Florida Department of EDUCATION

UF UNIVERSITY of FLORIDA

LIFE CYCLE COST GUIDELINES

FOR MATERIALS AND BUILDING SYSTEMS FOR FLORIDA'S PUBLIC EDUCATIONAL FACILITIES

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Life Cycle Cost Guidelines for Materials and Building Systems for Florida's Public Educational Facilities

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INTRODUCTION

Life Cycle Cost Guidelines for Materials and Building Systems for Florida's Public Educational Facilities, henceforth referred to as the *Guidelines*, is a publication designed to assist construction professionals in the selection of materials, products, and systems to use in the design and construction of public educational facilities in the State of Florida. In this publication, each material, product, or system typically or potentially used for educational facilities has been evaluated with respect to life cycle and other performance criteria. For this study, the useful life of a school building in Florida is 50 years, and the evaluation of components is based on this time frame. An easy-to-understand and interpretable color-coded matrix is employed for each major building system to make the assessment of alternatives as straightforward as possible. This approach permits a rapid overview of the options for each building system and facilitates decision-making. The major building systems for which alternatives are evaluated and ranked include the building superstructure, exterior materials, interior materials, substrate materials, HVAC systems, and lighting systems. In addition to the evaluation of alternatives for each major building system, information about green building certification, as it applies to the construction of new school buildings, is provided.

PURPOSE

This publication is designed to provide guidance to local Florida educational agencies and their supporting design teams to use in the selection of the most appropriate and cost-effective materials, products, and systems for designing and constructing school and college buildings. The *Guidelines* is an update to the Florida Department of Education's (FDOE) *Life Cycle Cost Guidelines for Materials and Building Systems for Florida's Public Educational Facilities* (1999). This updated publication reflects current materials, standards, and market conditions that affect pricing, and it addresses the issue of green building certification as it applies to school buildings. The new version of the *Guidelines* is intended to meet the needs of a wide range of users. Professionals involved in the design, construction, operation, maintenance, and daily use of Florida's schools will find the *Guidelines* useful in assisting their work. Administrators, facilities managers, and professional consultants, among others, can use the *Guidelines* to assist in decision-making throughout the life cycle of a built facility, including planning, construction, occupation, operation, adaptation, and expansion. The *Guidelines* is designed to provide a wide range of information suitable for use by the various parties who interact with the building process. The *Guidelines* assumes that any of the alternatives listed within the various chapters are reasonable choices to consider when designing and constructing a facility.

SCOPE

This publication applies Life Cycle Cost (LCC) and other performance criteria to materials, products, and systems to assist the decision-making process for school board and project teams engaged in the design and construction of school buildings in Florida. The scope includes the evaluation of materials, products, and systems currently available for use in construction or that have the potential for use in new educational facility construction. The range of alternatives chosen has not been restricted to materials and systems previously utilized in educational facilities in Florida. Emerging alternatives that are beginning to influence the construction market are also analyzed for their performance in new educational facility construction. The *Guidelines* addresses exterior systems and interior materials, as well as substrate materials, HVAC systems, and lighting systems, with the appropriate key criteria for each system being used as the basis for evaluation. This publication also includes a chapter on green building certification to assist school boards and their facility design teams in working with the commonly used certification systems, such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED), Green Globes, the Florida Green Building Coalition standard, and the U.S. Environmental Protection Agency's Energy Star program. This chapter also covers high-performance school programs and requirements in other states, such as the Collaborative for High Performance Schools (CHPS) program, which can assist a school board and a project team in providing state-of-the-art, high-performance schools for Florida's educational system.

ORGANIZATION

This publication is organized to optimize its utility based on it being primarily an electronic document with internal hyperlinks. It is organized into an Introduction and six chapters. The main sections of the *Guidelines* are described in the following paragraphs.

Introduction

The introduction provides information about the purpose, scope, methodology, and approach used in developing this updated version of the *Guidelines*. It describes the criteria used to evaluate the various alternatives for each major building system. The introduction also contains information about the assumptions for discount rate, inflation rates, and other factors used in the determination of the unit cost of an alternative during its lifetime.

Chapter 1 Superstructure

This chapter addresses materials and systems typically used to construct the superstructure of a building, including columns, beams, walls, floor systems, and roof structural systems.

Chapter 2 Exterior Materials

The exterior materials evaluated in this chapter include: exterior walls; exterior wall coverings; pitched, curved, and low-slope roof systems; windows; doors; and glazing.

Chapter 3 Interior Surface and Substrate Materials

Alternatives that can meet the interior finish and substrate requirements of an educational facility are evaluated in this chapter. This assessment includes the application of these materials to interior floors, partitions, walls, ceilings, interior door and window assemblies, wall bases, millwork, and countertops.

Chapter 4 HVAC Systems

Heating, ventilating, and air conditioning (HVAC) systems include the various components and systems used for heating, cooling, ventilating, and air conditioning all spaces and that ensure the health, safety, and comfort of students, teachers, administrators, and support personnel.

Chapter 5 Lighting Systems
Interior lighting systems applicable to the design of K-12 classrooms are covered in this chapter. The economics of these lighting systems and the integration of daylighting into the design of the lighting schemes for these spaces are also addressed.

Chapter 6 Green Building Certification Systems
The recent emergence of green building certification systems, as they apply to educational facilities, is included in this chapter. The U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) building certification system is described. A newer emerging certification system, Green Globes, is also covered, as well as the Florida Green Building Coalition's Commercial Building Standard and the U.S. Environmental Protection Agency's Energy Star standard. Several significant approaches to green school buildings, such as the California High Performance Schools (CHPS) program, are described for the purpose of supporting innovative approaches to energy-efficient, high-performance school buildings.

Appendix A Life Cycle Costing (LCC)
The results of the Life Cycle Costing evaluations in Chapter 1 through 3 can be found in this Appendix.

Appendix B Life Cycle Analysis (LCA)
Backup information about the Life Cycle Analysis ratings of the materials, products, and systems in Chapters 1 through 3 are contained in this Appendix.

Appendix C Heating, Ventilating, and Air-Conditioning (HVAC) Systems and Controls
The backup for the cost and other ratings shown in Chapter 4 for HVAC Systems are shown in Appendix C. Additionally an overview of HVAC controls is provided in this section of the *Guidelines.*

METHODOLOGY
This publication was developed by first reviewing the 1999 *Guidelines* edition to assess its utility for the intended audience. The results of this review were discussed with the Florida Department of Education and the Steering Committee for the development of the *Guidelines.* The purpose was to develop a new structure, add and delete systems, and expand the criteria upon which material, product, and system selection would be based. The first edition focused almost exclusively on First Cost and Life Cycle Cost criteria; the current edition includes a wide range of other performance criteria. The presentation of the material in the new *Guidelines* edition is based on it being primarily an electronic document, with internal hyperlinks for navigation, and an improved appearance with extensive use of color coding. Additionally, new chapters on lighting systems and green building rating systems are included as major enhancements compared to the first edition.

Systems to be evaluated in the *Guidelines* were selected as follows: review of existing cost studies and guidelines; review of trade journals; consideration of best practice procedures and guidelines; review of relevant codes, design and construction guidelines, and HVAC standards;

interviews with facilities' directors, custodial staff, subcontractors, general contractors, construction managers, architects, engineers, and material suppliers; and analysis of empirical evidence and accumulation of first-hand accounts from appropriate school personnel.

The evaluation of materials, products, and systems is based on using cost criteria and other performance criteria. Evaluating the cost of products and systems requires that two basic criteria be considered: First Cost and Life Cycle Cost. First Cost is the total purchase and installation cost of a material, product, or system. Life Cycle Cost (LCC) is First Cost plus the costs of operation, maintenance, repair, and periodic replacement of the material or product during its useful life. For the purpose of this analysis, these additional costs, which occur over time, are expressed in terms of their present value or worth by applying a discount rate, which converts future costs into their present equivalents. This approach, often referred to as Life Cycle Cost analysis, provides a far more complete picture of the true costs of a material or product. It is generally accepted that using First Cost as the deciding factor in component selection does not always result in the best selection decision and that using the Life Cycle Cost provides a far better picture of the economics of a selection decision.

In addition to cost criteria, a range of other performance criteria was considered: indoor air quality, sound transmission, environmental impact, and fire rating.

DESCRIPTION OF THE SELECTION CRITERIA

Several criteria for selecting products and materials are utilized in this new version of the *Guidelines* to assist the users in finding the best solution for particular applications. For each section of the *Guidelines*, cost and performance criteria are used as the basis for evaluating the options. The following terms are descriptions of the criteria used in the various sections.

COST CRITERIA

First Cost: The purchase and installation cost of the product or system.

Life Cycle Cost (LCC): The total cost of a product or system taking into account First Cost, Operational Cost, Maintenance Cost, and Replacement Cost.

Operational Cost: The cost of the energy, water, and wastewater required for the operation of the product or system.

Maintenance Cost: The cost of cleaning, repairing, adjusting, refinishing, or replacing subcomponents such as gaskets.

HVAC SYSTEM CRITERIA

Required Space: The space needed to house the HVAC system. Along with the footprint of the system, the required space may include required mechanical rooms and any space needed above the ceiling.

Complexity: The difficulty level of installing and maintaining the system.

Life of Unit: The average useful life of an HVAC unit.

Noise: The quantity of noise generated by the system during operation and its potential effect on the learning environment.

Temperature Control: The level of control the system has in maintaining the desired air temperature of the conditioned space.

Humidity Control: The ability of the system to regulate humidity levels within the conditioned space.

OTHER CRITERIA

Indoor Air Quality (IAQ): The relative impact of the product or system on the air quality of interior spaces.

Sound Transmission: The relative ability of a product or system to reduce sound/noise transmission between spaces.

Life Cycle Assessment (LCA): The relative environmental impact of the product or system.

Fire Rating: The relative ability of the product or system to resist combustion.

LIFE CYCLE COST (LCC) ANALYSIS AND PARAMETERS

LCC analysis is a methodology that may be used to evaluate key project elements or components. LCC analysis is a comprehensive economic analysis that uses standard accounting procedures to determine the total cost of competing alternatives over the 50-year life of a building. LCC can be applied to any project or capital expenditure regardless of service life since all costs associated with the project or alternatives are reduced to a common point in time for an objective comparison. The receipts and disbursements of competing alternatives are assessed by comparing their Net Present Worth (NPW), which uses the "time value of money" to bring all future cash flows to their present-day equivalent value.

Most building costs are incurred after the initial capital expenditure for construction. LCC impartially examines the associated ownership costs of competing alternatives by discounting the cost of a system to a common reference point—typically the onset of building use. Both the positive and negative cash flows throughout the system's service life are considered. For example, a positive cash flow may result from energy savings that occur as a result of the purchase of a specific system. Examples of negative cash flow are the cost of replacing the system and the operation and maintenance (O&M) expenses resulting from the use of the system.

Description of Cost Elements
LCC allows the most effective and efficient alternative to be chosen for funding or deployment based on five main categories: First Cost, Operating Cost, Maintenance Cost, Alteration Costs, and Replacement Costs.

First Cost is the initial cost of the system and includes the purchase price and the cost of installation.

Operating Costs are incurred during the normal functioning of the facility or building component, including regular custodial care. It includes energy and water expenditures.

Maintenance Costs are incurred as a result of repair, annual maintenance contracts, and the salaries of maintenance staff.

Alteration Costs are incurred during the process of significantly modifying a facility, space, or component, or the process of changing the function of a space. Alteration costs that do not exceed $5,000 are included in the maintenance cost category.

Replacement Costs are incurred as one-time or periodic events during the facility's useful life, and they are for the purpose of maintaining the original functionality of the facility.

LCC Methodology – Assumptions
The basic assumptions for the LCC analysis are based on standards set by the Florida Department of Education (FDOE), the Federal Energy Management Program (FEMP), and the National Institute of Science and Technology (NIST). Table I.1 identifies and explains the assumptions used for the LCC analysis.

Table I.1 LCC Assumptions

General Inflation Rate (i)	3%	Rate used to determine the future cost of a present expense.
Discount Rate (d)	0%	Rate used to determine the present value of a future cost.
O&M Inflation Rate	Variable	If no actual operation and maintenance information is available for a given system, an appropriate inflation rate for these costs is assumed. The O&M costs will increase geometrically, based on the assumed rate of inflation.
Repair and Replacement	Variable	For systems requiring repair and/or replacement, their service life is obtained from vendors, manufacturers, and historical data.

- Operation and maintenance (O&M) expenses are difficult to predict and quantify. In instances where the O&M could be determined, the actual numbers were quantified using manufacturer, supplier, and maintenance staff information. The maintenance costs were then converted into a percentage of the capital cost of the system for the LCC calculations.
- This analysis assumes that no salvage value exists for the system at the time of replacement.
- The Discount Rate is assumed to be 0% because the capital for educational facility construction is obtained from tax revenues. Additionally, at the present time the actual Federal discount rate is nearly 0%.
- The LCC disregards bonds as a revenue source for construction. It assumes that current funds are available for capital expenditure.

LCC Methodology – Calculations

The systems identified in the *Guidelines* were analyzed to determine the Net Present Worth (NPW) of their total cost. An example of the output of the LCC calculations is shown in Table I.2.

Table I.2 Example of an Evaluation of Alternative Systems

		Costs			Rank		
System	**Unit**	**Initial Cost**	**LCC**	**O&M**	**Initial Cost**	**LCC**	**O&M**
System-1	SF	$ 8.69	$ 18.49	1.00%	3	3	4
System-2	SF	$ 7.90	$ 8.79	0.10%	1	1	1
System-3	SF	$ 14.22	$ 94.42	5.00%	5	5	6
System-4	SF	$ 19.75	$ 102.32	0.10%	6	6	2
System-5	SF	$ 10.27	$ 85.57	6.50%	4	4	5
System-6	SF	$ 8.45	$ 17.99	1.00%	2	2	3
System-7	SF	$ 56.13	$ 182.76	2.00%	7	7	7

LCC Calculation Explanation

The LCC output tables provide the user with system information in addition to the results of the LCC analysis. The top line in the table indicates the “Costs” and “Rank” columns. The left-hand side of the table shows the system being analyzed and the unit of measurement. Under “Costs,” the “Initial Cost,” the “LCC,” and the “O&M” cost for each system are shown. The right-hand side of the table shows the the rating of each system for each category of cost, with “1” being the best option. Descriptions of the table’s columns are as follows:

System: A label for the system being analyzed.
Unit: The unit of measure that is being used for the evaluation. In this example the appropriate unit of measurement is square feet (SF) and the cost data are provided on a square foot basis.

Initial Cost: The purchase and installation cost for the system.
LCC: Calculated by combining the initial cost, replacement cost, and O&M costs. The replacement cost is based on the service life of the system and number of replacements, if any, during the life of the facility.

O&M: Expressed as a percentage of the initial cost of the system. For example, System-1 in Table I.2 has an Initial Cost of $8.69 and an annual O&M cost of 1%, or $0.0869 annually. The O&M Costs are calculated for a term of 50 years and include inflation.

Initial Cost, LCC, and O&M (Rank): These columns rank the systems to allow the reader to better understand the relative impact of the different costs. The point system is organized such that "1" is the least cost. If two systems have the same ranking, their costs are within 2% of each other.

Number of Replacement Systems
The number of replacements for a given system is based on the type of system under consideration. During a building life of 50 years, some systems (for example, the building structure) do not require any replacement. Other systems, such as the HVAC systems, some roofing systems, and most finishes, will be replaced one or more times during the facility's life. These replacements will add to the LCC of the respective system. Table I.3 shows how the Net Present Worth (NPW) of a system requiring replacement three times during its useful life is calculated.

Table I.3 Equation for Calculating the NPW of a System Requiring Three Replacements During Its Useful Life

$$NPW = P + P\,\frac{(1+i)^{n1}}{(1+d)^{n1}} + P\,\frac{(1+i)^{n2}}{(1+d)^{n2}} + P\,\frac{(1+i)^{n3}}{(1+d)^{n3}}$$

Where:

P = First Cost or Present Worth of the system

i = the general inflation rate

d = the discount rate

n1, n2, and n3 = the years in which the replacements happen

NPW =The First Cost of system (P) increases at the inflation rate (i) for the replacement time (n1, n2, and n3) and is then adjusted back to the Net Present Worth (NPW) using the discount rate (d).

Table I.4 is an example of a system with an initial cost (P) of $5,000 and a 15-year life, meaning that a system replacement will occur at years 15 (n1), 30 (n2), and 45 (n3). The NPW is the total present value of the three replacements, each being inflated at 3%, and then being brought back to the present with a discount rate of 0%.

Table I.4 Repair and Replacement of a System with a 15-Year Service Life, P = $5,000

	Replacement Cost at 15 years	**Replacement Cost at 30 years**	**Replacement Cost at 45 years**
$NPW = P +$	$P\,\dfrac{(1+0.03)^{15}}{(1+0.0)^{15}}$ +	$P\,\dfrac{(1+0.03)^{30}}{(1+0)^{30}}$ +	$P\,\dfrac{(1+0.03)^{45}}{(1+0)^{45}}$
$NPW = \$5{,}000 +$	$\$7{,}790$ +	$\$12{,}136$ +	$\$18{,}908$

$$NPW = \$43{,}834$$

Operation and Maintenance (O&M) Costs

Wherever possible, actual O&M Costs are used. This information is obtained from manufacturers, suppliers, and school maintenance staff. The maintenance costs are then converted into a percentage of the Initial Cost of the system. Table I.5 and Figure I.1 show an example of the O&M Costs for a system during a 50-year life span.

Initial Cost	$5,000.00
O&M as a percentage of the Initial Cost	1.0%
O&M = (Capital Cost)(Percentage)	$50.00
Service Life (in years)	50
Discount Rate	0%

Table I.5 Operation and Maintenance of a $5,000 System for 50 Years

Years	O&M	Years	O&M	Years	O&M	Years	O&M
0	$ 50.00	16	$ 80.24	32	$ 128.75	48	$ 206.61
1	$ 51.50	17	$ 82.64	33	$ 132.62	49	$ 212.81
2	$ 53.05	18	$ 85.12	34	$ 136.60	50	$ 219.20
3	$ 54.64	19	$ 87.68	35	$ 140.69		
4	$ 56.28	20	$ 90.31	36	$ 144.91		
5	$ 57.96	21	$ 93.01	37	$ 149.26		
6	$ 59.70	22	$ 95.81	38	$ 153.74		
7	$ 61.49	23	$ 98.68	39	$ 158.35		
8	$ 63.34	24	$ 101.64	40	$ 163.10		
9	$ 65.24	25	$ 104.69	41	$ 167.99		
10	$ 67.20	26	$ 107.83	42	$ 173.03		
11	$ 69.21	27	$ 111.06	43	$ 178.23		
12	$ 71.29	28	$ 114.40	44	$ 183.57		
13	$ 73.43	29	$ 117.83	45	$ 189.08		
14	$ 75.63	30	$ 121.36	46	$ 194.75		
15	$ 77.90	31	$ 125.00	47	$ 200.59		
						Total	**$ 5,859.04**

The NPW equation in Table I.3 was used to compute the annual O&M Costs. Figure I.1 is a graphical representation of the NPW of O&M costs.

