the mass of the emission in either air or water and its legal threshold limit in the respective media. The critical volume method estimates the aggregate impact of the disparate emissions to air or water on the life cycle inventory.

In the tool, the five categories are weighted to determine the composite impact estimate for each system. The weight for primary energy is 20%, for GWP is 30%, for resource use is 10%, and for water and air pollution indices is 20% for each. The composite impact estimate is used to rank each system in terms of LCA.

It may be noted that the systems available in this tool did not always match exactly with systems in Chapters 1 and 2. Additional data for these materials and systems were based on more detailed raw data within the Athena database. The relevant tables showing the quantitative data from the tool are presented below. For each system category, an average of the systems was calculated. The relative performance of each system is based on a comparison with this average value.

Columns

Legend: GOOD | FAIR | POOR

System	Primary Energy per SF (MMBtu)	Global Warming Potential per SF (lbs)	Weighted Resource Use per SF (lbs)	Air Pollution Index per SF	Water Pollution Index per SF	Composite Impact Estimate	LCA Ranking
Column Average:	**0.09**	**11.69**	**50.70**	**0.82**	**0.01**	**100%**	
Concrete	0.13	20.17	113.05	1.43	0.0050	148%	3
Hollow Structural Steel	0.07	6.72	17.49	0.46	0.0096	69%	1
Wide-flange Steel	0.09	8.19	21.55	0.57	0.0107	83%	2

Beams

Legend: GOOD | FAIR | POOR

System	Primary Energy per SF (MMBtu)	Global Warming Potential per SF (lbs)	Weighted Resource Use per SF (lbs)	Air Pollution Index per SF	Water Pollution Index per SF	Composite Impact Estimate	LCA Ranking
Beam Average:	**0.11**	**14.18**	**44.87**	**1.00**	**0.01**	**100%**	
Concrete	0.13	20.17	113.05	1.43	0.0050	133%	2
Wide-flange steel	0.09	8.19	21.55	0.57	0.0107	77%	1

Floors

Legend: GOOD | FAIR | POOR

System	Primary Energy per SF (MMBtu)	Global Warming Potential per SF (lbs)	Weighted Resource Use per SF (lbs)	Air Pollution Index per SF	Water Pollution Index per SF	Composite Impact Estimate	LCA Ranking
Floor Average:	**0.09**	**16.32**	**95.38**	**1.25**	**0.0083**	**100%**	
Concrete flat plate and slab column system 25% flyash	0.14	30.94	206.56	2.31	0.0025	154%	5
Precast double T concrete system	0.07	16.69	98.04	1.26	0.0006	78%	2
Concrete hollow core slab	0.06	14.14	90.33	1.31	0.0025	76%	1
Open web steel joist w/ steel decking system and concrete topping	0.07	11.62	64.85	0.84	0.0139	92%	3
Steel stud joist and steel decking w/concrete topping	0.09	8.23	17.13	0.53	0.0217	100%	4

Windows

Legend: GOOD | FAIR | POOR

System (All windows assume double-pane, Low-e, Argon-filled	Total Assembly R-value	Primary Energy per SF (MMBtu)	Global Warming Potential per SF (lbs)	Weighted Resource Use per SF (lbs)	Air Pollution Index per SF	Water Pollution Index per SF	Composite Impact Estimate	LCA Ranking
Window Average:		**0.42**	**68.69**	**91.41**	**8.46**	**0.0030**	**100%**	
Aluminum	2.08	0.54	67.28	102.24	9.38	0.0036	112%	2
Vinyl (PVC)	2.86	0.45	77.18	80.28	8.70	0.0044	114%	3
Curtainwall viewable glazing	1.67	0.27	61.60	91.70	7.30	0.0010	74%	1

Walls

Legend: GOOD | FAIR | POOR

System	Assembly R-value	Primary Energy per SF (MMBtu)	Global Warming Potential per SF (lbs)	Weighted Resource Use per SF (lbs)	Air Pollution Index per SF	Water Pollution Index per SF	Composite Impact Estimate	LCA Ranking
Wall Average:		**0.15**	**25.85**	**79.04**	**2.35**	**0.88**	**100%**	
Concrete block, brick cladding, rigid insulation, vapor barrier	11.80	0.21	30.34	56.96	3.25	0.0015	99%	12
Concrete block, steel cladding, rigid insulation, vapor barrier	11.61	0.23	46.68	40.31	3.84	4.3960	223%	16
Concrete block, stucco cladding, rigid insulation, vapor barrier	11.11	0.13	20.49	45.84	1.78	0.0023	63%	7
Concrete Block, EIFS, vapor barrier	16.51	0.12	18.52	32.69	1.68	0.0014	57%	4
Concrete block, rigid insulation, vapor barrier, gypsum board, latex paint	11.56	0.12	17.35	29.92	1.63	0.0014	54%	3
CIP Concrete, brick cladding, vapor barrier, rigid insulation, latex paint	11.28	0.19	31.04	134.00	3.17	0.0008	106%	14
CIP Concrete, steel cladding, vapor barrier, rigid insulation, latex paint	11.09	0.21	47.38	117.35	3.77	4.3952	230%	17
CIP Concrete, stucco cladding, vapor barrier, rigid insulation, latex paint	10.59	0.11	21.19	122.89	1.70	0.0016	70%	9
CIP Concrete, EIFS, vapor barrier, latex paint	15.99	0.10	19.22	109.74	1.61	0.0007	64%	8
CIP Concrete, rigid insulation, vapor barrier, gypsum board, latex paint	11.04	0.10	18.04	106.97	1.56	0.0007	61%	5
Concrete Tilt-up, brick cladding, rigid insulation, vapor barrier	11.44	0.19	31.17	135.43	3.17	0.0011	106%	14
Concrete Tilt-up, steel cladding, rigid insulation, vapor barrier	11.25	0.21	47.50	118.78	3.76	4.3956	231%	18
Concrete Tilt-up, stucco cladding, rigid insulation, vapor barrier	10.75	0.12	21.32	124.32	1.70	0.0020	71%	10
Concrete Tilt-up, EIFS cladding, vapor barrier	16.15	0.10	19.34	111.17	1.60	0.0010	64%	8
Concrete Tilt-up, rigid insulation, vapor barrier, gypsum board, latex paint	11.20	0.10	18.17	108.39	1.55	0.0010	62%	6
2x4 Steel stud 16"oc, brick cladding, gypboard sheathing, vapor barrier, gypsum board, latex paint	7.42	0.16	20.42	47.59	2.46	0.0090	73%	11
2x4 Steel stud 16"oc, steel cladding, gypboard sheathing, vapor barrier, gypsum board, latex paint	7.23	0.18	36.76	30.93	3.06	4.4034	197%	15
2x4 Steel stud 16"oc, stucco cladding, gypboard sheathing, vapor barrier, gypsum board, latex paint	6.73	0.08	10.57	36.47	0.99	0.0098	37%	2
2x4 Steel stud 16"oc, EIFS, gypsum board sheathing, vapor barrier, gypsum board, latex paint	21.57	0.08	9.42	20.87	0.89	0.0089	32%	1
Curtainwall: Opaque Glazing (with insulated backpan)	6.41	0.18	32.16	50.19	3.86	0.0046	101%	13

Roofs

Legend: GOOD | FAIR | POOR

System	Total Assembly R-value	Primary Energy per SF (MMBtu)	Global Warming Potential per SF (lbs)	Weighted Resource Use per SF (lbs)	Air Pollution Index per SF	Water Pollution Index per SF	Composite Impact Estimate	LCA Ranking
Roof Average:		**0.29**	**34.16**	**120.98**	**3.57**	**0.0065**	**100%**	
Concrete flat plate slab and column, EPDM membrane, vapor barrier, rigid insulation, latex paint	21.94	0.27	44.36	238.79	4.16	0.0027	109%	11
Concrete flat plate slab and column, PVC membrane, vapor barrier, rigid insulation, latex paint	21.94	0.24	41.16	236.70	3.75	0.0027	101%	10
Concrete flat plate slab and column, Modified Bitumen membrane, vapor barrier, rigid insulation, latex paint	21.94	0.22	39.11	234.35	3.14	0.0027	94%	9
Concrete flat plate slab and column, 4-ply built-up roofing, vapor	22.27	0.88	89.98	294.82	9.77	0.0044	231%	15
Concrete flat plate slab and column, Steel roofing, vapor barrier, rigid insulation, latex paint	22.55	0.23	41.25	239.72	3.29	0.0069	112%	12
Precast double-T, EPDM membrane, vapor barrier, rigid insulation, latex paint	20.74	0.15	20.59	67.49	2.40	0.0003	48%	3
Precast double-T, PVC membrane, vapor barrier, rigid insulation, latex paint	20.74	0.12	17.38	65.40	1.98	0.0003	41%	2
Precast double-T, Modified Bitumen membrane, vapor barrier, rigid insulation, latex paint	20.74	0.10	15.33	63.05	1.38	0.0003	34%	1
Precast double-T, 4-ply built-up roofing, vapor barrier, rigid insulation, latex paint	21.07	0.77	66.21	123.52	8.00	0.0020	171%	13
Precast double-T, Steel roofing, vapor barrier, rigid insulation, latex paint	21.35	0.12	17.48	68.41	1.52	0.0045	51%	4
Open-web steel joist w/ steel decking, EPDM membrane, vapor barrier, rigid insulation, gypsum board, latex paint	21.55	0.16	17.10	26.42	2.17	0.0130	80%	7
Open-web steel joist w/ steel decking, PVC membrane, vapor barrier, rigid insulation, gypsum board, latex paint	21.55	0.13	13.89	24.32	1.75	0.0130	73%	6
Open-web steel joist w/ steel decking, Modified Bitumen membrane, vapor barrier, rigid insulation, gypsum board, latex paint	21.55	0.11	11.84	21.97	1.15	0.0129	66%	5
Open-web steel joist w/ steel decking, 4-ply built-up roofing, vapor barrier, rigid insulation, gypsum board, latex paint	21.88	0.78	62.72	82.44	7.78	0.0146	203%	14

APPENDIX C
HEATING, VENTILATING, AND AIR-CONDITIONING (HVAC) SYSTEMS AND CONTROLS

This Appendix gives an explanation of how each of the selection criteria were calculated for the HVAC systems outlined in Chapter 4.

C.1 COST CRITERIA CALCULATIONS

C.1.1 First Costs

Table C-1 shows the First Costs used in the calculation of the Life Cycle Costs. These costs were obtained by reviewing manufacturer quotes received by mechanical contractors for HVAC equipment. These quotes include only the costs to furnish and install the unit itself. The cost of any other associated system equipment was omitted.

Table C-1 First Costs and Rankings of the DX and Chiller Systems Based on 2010 Dollars

Legend:

$0 to $600
$601 to $1000
$1001 and up

Unit Type	First Cost ($/ton)	Rank
4.1.1 Wall-Mounted Unit	$ 1,220.00	6
4.1.2 Package Rooftop	$ 1,160.00	5
4.1.3 Split System	$ 1,050.00	4
4.1.4 Water-Loop Heat Pump	$ 900.00	3
4.1.5 Geothermal Heat Pump	$ 1,240.00	6
4.2.1 Air-Cooled Chiller	$ 460.00	1
4.2.2 Water-Cooled Chiller	$ 530.00	2

The First Costs for the methods of distributing air were included in the air distribution system section (Section 4.3). The air distribution systems First Costs are based on a cost-per-unit rather than a cost-per-ton basis because different quantities of VAV boxes and fan-coil units will be used for different systems. It was also assumed that the constant volume method of air distribution was the baseline cost for all air distribution systems. As such, its First Cost was considered to be zero. Ductwork is needed to supply air to the conditioned space in all the methods of air distribution. For similarly sized systems, the ductwork to supply the air should be the same relative size. The only cost difference will come from the air terminal units. Table C-2 shows a summary and ranking of the First Cost per unit for the air distribution systems.

Table C-2 First Costs and Rankings of the Air Distribution Systems Based on 2010 Dollars

Legend:

$0 to $500
$501 to $1000
$1001 and up

Unit Type	First Cost ($/unit)	Rank
4.3.1 Constant Volume	$ -	1
4.3.2 VAV	$ 790.00	2
4.3.3 VVT	$ 790.00	2
4.3.4 Fan-Coil Unit	$ 1,360.00	3

Table C-3 shows the costs of an air-cooled chiller system that was installed in two elementary schools in Pasco County, Florida. Both schools used the same design. The facilities were each 81,422 sq ft and were cooled by two 150-ton air-cooled chillers with VAV boxes. This gives an approximate estimate of the total costs for a similar system.

Table C-3 Total Costs for the Installation of an Air-Cooled Chiller System in Two Pasco County Elementary Schools Based on 2010 Dollars

Watergrass Elementary	Cost per ton	Total Costs
Total Material Cost	$1,621.74	$486,521.04
Total Mechanical Contractor Amount	$3,971.60	$1,191,478.96
Total Cost for HVAC System	**$5,593.33**	**$1,678,000.00**
Total Construction Cost of School		$11,322,720.00
Percentage of Material Cost to Total Mechanical Cost	41%	
Percentage of Mechanical System Cost to Total Construction Cost	15%	

Gulf Trace Elementary	Cost per ton	Total Costs
Total Material Cost	$1,193.32	$357,997.16
Total Mechanical Contractor Amount	$3,770.68	$1,131,202.84
Total Cost for HVAC System	**$4,964.00**	**$1,489,200.00**
Total Construction Cost of School		$11,820,540.91
Percentage of Material Cost to Total Mechanical Cost	32%	
Percentage of Mechanical Cost to Total Construction Cost	13%	

C.1.2 Energy Costs

Tables C-4 and C-5 show the calculations of the unit Energy Costs during the life of the building for the DX and chiller systems. These costs reflect only the energy usage of the units themselves. The energy usage of other associated equipment, such as air handlers, pumps, or cooling towers, have been omitted from the calculations. These calculations are only estimated Energy Costs to show the relative magnitude of energy savings from systems with a higher efficiency. Water consumption charges were not included in this study. An Energy Inflation Rate of 4% and a Discount Rate of 0% were assumed. The Energy Costs of the air distribution systems were not calculated for this study because they will depend on the design of the school.