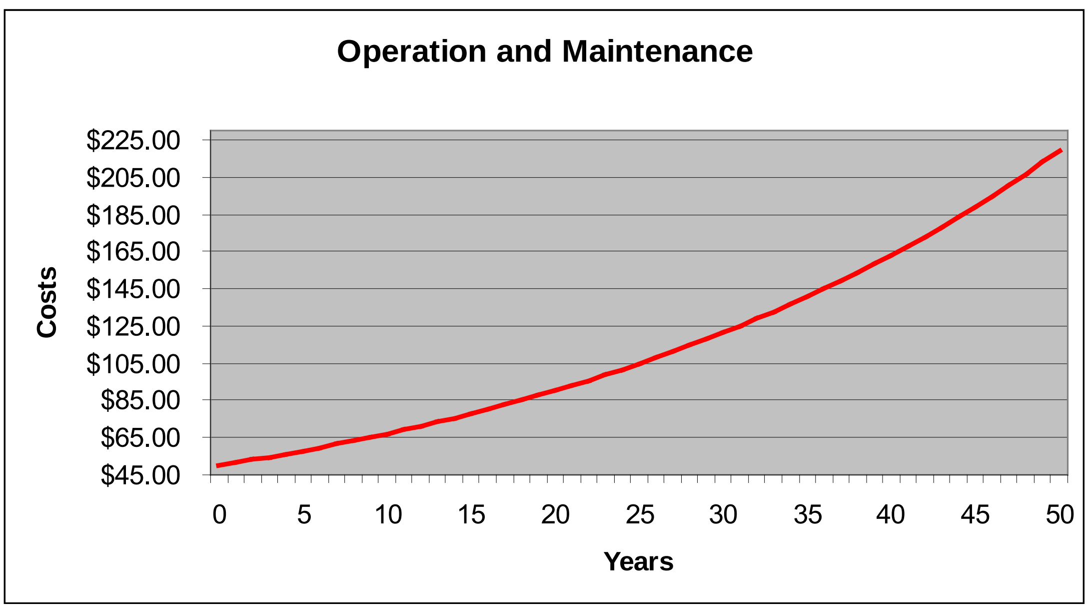


Figure I.1 Operation and Maintenance of a $5,000 system with a 1% O&M.

The total NPW for a $5,000 system, with a 1% annual O&M and a 15-year service life, can now be calculated for the 50-year service life of the building.

Initial Cost =	$ 5,000
Replacement Cost =	$38,834
Annual O&M =	$ 5,859
Total NPW=	*$49,693*

Qualitative Issues

Although the LCC analysis provides quantitative results based on certain assumptions, non-quantifiable or qualitative data must also be considered in the evaluation of alternatives. This includes issues such as building health, environmental impact, and aspects of the facility that are difficult to quantify.

SUMMARY

The updated *Guidelines* provides an evaluation of current and emerging materials, products, and systems for application to the construction of educational facilities in Florida, and this assessment is based on a wide range of cost and performance criteria. Current data regarding First Cost, Operation and Maintenance (O&M) Costs, and Replacement Costs were used in the life cycle evaluation of the materials, products, and systems. The ratings for each material, product, or system are indicated using a matrix of systems versus criteria for ranking the systems. The main criteria for evaluating each major system have been selected and used in the system matrix to compare the performance of each alternative. The rating for each item in the matrix is unweighted, and it is left to the decision-maker to weight the criteria, if so desired. For the Life Cycle Cost (LCC) analysis, the parameters used in the evaluation are applied consistently for each system. This publication is designed primarily to be an electronic document with internal hyperlinks to facilitate navigation. The *Guidelines* also contains a section (see Chapter 6) on green building certification systems, an emerging trend that affects the selection of materials and systems for schools. A case study of a recent green building project in Pasco County is provided in Chapter 6. This study indicates a strategy that allowed the project to earn a Gold rating in the U.S. Green Building Council's Leadership in Energy and Environmental Design for Schools (LEED-S) green building rating system.

CHAPTER 1
SUPERSTRUCTURE

1.0 INTRODUCTION

A building superstructure consists of the components that define the structural framework of the building. Secondary elements that are attached to the superstructure to support the exterior wall (not including girts, wind beams, or lintels) or interior finishes are not part of the superstructure. The structural engineer is responsible for the design and specification of the superstructure and its components.

The superstructure is designed to:

- Support vertical live loads.
- Support vertical dead loads.
- Resist lateral forces such as wind loads.
- Minimize movement and deflection that could cause damage to the building.
- Transfer all loads encountered above grade to the substructure (foundation).

The superstructure must also support the secondary elements to which are mounted the exterior wall and interior finishes. The superstructure must provide space for the installation of building services (HVAC, plumbing, electrical communications), often within the volume of the structural framework. Because of these additional functional requirements, the superstructure must accommodate a number of complex framing and fastening conditions for secondary structural elements.

1.1 COLUMNS

The primary function of columns is to transfer concentrated vertical axial loads from floor members, horizontal beams, and the roof structure to the foundation of the building. Columns are also often subjected to axial and bending stresses caused by wind load and the transfer of shear and bending stress from beams.

Table 1.1 Columns

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Maint.	LCA	Fire
1.1.1 Cast-in-Place (CIP) Reinforced Concrete	5	6	3	5	1
1.1.2 Precast Reinforced Concrete	6	5	2	4	1
1.1.3 Concrete Block Column	4	4	1	3	1
1.1.4 Steel Column, W-Shape	1	1	1	2	2
1.1.5 Round Hollow Structural Sections (HSS)	3	3	1	1	2
1.1.6 Square Hollow Structural Sections (HSS)	2	2	1	1	2

1.1.1 Cast-in-Place (CIP) Reinforced Concrete

Cast-in-place reinforced concrete columns are fabricated on site by pouring concrete into formwork. The concrete is usually premixed off site at a local ready mix plant and transported to the construction site. Concrete columns need to be reinforced, usually by means of steel reinforcing bars. Formwork can be either temporary (that is, it is removed after the concrete has sufficient strength) or the formwork can be permanent and becomes part of the final structure. The bulk of the cost of cast-in-place reinforced concrete columns is due to the preparation of formwork and reinforcement. The actual cost of the concrete material is typically just a minor part of the total cost. For this reason, the dimensions of columns are held constant as much as possible throughout the building so that reusable formwork or standard stay-in-place formwork can be used.

1.1.2 Precast Reinforced Concrete

Precast reinforced concrete columns are manufactured off site and can have standard shapes or be custom-built. Steel base plates are installed for convenient attachment to foundations or other parts of the building. These types of columns do not require on-site curing, resulting in substantial timesaving.

1.1.3 Concrete Block Column

Concrete block columns are an integral part of a concrete masonry wall. They are reinforced by inserting steel bars and pouring concrete into their hollow cores. Concrete block columns can be used to support beams and also increase the stiffness of the wall.

1.1.4 Steel Column, W-Shape

Wide flange steel columns are fabricated off site by specialized contractors. Base plates are provided for convenient attachment to foundations or other parts of the superstructure. Unlike concrete columns, steel columns need to be protected to make them fire-resistant.

1.1.5 Round Hollow Structural Sections (HSS)

This system is a hollow steel pipe column with a round cross-section that is fabricated off site. HSS has a high strength-to-weight ratio, superb compression support characteristics, and excellent torsional resistance. In exposed applications, it can provide a visually interesting element. HSS provides a uniformity of size, shape, strength, and tolerance that make its use totally predictable. In fabrication it can be readily bent, formed, punched, and drilled. New, improved methods for fastening HSS are making this system simpler and faster to use.

1.1.6 Square Hollow Structural Sections (HSS)

This system is similar to the Round Hollow Structural Sections (HSS) described in paragraph 1.1.5, but it has a square rather than a round cross-section.

1.2 BEAMS

The primary function of beams is to transfer loads from floor members and the roof to columns or load-bearing walls. In addition, columns and beams are often subjected to axial and torsional loads caused by wind or other external lateral forces. The systems compared for the Life Cycle Cost (LCC) analysis present the most appropriate use in educational facilities.

Table 1.2 Beams

Legend:	GOOD	FAIR	POOR

System	First Cost	LCC	Maint.	LCA	Fire
1.2.1 Cast-in-Place (CIP) Concrete	3	3	3	4	1
1.2.2 Reinforced Masonry	2	2	1	2	2
1.2.3 Precast Concrete	4	4	2	3	1
1.2.4 Steel W-Shape	1	1	1	1	2

1.2.1 Cast-in-Place (CIP) Concrete

Cast-in-place reinforced concrete beams are produced by a process similar to that used to produce cast-in-place concrete columns. Premixed concrete from a ready mix is poured into on-site formwork. Because concrete has almost no tensile strength, concrete beams need to be reinforced to resist bending, usually by means of steel reinforcing bars. The formwork used to make concrete beams is almost always temporary, and materials such as wood or steel are used for this purpose. Similar to cast-in-place concrete columns, the bulk of the cost of cast-in-place reinforced concrete beams is due to the on-site formwork. For this reason, the dimensions of beams are held constant as much as possible throughout the building so that reusable formwork can be used. For the LCC analysis, beams were assumed to be part of a project in which the entire superstructure was made of cast-in-place concrete.

1.2.2 Reinforced Masonry

Reinforced masonry beams are a structural masonry assembly composed of concrete masonry units (CMU), grout fill, and reinforcing bars. They are constructed on site and can be easily customized to fit any application.

1.2.3 Precast Concrete

Precast reinforced concrete beams are produced by a process similar to that used to produce precast concrete columns. Precast reinforced concrete beams are manufactured off site and can have standard shapes or be custom-built. Steel base plates are provided for convenient attachment to columns or other parts of the building. These types of beams are used to reduce on-site labor. In addition, they do not require on-site curing, resulting in substantial time savings.

1.2.4 Steel W-Shape

Similar to steel columns, wide-flange steel beams are pre-dimensioned off site by specialized contractors, and base plates may be provided for convenient attachment to parts of the superstructure. Unlike concrete beams, steel beams need to be protected to make them corrosion-resistant and fire-resistant.

1.3 FLOORS ABOVE GRADE – 30' to 40' SPAN

LCC comparison between floor systems was accomplished by considering two span ranges, from 30’ to 40’ and over 40’ to 60’. Larger or smaller spans than these are not generally used in educational facilities.

Table 1.3 Floors Above Grade – 30’ to 40’ Span

Legend:	GOOD	FAIR	POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
1.3.1 Steel Deck 1-1/2" + 4” Thick Concrete Cast On-Site + Open Web Steel Joist	1	1	1	1	2	2
1.3.2 Cast-in-Place Flat Concrete Plate, 4” Thick	3	3	3	1	3	1
1.3.3 Precast Plank with Concrete Topping	2	2	2	1	1	1

1.3.1 Steel Deck 1-1/2" + 4” Thick Concrete Cast On-Site + Open Web Steel Joist

This system is a composite of a galvanized steel deck with a concrete cover. The composite system is supported by a painted open web steel joist.

1.3.2 Cast-in-Place Flat Concrete Plate, 4” Thick

Cast-in-place reinforced concrete plates are produced by a process similar to that used to produce cast-in-place concrete columns, beams, and walls. Cast-in-place reinforced concrete plates are produced by pouring premixed concrete from a local ready-mix plant into formwork. The formwork for above-grade floors is typically a temporary structure supported from the floor below. The formwork is either wood framed on-site, constructed from a manufactured formwork system with reusable components, or a combination. The concrete is reinforced by casting steel welded wire fabric or steel reinforcing bars into the concrete plate.

1.3.3 Precast Plank with Concrete Topping

Precast concrete planks are manufactured off site by using an extrusion process with a dry concrete mixture. High strength steel reinforcement is incorporated into the planks during the extrusion process. Precast concrete planks often have hollow cores to reduce their weight. To achieve additional strength, the steel reinforcement can be pre-stressed. These prefabricated elements are transported to the building site and lifted in place by a crane. After placement, a thin concrete topping can be cast on top of the planks to increase the compressive zone of the members and to level the floor surface.

1.4 FLOORS ABOVE GRADE – OVER 40' to 60' SPAN

Table 1.4 Floors Above Grade – Over 40’ to 60’ Span

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
1.4.1 Steel Deck + 4” Thick Concrete Cast On-Site + Open Web Steel Joist + Steel	2	2	1	1	2	2
1.4.2 Precast Double Tees Floor Members with Topping	1	1	2	1	1	1

1.4.1 Steel Deck + 4” Thick Concrete Cast On-Site + Open Web Steel Joist + Steel

This system is similar to 1.3.1 Steel Deck 1-1/2" + 4” Thick Concrete Cast On-Site + Open Web Steel Joist, but additional beams, usually made of steel, are required for the longer spans.

1.4.2 Precast Double Tees Floor Members with Topping

Precast concrete double tees are manufactured off site using permanent steel forms called “casting beds.” High strength steel reinforcement is inserted into the beds and then pre-stressed. Concrete is then poured into the bed, vibrated to eliminate voids, and leveled. Welding plates can be inserted during the manufacturing process. These prefabricated elements are transported to the building site and lifted into place by a crane. After placement, a thin concrete topping can be cast on top of the tees to increase the compressive zone of the members and to level the floor surface.

1.5 ROOFS 30' to 40' SPAN

The comparison between floor or roof systems was accomplished using three separate span ranges. The spans considered were from 30’ to 40’, from over 40’ to 60’, and from over 60’ to 100’. These spans are often used in educational facilities.

Table 1.5 Roofs 30’ to 40’ Span

Legend:	GOOD	FAIR	POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
1.5.1 Steel Deck 1-1/2" Deep + Open Web Steel Joist	1	1	1	1	2	2
1.5.2 Cast-in-Place Flat Concrete Plate, 4” Thick	4	4	3	1	3	1
1.5.3 Precast Double Tees	3	3	2	1	1	1
1.5.4 Steel Purlins + Steel	5	5	1	1	2	2
1.5.5 Steel Deck 1-1/2” Deep + Cold-Form Light Gauge Steel Purlins + Cold-Form Light	2	2	1	1	1	2

1.5.1 Steel Deck 1-1/2" Deep + Open Web Steel Joist

This roof system is a galvanized steel deck supported by an open web steel joist.

1.5.2 Cast-in-Place Flat Concrete Plate, 4” Thick

This roof system is similar to 1.3.2 Cast-in-Place Flat Concrete Plate, 4” Thick, but the superimposed load requirements are usually less than for floor members, which results either in a thinner plate or less reinforcement.

1.5.3 Precast Double Tees

The precast double tees are similar to 1.3.3 Precast Plank with Concrete Topping, but the superimposed load requirements are usually less than for floor members, which results in either reduced height or less reinforcement.

1.5.4 Steel Purlins + Steel Beams

This system employs engineered steel purlins, which are horizontal structural members that transfer the roof load to steel roof beams. Purlins are typically fabricated from cold-formed steel C or Z sections that may be lapped and fastened to create a continuous beam configuration when additional length is required.

1.5.5 Steel Deck 1-1/2” Deep + Cold-Form Light Gauge Steel Purlins + Cold-Form Light Gauge Steel Trusses

This system includes a steel deck similar to 1.5.1 Steel Deck 1-1/2" Deep + Open Web Steel Joist, but with light gauge steel purlins and trusses atop the steel deck. The purlins and trusses in this system are made of cold-formed steel. A large variety of connectors, clips, and installation products are available for this light gauge system. This system utilizes trusses, which are prefabricated structural assemblies made up of connected triangular steel units, resulting in a sloped roofing system that is unlike the other flat roofing systems described in this section.

1.6 ROOFS OVER 40' to 60' SPAN

Table 1.6 Roofs Over 40’ to 60’ Span

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
1.6.1 Steel Deck 1-1/2" Deep + Open Web Steel Joist	1	1	1	1	2	2
1.6.2 Precast Double Tee	2	2	2	1	1	1
1.6.3 Steel Deck 1-1/2” Deep + Cold-Form Light Gauge Steel Purlins + Cold-Form Light	3	3	1	1	1	2

1.6.1 Steel Deck 1-1/2" Deep + Open Web Steel Joist

This roof system is similar to 1.5.1 Steel Deck 1-1/2” Deep + Open Web Steel Joist. Open web steel joists can span longer distances than heavier concrete and steel systems.

1.6.2 Precast Double Tees

The precast double tees are similar to 1.5.3 Precast Double Tees. Double tees can span longer distances than heavier concrete and steel systems.

1.6.3 Steel Deck 1-1/2” Deep + Cold-Form Light Gauge Steel Purlins + Cold-Form Light Gauge Steel Trusses

This roof system is similar to 1.5.5 Steel Deck 1-1/2” Deep + Cold-Form Light Gauge Steel Purlins + Cold-Form Light Gauge Steel Trusses. Light gauge roofing systems can span longer distances than heavier concrete and steel systems.

1.7 ROOFS OVER 60' to 100' SPAN

Table 1.7 Roofs Over 60’ to 100’ Span

Legend:	GOOD	FAIR	POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
1.7.1 Steel Deck 1-1/2" Deep + Open Web Steel Joist	2	2	1	1	2	2
1.7.2 Precast Double Tee	1	1	2	1	1	1
1.7.3 Steel Deck 1-1/2” Deep + Cold-Form Light Gauge Steel Purlins + Cold-Form Light Gauge Steel Trusses	1	1	1	1	1	2

1.7.1 Steel Deck 1-1/2" Deep + Open Web Steel Joist

Similar to 1.5.1 Steel Deck 1-1/2” Deep + Open Web Steel Joist, but open web steel joists can span longer distances than heavier concrete and steel systems.

1.7.2 Precast Double Tees

Similar to 1.5.3 Precast Double Tee, but double tees can span longer distances than heavier concrete and steel systems.

1.7.3 Steel Deck 1-1/2” Deep + Cold-Form Light Gauge Steel Purlins + Cold-Form Light Gauge Steel Trusses

This roof system is similar to 1.5.5 Steel Deck 1-1/2” Deep + Cold-Form Light Gauge Steel Purlins + Cold-Form Light Gauge Steel Trusses. Light gauge roofing systems can span longer distances than heavier concrete and steel systems.

CHAPTER 2
EXTERIOR MATERIALS

2.0 INTRODUCTION

Exterior or envelope materials perform several practical and aesthetic functions in buildings. The exterior material systems help maintain comfort in the interior environment by reducing unwanted air flow to and from interior spaces, controlling heat and moisture transfer between the interior and exterior. These exterior material systems also provide acoustical separation, daylighting, and visual access to the exterior.

The exterior envelope should be designed to:

- Resist the penetration of moisture in the form of a liquid or vapor;
- Regulate heat transfer to reduce mechanical system loads;
- Provide a level of acoustic separation from outdoor noise;
- Be durable and weather resistant given regional conditions;
- Provide security; and
- Provide an appropriate building image that is positively related to the community and reinforces the educational mission of the facility.

Not all materials and systems are included due to requirements related to educational facilities. For example, wood construction is precluded by code due to its combustibility. Any materials not conforming to the building code were excluded from the study.

2.1 EXTERIOR WALLS

Fourteen exterior wall systems and seven exterior wall coverings are included in the study. The exterior wall systems reviewed support their own weight, resist wind loads, and can be load bearing. The exterior wall systems may have additional exterior or interior finish materials applied to them.

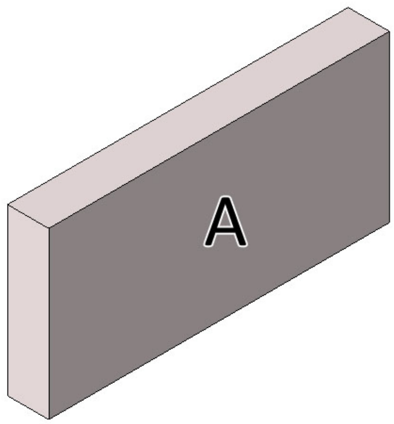
Table 2.1 Exterior Walls

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
2.1.1 Cast-in-Place (CIP) Reinforced Concrete Wall System	4	4	5	3	4	2
2.1.2 Precast Reinforced Concrete	2	2	1	3	4	2
2.1.3 Structural Precast Panels	7	8	8	3	4	2
2.1.4 Precast Concrete Wall Panel System	8	9	3	3	4	2
2.1.5 Lightweight Precast Aerated Concrete Wall Panel System	5	7	6	3	2	1
2.1.6 Tilt-Up/Tilt-Slab	3	3	4	3	4	2
2.1.7 Curtain Wall System	10	11	12	4	6	3
2.1.8 Concrete Masonry Units (CMU)	1	1	2	3	3	4
2.1.9 Double Wythe CMU	2	5	5	1	5	2
2.1.10 Lightweight Aerated Concrete Block	6	6	9	3	1	1
2.1.11 Double Wythe Brick Wall	9	12	13	2	4	3
2.1.12 Single Wythe Exterior Brick Facing over CMU	7	8	7	3	6	2
2.1.13 Single Wythe Brick Facing over Steel Studs	8	10	11	4	5	3
2.1.14 Single Wythe Brick Facing on Fully Reinforced Concrete Wall Panel	7	8	10	3	7	2

2.1.1 Cast-in-Place (CIP) Reinforced Concrete Wall System

A cast-in-place reinforced concrete wall system is primarily a structural system; however, the wall can be exposed to serve as the façade. A cast-in-place reinforced wall can have openings for doors, windows, vents, or openings that are filled with masonry or other cladding materials.