The unit efficiency rates used in the calculations were taken from the U.S. Department of Energy's website. These recommended rates are greater than the base rates dictated by ASHRAE Standard 90.1, but these rates are not the most efficient options available on the market. For the DX systems, the efficiency was given in terms of an energy efficiency ratio (EER). The EER was converted into kW per ton by Equation C-1.

$$\frac{kW}{ton} = \frac{12}{EER} \qquad \text{Equation C-1}$$

For this study, it was assumed that the units operated for 2,000 equivalent full load operating hours (EFLOH). The cost of electricity used was $0.15/kWh, and this included demand charges. The annual Energy Costs of the units were calculated using Equation C-2.

$$Annual\ Energy\ Cost\ per\ Ton = \frac{kW}{ton} * EFLOH * \frac{\$0.15}{kWh} \quad \text{Equation C-2}$$

The annual Energy Costs listed for these systems were rounded to the nearest $10 of the calculated costs due to the accuracy of the available data. The present value of this annual cost was computed for each year during the life of the building. These annual calculations are shown in Table C-6. These present values were summed to obtain the total present value of the unit Energy Cost during the 50-year building life. Table C-7 shows a summary and ranking of the cost per ton for the HVAC units.

Table C-4 Calculation of Energy Costs of DX Units Based on 2010 Dollars

Unit Type	EER	kW/Ton	Cost per kWh	Annual EFLOH Operating	kWh per Ton per Year	Annual Energy Cost per Ton	Energy Inflation Rate (%)	Discount Rate	Energy Cost per Ton over 50 Years
4.1.1 Wall-Mounted Unit	11	1.09	$0.15	2000	2182	$330	4%	0%	$50,380
4.1.2 Package Rooftop	11	1.09	$0.15	2000	2182	$330	4%	0%	$50,380
4.1.3 Split Systems	12	1.00	$0.15	2000	2000	$300	4%	0%	$45,800
4.1.4 Water-Loop Heat Pump	12	1.00	$0.15	2000	2000	$300	4%	0%	$45,800
4.1.5 Geothermal Heat Pump	14.1	0.85	$0.15	2000	1702	$260	4%	0%	$39,693

Table C-5 Calculation of Energy Costs of Chiller Systems Based on 2010 Dollars

Unit Type	kW/Ton	Cost per kWh	Annual EFLOH Operatin	kWh per Ton per Year	Annual Energy Cost per Ton	Energy Inflation Rate (%)	Discount Rate	Energy Cost per Ton over 50 Years
4.2.1 Air-Cooled Chiller	0.98	$0.15	2000	1960	$290	4%	0%	$44,273
4.2.2 Water-Cooled Chiller	0.49	$0.15	2000	980	$150	4%	0%	$22,900

Table C-6 Calculation of Total Present Value of Unit Energy Cost per Ton Over 50 Years Based on 2010 Dollars

Year	4.1.1	4.1.2	4.1.3	4.1.4	4.1.5	4.2.1	4.2.2
0	$ 330	$ 330	$ 300	$ 300	$ 260	$ 290	$ 150
1	$ 343	$ 343	$ 312	$ 312	$ 270	$ 302	$ 156
2	$ 357	$ 357	$ 324	$ 324	$ 281	$ 314	$ 162
3	$ 371	$ 371	$ 337	$ 337	$ 292	$ 326	$ 169
4	$ 386	$ 386	$ 351	$ 351	$ 304	$ 339	$ 175
5	$ 401	$ 401	$ 365	$ 365	$ 316	$ 353	$ 182
6	$ 418	$ 418	$ 380	$ 380	$ 329	$ 367	$ 190
7	$ 434	$ 434	$ 395	$ 395	$ 342	$ 382	$ 197
8	$ 452	$ 452	$ 411	$ 411	$ 356	$ 397	$ 205
9	$ 470	$ 470	$ 427	$ 427	$ 370	$ 413	$ 213
10	$ 488	$ 488	$ 444	$ 444	$ 385	$ 429	$ 222
11	$ 508	$ 508	$ 462	$ 462	$ 400	$ 446	$ 231
12	$ 528	$ 528	$ 480	$ 480	$ 416	$ 464	$ 240
13	$ 549	$ 549	$ 500	$ 500	$ 433	$ 483	$ 250
14	$ 571	$ 571	$ 520	$ 520	$ 450	$ 502	$ 260
15	$ 594	$ 594	$ 540	$ 540	$ 468	$ 522	$ 270
16	$ 618	$ 618	$ 562	$ 562	$ 487	$ 543	$ 281
17	$ 643	$ 643	$ 584	$ 584	$ 506	$ 565	$ 292
18	$ 669	$ 669	$ 608	$ 608	$ 527	$ 587	$ 304
19	$ 695	$ 695	$ 632	$ 632	$ 548	$ 611	$ 316
20	$ 723	$ 723	$ 657	$ 657	$ 570	$ 635	$ 329
21	$ 752	$ 752	$ 684	$ 684	$ 592	$ 661	$ 342
22	$ 782	$ 782	$ 711	$ 711	$ 616	$ 687	$ 355
23	$ 813	$ 813	$ 739	$ 739	$ 641	$ 715	$ 370
24	$ 846	$ 846	$ 769	$ 769	$ 666	$ 743	$ 384
25	$ 880	$ 880	$ 800	$ 800	$ 693	$ 773	$ 400
26	$ 915	$ 915	$ 832	$ 832	$ 721	$ 804	$ 416
27	$ 952	$ 952	$ 865	$ 865	$ 750	$ 836	$ 433
28	$ 990	$ 990	$ 900	$ 900	$ 780	$ 870	$ 450
29	$ 1,029	$ 1,029	$ 936	$ 936	$ 811	$ 904	$ 468
30	$ 1,070	$ 1,070	$ 973	$ 973	$ 843	$ 941	$ 487
31	$ 1,113	$ 1,113	$ 1,012	$ 1,012	$ 877	$ 978	$ 506
32	$ 1,158	$ 1,158	$ 1,052	$ 1,052	$ 912	$ 1,017	$ 526
33	$ 1,204	$ 1,204	$ 1,095	$ 1,095	$ 949	$ 1,058	$ 547
34	$ 1,252	$ 1,252	$ 1,138	$ 1,138	$ 987	$ 1,100	$ 569
35	$ 1,302	$ 1,302	$ 1,184	$ 1,184	$ 1,026	$ 1,144	$ 592
36	$ 1,354	$ 1,354	$ 1,231	$ 1,231	$ 1,067	$ 1,190	$ 616
37	$ 1,408	$ 1,408	$ 1,280	$ 1,280	$ 1,110	$ 1,238	$ 640

Table C-6 Continued

Year	4.1.1	4.1.2	4.1.3	4.1.4	4.1.5	4.2.1	4.2.2
38	$ 1,465	$ 1,465	$ 1,332	$ 1,332	$ 1,154	$ 1,287	$ 666
39	$ 1,523	$ 1,523	$ 1,385	$ 1,385	$ 1,200	$ 1,339	$ 692
40	$ 1,584	$ 1,584	$ 1,440	$ 1,440	$ 1,248	$ 1,392	$ 720
41	$ 1,648	$ 1,648	$ 1,498	$ 1,498	$ 1,298	$ 1,448	$ 749
42	$ 1,714	$ 1,714	$ 1,558	$ 1,558	$ 1,350	$ 1,506	$ 779
43	$ 1,782	$ 1,782	$ 1,620	$ 1,620	$ 1,404	$ 1,566	$ 810
44	$ 1,853	$ 1,853	$ 1,685	$ 1,685	$ 1,460	$ 1,629	$ 842
45	$ 1,928	$ 1,928	$ 1,752	$ 1,752	$ 1,519	$ 1,694	$ 876
46	$ 2,005	$ 2,005	$ 1,822	$ 1,822	$ 1,579	$ 1,762	$ 911
47	$ 2,085	$ 2,085	$ 1,895	$ 1,895	$ 1,643	$ 1,832	$ 948
48	$ 2,168	$ 2,168	$ 1,971	$ 1,971	$ 1,708	$ 1,905	$ 986
49	$ 2,255	$ 2,255	$ 2,050	$ 2,050	$ 1,777	$ 1,982	$ 1,025
Total Energy Cost per Ton	$50,380	$50,380	$ 45,800	$ 45,800	$39,693	$44,273	$ 22,900

Table C-7 Summary and Ranking of Energy Costs for the DX and Chiller Units Based on 2010 Dollars

Legend:

$0 - $150
$151 - $300
$301 or greater

Unit Type	Annual Energy Cost per Ton	Rank
4.1.1 Wall-Mounted Unit	$ 330.00	5
4.1.2 Package Rooftop	$ 330.00	5
4.1.3 Split Systems	$ 300.00	4
4.1.4 Water-Loop Heat Pump	$ 300.00	4
4.1.5 Geothermal Heat Pump	$ 260.00	2
4.2.1 Air-Cooled Chiller	$ 290.00	3
4.2.2 Water-Cooled Chiller	$ 150.00	1

C.1.3 Maintenance Costs

Table C-8 shows the calculation of the unit Maintenance Cost per ton during the life of the building for the DX and chiller systems. These costs were based on general quotes from mechanical contractors to perform regular preventive maintenance on the units, such as changing filters, lubricating bearings and motors, and inspecting all equipment and controls. It was assumed that the General Inflation Rate was 3% and the Discount Rate was 0%. The Maintenance Costs of the air distribution systems were not included in this study because normal maintenance contracts do not include regular servicing of the devices that distribute the conditioned air.

Table C-8 Present Value of the Maintenance Cost per Ton for DX and Chiller Systems Based on 2010 Dollars

Unit Type	Annual Cost for 5 Ton Unit	Cost per Year ($/ton)	General Inflation Rate (%)	Maintenance Cost per Ton over 50 Years
4.1.1 Wall-Mounted Unit	$ 800.00	$ 160	3%	$ 18,047
4.1.2 Package Rooftop	$ 800.00	$ 160	3%	$ 18,047
4.1.3 Split Systems	$ 450.00	$ 90	3%	$ 10,152
4.1.4 Water-Loop Heat Pump	$ 600.00	$ 120	3%	$ 13,536
4.1.5 Geothermal Heat Pump	$ 600.00	$ 120	3%	$ 13,536
4.2.1 Air-Cooled Chiller	$ -	$ 9.30	3%	$ 1,049
4.2.2 Water-Cooled Chiller	$ -	$ 9.30	3%	$ 1,049

The present value of this annual cost was computed for each year during the 50-year life of the building. These calculations are shown in Table C-9. These present values were added to obtain the total present value of the unit Maintenance Cost during the 50-year building life. Table C-10 shows the ranking of Maintenance Costs for the units.

Table C-9 Calculation of the Total Present Value of Unit Maintenance Cost per Ton Based on 2010 Dollars

Year	4.1.1	4.1.2	4.1.3	4.1.4	4.1.5	4.2.1	4.2.2
0	$ 160	$ 160	$ 90	$ 120	$ 120	$ 9	$ 9
1	$ 165	$ 165	$ 93	$ 124	$ 124	$ 10	$ 10
2	$ 170	$ 170	$ 95	$ 127	$ 127	$ 10	$ 10
3	$ 175	$ 175	$ 98	$ 131	$ 131	$ 10	$ 10
4	$ 180	$ 180	$ 101	$ 135	$ 135	$ 10	$ 10
5	$ 185	$ 185	$ 104	$ 139	$ 139	$ 11	$ 11
6	$ 191	$ 191	$ 107	$ 143	$ 143	$ 11	$ 11
7	$ 197	$ 197	$ 111	$ 148	$ 148	$ 11	$ 11
8	$ 203	$ 203	$ 114	$ 152	$ 152	$ 12	$ 12
9	$ 209	$ 209	$ 117	$ 157	$ 157	$ 12	$ 12
10	$ 215	$ 215	$ 121	$ 161	$ 161	$ 12	$ 12
11	$ 221	$ 221	$ 125	$ 166	$ 166	$ 13	$ 13
12	$ 228	$ 228	$ 128	$ 171	$ 171	$ 13	$ 13
13	$ 235	$ 235	$ 132	$ 176	$ 176	$ 14	$ 14