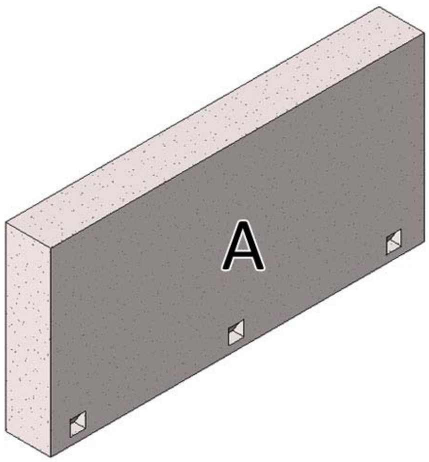
A: Cast-in-Place Reinforced
Concrete Wall

Described in paragraph above.

2.1.2 Precast Reinforced Concrete

Precast reinforced concrete walls are manufactured entirely off site. Typically, steel plates attach the walls to structural elements such as the foundation, columns, and beams. The exterior and interior surfaces of precast concrete walls can be finished in a number of textures and styles. The exterior surface of precast concrete can vary from an exposed aggregate finish to a form face finish that is similar to cast-in-place. The precast concrete wall elements must be designed for appearance and detailed for weatherproofing. In addition, the structural connections and loads must be evaluated by a structural engineer. Typically, each precast panel is independently supported by the building structure using metal anchors. A precast concrete manufacturer must consider the erection sequence and loads placed on the wall elements and the connection details. An elastomeric sealant is typically used in the joints at the edges of precast panels.

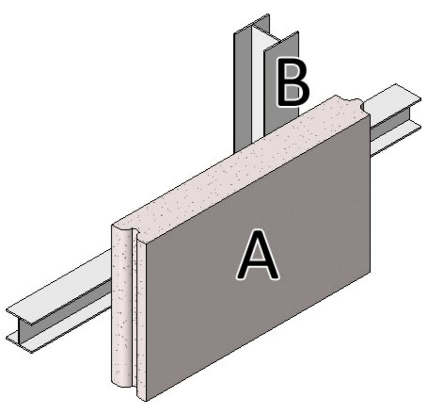
2.1.3 Structural Precast Panels
Structural precast panels are manufactured entirely off site. They can have standard shapes or can be built to custom specifications. Typically, steel plates attach the wall panels to the structural elements of the building. This system functions both as a load-bearing wall and an exterior finish. Different finishes are possible and thermal insulation can be incorporated in the panel.



A: Structural Precast Wall Panel

Described in paragraph above.

2.1.4 Precast Concrete Wall Panel System
Precast wall panel elements are cast off site and transported to the site for erection. The precast elements can be load bearing or non-structural. The illustrated system is a non-structural precast wall panel that is attached to a structural steel framework and a secondary girt system. Typically, the exterior surface of the precast panel is exposed and serves as the finish surface.

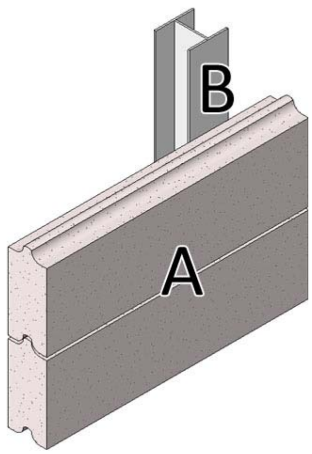


A: Precast Concrete Panel
B: Steel Support

Described in paragraph above.

2.1.5 Lightweight Precast Aerated Concrete Wall Panel System

Lightweight precast aerated concrete wall panels are manufactured with concrete that has been infused with an expanding agent that produces a uniform, gas-entrained cellular structure. The panel has a reduced density and therefore less weight compared to a conventional precast concrete panel of the same size. The material is non-combustible and has a thermal resistance or R-value of approximately 1.0 per inch of wall thickness.



A: Lightweight Precast Aerated Concrete Panel
B: Steel Superstructure

Described in paragraph above.

2.1.6 Tilt-Up/Tilt-Slab

Tilt-up/tilt-slab construction is site-cast concrete that addresses the high cost of formwork. In this method, modular concrete elements are formed on a concrete slab, usually the building floor, but sometimes a temporary concrete casting surface near the building. After the concrete has cured, the elements are placed with a crane and braced until the remaining structural components of the building are placed and secured. Tilt-up differs from precast in that the molds are designed for a specific building and usually not reused.

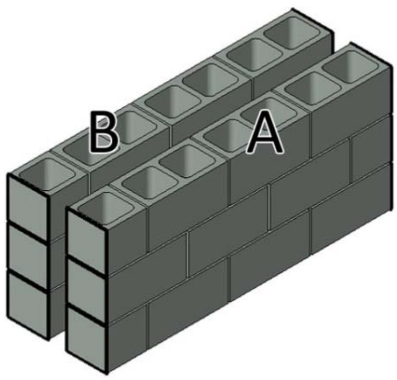
2.1.7 Curtain Wall System

A curtain wall is an exterior wall system whose primary function is to resist air and water infiltration. Structurally, the curtain wall carries only its own weight and transfers horizontal wind loads and other forces upon it to the main building structure through connections at the floors or columns of the building. It can be made of a lightweight material, which can reduce construction costs. Glass in an aluminum frame is often used in curtain wall systems.

2.1.8 Concrete Masonry Units (CMU)

This system is a single wythe or layer of CMU. The wall system can be load bearing or non-load bearing. Concrete masonry can be reinforced both vertically and horizontally to achieve the required flexural resistance. Vertical reinforcement, which is installed within the cells of the concrete masonry, is generally grouted solid. Horizontal reinforcement is typically installed using prefabricated welded wires that are embedded in the mortar bed joints. The horizontal reinforcement improves the strength of the masonry for horizontal spans and serves to control shrinkage cracking.

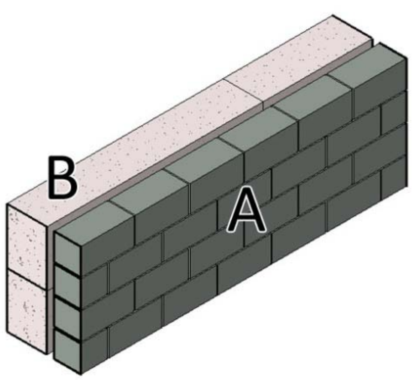
2.1.9 Double Wythe CMU
In a double wythe CMU cavity wall, a composite wall is built in which the wythes act as a unit to resist loads or as a non-composite wall in which the individual wythes act independently. Typically, either an exterior barrier such as a masonry coating should be provided, or a cladding system such as an exterior insulated finishing system [EIFS], metal panel, or stucco finish system should be added to prevent water penetration. Admixtures that reduce the amount of water penetration can be used in concrete masonry units and the mortar; however, admixtures should not be relied upon to eliminate water penetration.



A: Exterior CMU
B: Interior CMU

Described in paragraph above.

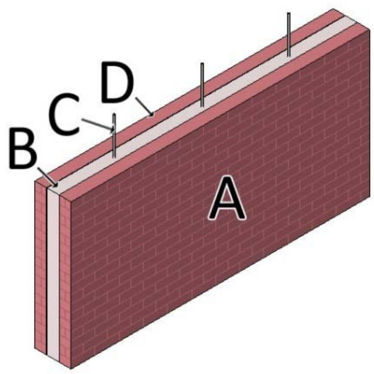
2.1.10 Lightweight Aerated Concrete Block
Aerated concrete block is typically made from a combination of sand, cement, lime, water, and gypsum. Small amounts of aluminum oxide or other compounds are added as foaming agents. The entrained gas acts as an insulator similar to closed-cell foam insulation. The resulting block is lightweight and insulating, with a typical weight between 35 lb/sf and 40 lb/sf of 8' high wall. Aerated concrete typically achieves a four-hour fire rating with as little as 4" of thickness. Insulation values typically range between R-1 and R-1.25 per inch compared to a typical R-0.125 for conventional masonry. The thermal mass of the concrete portion of the block further contributes to the comfort and energy performance. The weight of aerated block is about 20% of a standard mid-strength CMU. Theoretically, this diminished weight reduces the cost of transportation and reduces the strength requirements for the foundation. The aerated block may not be exposed as the exterior or interior finish material.



A: Exterior Aerated Concrete Block
B: Interior Aerated Concrete Block

2.1.11 Double Wythe Brick Wall

A double wythe brick wall is typically a load bearing wall where both the exterior and interior finishes are brick. Brick walls are mortared and the most widely used grout is a mixture of Portland cement, aggregate, and water. American Society for Testing and Materials (ASTM) C476 specifies the proportions and qualities of grout for use in filling masonry load-bearing walls. The system specified here is double-wythe brick construction. A single-wythe, hollow-core brick system is possible for relatively small-scale construction.

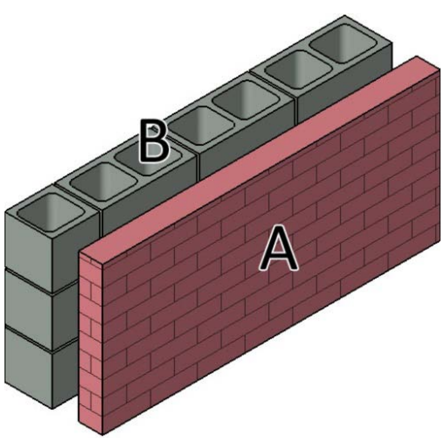


A: Exterior Brick
B: Grout-Filled Cavity
C: Steel Reinforcing
D: Interior Brick

Described in paragraph above.

2.1.12 Single Wythe Exterior Brick Facing over CMU

In this system, CMU is the primary structural element and the brick wythe is the exterior finish. The specifications of the brick are identical to those in 2.1.11 Double Wythe Brick Wall. The CMU in this report is assumed to be hollow block. The most common nominal dimensions for CMU are 8” x 8” x 16”, and the actual dimensions are 7 5/8” x 7 5/8” x 15 5/8”, allowing for a 3/8” thick mortar joint. The nominal dimensions of a standard brick in the United States are 8” x 4” x 2 ¼”, meaning that the vertical courses of CMU and brick correspond and therefore the integration of these materials is straightforward. The grout is a mixture of Portland cement, aggregate, and water. ASTM C476 specifies the proportions and qualities of grout for use in filling masonry load-bearing walls. This system utilizes lateral reinforcement.



A: Exterior Brick
B: CMU

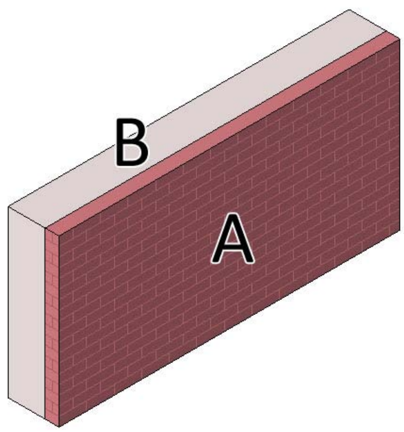
Described in paragraph above.

2.1.13 Single Wythe Brick Facing over Steel Studs

From the exterior, this system looks like solid masonry. The steel stud wall system, which is lighter weight than CMU, also reduces costs. This system maintains many of the benefits of a masonry façade: durability, low maintenance, high fire rating, and numerous material choices. It is important to properly detail the moisture drainage in the cavity between the brick and steel stud backup wall system in order to keep the interior dry.

2.1.14 Single Wythe Brick Facing on Fully Reinforced Concrete Wall Panel

This system is a precast reinforced wall panel with brick facing that is fully formed and cured off site, then transported and erected as any other precast wall panel. A cast-in-place (CIP) wall panel could be used if required, but would cost more, with higher labor costs.



A: Brick Facing
B: Precast Wall Panel

Described in paragraph above.

2.2 EXTERIOR WALL COVERINGS

Exterior wall coverings are the finishes applied to the exterior of a wall system. These finishes are not self-supporting and, therefore, must be mounted or applied to an exterior wall system.

Table 2.2 Exterior Wall Coverings

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
2.2.1 Paint	1	1	5	3	1	2
2.2.2 Stucco	2	1	4	2	3	2
2.2.3 Exterior Insulated Finishing System	5	6	6	1	2	2
2.2.4 Copper: Flat-Seam Field Formed Wall System	4	3	2	2	6	1
2.2.5 Zinc-Copper Alloy: Flat-Seam Field Formed Wall System	5	4	3	2	6	1
2.2.6 Stainless Steel: Flat-Seam Field Formed Wall	3	2	1	2	5	1
2.2.7 High-Performance Coated Metal Panel Wall System	6	5	3	2	4	1

2.2.1 Paint

Paint is a protective and/or decorative coating that is commonly applied to many building materials. Paints are pigmented and develop an opaque protective film on the surface of the material. Coatings commonly referred to as stains are absorbed into the surface of the material in order to alter its appearance. However, some stains may be pigmented to the extent that they approach paint in film thickness. Non-pigmented finishes such as varnishes and clear polyurethanes provide a clear or nearly clear finish that is typically used to protect stained or unstained wood.

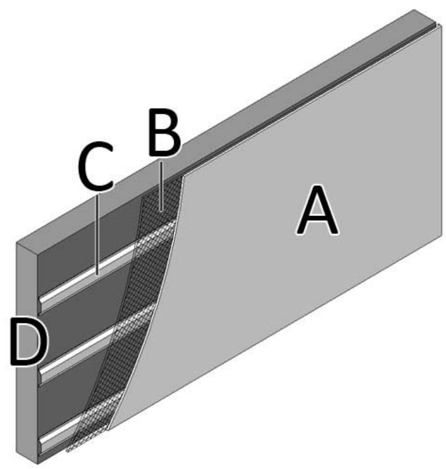
In addition to appearance, paints can protect steel from corrosion and intumescent coatings can provide a level of fire resistance for steel. These are referred to as industrial coatings and common polymers include polyurethane, epoxy, fluoropolymer, and moisture-cure urethane.

Latex emulsion primer and finish paints are typically used for wall finishes because they contain a low level of volatile organic compounds or no volatile organic compounds in the formulation, resulting in low or no volatile organic compound emissions. This reduces worker and occupant exposure and results in a low odor level in the workplace. Paints are available in finishes from flat, which has low sheen, to gloss, which has the highest sheen.

2.2.2 Stucco

Stucco is an exterior finish system that usually consists of three coats of material that is a mix of aggregates, cementitious ingredients, and water and/or admixtures. Three-coat stucco consists of a scratch coat that embeds metal reinforcement and has a rough surface, a brown coat that levels the wall plane, and a finish coat. Portland cement is commonly used for stucco and reinforcement is commonly expanded metal lath.

Stucco requires a uniform surface, such as concrete or concrete masonry that can support the design load with low deflection. Control and expansion joints in the supporting wall and the stucco reduce cracking. The finish color is often integral to the finish coat of stucco. Finishes range from a relatively smooth float finish to rough textured brushed or dashed finishes.



A: Stucco
B: Metal Lath
C: Metal Furring Strips
D: Wall

Described in paragraph above.

2.2.3 Exterior Insulated Finishing System (EIFS)

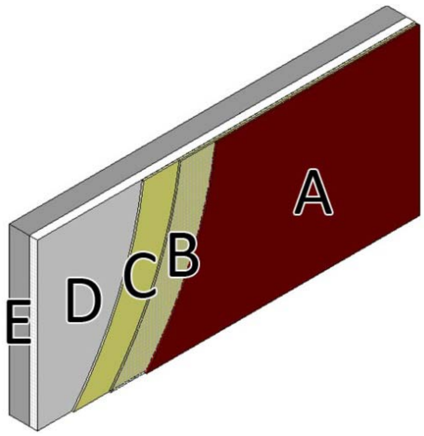
An exterior insulated finishing system (EIFS) is an exterior cladding system that consists of a rigid insulation board, a polymer/glass fiber reinforcing mesh, and a thin layer of cement-like/polymer surfacing material or stucco. The number of actual layers and the precise composition of each layer are dependent upon the manufacturer of the system. The insulation is most often a typical rigid foam insulation board, and the reinforcing mesh is usually composed of glass fibers. The system needs to be applied over a uniformly planar surface, such as a concrete or concrete masonry, or framed walls with a rigid substrate such as water-resistant fiberglass reinforced gypsum sheathing. A water resistive barrier may be required.

Two distinct types of EIFSs are available:

- Polymer-based EIFSs utilize an expanded polystyrene foam rigid insulation board attached to the substrate wall with glass reinforcing mesh embedded in a thin layer of either Portland cement or acrylic polymer. The final finish, acrylic polymer matrix layer, is applied over the glass fiber.

- Polymer-modified EIFSs utilize an extruded polystyrene insulation board attached to the backup wall. Next, a light gauge metal-reinforcing mesh is embedded within a Portland cement base coat. The finish layer generally consists of a Portland cement mixture with acrylic modifiers.

There are a wide number of choices for finish color and texture for both systems.

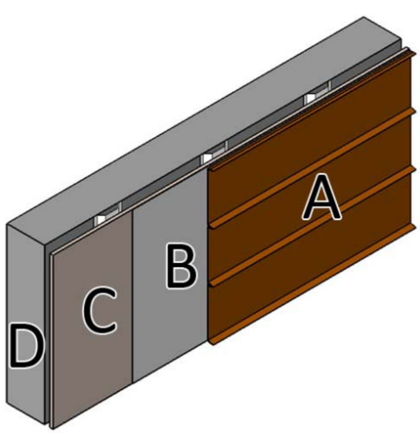


A: Finish Coat
B: Glass Fiber Reinforced Mesh
C: Primer Base Coat
D: Rigid Insulation
E: Wall

Described in paragraph above.

2.2.4 Copper: Flat-Seam Field Formed Wall System
Copper and the major copper alloys are used extensively in construction. Copper is an easily workable material and will develop a self-protecting oxide coating or patina that is green to indigo in color. The commercially pure alloys of copper, with a copper purity of 99.9%, are used most often in building construction. These alloys have good soldering and brazing properties. Three general sheet copper types exist, as specified in ASTM B370: cold-rolled temper, soft temper, and lead coated. Cold-rolled copper is most often used for roof and wall applications.

Copper wall panel systems are similar to roof panel construction and consist of copper panels with lapped and seamed joints over a substrate of rosin paper and 30 pound asphalt-saturated felt. The flat-seam wall can have several profiles. The individual copper pans are attached to each other and then connected to the substrate by a system of metal cleats. The copper pans are most often shop-fabricated and then assembled on the wall on-site.



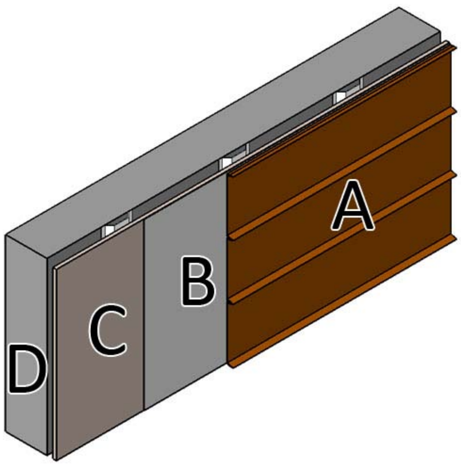
A: Copper Sheet
B: Rosin Paper / Asphalt-Saturated Felt Paper
C: Substrate
D: Wall

Described in paragraph above.

2.2.5 Zinc-Copper Alloy: Flat-Seam Field Formed Wall System

Zinc-copper alloy uses the same system of construction as 2.2.4 Copper: Flat-Seam Field Formed Wall System. Zinc-copper alloy is not a true alloy, but is simply a coating of zinc over copper substrate. The zinc coating is used as a protective layer against weathering. Zinc sheet metal is specified in ASTM B69.

Zinc is a soft and malleable material whose forming should approximate that of copper. The surface undergoes a number of complex oxidizing steps before it stabilizes with a final coating of zinc carbonate. This final coating is a resilient surface that should resist a very large range of climatic conditions. Zinc can be used successfully throughout Florida. Zinc has good results in coastal regions, as well as inland wetland, and arid regions.

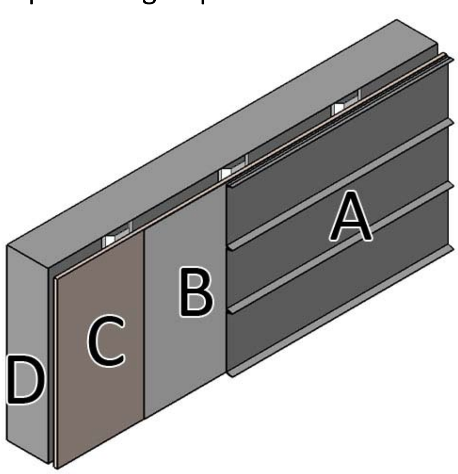


A: Zinc-Copper Alloy Sheet
B: Rosin Paper / Asphalt-Saturated Felt Paper
C: Substrate
D: Wall

Described in paragraph above.

2.2.6 Stainless Steel: Flat-Seam Field Formed Wall System

Stainless steel has excellent corrosion-resistant properties through the addition of from 1% to 35% chromium alloy to steel. The chromium inhibits corrosion typically for the lifetime of the building. Stainless steel is a hard metal relative to other metals typically used in building construction. As a result, it is a good choice for heavy pedestrian traffic and wear areas. However, stainless steel is a difficult material to work with and therefore, allow for as much shop-forming as possible.



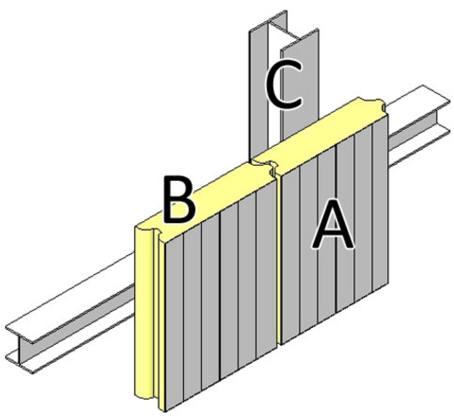
A: Stainless Steel Sheet
B: Rosin Paper / Asphalt-Saturated Felt Paper
C: Substrate
D: Wall

Described in paragraph above.

2.2.7 High-Performance Coated Metal Panel Wall System

High-performance coated metal panel wall systems are manufactured by a number of large companies in the United States. They consist of several layers of polymer-based and organically derived and/or metallic films that increase the metal's resistance to corrosion. In addition, metal panel systems can have insulation between two metal pans. Typically, two metal pans are assembled as a unit with the insulation encapsulated in a shop and delivered to the site for erection on a system of steel girts (horizontal or vertical). This system is most commonly used for industrial buildings in which a large area of exterior wall needs to be quickly assembled with a minimum amount of surface articulation or volumetric variation. Although not applicable as a uniform finish wall material, appropriate uses can be cladding large assembly spaces, gymnasiums, cafeterias, mechanical penthouses, and other utility spaces.

Prices for these systems vary widely, primarily depending on the number of layers and type of coating on the exterior metal panel. The system priced is a four-coat product with a lifetime of 20 years. Lesser systems may achieve lifetimes of only 10 to 15 years, and better and more expensive systems can reasonably be expected to last 40 years.



A: Coated Metal Panel
B: Integral Insulation
C: Superstructure Steel

Described in paragraph above.

2.3 PITCHED AND CURVED ROOF SYSTEMS

Pitched and curved roofs are composed of:

1) A deck that serves as the structural substrate,
2) Thermal insulation in various forms,
3) A ventilated, nailable deck [non-combustible],
4) A vapor retarder that restricts the movement of moisture,
5) Rosin paper that facilitates thermal expansion of the metal sheet,
6) Asphalt-impregnated felt, and
7) A waterproof layer that sheds water and inhibits moisture transfer to the interior.

The waterproof layer in pitched and curved roofs can be made of shingles or sheet metal systems. Required slopes and curvatures depend on building codes and design guidelines for the particular systems.

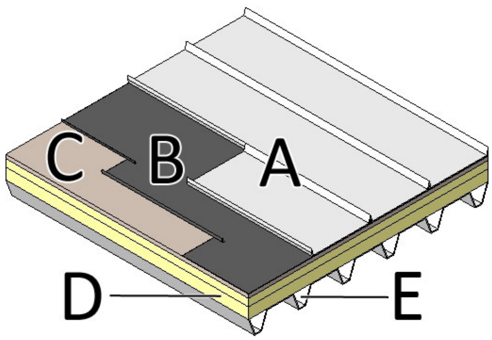
Table 2.3 Pitched and Curved

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
2.3.1 Steel, Flat Profile, 1-3/4" Standing Seam, 10" Wide, Zn/Al	3	2	2	1	1	2
2.3.2 Copper, Standing Seam, 20 oz., 150 lb/100 square feet	4	2	3	1	2	2
2.3.3 Zinc-Copper Alloy, Standing Seam, 0.32" Thick	5	1	1	1	2	2
2.3.4 Asphalt Shingles, Class A, 300-385 lb/100 square feet, 5 Bundles/100 square feet	1	5	5	1	4	1
2.3.5 Concrete Tiles	2	3	4	1	3	2
2.3.6 Metal Tiles	3	4	2	1	1	2

2.3.1 Steel, Flat Profile, 1-3/4" Standing Seam, 10" Wide, Zn/Al

Standing seam metal roofing is composed of sheet metal pans formed in a shop and attached by cleats onto a nailable deck. An automatic roll sealer is used to roll the standing seams together in a watertight joint. Cleats and all other metal parts used for attaching the pans have to be the same metal to prevent corrosion due to differences in galvanic activity. Design guidelines and building codes for the particular system need to be consulted.

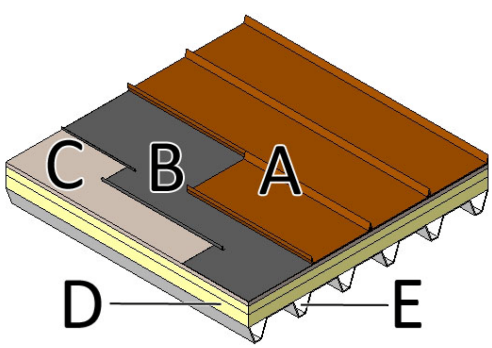


A: Sheet Metal Pan
B: Rosin Paper / Asphalt-Saturated Felt Paper
C: Ventilated Nailable Deck (Non-Combustible)
D: Insulation
E: Metal Deck

Described in paragraph above.

2.3.2 Copper, Standing Seam, 20 oz, 150 lb/100 square feet

Standing seam copper roofing is composed of sheet metal pans that can be formed in a shop. The copper pans can also be made on site by rolling the upstanding edges with special equipment. This process has the advantage of providing a continuous sheet. Upon placement on the roof, the copper pans are attached by cleats onto a nailable deck and then an automatic roll sealer is used to roll the standing seams together in a watertight joint. Cleats and all other metal parts used for attaching the pans must be of the same metal to prevent corrosion due to differences in galvanic activity. Design guidelines and building codes for the particular system need to be consulted.

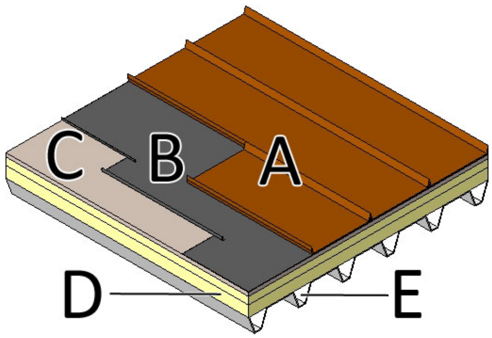


A: Copper Pan
B: Rosin Paper / Asphalt-Saturated Felt Paper
C: Ventilated Nailable Deck (Non-Combustible)
D: Insulation
E: Metal Deck

Described in paragraph above.

2.3.3 Zinc-Copper Alloy, Standing Seam, 0.32" Thick

Standing seam zinc-copper alloy roofing is similar in composition and placement to standing seam copper roofing. Design guidelines and building codes for the particular system need to be consulted.

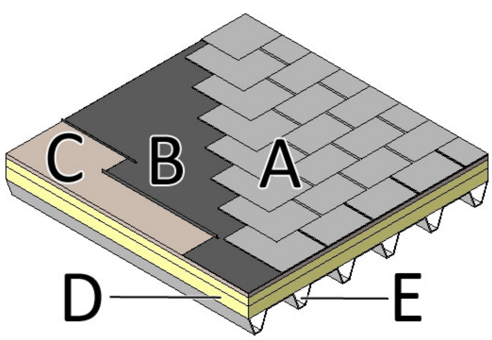


A: Zinc-Copper Alloy Pan
B: Rosin Paper / Asphalt-Saturated Felt Paper
C: Ventilated Nailable Deck (Non-Combustible)
D: Insulation
E: Metal Deck

Described in paragraph above.

2.3.4 Asphalt Shingles, Class A, 300-385 lb/100 square feet, 5 Bundles/100 square feet

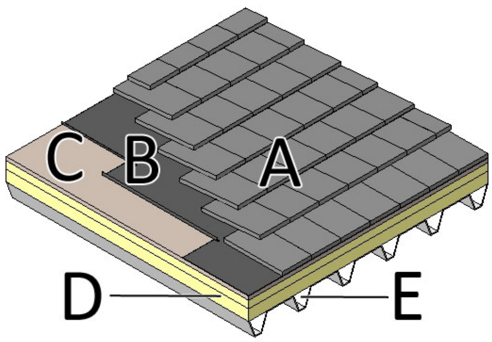
Asphalt shingles are often referred to as fiberglass shingles, but can be made of waste paper products as well. This system refers specifically to fiberglass shingles that are die-cut from heavy sheets of asphalt impregnated felt, which are faced with mineral granules that provide wear protection. Typical dimensions for shingles are 12” x 36”; each shingle is slotted so that it looks as if the roof was made of smaller shingles. The shingles are nailed onto the deck on top of an asphalt-saturated felt. Synthetic felt can be used in place of asphalt-saturated felt. Synthetic felt is more durable in an exposed state and so is ideal for unforeseen weather conditions and natural disasters. Synthetic felt is lighter and stronger than traditional felt paper, but has a lower perm rating and usually represents a slightly higher cost.



A: Asphalt Shingle
B: Asphalt-Saturated Felt
C: Ventilated Nailable Deck (Non-Combustible)
D: Insulation
E: Metal Deck

Described in paragraph above.

2.3.5 Concrete Tiles
Concrete roof tiles are available in shapes and colors that mimic traditional Mission-style clay tile, slate, or wood shake roof products. Concrete roof tiles must adhere to national roofing standards with regard to water permeability, freeze-thaw resistance, and weathering. Roof system installation details for high wind areas are available.



A: Concrete Tiles
B: Asphalt-Saturated Felt Paper
C: Ventilated Nailable Deck (Non-Combustible)
D: Insulation
E: Metal Deck

Described in paragraph above.

2.3.6 Metal Tiles
Metal roof tiles can be steel or aluminum, and may have a stone coating to look like stone tiles. They are much lighter than stone or concrete tiles and typically have a lifetime warranty.

2.4 LOW-SLOPE ROOF SYSTEMS

A low-slope roof is composed of:

1) A deck that serves as the structural substrate,
2) Thermal insulation in various forms,
3) A vapor retarder that restricts the movement of moisture,
4) A membrane waterproof layer that sheds water and inhibits moisture transfer to the interior,
5) A method of securing these layers in place such as mechanical fastening, adhesive, or ballast of various forms (most often river rock), and
6) Flashing and drainage components that direct water down and away from the roof and building.

A low-slope roof establishes a horizontal exterior envelope and directs water away from the building through the use of carefully designed slopes that are 1/4" vertical rise per foot of run. A low-slope roof is accomplished by sloping the actual structural beams that carry the roof or using tapered insulation.

Table 2.4 Low-Slope Roof Systems

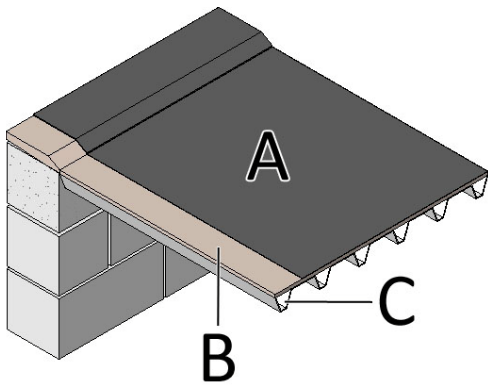
Legend:

GOOD	FAIR	POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
2.4.1 Built-Up Roofing, 4 plies #15 Asphalt Felt	7	8	6	1	6	1
2.4.2 SBS Modified Bitumen, Hot Mopped	6	7	5	1	1	2
2.4.3 Coal-Tar Pitch	8	3	3	1	3	1
2.4.4 Spray Polyurethane Foam (SPF)	3	2	2	1	5	1
2.4.5 SBS Modified Bitumen, Cold Applied	2	1	1	1	1	2
2.4.6 Ethylene Propylene Diene Monomer (EPDM), Single-Ply, 45 mil, Fully Adhered, No Ballast	6	9	7	1	3	2
2.4.7 Thermoplastic Olefin (TPO), Single-Ply, 45 mil, Fully Adhered, No Ballast	4	6	6	1	3	1
2.4.8 Polyvinyl Chloride (PVC) Single-Ply, Reinforced 50 mil, Fully Adhered, No Ballast	5	5	5	1	2	1
2.4.9 Ketone Ethylene Ester (KEE) Membrane, Mechanically Attached	1	4	4	1	3	1

2.4.1 Built-Up Roofing, 4 plies #15 Asphalt Felt

Built-up roofing (BUR) membranes are composed of multiple layers of asphalt-saturated reinforcing felt or other fabric and bitumen or pitch. Asphalt or coal tar is hot-mopped onto the roof. The membranes are roll-pressed into this asphalt or coal tar so that the asphalt of the membrane merges with the hot adhesive. Different plies of membrane are placed in overlapping layers to increase the durability of the roof. To protect the roof from weathering, the top layer membrane may have crushed minerals embedded in it.



A: Built-Up Roofing, 4 Plies
B: Substrate
C: Steel Deck

Described in paragraph above.

2.4.2 SBS Modified Bitumen, Hot Mopped

The modified bitumen roofing system is a hybrid built-up roof (BUR). This system has the benefits of the built-in redundancy of the BUR, along with the added strength, flexibility, and UV resistance of a modified membrane. Modified bitumen, called "modbit" membranes, consists of an asphalt and polymer blend that allows the asphalt to take on characteristics of the polymer. Styrene-butadiene-styrene (SBS) synthetic rubber is one of the more common bitumen modifiers. Several surfacing options for this system exist, which include a factory-applied mineral surface, a gravel surface laid in bitumen, or a liquid-applied coating that is typically reflective in nature.

2.4.3 Coal-Tar Pitch

Coal-tar roofing pitch is derived from coal tar produced during the high-temperature carbonization of bituminous coal for the production of coke. To produce roofing pitch, the coal tar is distilled, causing the more volatile constituents of the tar to be removed. The residual distilled product, amounting to about 75% of the crude tar, is roofing pitch of specified consistency or softening point. The distillate must be removed from the crude tar to produce roofing pitch.

The properties of coal-tar roofing pitch that account for its natural long-term waterproofing ability at the same time limit its application to roofs whose slopes are 1/4” up to I” per foot. Coal-tar pitch can be applied on slopes up to 2” per foot under certain construction requirements when so desired. As evidenced by the recorded service life of water-cooled roofs specifically designed to hold water, standing water will not affect level or low-sloped coal-tar roofs.

Pitch is a super-cooled liquid. Because of coal-tar pitch’s consistency at various temperatures, it is primarily used in no-slope roofs. Roofing felts must be nailed for roofs with slopes greater than I” per foot. Nailing felts to roof slopes, which are between 1” and 2”, permits the pitch to be held in place and the roofing to be stabilized. It must be contained by proven construction methods and details. Felts should be enveloped at the eaves and at all projections through the roof, or suitable bitumen dams should be specified.

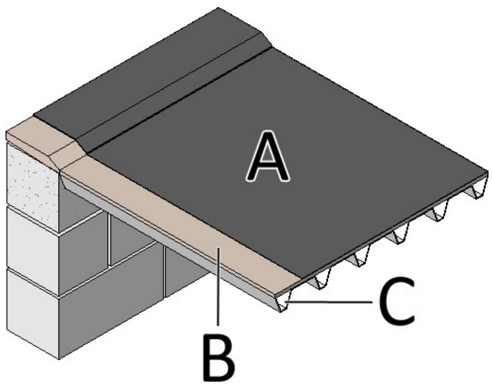
2.4.4 Spray Polyurethane Foam (SPF)

Spray polyurethane foam (SPF) roof systems are constructed by mixing and spraying a two-component liquid that forms the base of an adhered roof system. SPF can be installed in various thicknesses to provide slope to drain or meet a specified thermal resistance (R-value). A protective surfacing is then applied to the foam to provide resistance to weathering. The first component of an SPF-based roof system is rigid, closed cell, spray polyurethane foam insulation. The foam is composed of two components: isocyanate and polyol. Transfer pumps are used to get the components to a proportioning unit that properly meters the two at a one-to-one ratio and heats and pumps them through dual hoses. The components are mixed at the spray gun, which is used to apply them to a substrate.

The second component, the protective surfacing, is typically a spray-applied elastomeric coating, though hand and power rollers can be used. The protective surfacing also can be a membrane, such as a fleece-backed, thermoset single-ply membrane. The purpose of the surfacing is to create weatherproofing, protect the foam from UV exposure, provide protection from mechanical damage, and assist with the fire-resistant characteristic of the roof system.

2.4.5 SBS Modified Bitumen, Cold Applied

This system is composed of a single-ply polymer modified bitumen membrane reinforced with a polyester mat. Blending bitumen with polymers, such as SBS, improves the elasticity, toughness, and flow resistance of the bituminous membrane. This system can be loose-laid with ballast on top, adhered with special adhesives, or embedded in asphalt. Seams are sealed by torch or by using asphalt as adhesive. To protect the roof from weathering, a layer of crushed mineral granules is embedded on top.

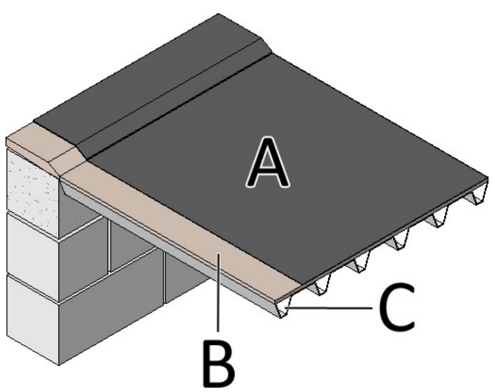


A: Single-Ply SBS Modified Bitumen
B: Substrate
C: Steel Deck

Described in paragraph above.

2.4.6 Ethylene Propylene Diene Monomer Rubber (EPDM), Single-Ply, 45 mil, Fully Adhered, No Ballast

EPDM is a synthetic rubber produced by vulcanization of an ethylene-propylene-diene copolymer, which is used extensively as a single-ply roofing membrane. This system consists of a single-ply fully adhered EPDM membrane with no ballast.



A: Single-Ply, EPDM Fully Adhered & No Ballast
B: Substrate
C: Steel Deck

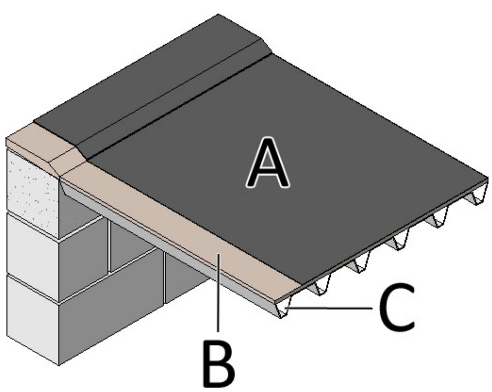
Described in paragraph above.