Table C-9 Continued

Year	4.1.1	4.1.2	4.1.3	4.1.4	4.1.5	4.2.1	4.2.2
14	$ 242	$ 242	$ 136	$ 182	$ 182	$ 14	$ 14
15	$ 249	$ 249	$ 140	$ 187	$ 187	$ 14	$ 14
16	$ 257	$ 257	$ 144	$ 193	$ 193	$ 15	$ 15
17	$ 264	$ 264	$ 149	$ 198	$ 198	$ 15	$ 15
18	$ 272	$ 272	$ 153	$ 204	$ 204	$ 16	$ 16
19	$ 281	$ 281	$ 158	$ 210	$ 210	$ 16	$ 16
20	$ 289	$ 289	$ 163	$ 217	$ 217	$ 17	$ 17
21	$ 298	$ 298	$ 167	$ 223	$ 223	$ 17	$ 17
22	$ 307	$ 307	$ 172	$ 230	$ 230	$ 18	$ 18
23	$ 316	$ 316	$ 178	$ 237	$ 237	$ 18	$ 18
24	$ 325	$ 325	$ 183	$ 244	$ 244	$ 19	$ 19
25	$ 335	$ 335	$ 188	$ 251	$ 251	$ 19	$ 19
26	$ 345	$ 345	$ 194	$ 259	$ 259	$ 20	$ 20
27	$ 355	$ 355	$ 200	$ 267	$ 267	$ 21	$ 21
28	$ 366	$ 366	$ 206	$ 275	$ 275	$ 21	$ 21
29	$ 377	$ 377	$ 212	$ 283	$ 283	$ 22	$ 22
30	$ 388	$ 388	$ 218	$ 291	$ 291	$ 23	$ 23
31	$ 400	$ 400	$ 225	$ 300	$ 300	$ 23	$ 23
32	$ 412	$ 412	$ 232	$ 309	$ 309	$ 24	$ 24
33	$ 424	$ 424	$ 239	$ 318	$ 318	$ 25	$ 25
34	$ 437	$ 437	$ 246	$ 328	$ 328	$ 25	$ 25
35	$ 450	$ 450	$ 253	$ 338	$ 338	$ 26	$ 26
36	$ 464	$ 464	$ 261	$ 348	$ 348	$ 27	$ 27
37	$ 478	$ 478	$ 269	$ 358	$ 358	$ 28	$ 28
38	$ 492	$ 492	$ 277	$ 369	$ 369	$ 29	$ 29
39	$ 507	$ 507	$ 285	$ 380	$ 380	$ 29	$ 29
40	$ 522	$ 522	$ 294	$ 391	$ 391	$ 30	$ 30
41	$ 538	$ 538	$ 302	$ 403	$ 403	$ 31	$ 31
42	$ 554	$ 554	$ 311	$ 415	$ 415	$ 32	$ 32
43	$ 570	$ 570	$ 321	$ 428	$ 428	$ 33	$ 33
44	$ 587	$ 587	$ 330	$ 441	$ 441	$ 34	$ 34
45	$ 605	$ 605	$ 340	$ 454	$ 454	$ 35	$ 35
46	$ 623	$ 623	$ 351	$ 467	$ 467	$ 36	$ 36
47	$ 642	$ 642	$ 361	$ 481	$ 481	$ 37	$ 37
48	$ 661	$ 661	$ 372	$ 496	$ 496	$ 38	$ 38
49	$ 681	$ 681	$ 383	$ 511	$ 511	$ 40	$ 40
Total Maintenance Cost per Ton	$18,047	$18,047	$ 10,152	$ 13,536	$ 13,536	$ 1,049	$ 1,049

Table C-10 Summary and Ranking of Unit Maintenance Costs Based on 2010 Dollars

Legend:
$0 - $50
$51 - $150
$151 and up

Unit Type	Annual Maintenance Cost per Ton ($/ton)	Rank
4.1.1 Wall-Mounted Unit	$ 160	4
4.1.2 Package Rooftop	$ 160	4
4.1.3 Split Systems	$ 90	2
4.1.4 Water-Loop Heat Pump	$ 120	3
4.1.5 Geothermal Heat Pump	$ 120	3
4.2.1 Air-Cooled Chiller	$ 9.30	1
4.2.2 Water-Cooled Chiller	$ 9.30	1

C.1.4 Replacement Costs

Replacement Costs were divided into the costs to replace the HVAC unit at the end of its useful life and the costs to replace miscellaneous equipment during the life of the HVAC unit. These two costs were totaled to determine the annual unit Replacement Cost.

Table C-11 provides the calculation of the present value of the periodic Replacement Costs of the HVAC units. The periodic Replacement Costs occur at the end of the service life of the HVAC unit. The Replacement Costs for the units were assumed to be the same price as the First Costs of the units. The year(s) of replacement was based on the life of the unit. It was assumed that the General Inflation Rate was 3% and the Discount Rate was 0%.

For air distribution systems, it was assumed that the associated ductwork and grilles would not be replaced during the life of the building. However, the VAV boxes and fan-coil units would need to be replaced during the life of the building. These were the only Replacement Costs associated with the air distribution systems.

Table C-11 Calculation of Periodic Unit Replacement Costs

Unit Type	Life of Unit	# of Replacements over 50 Years	Replace at Year	First Cost per Ton (2010 Dollars)	PV of Replacements per Ton ($/Ton)
4.1.1 Wall-Mounted Unit	15	3	15, 30, 45	$ 1,220.00	$ 9,476
4.1.2 Package Rooftop	15	3	15, 30, 45	$ 1,160.00	$ 9,010
4.1.3 Split Systems	15	3	15, 30, 45	$ 1,050.00	$ 8,155
4.1.4 Water-Loop Heat Pump	24	2	24, 48	$ 900.00	$ 5,549
4.1.5 Geothermal Heat Pump	24	2	24, 48	$ 1,240.00	$ 7,645
4.2.1 Air-Cooled Chiller	25	1	25	$ 460.00	$ 963
4.2.2 Water-Cooled Chiller	25	1	25	$ 530.00	$ 1,110

Replacement Costs for air distribution systems are given in cost per unit

4.3.1 Constant Volume	50	0	-	$ -	$ -
4.3.2 Variable Air Volume	20	2	20, 40	$ 790.00	$ 4,004
4.3.3 Variable Volume & Temp	20	2	20, 40	$ 790.00	$ 4,004
4.3.4 Fan-Coil Units	20	2	20, 40	$ 1,360.00	$ 6,893

Table C-12 shows the calculations of the cost to replace miscellaneous unit equipment. For this study, it was assumed that the cost to replace miscellaneous equipment was 6% of the system's First Cost. The miscellaneous equipment Replacement Cost is an annual cost during the life of the unit except for the first year after installation. The contractor and/or manufacturer will normally provide the first year's parts and labor warranty. The present value of this annual cost was computed for each year during the life of the building. These calculations are shown in Table C-13. The present values were summed to get the total present value of the miscellaneous equipment Replacement Cost during the 50-year building life.

Table C-14 provides a summary of the total Replacement Costs for the DX and chiller units. Table C-15 gives a summary of the total Replacement Costs for the air distribution systems. The total Replacement Costs were found by summing the present value of the periodic unit Replacement Costs and the present value of the miscellaneous Equipment Costs.

Table C-12 Calculation of Miscellaneous Equipment Costs Based on 2010 Dollars

Unit Type	First Cost per Ton (2010 Dollars)	Annual Misc Replacement Costs (6% of First Cost)	PV of Misc Replaceme nt Costs ($/Ton)
4.1.1 Wall-Mounted Unit	$ 1,220.00	$ 73	$ 8,184
4.1.2 Package Rooftop	$ 1,160.00	$ 70	$ 7,781
4.1.3 Split Systems	$ 1,050.00	$ 63	$ 7,043
4.1.4 Water-Loop Heat Pump	$ 900.00	$ 54	$ 6,037
4.1.5 Geothermal Heat Pump	$ 1,240.00	$ 74	$ 8,318
4.2.1 Air-Cooled Chiller	$ 460.00	$ 28	$ 3,086
4.2.2 Water-Cooled Chiller	$ 530.00	$ 32	$ 3,555

Table C-13 Calculation of the Total Present Value of Miscellaneous Unit Replacement Costs per Ton Based on 2010 Dollars