2.4.7 Thermoplastic Olefin (TPO), Single-Ply, 45 mil, Fully Adhered, No Ballast

TPO single-ply roof membranes are typically manufactured by polymerizing polypropylene and ethylene propylene rubber. TPO membranes are designed to combine the durability of rubber with the proven performance of hot-air weldable seams. They have excellent resistance to ozone. TPO members are algae-resistant, environmentally friendly, and safe to install. The material's manufacturers are so confident in properly welded seams that the material is sometimes advertised as a monolithic (seamless) roof. Seam strengths are reportedly three to four times those of EPDM's adhesive and tape seams. TPO is highly resistant to tears, impacts, and punctures with good flexibility to allow for building movement. The width of the membrane depends on the manufacturer, but the membranes usually come in widths of 6' to 6.5' and are 100' in length. This system is fully adhered, that is, the roof is glued to the substrate using a special adhesive. The glue creates a chemical bond with the membrane.

2.4.8 Polyvinyl Chloride (PVC) Single-Ply, Reinforced 50 mil, Fully Adhered, No Ballast

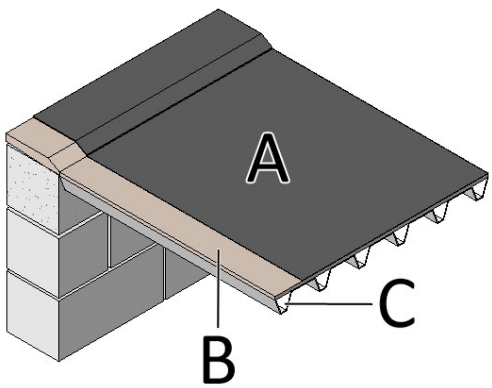
PVC membranes are manufactured from a combination of PVC resin, stabilizers, pigments, fillers, plasticizers, biocides, and various processing aids. Unlike TPO membranes, which require additives to increase fire resistance, PVC membranes are naturally fire-retardant. Problems with PVC membranes dating from the 1960s may have colored some professionals' views of thermoplastic roofs, but chemical plasticizers that evaporated (causing embrittlement and shrinkage) have long since been discontinued. Fully adhered systems are totally reliant on the substrate—to which the membrane is adhered—to keep the roof secure. Fasteners and plates or bars do not need to be used. The membrane is simply adhered to the substrate—sometimes right to the deck material, insulation, and in some cases, an existing membrane. While mechanical fastening involves the expense of increased labor time and materials, fully adhered systems can be quite economical.



A: Single-Ply, PVC Fully Adhered
B: Substrate
C: Steel Deck

Described in paragraph above.

2.4.9 Ketone Ethylene Ester (KEE) Membrane, Mechanically Attached
KEE roofing membrane is a high-performance thermoplastic membrane. KEE is a white polyester reinforced roofing membrane with built-in chemical, UV, and fire resistance, which results in a highly reflective, low-maintenance roof surface. The 78” wide membrane saves in labor costs for installation—20% fewer seams to weld and 20% fewer fasteners and plates. Chemical, ozone, and UV exposure do not affect surface pliability or functional integrity. KEE has been effectively tested to perform in high wind situations and meets Factory Mutual 1-180 uplift requirements. KEE is ideal for use as a mechanically attached membrane for new construction and re-roofing. The membrane is lightweight—just a few ounces per square foot—making it ideal for re-roofing projects where a tear-off can be avoided. The membrane has several fastener and plate options available to meet a wide range of wind uplift requirements. The 78” wide membrane allows for a faster, lower cost installation than other mechanically attached roof membrane systems.



A: Ketone Ethylene Ester (KEE) Membrane, Mechanically Attached
B: Substrate
C: Steel Deck

Described in paragraph above.

2.5 WINDOWS

Table 2.5 Windows

Legend:	GOOD	FAIR	POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
2.5.1 Aluminum Frame	1	1	1	3	1	2
2.5.2 Aluminum Frame, Thermally Broken	2	2	2	2	1	2
2.5.3 Vinyl (PVC) Frame	2	3	2	1	2	1

2.5.1 Aluminum Frame

An aluminum frame of extruded aluminum profiles connected with aluminum inserts that are either screwed or pressed. The aluminum frames can be finished by such techniques as anodizing, liquid coating, and powder coating before or after assembly of the frame.

2.5.2 Aluminum Frame, Thermally Broken

Similar to 2.5.1 Aluminum Frame, but thermally broken. To be classified as thermally broken, a window must have system members with a minimum of 0.2" separation provided by a low-conductance material or open-air space between the interior and exterior surfaces. Such systems include members with exposed interior or exterior trim attached with clips and all skip/debridged systems.

2.5.3 Vinyl (PVC) Frame

Vinyl's low thermal conduction properties make it ideal for use in window frames. Like aluminum frames, vinyl window frames are extrusions, but because vinyl is not as rigid as aluminum, several internal hollow chambers are often added to provide strength. These chambers also trap air, increasing the energy performance and improving the sound deadening qualities of the frame. In general, the more internal chambers, the stronger and more energy efficient the vinyl frame will be. As with aluminum windows, the design of the extrusion is critical to the energy performance, structural strength, and economic success of the product.

Metal reinforcement can be added to the hollow sections of vinyl frames to add rigidity and strength to the frame. This reinforcement is typically installed where the fixed and operable panels meet (the interlock) in most sliding windows, and on selected sections of large frames. Metal reinforcement of vinyl frames normally has a minor effect on the overall energy performance of the window.

2.6 DOORS

Table 2.6 Doors

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
2.6.1 Glazed Entry, Aluminum Frame	2	2	3	4	2	1
2.6.2 Glazed Entry, Aluminum Frame, Thermally Broken	2	2	3	3	2	1
2.6.3 Hollow Metal, Painted	1	1	1	2	1	1
2.6.4 Roll-Up Overhead Service	3	3	2	1	3	1

2.6.1 Glazed Entry, Aluminum Frame

An aluminum framed metal door with a glazing component to allow for a visual observation through the door.

2.6.2 Glazed Entry, Aluminum Frame, Thermally Broken

Similar to 2.6.1 Glazed Entry, Aluminum Frame, but thermally broken as in 2.5.2 Aluminum Frame, Thermally Broken.

2.6.3 Hollow Metal, Painted

This system typically consists of a painted steel door and frame. Doors can be glazed. Hollow metal doors and frames can be manufactured to meet specific requirements such as fire rating, thermal insulation, and acoustic isolation. Typically the doors and frames are manufactured as a unit and delivered to the site primed for paint; hollow metal doors and frames can also be manufactured in stainless steel.

2.6.4 Roll-Up Overhead Service

Roll-up service doors consist of multiple slats, typically 2” to 3” in height. The total height of the roll-up service door is increased by connecting multiple slates for the desired height requirement. Widths are custom-cut to the door width requirement. When the door is open, the slats roll up into a roll and are stored inside a barrel enclosure that incorporates a spring. This roll-up barrel mounts to the wall above the door opening. The advantage for this type of door is that the interior overhead access is not lost when the door is open. Small window slat portals are optional to gain visibility from the inside looking out to see when trucks or people are outside the door. Insulated slats are also available.

2.7 GLAZING

Table 2.7 Glazing

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Maint.	Energy	LCA	Fire
2.7.1 1/4" Float Glass with Low Emissivity Coating	1	2	1	3	1	1
2.7.2 1/4" Float Glass, Tinted	2	4	2	5	1	1
2.7.3 1/4" Tempered Float Glass, Clear	2	4	2	6	1	1
2.7.4 1/4" Tempered Float Glass, Tinted	3	5	3	5	1	1
2.7.5 Laminated Float Glass, Clear	5	6	5	6	1	1
2.7.6 Laminated Float Glass, Tinted	6	7	6	5	1	1
2.7.7 Double Glazed	8	3	8	4	1	1
2.7.8 Double Glazed, Tinted	7	8	7	3	1	1
2.7.9 Triple Glazed	9	9	9	2	1	1
2.7.10 Triple Glazed, Tinted	10	10	10	1	1	1
2.7.11 Polycarbonate	4	1	4	6	1	1

2.7.1 Float Glass (1/4”) with Low Emissivity Coating

Float glass is manufactured using a melt process in which recycled glass, silica sand, lime, potash, and soda are melted in a furnace and floated onto a bed of molten tin. The molten mass solidifies slowly while flowing over the bed of molten tin, after which it is annealed to remove stresses induced during the cooling process. Annealing also allows the glass to reach a more stable state, resulting in a higher density and higher refractive index.

Low emissivity (low-e) coatings are metal or metal oxide coatings that reflect long-wave infrared radiation and transmit short-wave visible light. Low-e coatings have been developed not only to have high transparency in the visible region of the light spectrum, but also to have high reflectivity in the infrared region of the spectrum. This reduces heat transfer through thermal radiation in multi-layer glazing and therefore lowers the overall U-value of the glazing unit.

2.7.2 Float Glass (1/4”), Tinted

Tinted float glasses are made by adding coloring agents during the melt process. Common colors include gray (cobalt oxide and nickel), blue-green (ferrous iron), and bronze (selenium). While tinting may provide aesthetic alternatives to clear glass, tinted glasses also provide materials with different properties, including heat and light transmission (and/or reflectance), ultraviolet transmission, and insulation properties.

2.7.3 Tempered Float Glass (1/4”), Clear
Tempered float glass is produced by the reheating and rapidly cooling of regular glass, which increases the strength of the glass. Tempered glass is regarded as a safety glazing system because it fractures into relatively small pieces without having sharp edges when broken.

2.7.4 Tempered Float Glass (1/4”), Tinted
Similar to 2.7.3 1/4" Tempered Float Glass, Clear, but tinted as in 2.7.2 1/4" Float Glass, Tinted.

2.7.5 Laminated Float Glass, Clear
Laminated glass is a type of safety glass that holds together when shattered. In the event of breaking, it is held in place by an interlayer, typically of polyvinyl butyral (PVB), between its two or more layers of glass. The interlayer keeps the layers of glass bonded even when broken, and its high strength prevents the glass from breaking into large sharp pieces. This produces a characteristic "spider web" cracking pattern when the impact is not enough to completely pierce the glass.

2.7.6 Laminated Float Glass, Tinted
Similar to 2.7.5 Laminated Float Glass, Clear, but tinted as in 2.7.2 1/4" Float Glass, Tinted.

2.7.7 Double Glazed
Double glazed glass units are composed of two panes separated by a spacer to create a cavity. The cavity is usually filled with dry air or an inert gas and acts as a thermal insulator between the exterior and interior of the building.

2.7.8 Double Glazed, Tinted
Similar to 2.7.7 Double Glazed, but tinted as in 2.7.2 1/4" Float Glass, Tinted.

2.7.9 Triple Glazed
Similar to 2.7.7 Double Glazed, but composed of three panes separated by spacers.

2.7.10 Triple Glazed, Tinted
Similar to 2.7.9 Triple Glazed, but tinted as in 2.7.2 1/4" Float Glass, Tinted.

2.7.11 Polycarbonate
Polycarbonate is a transparent thermoplastic polymer with good impact resistance and dimensional stability. Polycarbonate has a faintly amber color that may darken with outdoor exposure. It can be used as high impact security glazing and skylights.

CHAPTER 3
INTERIOR SURFACES AND SUBSTRATE MATERIALS

3.0 INTRODUCTION

This chapter addresses the selection of interior materials and assemblies used to construct interior spaces in educational facilities. Interior surface and substrate materials can be natural, converted, or synthetic products. In this chapter, the interior materials and assemblies are categorized as floor, wall, or ceiling systems. The products used in the interiors of buildings are required to perform a wide variety of practical and aesthetic functions. The acoustic performance, indoor air quality, and visual comfort of a space affect the well-being of the occupants and these attributes are directly related to the interior materials and assemblies. Potential performance criteria for interior surface and substrate materials are as follows:

Surface materials:

- Sunlight, temperature, and moisture resistance
- Fire resistance
- Acoustic properties
- Lighting properties
- General wear and resistance to physical impact
- Stability
- Emission, adsorption, and absorption rates
- Aesthetic qualities

Substrate materials:

- Structural support and stabilization of finish materials
- Shear and withdrawal strength of fasteners and adhesives
- Acoustic properties
- Thermal properties
- Moisture transmission, resistance, and stability in high moisture environments
- Fire resistance
- Chemical stability
- Resistance to physical impact
- Emission, adsorption, and absorption rates

3.1 INTERIOR FLOOR SURFACES

Interior floor surfaces (see Table 3.1) are systems used to finish interior floors. Interior floor surfaces include the finishing materials, the substrate or subfloor to which they are applied, and the materials used to attach the finish to the substrate. For this analysis it is assumed that a concrete subfloor is used as the substrate. The Life Cycle Cost (LCC) analysis compares floor surface materials commonly used in Florida's school facilities and includes several other materials with characteristics and properties that make them suitable for use in educational buildings. In this analysis, the operation and maintenance costs for floor surface materials reflect the cleaning and repair procedures required to ensure the material's expected lifetime.

Table 3.1 Interior Floor Surfaces

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Acoustics	LCA	IAQ
3.1.1 Vinyl Composition Tile	2	7	12	7	13
3.1.2 Vinyl Sheet	3	8	12	12	13
3.1.3 Linoleum	6	7	12	9	12
3.1.4 Rubber Flooring	7	9	3	2	10
3.1.5 Ceramic Tile	10	1	13	6	1
3.1.6 Quarry Tile	8	2	13	4	1
3.1.7 Carpet	5	5	1	13	7
3.1.8 Cork	4	10	2	10	6
3.1.9 Exposed Concrete	1	3	13	1	2
3.1.10 Terrazzo	9	4	13	3	11
3.1.11 Solid Wood Strip or Plank	11	11	11	8	8
3.1.12 Wood Laminate	12	6	10	6	9
3.1.13 Bamboo Flooring	13	12	11	5	5
3.1.14 Resinous Flooring	9	4	13	3	11

3.1.1 Vinyl Composition Tile (VCT)

Vinyl composition tile (VCT) is primarily used in commercial and institutional applications. Vinyl tiles are composed of colored vinyl chips that are formed by heat and pressure into solid sheets of varying thicknesses and then cut into 12" squares. Vinyl tile is a flooring material that is generally inexpensive, easy to install, and easy to maintain. Made primarily from polyvinyl chloride resins and plasticizers, these flooring tiles are water resistant and very durable. A floor covered with vinyl tile, if maintained properly, can last many years without appearing old or worn. In addition to basic colors and patterns, vinyl floor tiles are now being manufactured to simulate the look of other types of more expensive flooring, such as wood strip, marble, and inlaid wood designs.

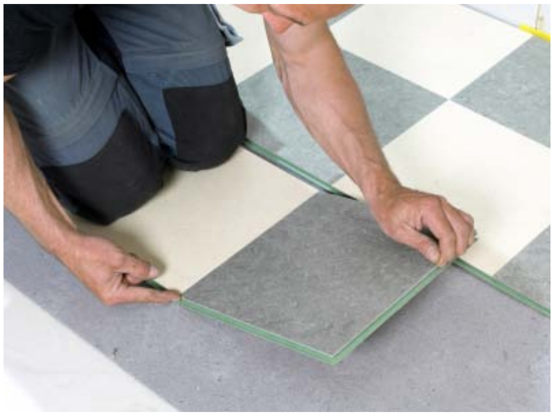
Most vinyl floor tiles for commercial applications are secured to the floor with an applied adhesive. Some vinyl tiles have self-adhesive backing, making them easy to install. To maintain a vinyl tile floor properly, it should be vacuumed daily. Walking on a gritty or dirty vinyl floor can cause scratching. The floor should be mopped at least once a month with water or a specialized vinyl cleaning product. To maintain vinyl tiles with high gloss or satin finishes, specialized clear coatings should be applied. Detergents, abrasives, and waxes should not be used on vinyl floor tiles.

3.1.2 Vinyl Sheet

Sheet vinyl is durable and easy to install and is supplied in two basic forms: perimeter-bond and full-bond. Perimeter-bond sheet vinyl is adhered to a flat surface by placing adhesive around the outer edges of the sheet. In contrast, full-bond vinyl is installed by placing glue across the entire backside of the sheet. Both types of vinyl are durable, but full-bonded vinyl will last longer. Sheet vinyl is relatively easy to install; however, the surface area must be properly prepared prior to installation. If older vinyl flooring already exists, it is not necessary to remove it prior to installing a new floor. All base flooring must be properly washed and dried before installing new sheet vinyl. In addition, any gaps or holes should be filled in before new floors are installed. Modern vinyl often mimics wood, stone, and tile, but it is unlikely to last as long as those materials.

3.1.3 Linoleum

Linoleum is a type of flooring that combines linseed oil, also called linoxyn, with either wood or cork dust, and is then backed with canvas or burlap. It is a durable floor and is water-resistant, easy to clean, and low-maintenance. Linoleum is flexible and unaffected by ordinary floor temperatures, and it does not readily burn. It is specially hardened to resist indentation, and it is not susceptible to damage from fats, oils, greases, or organic solvents. Linoleum is popular in commercial applications because of its ability to withstand heavy foot traffic, and it tends to be less expensive than carpet, tile, or wood flooring. However, if the floor is gouged, it can be difficult to repair. Linoleum is available in a variety of patterns and is usually sold in rolls. Prices per square foot vary, and custom designs may result in a higher price, depending on the intricacy of the design.

3.1.4 Rubber Flooring

Rubber flooring is specifically designed to ease the strain on feet and legs and is sometimes called “anti-fatigue” flooring. Bacteria resistance is another useful trait of rubber flooring. Because it resists bacteria, rubber flooring can be used in operating rooms and other environments with a high risk of disease transmission. Resilience, dimensional stability, and endurance are natural characteristics of rubber flooring. Maintenance is minimal and underfoot comfort is excellent. It is a good choice for schools, including corridors, gymnasiums, auditoriums, classrooms, theaters, cafeterias, and other meeting rooms.

3.1.5 Ceramic Tile

Ceramic tiles are made from ceramic materials, such as earthenware and porcelain, and they are available in many shapes, colors, and sizes. Ceramic tile flooring has a number of advantages. It tends to be extremely durable, and radiant heating and cooling systems can be installed underneath it. Many people also find tile flooring aesthetically pleasing and easy to clean, especially in situations where floor drains allow the tiles to be hosed down. Some tiles are not treated to withstand water in which case they are not designed to be used in wet locations. Other tiles may have design features such as ribbed backs, which make installation on certain surfaces easier. Ceramic tiles are available in glazed and unglazed forms. Some unglazed tiles can be custom-painted and refired to set the glaze.

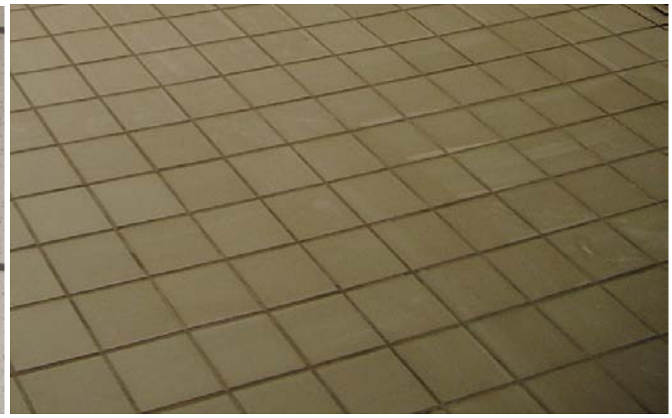
3.1.6 Quarry Tile

Quarry tile is a type of unglazed tile known for being inexpensive, durable, and natural. This type of tile is often used in industrial settings. The manufacturing process for quarry tile involves blending clays with other materials, such as shale, to create a coarse mixture. This coarse mixture is run through an extruder to form dense tiles. After the tiles are cut, they are fired at high temperatures, changing the chemical composition of the clay to make a heavy, hard, and extremely strong tile. Common shades for quarry tiles are reds and oranges, but grays and sometimes greens are also available.

Typically, the bottom side of a quarry tile is ridged to encourage adhesion to grout. The top of the tile has a coarse surface because it is not glazed. This surface encourages traction, which can be very useful in environments such as pathways and kitchens. When quarry tile is laid, it is applied over a layer of thinset mortar with grout between the tiles.

The primary disadvantage of quarry tile is that it is porous because it has not been glazed. This makes it susceptible to water damage because water can seep through the tile and provide a hospitable environment for mold and fungus. For this reason, many people seal quarry tile and its grout after it is installed. Some installers also apply a layer of wax to the tile to ensure that the sealer remains in place.

As quarry tile ages, it acquires a natural patina, and it can also pick up stains. Since the color of the tile naturally varies, the stains are sometimes hard to detect, which can be advantageous in a kitchen where dropped food can cause stains. The durability of the tile makes it less prone to chips and scratches, which can be caused by hard wear.

3.1.7 Carpet

Carpet is a textile floor covering consisting of an upper layer of "pile" attached to a backing. The pile is generally made from wool or a man-made fiber such as polypropylene. Carpet usually consists of twisted tufts, which are often heat-treated to maintain their structure, and can be looped or cut. Carpet is commonly manufactured in widths of 12’ and 15’, and, where necessary, different widths can be fused together with a seaming iron and seam tape. The carpet can be affixed to a floor over a cushioned underlayment (pad) using nails, tack strips, or adhesives. For environmental reasons, organic wool, natural bindings, natural padding, and formaldehyde-free glues are becoming more common. These options are almost always at a premium cost but with no sacrifice in performance.

Carpet tiles are also available and are typically 20” square. These tiles are normally used in commercial settings. The tiles are affixed using a special pressure sensitive glue, which holds them in place while allowing for easy removal or allowing for rearrangement to spread wear.


3.1.8 Cork

Cork flooring is comfortable, durable, sustainable, and is made from the bark of the fast growing cork oak tree. Harvested without damaging the tree, the bark is regenerated in about 10 years. Because of its natural, honeycomb-like cellular structure, cork has a soft and cushiony feel and is a good insulator. It also absorbs sound and is resistant to moisture, mold, and rot. Cork flooring is available in easy-to-install cork tiles as well as sheet sections that can be used to create cork floors. Cork flooring is usually pretreated with a variety of stains and colors, making the cork floor tiles and sheets a workable option for many applications.

Along with the natural, unfinished sheets, cork flooring is also available with special treatments. Waxed cork flooring is ideal for maintaining a natural look, is resistant to dirt, and is a good option for heavy traffic areas. Resin-reinforced cork flooring has an extra layer of protection for the shine of the floor, making cork flooring an ideal choice for spaces such as conference rooms. Vinyl impregnated cork flooring comes in a wide range of colors, and can be used in kitchens or toilet rooms.

3.1.9 Exposed Concrete

Exposed concrete floors can be a cost-effective alternative to other finish solutions, such as carpet or tile. Typically, a concrete slab functions as a substrate for a finish material such as hardwood flooring, vinyl or ceramic tile, and carpet. The emergence of a variety of concrete coloring, staining, and finishing techniques has made interior exposed concrete floors and surfaces an additional finish option with a unique aesthetic.

Leaving interior concrete floors exposed has many benefits. Generally, exposed concrete floors are less expensive than most other finish flooring options. Economic advantages include not having to purchase and install another finish material on top of the floor slab. Additionally, the inherent durability of concrete also saves long-term maintenance and replacement costs associated with conventional finish flooring. Concrete is a thermally comfortable surface, slow to heat up and cool off, helping to moderate the indoor climate. It is also a good choice for radiant floor applications. Health benefits include better indoor air quality because the need for flooring adhesives is eliminated and indoor allergens that typically accompany carpeting are eliminated. Exposed concrete floors are very low maintenance, requiring only a wet mop for cleaning.

3.1.10 Terrazzo

Terrazzo is a flooring technique that results in an attractive, durable floor that is easy to maintain. Typically created with pieces of marble, glass, or stone chips, terrazzo is an excellent option for a number of decorating schemes. A cement binder provides the medium for arranging the chips, making it possible to create terrazzo floors that are unique in color, composition, and design.

Traditional terrazzo flooring is created on-site. Any existing flooring in the space is removed or prepared to receive the layer of concrete that forms the basis for the terrazzo. After smoothing the wet cement into place, the surface is embedded with colorful glass, stones, and marble chips. At this point in the process, the arrangement of the chips can be very free form or carefully placed to create a specific design.

Once the chips are in place, trowels and other tools are used to make the surface as smooth as possible. The smoothing process does not have to be exact because the goal is to ensure the pieces are firmly in place before the concrete sets. After the cement has dried, grinding machinery is used to achieve an even floor surface and polish.

The final step in preparing the terrazzo floor involves cleaning and sealing the surface. Slip-resistant treatments can be added if necessary. It is also important to note that harsh cleaners and sealers can damage terrazzo. Only cleaning materials with a pH between 7 and 10 should be used when scrubbing or mopping. After the polishing is completed, any residue is removed from the surface and a thin layer of sealant is applied. The end result is a colorful floor that will hold up well to heavy foot traffic, be easy to maintain, and will last for many years.

Specially designed terrazzo tiles may be affixed to an existing floor in a process that is similar to the installation of linoleum tiles. While the design styles are more limited than the site installed approach, installation generally takes less time and requires less preparation.

3.1.11 Solid Wood Strip or Plank

Wood plank flooring is made from solid wooden planks. Flooring planks are typically wide and thick, designed to withstand a lifetime of use, and they can be stained, painted, or left untreated. A wide assortment of woods can be used for plank flooring. As a general rule, softer woods, such as pine, are not used because of durability. Various oak species are common, and other hardwoods such as cherry, ash, and walnut as well as more exotic woods such as ebony, ironwood, or other tropical species, are also used. One of the major advantages to wood plank flooring is that if a single plank fails, it can be replaced with another one without the need to tear up the entire floor. This trait can be very useful in heavy traffic areas.

Maintaining plank flooring varies and depends on the type of wood and whether or not the wood has been sealed. As a general rule, frequent sweeping is recommended to avoid grit and dirt, which could be ground into the floor. If the floor has been sealed, it can also be mopped to keep it clean.

3.1.12 Wood Laminate

Wood laminate flooring is a man-made floor covering that is a less costly alternative to traditional hardwood floors. Wood laminate flooring is sold in planks and is made of four different layers of materials pressed together. The bottom layer is melamine plastic which makes the laminate planks more stable than traditional hardwood. Additionally, the melamine plastic helps resist moisture that may come from the subfloor. The second layer of flooring is the dense inner core. Most laminate manufacturers make the inner core out of pressed particle board or high density fiberboard. On top of the core is a decorative layer, which is actually a high resolution photograph of wood grain that mimics a real hardwood floor. The final layer is the wear layer, a coating of aluminum oxide mixed with melamine resin that creates extra durability. Aluminum oxide protects the laminate from scratching and denting caused by shoes, furniture, and dropped items. Laminate flooring is more durable than real hardwood. The aluminum oxide coating helps with stain resistance and also decreases fading, which may occur in the sunlight. Laminate floors are most often installed as glueless floating floors. Along with its many benefits, laminate flooring has a few disadvantages. Walking on laminate flooring makes an echoing sound, although this sound can be reduced by using a special underlayment. Laminate flooring cannot be refinished. Once it is damaged, it must be replaced. Even though laminate flooring is moisture-resistant, it may still warp in high moisture areas, and may cause the top two layers to peel back from the core.

3.1.13 Bamboo Flooring

Bamboo flooring is available as solid bamboo or as an engineered floor with cross-laminated layers of bamboo. It is an environmentally friendly alternative to traditional hardwood floors because bamboo is rapidly renewable. Although bamboo flooring is often advertised as equivalent to traditional hardwood floors, bamboo is actually a softer material. Dark bamboo flooring is comparable to black walnut in terms of hardness, with lighter colors being slightly harder, similar to maple. In spite of its flaws, bamboo flooring offers the potential for environmental sustainability with qualities comparable to traditional hardwoods.

3.1.14 Resinous Flooring

Resinous flooring is made of three components: a resinous binder, a catalyst and a dry mix such as fillers, pigment, additives and decorative chips. Resinous binders have good chemical and abrasion resistance and high-impact strength. They bond well with most sub-floor materials and can be applied in 1/4” to 1/2” thick toppings. Resinous binders include epoxy, polyacrylate and polyester binders. Epoxy terrazzo flooring, a type of epoxy resinous flooring, can be used in school areas where monolithic, heavy duty floor surface is needed. Epoxy terrazzo is composed of epoxy resin binder and decorative aggregate such as marble or glass. This mix is applied by trowel in a 1/4” to 3/8” nominal thickness, followed by grinding, polishing and sealing. Resinous flooring made of epoxy resinous binders and decorative vinyl flakes is also available for applications in schools. This flooring system is easy to maintain because of its dense and non-porous structure and its high resistance to chemicals and dirt. The quartz resinous flooring system is composed of graded quartz as an aggregate and epoxy resinous binder. The floor is finished with clear catalyst-cured coats of resin in either satin or gloss finish. The thickness of this flooring system is 1/8” to 1/4” and it can be either smooth or textured. Elastomeric resinous flooring consists of 1/4” thick flexible epoxy mortar, containing colored rubber chips, polished to a smooth finish. This material can be used in school areas where noise reduction is required. Elastomeric resinous 1/8” thick system contains flexible elastomeric urethane and can be used in areas where waterproofing is required such as labs, kitchens, and toilets.

3.2 INTERIOR PARTITIONS

Interior partitions (see Table 3.2) are walls that are not typically part of the load bearing building structure or the building envelope. The LCC analysis in this section includes interior partition systems commonly used in Florida's school facilities and several other wall systems whose characteristics and properties make them suitable for educational buildings. This section addresses the basic materials of the interior partitions. The finish materials are evaluated separately. Operation and maintenance costs reflect only the costs of typical repair procedures to the subsurface or system and not the costs of cleaning the surface.

Table 3.2 Interior Partitions

Legend:	GOOD	FAIR	POOR

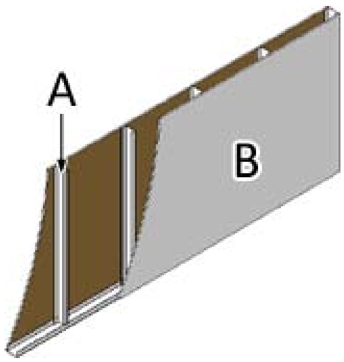
System	First Cost	LCC	Acoustics	LCA	Fire
3.2.1 Gypsum Wallboard	1	6	6	2	4
3.2.2 Very High-Impact (VHI) Wallboard	7	7	5	4	3
3.2.3 Fiberboard Panels	3	5	4	3	5
3.2.4 Green Board	2	4	6	2	4
3.2.5 Blue Board and Veneer Plaster	2	4	7	6	3
3.2.6 Metal Lath and Plaster	6	7	7	7	3
3.2.7 Precast Concrete Panels	4	1	9	5	1
3.2.8 Concrete Masonry Units (CMU)	8	2	8	1	2
3.2.9 Glass Block	9	3	10	9	3
3.2.10 Demountable Partitions	5	8	1	10	3

3.2.1 Gypsum Wallboard

Gypsum wallboard is made by sandwiching a layer of gypsum plaster between two layers of reinforced paper. Various types of gypsum wallboard are available such as moisture resistant and fire resistant types. The paper surface of moisture-resistant wallboard is treated to resist water and mold, and the gypsum plaster in the fire-resistant Type X wallboard is blended with glass fibers to increase its fire resistance. Wallboard is also referred to as plasterboard, drywall, or sheetrock, after the Sheetrock® brand. It is sold in large sheets, which can be cut to size as needed for wall framing.

Gypsum wallboard is typically covered with a layer of paint or textured plaster. Unlike lath and plaster, which can take a week or more to install, gypsum wallboard can be installed quickly and efficiently. Therefore, it decreases construction costs and helps speed up the construction process. After the walls of a building are framed in, the wallboard is screwed to the studs. The joints are then covered with a special tape and joint compound is applied on top of the seams and screw holes. The entire wall can later be given a thin coating of finishing compound, called a skim layer. The skim layer will increase construction costs and is not required.

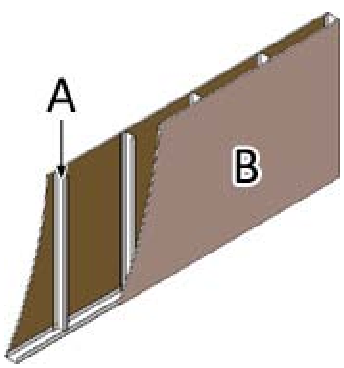
Several companies make environmentally friendly versions of this product with recycled materials and recycling waste gypsum wallboard from the construction process is possible.



A: Metal Stud
B: Gypsum Board

Described in paragraph above.

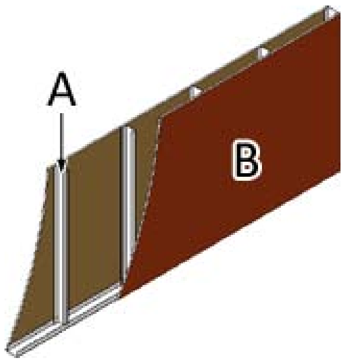
3.2.2 High-Impact Wallboard
High-impact wallboard is a manufactured panel with a gypsum core. The core is encased in tough, robust paper with a Lexan substrate bonded to the back side of the panel. Various aggregates are added to the core to enhance its fire-resistant qualities. High-impact wallboard is designed to provide greater resistance to surface abuse, indentation, and impact/penetration than standard gypsum panels. The face of the panel is highly resistant to scuffing when sanding wallboard joints and fasteners, providing a superior surface for finishing.



A: Metal Stud
B: High-impact Board

Described in paragraph above.

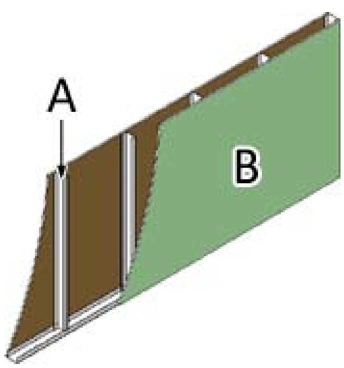
3.2.3 Fiberboard Panels
Fiberboard is an engineered wood product made from wood fibers. Types of fiberboard include particle board, medium density fiberboard, and hardboard. Fiberboard is sometimes used as a synonym for particle board, but particle board usually refers to low-density fiberboard. For pieces that will be visible, a veneer of wood is often glued onto the fiberboard to give it the appearance of conventional wood. Certain types of fiberboard are considered to be "green" building products, consisting of bio-based, secondary raw materials (wood chip or sugarcane fibers) recovered from within 100 miles of manufacturing facilities. The binding agent used in this type of fiberboard is a natural product, a vegetable starch containing no added formaldehydes.



A: Metal Stud
B: Fiberboard

Described in paragraph above.

3.2.4 Green Board
Green board is a type of water-resistant drywall with a green paper covering that has been specially treated to resist moisture and is designed for use in high humidity applications. Regular drywall absorbs moisture easily. If regular drywall is installed in an area regularly exposed to dampness and humidity, such as toilet rooms, it can become soft or even fall apart. Green board reduces these risks. After the walls of a building are framed in, green board is screwed to the studs. The joints are covered with a special tape, then joint compound is applied on top. The entire wall can then be given a thin skim coating of finishing compound. However this will increase construction cost and is not required. It is important to note that green board drywall is water resistant, not waterproof. Although it can function well in toilet rooms, it should not be installed behind showers or bathtubs where it is more likely to get wet. In these cases, a cement backer board is recommended.



A: Metal Stud
B: Green board

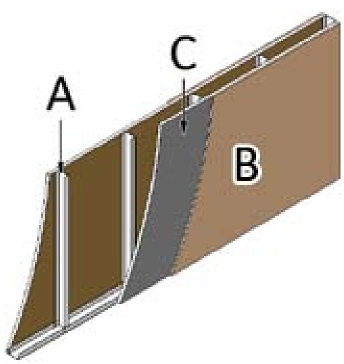
Described in paragraph above.

3.2.5 Blue Board and Veneer Plaster
Blue board is very similar to regular drywall gypsum board. As with drywall, it comes in 4’ wide boards at lengths of 8’, 12’, and 16’. It can be cut with a knife and it fastens to steel wall studs with screws. It also has the same gypsum core material as drywall. The difference is in the paper covering. Blue board's characteristic blue face comes from the special paper on the board's surface, which is treated to bond well to a skim coat of specially formulated plaster. When finishing blue board, instead of applying several coats of joint compound to the seams between boards, a quick tape-and-plaster treatment to the joints is applied. Then the entire wall surface is covered with one or two thin (1/8” thick) coats of plaster.

Blue board and veneer plaster offer two advantages over regular drywall, quality and convenience. Veneer plaster is much harder than a regular drywall surface, making unsightly dents and scratches less likely. The top surface of veneer plaster is continuous over the entire wall so that joints almost never show, unlike common drywall joints. Veneer plaster's continuous surface is also a better base for paint. On a drywall surface, paint can dry differently on the paper surface than on the joint compound base at drywall seams. Even the most skillfully made drywall joints may be visible under some lighting conditions. Veneer plaster is much less likely to display any sort of visible shading difference.

Painting veneer plaster is not required. The plaster's natural off-white color and smooth surface are attractive even if not painted. It is also possible to colorize the plaster coat itself, either by adding a high quality paint to the plaster at the mixing stage or by using proprietary coloring systems. Veneer plaster application is typically a one-day operation. Plastering immediately follows the joint treatment, and a second coat, if needed, is applied over the first after only a brief period. In remodeling, this convenience becomes apparent.

Blue board and veneer plaster can cost 20% to 30% more than a drywall installation. The price difference reflects the greater skill needed to apply veneer plaster. Choosing a one-coat or two-coat veneer can also affect the final cost. However, prices for veneer plaster are becoming competitive with drywall. Time savings and avoided cleanup costs can make the bottom line difference negligible.

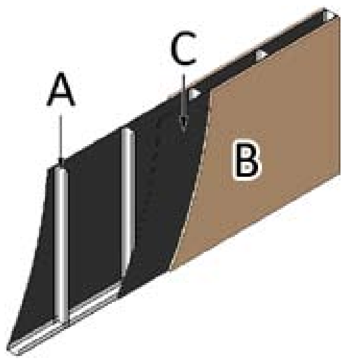


A: Metal Stud
B: Veneer Plaster
C: Gypsum Core

Described in paragraph above.

3.2.6 Metal Lath and Plaster

One of the oldest and most durable cladding systems is metal lath and plaster, and it is still in use today. Metal lath is used as a platform to embed and attach the stucco membrane to the structural members of the building. Without the lath, installers would have little or no way to apply stucco to exposed framing or sheathed construction. However, accessories, such as foundation weep screeds, corner beads, casing beads, and expansion joints make the basic lath system feasible for other difficult applications. Reveals, soffit vents, and banding beads allow for buildings to breathe and look appealing.

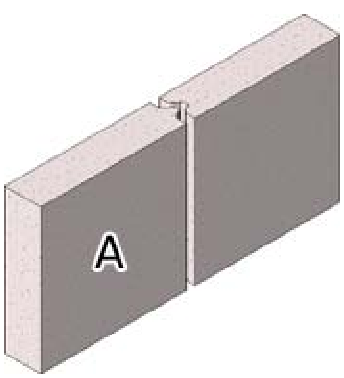


A: Metal Stud
B: 3/4” Plaster
C: Metal Lath

Described in paragraph above.