Year	4.1.1	4.1.2	4.1.3	4.1.4	4.1.5	4.2.1	4.2.2
1	$ 75	$ 72	$ 65	$ 56	$ 77	$ 28	$ 33
2	$ 78	$ 74	$ 67	$ 57	$ 79	$ 29	$ 34
3	$ 80	$ 76	$ 69	$ 59	$ 81	$ 30	$ 35
4	$ 82	$ 78	$ 71	$ 61	$ 84	$ 31	$ 36
5	$ 85	$ 81	$ 73	$ 63	$ 86	$ 32	$ 37
6	$ 87	$ 83	$ 75	$ 64	$ 89	$ 33	$ 38
7	$ 90	$ 86	$ 77	$ 66	$ 92	$ 34	$ 39
8	$ 93	$ 88	$ 80	$ 68	$ 94	$ 35	$ 40
9	$ 96	$ 91	$ 82	$ 70	$ 97	$ 36	$ 41

Table C-13 Continued

Year	4.1.1	4.1.2	4.1.3	4.1.4	4.1.5	4.2.1	4.2.2
10	$ 98	$ 94	$ 85	$ 73	$ 100	$ 37	$ 43
11	$ 101	$ 96	$ 87	$ 75	$ 103	$ 38	$ 44
12	$ 104	$ 99	$ 90	$ 77	$ 106	$ 39	$ 45
13	$ 107	$ 102	$ 93	$ 79	$ 109	$ 41	$ 47
14	$ 111	$ 105	$ 95	$ 82	$ 113	$ 42	$ 48
15	$ 114	$ 108	$ 98	$ 84	$ 116	$ 43	$ 50
16	$ 117	$ 112	$ 101	$ 87	$ 119	$ 44	$ 51
17	$ 121	$ 115	$ 104	$ 89	$ 123	$ 46	$ 53
18	$ 125	$ 118	$ 107	$ 92	$ 127	$ 47	$ 54
19	$ 128	$ 122	$ 110	$ 95	$ 130	$ 48	$ 56
20	$ 132	$ 126	$ 114	$ 98	$ 134	$ 50	$ 57
21	$ 136	$ 129	$ 117	$ 100	$ 138	$ 51	$ 59
22	$ 140	$ 133	$ 121	$ 103	$ 143	$ 53	$ 61
23	$ 144	$ 137	$ 124	$ 107	$ 147	$ 54	$ 63
24	$ 149	$ 141	$ 128	$ 110	$ 151	$ 56	$ 65
25	$ 153	$ 146	$ 132	$ 113	$ 156	$ 58	$ 67
26	$ 158	$ 150	$ 136	$ 116	$ 160	$ 60	$ 69
27	$ 163	$ 155	$ 140	$ 120	$ 165	$ 61	$ 71
28	$ 167	$ 159	$ 144	$ 124	$ 170	$ 63	$ 73
29	$ 173	$ 164	$ 148	$ 127	$ 175	$ 65	$ 75
30	$ 178	$ 169	$ 153	$ 131	$ 181	$ 67	$ 77
31	$ 183	$ 174	$ 158	$ 135	$ 186	$ 69	$ 80
32	$ 188	$ 179	$ 162	$ 139	$ 192	$ 71	$ 82
33	$ 194	$ 185	$ 167	$ 143	$ 197	$ 73	$ 84
34	$ 200	$ 190	$ 172	$ 148	$ 203	$ 75	$ 87
35	$ 206	$ 196	$ 177	$ 152	$ 209	$ 78	$ 89
36	$ 212	$ 202	$ 183	$ 157	$ 216	$ 80	$ 92
37	$ 219	$ 208	$ 188	$ 161	$ 222	$ 82	$ 95
38	$ 225	$ 214	$ 194	$ 166	$ 229	$ 85	$ 98
39	$ 232	$ 220	$ 200	$ 171	$ 236	$ 87	$ 101
40	$ 239	$ 227	$ 206	$ 176	$ 243	$ 90	$ 104
41	$ 246	$ 234	$ 212	$ 181	$ 250	$ 93	$ 107
42	$ 253	$ 241	$ 218	$ 187	$ 257	$ 96	$ 110
43	$ 261	$ 248	$ 225	$ 192	$ 265	$ 98	$ 113
44	$ 269	$ 256	$ 231	$ 198	$ 273	$ 101	$ 117
45	$ 277	$ 263	$ 238	$ 204	$ 281	$ 104	$ 120

Table C-13 Continued

Year	4.1.1	4.1.2	4.1.3	4.1.4	4.1.5	4.2.1	4.2.2
46	$ 285	$ 271	$ 245	$ 210	$ 290	$ 108	$ 124
47	$ 294	$ 279	$ 253	$ 217	$ 298	$ 111	$ 128
48	$ 302	$ 288	$ 260	$ 223	$ 307	$ 114	$ 131
49	$ 312	$ 296	$ 268	$ 230	$ 317	$ 117	$ 135
Total Misc Replace Cost per Ton	$ 8,184	$ 7,781	$ 7,043	$ 6,037	$ 8,318	$ 3,086	$ 3,555

Table C-14 Summary and Ranking of DX and Chiller Replacement Costs Based on 2010 Dollars

Legend:

$0 to $7,500
$7,501 to $15,000
$15,001 or greater

Unit Type	Total PV of Replacement Costs per Ton	Rank
4.1.1 Wall-Mounted Unit	$17,659	6
4.1.2 Package Rooftop	$16,791	5
4.1.3 Split Systems	$15,198	4
4.1.4 Water-Loop Heat Pump	$11,586	3
4.1.5 Geothermal Heat Pump	$15,962	4
4.2.1 Air-Cooled Chiller	$4,049	1
4.2.2 Water-Cooled Chiller	$4,665	2

Table C-15 Summary and Ranking of Air Distribution Replacement Costs Based on 2010 Dollars

Legend:

$0 to $2,500
$2,501 to $5,000
$5,001 or greater

Unit Type	Total PV of Replacement Costs per Unit	Rank
4.3.1 Constant Volume	$0	1
4.3.2 Variable Air Volume	$4,004	2
4.3.3 Variable Volume & Temp	$4,004	2
4.3.4 Fan-Coil Units	$6,893	3

C.1.5 Life Cycle Costs

Table C-16 summarizes all the associated costs for the DX and chiller units over the life of the building. The Life Cycle Costs of the unit include the First Costs, Energy Costs, Maintenance Costs, and Replacement Costs. These costs were summed to get the total Life Cycle Cost for the unit. Table C-17 summarizes all the associated costs for the air distribution systems over the life of the building. The only Life Cycle Costs associated with the air distribution systems were the First Costs and the unit Replacement Costs.

Table C-16 Summary of DX and Chiller System Life Cycle Costs Based on 2010 Dollars

Legend:
$0 to $40,000
$40,001 to $80,000
$80,001 or greater

Unit Type	First Cost	PV Energy Cost	PV Maintenance Cost	PV Replacement Cost	Life Cycle Cost	Rank
4.1.1 Wall-Mounted Unit	$1,220	$50,380	$18,047	$17,659	$87,307	5
4.1.2 Package Rooftop	$1,160	$50,380	$18,047	$16,791	$86,378	5
4.1.3 Split System	$1,050	$45,800	$10,152	$15,198	$72,200	4
4.1.4 Water-Loop Heat Pump	$900	$45,800	$13,536	$11,586	$71,821	4
4.1.5 Geothermal Heat Pump	$1,240	$39,693	$13,536	$15,962	$70,431	3
4.2.1 Air-Cooled Chiller	$460	$44,273	$1,049	$4,049	$49,831	2
4.2.2 Water-Cooled Chiller	$530	$22,900	$1,049	$4,665	$29,144	1

Table C-17 Summary of Air Distribution System Life Cycle Costs Based on 2010 Dollars

Legend:
$0 to $2,500
$2,501 to $5,000
$5,001 or greater

Unit Type	First Cost	PV Replacement Cost	Life Cycle Cost	Rank
4.3.1 Constant Volume	$0	$0	$0	1
4.3.2 Variable Air Volume	$790	$4,004	$4,794	2
4.3.3 Variable Volume & Temp	$790	$4,004	$4,794	2
4.3.4 Fan-Coil Unit	$1,360	$6,893	$8,253	3

C.2 DESIGN CRITERIA CALCULATIONS

C.2.1 Required Space

Table C-18 provides the ratings of the required space criteria of the DX and chiller systems. Table C-19 provides the ratings of the required space criteria for the air distribution systems. The space characteristics of a system were rated on a level of “1” to “3”. These levels carried a different meaning for each of the space characteristics. In general, a “1” denoted a characteristic that required little to no space, while “3” denoted a characteristic that required a large amount of space. Table C-20 lists the meaning of the rating level for each of the space characteristics.

Table C-18 Calculation of the Amount of Required Space Needed for DX and Chiller Systems

Legend:
1.00 to 1.49
1.50 to 2.00
2.01 to 3.00

Unit Type	Size of the Unit	Piping Required	Mechanical Room Space Required	Outdoor Space Required	Average	Rank
4.1.1 Wall-Mounted Unit	1	1	1	1	1	1
4.1.2 Package Rooftop Unit	2	1	1	2	1.5	2
4.1.3 Split Systems	2	2	2	2	2	3
4.1.4 Water-Loop Heat Pump	2	3	2	2	2.25	4
4.1.5 Geothermal Heat Pump	2	3	2	1	2	3
4.2.1 Air-Cooled Chiller	3	3	2	3	2.75	5
4.2.2 Water-Cooled Chiller	3	3	3	3	3	6

Table C-19 Calculation of Required Space for Air Distribution Systems

Legend:
1.00 to 1.49
1.50 to 2.00
2.01 to 3.00

System Type	Piping	Amount of Equipment in Ceiling Space	Average	Rank
4.3.1 Constant Volume	1	1	1	1
4.3.2 Variable Air Volume	1	2	1.5	2
4.3.3 Variable Volume & Temp	1	2	1.5	2
4.3.4 Fan-Coil Units	3	2	2.5	3

Table C-20 Explanation of Rating System for the Required Space Criterion

Criteria	1	2	3
Size of the Unit	Small	Medium	Large
Piping Required	No Piping	Refrigerant Piping	Chilled Water Piping
Mechanical Room Space Required	No Mechanical Room	Small Mechanical Room	Large Mechanical Room
Outdoor Space Required	Little or No Outdoor Space	Moderate Outdoor Space	Large Outdoor Space
Amount of Equipment in Ceiling Space	Basic Ductwork	Typical Air Terminal Units	Large Air Terminal Units

C.2.2 Complexity

Table C-21 shows the calculation of the complexity ranking of the DX and chiller systems. Each system complexity characteristic was rated on a scale from "1" to "3," with "1" being the least complex.

Table C-21 Ranking of the Complexity of the DX and Chiller Systems

Legend:
1: Little to None
2: Average
3: Excessive
1.00 to 1.99
2.00 to 2.50
2.51 to 3.00

Unit Type	Components to Install	Points of Maintenance	Average	Rank
4.1.1 Wall-Mounted Unit	1	1	1	1
4.1.2 Package Rooftop	1	1	1	1
4.1.3 Split Systems	2	1	1.5	2
4.1.4 Water-Loop Heat Pump	3	3	3	4
4.1.5 Geothermal Heat Pump	2	2	2	3
4.2.1 Air-Cooled Chiller	3	3	3	4
4.2.2 Water-Cooled Chiller	3	3	3	4

Table C-22 shows the calculation of the complexity ranking of the air distribution systems. Each system complexity characteristic was rated on a scale from “1” to “3” with “1” being the least complex.

Table C-22 Ranking of the Complexity of the Air Distribution Systems

Legend:
1: Little to None
2: Average
3: Excessive
1.00 to 1.99
2.00 to 2.50
2.51 to 3.00

Unit type	Components to Install	Points of Maintenance	Average	Rank
4.3.1 Constant Volume	1	1	1	1
4.3.2 Variable Air Volume	2	2	2	2
4.3.3 Variable Volume & Temp	2	2	2	2
4.3.4 Fan-Coil Units	3	2	2.5	3

C.2.3 Life of the Unit

Table C-23 gives the unit median service life used in this study to compute the Life Cycle Costs. The median service life was found in the *2007 ASHRAE Handbook: Applications,* which indicated that unit life ranged from 15 years to 30 years. Any units with a life of 15 years to 20 years were considered to be poor. Units with a service life of 20 years to 25 years were considered to have an average service life. Units with a service life of 25 years or greater were deemed to have an above average service life.

Table C-23 Unit Service Life Used in the Study

Legend:

25 or greater
20 – 24
15 – 19

Unit Type	Service Life Used in Study	Rank
4.1.1 Wall-Mounted Unit	15	2
4.1.2 Package Rooftop	15	2
4.1.3 Split Systems	15	2
4.1.4 Water-Loop Heat Pump	24	1
4.1.5 Geothermal Heat Pump	24	1
4.2.1 Air-Cooled Chiller	20	2
4.2.2 Water-Cooled Chiller	25	1
4.3.1 Constant Volume	50	1
4.3.2 Variable Air Volume	20	2
4.3.3 Variable Volume & Temp	20	2
4.3.4 Fan-Coil Units	20	2

C.2.4 Noise

Table C-24 summarizes the potential sources of noise heard in the classroom. This table was used in the rating of the noise characteristics of the HVAC systems, which are calculated in Table C-25. The systems were rated on the sources of noise in the classroom, sources near the classroom, and other potential source noise. Each noise characteristic was rated from “1” to “3” with “1” being no noise, “2” being a potential noise source, and “3” being a noise source. An average value for each noise characteristic was taken, and the systems were ranked according to these averages.

These rankings do not guarantee that a system will fall within the required 35 dB sound level required by ANSI Standards. It highlights only the potential of the system to generate noise in the classroom. The design professional must take measures to reduce system-generated noise in the specific design of the system.