3.2.7 Precast Concrete Panels

Precast concrete panels are cast and cured in a controlled factory environment, which means no delays resulting from adverse weather conditions. Casting the panels in a controlled factory environment increases the quality of the resulting product. Precast wall panel systems are offered in a variety of textures, finishes, and unique color options. They offer greater design flexibility and can accommodate almost any aesthetic or functional constraints. The panels can be load-bearing, which can ultimately reduce the foundation and framing costs, while opening up an entire new range of opportunities for designers. These systems have a quick and easy installation process, allowing for faster building enclosure. Precast concrete is resistant to conditions that can damage or destroy other buildings, such as fire, flood, wind, or high impact rain. Wall panels can be an energy-efficient alternative to steel and masonry, providing a hard wall and eliminating the need for exterior columns. They are faster to install than most other wall systems, require less maintenance, are more durable, and have an attractive and unique aesthetic design.

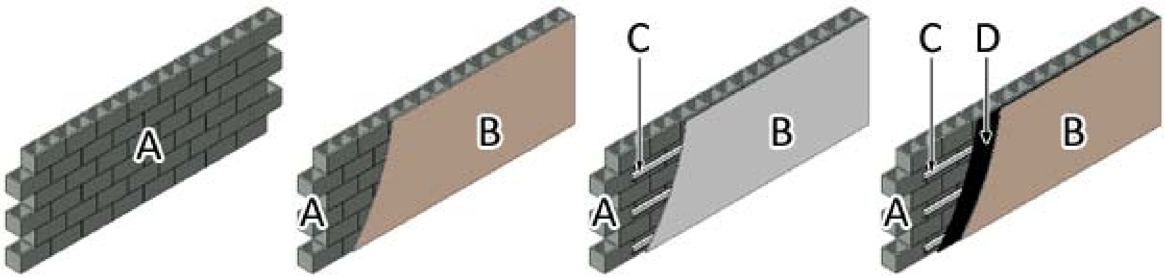


A: Precast Concrete Panel

Described in paragraph above.

3.2.8 Concrete Masonry Units (CMU)

Concrete masonry units (CMU) are construction blocks manufactured of concrete. The aggregate used in the manufacture of concrete block is sometimes comprised of fly ash or bottom ash. Both fly ash and bottom ash are the residue, or cinders, resulting from burning coal. Hence, some concrete blocks are known as cinder blocks. The most common concrete block is a 40 lb to 45 lb rectangular cored block, having either two or three holes in the center of the block. This reduces the weight of the block and allows rebar to be inserted through the cores to reinforce a load-bearing wall. The cores may also be concrete-filled for additional reinforcement. Concrete blocks nominally measure 8” x 8” x 16”. Because of its rather bland appearance, concrete block is used more frequently in utilitarian structures; however, blocks can be painted or coated with a thin, tinted cement veneer to make them more attractive. Blocks can also be coated to ensure proper weatherization.



A: CMU

A: CMU
B: Veneer Plaster

A: CMU
B: Gypsum Board
C: Metal-furring

A: CMU
B: 3/4” Plaster
C: Metal-furring Strips
D: Metal Lath

Described in paragraph above.

3.2.9 Glass Block

Glass blocks are made of glass or acrylic materials. Shaped and laid in a process similar to that used for brick, glass blocks are available in several different sizes and are commonly used as an alternative to traditional windows. Glass blocks are also used to construct shower walls and uniquely shaped windows, and can be employed as a design element to allow natural light into a space. They can be used to construct non-load-bearing walls and partitions. Glass blocks come in a variety of designs and sizes. They may be opalescent, clear, or tinted with various colors. Installation typically involves mortar and grout, but some manufacturers of acrylic glass blocks use alternative installation methods such as interlocking PVC joints.

3.2.10 Demountable Partitions

Demountable partitions are movable furniture system walls that permit the relocation, reconfiguration, and reuse of the wall partition components. This wall system uses modular predecorated vinyl drywall panels with special base and ceiling moldings to hide the panels’ edges.

3.3 INTERIOR WALL FINISHES

Interior wall finishes (see Table 3.3) are materials applied to an interior wall subsurface and are usually exposed to the occupants of a space. This section includes wall finishes that are commonly used in Florida's educational facilities. Operation and maintenance costs for wall finishes are based on the custodial care and repair procedures required to ensure the finishing material's expected lifetime.

Table 3.3 Interior Wall Finishes

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	IAQ	LCA	Fire
3.3.1 Waterborne Paint	1	3	3	2	6
3.3.2 Epoxy Paint	5	5	6	7	2
3.3.3 Acoustical Panels	7	6	4	3	5
3.3.4 Ceramic Tile	6	2	1	1	1
3.3.5 Vinyl Wall Coverings	3	7	7	6	3
3.3.6 Wallpaper	2	4	5	5	4
3.3.7 Fiberglass Reinforced Plastic (FRP)	4	1	2	4	7

3.3.1 Waterborne Paint

Waterborne (or latex) paints are composed of synthetic resins and pigments that are kept dispersed in water by surfactants. These paints contain small amounts of coalescing solvents, but they have significantly lower levels of volatile organic compounds (VOCs) than conventional solvent-based paints. Waterborne paints dry by evaporation of the water. The coalescing solvents allow the resin particles to fuse as the water evaporates to form a continuous coating. Waterborne paints must be protected from freezing and applied at a minimum temperature of 50 degrees Fahrenheit. Waterborne paints can rust unprimed steel and can sometimes attack aluminum. Application equipment, including paint brushes, must be constructed of a corrosion-resistant material such as 316 stainless steel, or they will be subjected to corrosion. In general, the price of waterborne paints is comparable to the price of solvent-based paints.

3.3.2 Epoxy Paint

Epoxy paints are available as a single-component product or a two-component product. A single-component epoxy is an oil-based paint that contains epoxy ester and comes in one container. Two-component epoxy paint comes in two containers, components A and B, that are mixed in a precise ratio and stirred vigorously. In schools, two-component epoxy meets impervious finish requirements in toilet rooms and kitchens.

3.3.3 Acoustical Panels

Acoustical panels are used for sound reduction and reverberation control. Ideal acoustical panels are those without a face or finish material that interferes with the acoustical infill or substrate. Using fabric-covered panels that cover an acoustical substrate is one approach to increasing acoustical absorption. Mineral fiberboard, or Micore, is a commonly used acoustical substrate. Finish materials often consist of fabric, wood, or acoustical tile. Fabric can be wrapped around substrates to create a "prefabricated panel" and can provide good noise absorption if applied to a wall. Prefabricated panels are limited to the size of the substrate and range in size from 2'x 4' to 4' x 10'. Fabric retained in a wall-mounted perimeter track system is referred to as an "on-site acoustical wall panel." These panels are constructed by framing the perimeter track into shape, infilling the acoustical substrate, and then stretching and tucking the fabric into the perimeter frame system. On-site wall panels can be constructed to accommodate door frames, baseboards, or any other intrusions. Large panels (generally greater than 50 sq ft) can be created on walls and ceilings using this method.

3.3.4 Ceramic Tile
Ceramic tiles are made from ceramic materials, such as earthenware and porcelain, and are available in many shapes, colors, and sizes. They tend to be an extremely durable wall covering, and many people find ceramic tile aesthetically pleasing and easy to clean. Some tiles are not treated to withstand water and as a result they are not designed to be used in wet locations. Others may have features, such as ribbed backs, which make installation on certain surfaces easier. Ceramic tiles are available in a glazed as well as unglazed form. Some unglazed tiles can be custom-painted and refired to set the glaze.

3.3.5 Vinyl Wall Coverings
Vinyl wall coverings are suitable for walls that are prone to moisture exposure such as in toilet rooms. When installed above a non-pervious finish, regular wallpaper does not wear well and can become dingy or discolored from mold, while vinyl can be wiped clean. Vinyl is available in grades of thickness, labeled as #1, #2, and #3. Grade #1 is most commonly used in residential applications, while #3 is suited for heavy traffic areas, such as in businesses, schools, hotels, and hospitals. Vinyl wall coverings will stand up to years of heavy use. Some are even manufactured with different coatings for special applications such as in medical offices and hospitals.

Solid vinyl is most suited for areas with consistently humid conditions because it is waterproof; however, to avoid mold growth, it should not be used on the inside of exterior walls. These wall coverings are easily cleaned and repaired should damage occur. Vinyl wall coverings generally have good fire ratings, a definite advantage for school applications.

3.3.6 Wallpaper
Wallpaper is used to cover and decorate interior walls with patterns and textures instead of paint. Wallpaper is typically sold in rolls and installed using wallpaper paste. Modern wallpaper is available in diverse forms. Two of the most common factory-trimmed sizes of wallpaper are referred to as "American" and "European" rolled goods. American rolled goods are 27” wide x 27’ in length. European rolled goods are 21.5” wide x 33’ in length. Both are approximately 60 sq ft in surface area. Most wallpaper borders are sold by the linear foot, with a wide range of widths from which to choose.
There are numerous types of wallpaper available to match the wide variety of potential finish applications. Cloth-backed vinyl is fairly common and durable; lighter vinyls are easier to handle and hang. Paper-backed vinyls are generally more expensive, significantly more difficult to

hang, and can be found in wider untrimmed widths. Foil wallpaper generally has paper backing and can be up to 36” wide, and can be very difficult to handle and hang. Textile wallpapers include silks, linens, grass cloths, strings, rattan, and actual impressed leaves.

Solid vinyl with a cloth backing is the most common commercial wall covering. It is manufactured untrimmed at approximately 54” and is overlapped and double cut by the installer. This same type can be pretrimmed at the factory to approximately 27”. As with paint, wallpaper requires proper surface preparation before application. Additionally, wallpaper is not suitable for all areas, especially where excessive steam occurs. Proper preparation includes the repair of any defects in the drywall or plaster and the removal of loose material or old adhesives. Accurate room measurements, along with the number of window and door openings, are essential when ordering. Large drops, or repeats, in a pattern can be cut and hung more economically by working from alternating rolls of paper. Paper is sold, with very few exceptions, in double rolls. The simplest removal option is to brush the paper with water. Water soaks through the paper and saturates the glue, allowing the paper to be peeled off. Other methods of removal include a chemical stripper and steam.

3.3.7 Fiberglass Reinforced Plastic (FRP)

Fiberglass Reinforced Plastic (FRP) wall panels are suitable for use in educational facilities. Coated with a sanitary sealer, they provide excellent resistance to mold, mildew, and stains. FRP wall panels are easy to clean without scrubbing or brushing and will not chip or crack like ceramic tile. Sealed score lines do not deteriorate or attract mold like grout lines. These panels are also easy to install. The panels are attached to the subwall with adhesive and the joints between panels are sealed and waterproofed.

3.4 INTERIOR CEILINGS

A ceiling (see Table 3.4) consists of the horizontal surface above the walls and may expose or enclose structural elements of a building. In most of Florida's educational facilities, the ceilings enclose or hide the structural, mechanical, and electrical elements below the roof or floor above, presenting a limited range of elements and materials to be compared. These *Guidelines* consider concrete structural elements or metal deck and open web steel joists as the two main options for exposed structure. The LCC analysis includes the typical variety of ceiling systems used in Florida's school facilities and several other materials with characteristics and properties that make them suitable for use in educational activities. In the LCC analysis, the operations and maintenance costs for ceiling systems reflect only the costs of typical repair procedures for each system.

Table 3.4 Interior Ceilings

Legend:	GOOD	FAIR	POOR

System	First Cost	LCC	Acoustics	LCA	Fire
3.4.1 Painted Cement Plaster	9	3	8	1	1
3.4.2 Standard Drywall	6	4	6	2	4
3.4.3 Blue Board and Veneer Plaster	8	5	7	4	2
3.4.4 Suspended Metal Grid System	2	3	5	8	1
3.4.5 Mineral Wool Acoustical Tiles	5	6	1	5	3
3.4.6 Fiberglass Acoustical Tiles	7	7	4	6	3
3.4.7 Cellulose Fiber Acoustical Tiles	3	2	2	3	3
3.4.8 Moisture-Resistant Mylar Tiles	4	7	3	7	3
3.4.9 Painted Metal Deck and Steel Frame	1	1	9	9	1

3.4.1 Painted Cement Plaster

Cement plaster is a versatile facing material made of Portland cement, sand, and water. Cement plaster has been used for more than a century as a surface finish because of its utility and low maintenance. It may be applied directly to a base, such as masonry or concrete, or it can be applied to a metal lath attached to frame construction. Cement plaster is a breathable material, resistant to rot and fungus, which helps protect indoor air quality. The final appearance of the finish can be varied in many ways: changing the size and shape of the aggregate, using colored cement, adding pigments, changing the consistency of the finish mix, or changing the method or equipment used for plastering. By using an integral color, the need for paint can be eliminated.

3.4.2 Standard Drywall

Standard drywall is classically covered with a layer of paint or textured plaster. It was introduced as a replacement for traditional lath and plaster finishing. Unlike lath and plaster, which can take a week or more to install properly, drywall can be installed quickly and efficiently in an entire structure by a relatively small team. This reduces construction costs and saves time. The wallboard is screwed to the framing members. The joints are covered with a special tape, then joint compound is applied on top. The entire ceiling can later be given a thin coating of finishing compound, called a skim layer, but this is not required. Gypsum-wallboard is made by sandwiching a layer of gypsum plaster between two layers of reinforced paper. Moisture resistant gypsum-wallboard has paper that has been treated to resist water and mold. Fire-resistant Type X gypsum wallboard contains gypsum plaster that has been blended with glass fibers to increase its fire resistance.

Unlike plaster and lath, drywall can be handled by people who are not experienced with construction. Relatively unskilled workers can safely and competently install this product or make repairs to existing installations. The real challenge is the taping, mudding, and sanding of the seams after installation to prepare it for painting or other finishing techniques.

The key advantages of drywall over other ceilings are its relatively simple installation and its low cost. But drywall ceilings also have a few disadvantages. Gypsum does not absorb sound very well, so other types of materials may be preferable if soundproofing is a concern. In addition, gypsum products are very susceptible to water damage. For areas that have high moisture content, such as toilet rooms, a chemically treated gypsum wallboard that is moisture-resistant should be used.

3.4.3 Blue Board and Veneer Plaster

Blue board is very similar to regular drywall gypsum board. As with drywall, it comes in 4’ wide boards at lengths of 8’, 12’, and 16’. It can be cut with a knife and it fastens to steel wall studs with screws. It also has the same gypsum core material as drywall. The difference is in the paper covering. Blue board's characteristic blue face comes from the special paper on the board's surface, which is treated to bond well to a skim coat of specially formulated plaster. When finishing blue board, instead of applying several coats of joint compound to the seams between boards, a quick tape-and-plaster treatment to the joints is applied. Then the entire wall surface is covered with one or two thin (1/8” thick) coats of plaster.

Blue board and veneer plaster offer two advantages over regular drywall - quality and convenience. Veneer plaster is much harder than a regular drywall surface, making unsightly dents and scratches less likely. The top surface of veneer plaster is continuous over the entire wall so that joints almost never show, unlike common drywall joints. Veneer plaster's continuous surface is also a better base for paint. With drywall, paint can dry differently on the paper surface than on the joint compound base at drywall seams. Even the most skillfully made drywall joints may be visible under some lighting conditions. Veneer plaster is much less likely to display any sort of visible shading difference.

Painting veneer plaster is not required. The plaster's natural off-white color and smooth surface are attractive even if not painted. It is also possible to colorize the plaster coat itself, either by adding a high quality paint to the plaster at the mixing stage or by using proprietary coloring systems. Veneer plaster application is typically a one-day operation. Plastering immediately follows the joint treatment, and a second coat, if needed, is applied over the first after only a brief period.

Blue board and veneer plaster can cost 20% to 30% more than a drywall installation. The price difference reflects the greater skill needed to apply veneer plaster. Choosing a one-coat or two-coat veneer can also affect the final cost. However, prices for veneer plaster are becoming competitive with drywall. Time and cleanup savings can make the cost difference negligible.

3.4.4 Suspended Metal Grid System

A suspended ceiling is a type of finish system that is hung below the ceiling structure within a room or building. It may be suspended from a roof or ceiling deck, which consists of structural framing joists that support loads above and below the deck. Most suspended ceiling systems consist of a steel grid and acoustical tiles, but other materials can also be used. Metal hanger wires are used to suspend these systems anywhere from 3” to more than 1’ below the deck.

These ceilings can be installed over existing drywall, steel joists, or even tile ceiling finishes. In a typical suspended ceiling system, the tile is supported by thin metal frames that run in a grid pattern across the room. Wall molding is attached to the wall around the entire perimeter of the room. The remainder of the grid is suspended by hanger wires, but the ends of each grid section rest on the wall molding for extra support. The grid may be arranged in a 2’ x 2’ or 2’ x 4’ pattern, based on the standard acoustical tile sizes. Recessed light fixtures are often used with these ceilings, and they are designed to fit within the regular grid patterns. Heating and air conditioning supply diffusers and return grilles are also available in standard tile sizes and can be fit into a suspended ceiling grid.

A suspended ceiling offers many advantages over other types of ceiling finishes. Since it is suspended below the deck, the interstitial space can serve as an air plenum for ventilation. This space can also be used to hide pipes, ducts, and electrical wiring. Because the tiles are easily removable, it is still possible to access mechanical and electrical equipment above the ceiling for regular maintenance and service. Suspended grid systems are also relatively affordable and can be installed quickly and easily.

However, a number of potential drawbacks should also be considered when choosing a suspended ceiling. Acoustical tiles tend to yellow over time and can make a room look dated. They need to be replaced regularly, and they are susceptible to stains and damage due to moisture or impact. Although the 2‘ x 2‘ grid helps prevent sagging tiles, this can become an issue in humid climates when air-conditioning units are shut off for extended periods of time.

3.4.5 Mineral Wool Acoustical Tiles

Mineral wool acoustical tile derives its name from rock or slag wool, which are by-products of the steel manufacturing process. The tile consists of a combination of materials that typically include corn starch, cellulose, and perlite, but may also include fiberglass. The face of the ceiling tile is generally coated with an acrylic latex paint. The face may also be covered by a polyvinyl chloride (PVC) or plastic scrim sheet for applications in high humidity areas or where scrubbing is important. The tiles can have a recycled content of up to 80%, as well as excellent light reflectance values and noise reduction coefficients. The International Agency Research and the

National Toxicology Program have identified rock wool as possibly being carcinogenic. Formaldehyde may be present in mineral wool tile containing fiberglass so it is important to select tiles that are formaldehyde-free. In addition, biocides are used in ceiling tiles with components such as corn starch to prevent the growth of mold or bacteria.

3.4.6 Fiberglass Acoustical Tiles

Fiberglass acoustical tiles are manufactured with a high percentage of glass fiber and a formaldehyde binder. Fiberglass tiles may have as much as 40% reclaimed glass fiber. Most fiberglass tiles are faced with a plastic scrim sheet. The noise reduction coefficient of fiberglass tiles is typically superior to mineral wool products, while light reflectance values are similar. An international manufacturer of high-performance fiberglass ceiling tiles claims up to 90% post-consumer recycled content with excellent scrubbing characteristics. As a general rule, fiberglass ceiling tiles cannot be included in ceiling tile reclamation programs.

3.4.7 Cellulose Fiber Acoustical Tiles

Cellulose fiber tiles are acoustical tiles manufactured from small wood chips, water, and lime or from fungicides and recycled newspaper that is fire-retardant. They can have a smooth surface or be embossed with a variety of patterns. The tiles have a final coating of flat paint and are used in suspended ceiling systems.

3.4.8 Moisture-Resistant Mylar Tiles

Mylar tiles have a film facing material that offers superior scrubbability without compromising the tile finish or integrity. This fact makes them suitable for clean rooms and schools. Excellent humidity resistance prevents the tiles from sagging and helps maintain a healthy indoor environmental quality.

3.4.9 Painted Metal Deck and Steel Frame

A painted metal deck and exposed steel framing system is a cost-efficient ceiling solution. If this approach is selected, appropriate acoustical dampening is required.

3.5 INTERIOR DOOR ASSEMBLIES

This section of the *Guidelines* refers to doors located in interior partitions (see Table 3.5). Even though door assemblies include the frame, panels, and hardware, only the frame and panel components of interior doors are compared in this analysis. The LCC analysis includes door assemblies commonly used in Florida's school facilities. For the purpose of the LCC analysis, the operations and maintenance costs for interior doors reflect only the costs of typical repair procedures for each system.