Table C-24 Potential Sources of Noise in Classroom

Unit Type	Equipment in Classroom	Equipment Near Classroom	Other Sources of Noise in Classroom
4.1.1 Wall-Mounted Unit	Fan	Compressor & condenser on outside wall of classroom	Vibration of building structure
4.1.2 Package Rooftop	None	None	Rooftop rumble
4.1.3 Split Systems	None	AHU in mechanical closet; Condensing unit outside	None
4.1.4 Water-Loop Heat Pump	None	AHU in mechanical closet	None
4.1.5 Geothermal Heat Pump	None	AHU in mechanical closet	None
4.2.1 Air-Cooled Chiller	None	AHU in central mechanical room/closet	None
4.2.2 Water-Cooled Chiller	None	AHU in central mechanical room/closet	None
4.3.1 Constant Volume	Ductwork above ceiling	None	Air moving through ductwork
4.3.2 Variable Air Volume	VAV boxes above ceiling (no fan)	Potential placement of VAV above corridor	Air moving through ductwork
4.3.3 Variable Volume & Temp	VVT boxes above ceiling (no fan)	Potential placement of VVT above corridor	Air moving through ductwork
4.3.4 Fan-Coil Units	Fan-coil above ceiling or in mechanical closet	Potential placement of fan-coil above corridor	Air moving through ductwork

Table C-25 Rating of Noise Characteristics for HVAC Systems

Legend:

1: No Noise from Equipment
2: Possible Source of Noise
3: Source of Noise
1.00 to 1.49
1.50 to 2.49
2.50 to 3.00

Unit Type	Sources of Noise in Classroom	Sources of Noise Near Classroom	Other Sources of Noise in Classroom	Average	Ranking
4.1.1 Wall-Mounted Unit	3	3	3	3	4
4.1.2 Package Rooftop	1	1	2	1.33	1
4.1.3 Split Systems	1	3	1	1.67	3
4.1.4 Water-Loop Heat	1	2	1	1.33	1
4.1.5 Geothermal Heat	1	2	1	1.33	1
4.2.1 Air-Cooled Chiller	1	2	1	1.33	1
4.2.2 Water-Cooled Chiller	1	2	1	1.33	1
Air distribution systems were rated separately from the DX and chiller systems					
4.3.1 Constant Volume	1	1	2	1.33	1
4.3.2 Variable Air Volume	1	1	2	1.33	1
4.3.3 Variable Volume &	1	1	2	1.33	1
4.3.4 Fan-Coil Units	2	2	2	2	2

C.2.5 Temperature Control

Temperature control was examined only for the air distribution systems. Table C-26 shows the ranking of these systems' ability to control temperature in the conditioned space.

Table C-26 Ranking of the Air Distribution Systems' Ability to Control Temperature of the Space

Legend:
GOOD
FAIR
POOR

Unit Type	Control Type	Rank
4.3.1 Constant Volume	On/Off	2
4.3.2 Variable Air Volume	Modulating	1
4.3.3 Variable Volume & Temp	Modulating	1
4.3.4 Fan-Coil Units	Modulating	1

The constant volume air method is considered to be the standard method of air distribution. It delivers air to the space by cycling the HVAC unit on or off as needed. The VAV, VVT, and fan-coil methods of air distribution use modulating controls to regulate the temperature of the conditioned space, which allows for better control of the temperature of the space.

C.3 HVAC CONTROLS

In 2010, HVAC controls are almost exclusively electronic. Electronic controls have benefits and problems, the most obvious problem being obsolescence. At the same time, sophisticated products are available that are supported by their manufacturer for as long as 30 years. The opportunity therefore exists to install systems that are a better long-term value than other systems. In addition, other factors need to be considered in selecting an HVAC controls system that can have a profound effect on the school district's and college's overall financial picture.

C.3.1 Types of Controls

In this discussion, controls will be divided into four types.

1. *Mechanical/Electrical* – These systems consist of a 120- or 24-volt thermostat, relays, time clocks, and so forth. They are classified here as "mechanical/electrical" because their inner workings consist of bimetal strips in thermostats, gears in time clocks, and so forth that make an electrical contact to make a system change. These systems have an extremely low First Cost, and they do a rudimentary job of keeping simple systems "running."

2. *Basic Electronic Thermostat* – This category represents programmable thermostats. They have an extremely low First Cost, and they do a rudimentary job of keeping simple systems "running." They have the advantage of reduced Energy Costs due to their ability to be programmed to higher or lower temperatures during evenings and on weekends.

3. *Internet Protocol (IP)-Based Thermostat* – At the time of this writing, only one manufacturer was producing direct IP-based thermostats, but it is almost certain that other manufacturers will follow suit. The advantage of these systems is that they can be manipulated from any computer connected to the Internet (with

password), thereby giving maintenance personnel the ability to control the room environment remotely. This type of system is low cost after a modest school district investment in the interface software. Advantages include mass commands and remote viewing of room conditions. This ability is especially valuable during school district and college vacations when the room is unoccupied and therefore unmonitored by occupants. This real-time notice of problems can save a school district or college enormous sums of remediation costs in mold cleanup.

4. *Direct Digital Control* – This type of system is extremely capable and flexible, seemingly without limitation. This system has a significant installation cost, which is greatly offset by energy savings. It also offers a better learning environment due to the ability to control and adjust the classroom temperature with the use of distributed control software. Other significant capabilities include alarm detection, e-mailing alarms to smart phones, flexible scheduling of equipment, and trending data, which provide critical insight to HVAC staff as to what the system is doing at all times.

   Significant energy savings can be realized since these systems have the ability to be programmed: 1) for evening activities rather than run systems every evening to cover those evenings with activities, 2) when schools are on vacation to run only to control relative humidity, and 3) to adjust automatically to indoor and outdoor conditions to maximize energy conservation.

C.3.2 Ways to Reduce the Life Cycle Costs of HVAC Controls

1. Install surge suppression devices.

2. For direct digital control (DDC), specify the number of years that a system's components will remain available from the manufacturer, require a warranty to cover that time period, install new components at no cost to the school district, or provide migration paths to connect new devices to existing devices. Investment through planned modernization must be protected.

3. Require that all user interfaces be identical for any one manufacturer. This approach results in consistent operational and troubleshooting procedures and reduces service calls.

4. Require that all system parameters be adjustable by the system operators. This action reduces service calls and provides greater control in adjusting the system to varying space conditions.
5. For new installations, require system point naming to be consistent and programs to be constructed using similar architecture to existing school district installations. Each programmer has his own way of achieving a given sequence

of operations. Service costs are reduced when the service technician is familiar with the system architecture produced by the programmer.

6. Better systems use a Web interface that does not require licensed software for each user. These systems provide access from any location (including home computers to monitor after-hour school indoor conditions), and they offer access using laptops for on-site maintenance personnel.

7. Make certain that an installed system is capable of communicating with the industry standard equipment protocols (BACnet, LON, Modbus) so that equipment purchased in the future is easily integrated into the system.

8. Make certain that the control equipment supplier offers the full scope of local training.