Table 3.5 Interior Door Assemblies

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Acoustics	LCA	Fire
3.5.1 Steel Door	3	2	4	2	1
3.5.2 Hollow Core Wood Door	1	1	3	1	3
3.5.3 Solid Core Wood Door	2	1	1	1	2
3.5.4 Aluminum Door	4	3	2	4	2
3.5.5 Fiberglass Door	5	4	1	3	4

3.5.1 Steel Door

A commercial steel door is a metal door that can withstand frequent heavy use while keeping a building secure. Steel doors are used in commercial settings, including schools, industrial buildings, and storage facilities. Steel doors are hung in steel frames, which can provide a better level of support and security than a wood frame. The term "hollow metal door" is commonly used to refer to a steel commercial door to help distinguish a swinging door from an overhead roll-up steel door.

While steel doors may be used in the interior of structures, they are almost always the best choice for exterior applications. A commercial steel door is one of the strongest and most durable options for securing a building, and it is highly resistant to rain and extreme temperatures. Construction of a commercial steel door starts with selecting a core. Standard cores are made of honeycombed cardboard, which is treated with a resinous strengthening agent. For additional insulation, polystyrene or polyurethane cores may be used. If the door must be fire-rated, a mineral fiber core, which is able to withstand flames and high temperatures for up to three hours, is used.

A steel skin is stretched across the core, with additional pieces welded along the edges. The skin can be made from galvanized steel that is resistant to rust and corrosion or from cold-formed steel, which is better for interior applications. These sheets come in various thicknesses, generally from 14 to 20 gauge sheet steel; the lower the gauge, the stronger the door will be. Before a commercial steel door is shipped, it will often be prepared to receive hinges, locks, and other door hardware. In many cases, each door will also be numbered to match the project documents, making it easy for installers to determine the location of each unit.

A basic commercial steel door is flush; that is, it is smooth on both sides with no windows or openings. On stairwells and other paths of travel, a small window, or lite, is added to allow users to see through before opening the door. On some doors, a louver is added to help with ventilation. This is especially common for rooms with large pieces of mechanical or industrial equipment. Some specialty options include embossed panel designs on the face of the door or embossed wood grain texture, which provides the look of a wood door with the strength of a metal door.

3.5.2 Hollow Core Wood Door

A hollow core wood door is manufactured from a variety of wood species and is typically stained or painted. A hollow core wood door is an interior door without solid material inside its frame. These doors are lightweight and used in many types of buildings. Hollow core wood doors do not buffer sound well, but are an affordable alternative to solid core doors. Scrap wood and artificial wood finishes are typically used for hollow core doors. The use of lower cost materials results in these lightweight interior doors being less expensive than solid core doors. The hollow core wood door is considered environmentally friendly because manufacturers can use wood products that would otherwise be wasted. Hollow core wood doors need some type of inner structure to add some support to the frame. One common type of hollow core wood door filling is structural paper. The structural paper is formed into a honeycomb and then glued inside the hollow door frame. Other types of inner structure include foam blocks and pieces of board placed in sections inside the door frame. Hollow core wood doors should not be used for exterior doors because they are not strong enough to resist intrusion. These doors are designed to be all-purpose interior doors only and should be installed in a metal door frame for educational facility applications.

3.5.3 Solid Core Wood Door

A solid core wood door is manufactured from a variety of wood species and is typically stained or painted. Solid core doors are more expensive than hollow core doors, but are an excellent choice for areas that require privacy. As the name implies, solid core wood doors have a solid wood core to help deaden ambient sounds between rooms. These doors should be installed in a metal door frame for educational facility applications.

3.5.4 Aluminum Door

An aluminum door is made from extruded aluminum components. However, aluminum doors can also be constructed from formed sheet aluminum. Sheet aluminum is often used for door faces. Aluminum doors should be installed in a metal door frame for educational facility applications. Aluminum stile-and-rail doors have a tubular extruded aluminum frame, usually filled with glass. Aluminum flush-panel doors have an extruded channel or angle frame, bracing members, and sheet aluminum facing panels. Aluminum door assemblies are usually either coated with a baked-on finish or anodized. Aluminum doors are low-maintenance doors, designed and manufactured for reliable performance and smooth operation. They open and close easily and quietly.

3.5.5 Fiberglass Door

A fiberglass door consists of a core of rigid insulation and a clad of a fiber-reinforced polymer. Fiberglass doors are made in both flush and stile-and-rail configurations. Fiberglass doors are selected for their appearance as well as their scratch and dent resistance, which makes them an ideal solution for schools. They are paintable, durable, and low maintenance; however, good quality fiberglass doors are usually more expensive than wooden doors and are not often chosen for indoor use. The quality of the fiberglass is important because cheap fiberglass may crack and fall apart. Fiberglass doors even offer a wood grain texture.

3.6 INTERIOR WINDOW ASSEMBLIES

This section of the *Guidelines* addresses windows located in interior partitions (see Table 3.6). Even though window assemblies include the frame, panels, and hardware, this analysis considered only the frame component of interior windows. The LCC analysis includes window assemblies commonly used in Florida's educational facilities. For the purpose of this analysis, the operation and maintenance costs for interior windows reflect only the costs of typical repair procedures for each system.

Table 3.6 Interior Window Assemblies

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Acoustics	LCA	Fire
3.6.1 Aluminum Frame Window	2	2	2	3	2
3.6.2 Steel Frame Window	1	1	3	1	1
3.6.3 Vinyl Frame Window	1	3	1	2	3

3.6.1 Aluminum Frame Window

An aluminum window has a casing or frame made of aluminum rather than wood, vinyl, or some other material. They are among the most popular types of windows, especially for commercial and industrial buildings. Aluminum was one of the first metals used for window frames, and the advantages of aluminum windows are numerous. They have a good strength-to-weight ratio and aluminum can be formed into custom profiles. Aluminum windows are excellent for controlling noise, making them a regular selection for schools. In addition, both the purchase and maintenance costs are reasonable. Aluminum windows need very little maintenance to maintain peak performance.

3.6.2 Steel Frame Window

Steel frame windows were popular in buildings in the early to mid-1900s, but are not used very frequently today. Steel framed windows may be specified where fire protection and extra-high strength assemblies are required by code. In general, steel windows are made of hot-rolled structural-grade new billet steel; however, the main members of windows are cold-formed from new billet strip steel. Steel windows must be properly protected against corrosion by shop paint finish and field painting. Shop finishes are usually acrylic or polyester baking/finishing enamel. Galvanized steel windows are sometimes shop finished for field painting and are sometimes left unpainted.

3.6.3 Vinyl Frame Window

A vinyl window frame is an extrusion with several internal hollow chambers often added to provide strength. These chambers also trap air, increasing the energy performance and improving the sound-deadening qualities of the frame. In general, the more internal chambers in the frame, the stronger it will be. The design of the extrusion is critical to the energy performance, structural strength, and economic success of the product. Metal reinforcement can be added to the hollow sections of vinyl frames to increase the rigidity and strength of the frame. Reinforcement is typically used where the fixed and operable panels meet (the interlock) in most sliding windows and on selected sections of large frames.

3.7 SPECIALTY ITEMS: WALL BASES

Wall base is an element applied to the face of the wall material where the wall intersects the floor (see Table 3.7). Wall bases can be manufactured from a variety of materials with the same characteristics as the flooring surface materials described earlier. (See **3.1 Interior Floor Surfaces** for detailed descriptions of wall base materials.)

Table 3.7 Specialty Items: Wall Bases

Legend: GOOD | FAIR | POOR

System	First Cost	LCC	Acoustics	LCA	IAQ
3.7.1 Vinyl	1	2	2	6	6
3.7.2 Ceramic Tile	3	5	6	4	1
3.7.3 Quarry Tile	4	1	6	3	1
3.7.4 Terrazzo	5	4	5	2	5
3.7.5 Wood	2	6	4	5	3
3.7.6 Rubber	1	3	1	1	4
3.7.7 Medium Density Fiberboard (MDF)	2	5	4	5	5
3.7.8 Resinous Base	5	4	5	2	5

3.7.1 Vinyl

Vinyl base is a resilient material made from polyvinyl chloride resins, various fillers, and pigments, layered over a backing material such as paper or foamed plastic. Plasticizers are added to the resin to impart flexibility. Other additives such as fungicides may be present.

3.7.2 Ceramic Tile

Ceramic tile baseboards are generally a bullnose tile that typically extends 5” or less up the wall. These tiles can be applied using mortar and grout (thick set) or mastic (thin set).

3.7.3 Quarry Tile

Quarry tile is a glazed or unglazed ceramic tile manufactured from extruded shale, clay, and other earthen materials with a thickness between 1/2” and 3/4”. Quarry tiles are characterized by a water absorption rate of less than 5%.

3.7.4 Terrazzo

Applied to the base of a wall, terrazzo is a hard, non-resilient, polished surface divided into “tiles” by brass strips. Terrazzo is a mixture of marble chips and Portland cement. Once the mixture hardens, the surface is ground and sealed.

3.7.5 Wood

Wood base is solid wood, usually 1/2” to 3/4” thick. The type of wood used may vary. Wood base is available from manufacturers already finished or ready to be finished on-site.

3.7.6 Rubber
Rubber can be manufactured from an organic source, such as rubber trees, or be synthetically produced from hydrocarbons. Both kinds of rubber can be used for producing a rubber base.

3.7.7 Medium Density Fiberboard (MDF)
Medium density fiberboard (MDF) is a composite wood product and consists of wood waste fibers glued together with resin, heated, and placed under pressure. MDF is smooth, uniform, and does not warp. MDF is smooth because the wood fibers used in its manufacture are uniform and fine. This structure creates a low "tear-out," which means when sawed, the end has a smooth cut instead of a jagged edge. This also means that a coat of primer and a few coats of paint will create an attractive, finished surface, unlike other composite wood products. MDF also has a mild reaction to moisture; that is, it will not warp or swell in high-humidity applications. MDF is made solely from waste products, the leftover scraps that would otherwise be dumped in a landfill. [See **3.8.2 Medium Density Fiberboard (MDF)** for a detailed description of MDF].

3.7.8 Resinous Base
Resinous wall base consists of a resinous binder, a catalyst, and a dry mix such as fillers, pigment, additives, or decorative chips. Resinous binders have good chemical and abrasion resistance, high-impact strength and adhesive properties. They can be applied in 1/4” to 1/2” thick toppings. Resinous binders include epoxy, polyacrylate, and polyester binders [see **3.1.14 Resinous Flooring** for a detailed description of resinous systems].

3.8 SPECIALTY ITEMS: MILLWORK – BUILT-IN CABINETRY

Millwork refers to built-in cabinetry. Millwork can be manufactured from several types of wood products such as plywood, particleboard, medium density fiberboard (MDF), or Mylar-faced particle board (see Table 3.8). Millwork substrates may also be finished with a wood veneer or plastic laminate.

Table 3.8 Specialty Items: Millwork – Built-In Cabinetry

Legend:	GOOD	FAIR	POOR

System	First Cost	LCC	IAQ	LCA	Fire
3.8.1 Plywood	3	1	1	3	4
3.8.2 Medium Density Fiberboard (MDF)	3	2	3	2	3
3.8.3 Particle Board	2	4	1	1	2
3.8.4 Melamine Board	1	3	4	4	1

3.8.1 Plywood

Plywood is a wood product manufactured out of sheets of veneer, or plies, pressed together and glued, with the grain of each layer alternating in opposite directions. Plywood is strong, and can be treated in several ways based on its intended application. Because of the way plywood is manufactured, it resists cracking, bending, warping, and shrinkage. The plies that form plywood are generally cut on a rotary lathe, which cuts a continuous roll of wood while a log, called a peeler, is turned against it. Rotary lathing is rapid and makes efficient use of the wood while turning out veneers highly suitable for plywood. Rotary lathed veneers tend to be dull in appearance but are perfectly functional. After the veneers are cut, they are overlaid with layers of glue and pressed together until dry to form a flat, even, tight piece of plywood. Plywood is sturdier than regular sheets or panels of wood because the veneer layers are laid with opposing grain, which causes the wood product to resist warping.

Plywood comes in a number of forms, including softwood, which is made from pine, fir, or spruce. Softwood plywood is usually pale in color and is used in construction applications. Plywood can also be decorative with a wide selection of domestic and imported hardwood face veneers.

If plywood is destined for indoor use, it is made with urea-formaldehyde glue, which dries quickly and is inexpensive. For plywood intended for use in outdoor applications or wet environments, a water-resistant glue is used to prevent the plies from coming apart or delaminating, thus compromising the strength of the plywood. Plies range in thickness from 1/10” to 1/6”. Standard plywood sizes consist of 4’ x 8’ sheets with three, five, seven or more 1/4” to 1 1/8” thick plies. The end user can cut, reshape, or sand these sheets to needed specifications.

3.8.2 Medium Density Fiberboard (MDF)

Medium density fiberboard (MDF) is a composite wood product similar to particleboard and consists of waste wood fibers that are glued together with resin, heated, and then placed under pressure. MDF is appropriate for many applications, from cabinetry to molding, because it is smooth, uniform, and does not warp. MDF has many advantages over plank wood, particleboard, or high density fiberboard. It is smooth because the wood fibers used in its manufacture are uniform and fine. This structure creates a low "tear out," which means when sawed, the end has a smooth cut instead of a jagged edge. This also means that a coat of primer and a few coats of paint will create an attractive, finished surface, unlike other composite wood products. MDF also has just a mild reaction to moisture; that is, it will not warp or swell in high-humidity applications such as toilet room cabinets.

Builders use MDF in many applications, such as in furniture, shelving, laminated flooring, decorative molding, and doors. MDF can be nailed, glued, screwed, stapled, or attached with dowels, making it as versatile as plank wood. People working with MDF usually use a carbide saw fitted with a vacuum to reduce the amount of airborne dust. Since MDF is strengthened with a resin containing formaldehyde, individuals exposed to it should try to reduce their risk of inhalation or use special MDF with lower formaldehyde levels.

Reconstituted, engineered wood products such as MDF are often covered in a veneer or laminate. These thin layers of vinyl or real wood disguise the MDF, especially along visible edges. Some people prefer using MDF over regular lumber because it has a lower impact on the environment. MDF is made solely from waste products, the leftover scraps that would otherwise be dumped in a landfill. This feature has helped increase its popularity, especially for green building projects.

3.8.3 Particle Board

On any given day, sawmills and other wood-processing factories generate a significant amount of scrap material. Most of these wood shavings and piles of sawdust are used in the mill process, but some of this material ends up as an engineered product called particle board. Particle board is an inexpensive alternative to solid wood paneling or boards. It is primarily intended for interior projects where appearance and durability are not a priority.

Particle board is produced by combining sawdust and other waste wood with a special resin. This slurry of wood chips and glue is then pressed through an extrusion machine to form long sheets of particle board. Customized saws cut these sheets into various sizes, according to the needs of the customer. Manufacturers of inexpensive home furnishings, such as shelving, entertainment centers, and bookcases, often use particle board for their do-it-yourself kits.

Although unfinished particle board bears little resemblance to traditional hardwoods, producers may add a wood veneer face to improve its appearance. Particle board can also be painted or laminated. Particle board cannot handle exposure to moisture. Water causes particle board to stain and warp, which limits its application. Once particle board becomes wet, it loses much of its tensile strength.

Depending on the manufacturer and the quality of the resin, particle board can be surprisingly durable. Particle board may not be able to withstand stress as well as hardwood products, but it performs well enough for light duty projects such as closet shelving or portable cabinetry.

3.8.4 Melamine Board

Melamine board is an engineered wood product that contains melamine, a compound used in almost all chipboard products, and which is also used as a facing material to make veneers and laminates. Health concerns with melamine have raised some issues with products containing this chemical; however, in the case of melamine chipboard, it is generally viewed as a safe product because it is embedded inside the material, thus limiting exposure. Similar to particleboard, melamine board is made from a variety of scrap wood materials, including sawdust and paper. These materials are glued together with melamine resin, a mixture of melamine and formaldehyde, which helps the board hold its shape. The resulting product is very dense and extremely strong. It can in fact be superior to actual wood in some applications such as flooring, where high strength is desired. It is also used in products, such as furniture, to increase sturdiness and lower costs.

Melamine adds some fire-retardant properties to the products on which it is used. It also adds strength and can help resist bacterial and fungal colonization. All these properties make melamine a useful building material. However, it can be toxic in some settings. The primary concern with melamine board is that the board can be damaged, allowing people to inhale or consume melamine particles, which could cause health problems. The formaldehyde used in the resin can also cause health problems as a result of off-gassing.

3.9 SPECIALTY ITEMS: COUNTERTOPS

Countertops are horizontal working surfaces and may or may not incorporate a sink (see Table 3.9).

Table 3.9 Specialty Items: Countertops

Legend:	GOOD	FAIR	POOR

System	First Cost	LCC	IAQ	LCA	Fire
3.9.1 Granite	5	2	1	6	1
3.9.2 Chemical-Resistant Solid Surfacing	3	4	3	1	3
3.9.3 Linoleum over Plywood	1	5	2	2	4
3.9.4 Plastic Laminate over Plywood	2	6	2	4	5
3.9.5 Stainless Steel	6	3	1	3	2
3.9.6 Quartz	4	1	1	5	1

3.9.1 Granite

Granite consists of quartz, silica, mica, obsidian, feldspar, and other natural minerals. Each slab of granite has unique crystals, depth, and variations in color. Granite never changes colors so it does not lose its brilliance over time. The cost of granite countertops will vary according to square footage, as well as other factors, such as edge and backsplash selections. Round, 1/4" beveled edges are standard. A special edge increases the price. Although granite countertops are extremely durable, the material itself cannot have a warranty placed on it because it is a natural stone; however, an installer can warranty its installation.

Granite countertops can stain and do not resist acidic chemicals; however, granite is heat-resistant, and will not scratch, blister, or crack with normal use. Granite can be cleaned with warm water and soap. Special stone cleaners are also available.

Granite will need to be resealed when water soaks in rather than beading up. Granite countertops must be resealed once or twice a year. Some professionals recommend a twice-yearly application of a non-yellowing paste wax. No special expertise is necessary to reseal granite countertops.

Because each piece of granite is unique, if a part of a countertop needs to be replaced due to damage, it will not match the original countertop. Although most installers try to avoid seams, granite countertops typically have some seams, as opposed to a solid surface countertop. The location of the seams will depend on the layout of the countertop and the support needed. Seams are filled with color-coordinated epoxy to disguise their appearance.

Granite countertops are heavy, about 25 lb to 30 lb per square foot, and adequate support must be provided. No sub-deck is required between cabinets and granite countertops.

3.9.2 Chemical-Resistant Solid Surfacing
Solid surface countertops are a man-made product, which means great variety when it comes to color and texture variations. The materials in these countertops include: resin, an acrylic or modified polyester; alumina trihydrate, a filler which allows for a Class 1 fire rating; color pigments; and added particles that give a mottled, veined, or textured look to the surface. The surface is machinable and can be cut into any shape imaginable. It also can be heated and molded. It is the only material that features molded sinks seamed directly to the countertop with no gaps or caulks. Built-in coved backsplashes can be fused to the countertop to create a water-tight transition.

Solid surface countertops offer the benefits of a warm-to-the-touch surface with low-maintenance requirements. Normal wear and tear requires only soap and water cleanup. The solid-surface countertops are stain, chemical, and scratch resistant and are homogenous; that is, the color and pattern are consistent throughout. Solid-surface countertops have no veneers to chip, crack, peel, or wear out, making them an extremely durable surface. Unlike granite, solid surface countertops are generally guaranteed for 10 years.

Chemical-resistant solid surfacing is manufactured to be stain, chemical, and scratch resistant, but it is not impervious to harm. It can be scorched and may crack if incorrectly installed too close to a high heat-producing appliance or if hot pans are placed on it. Extreme heat must be avoided to prevent damage. Wine, mustards, and other high stain producers could leave a mark if not quickly wiped up. Damage can be repaired and the product restored often by using a non-woven scrubbing pad or an abrasive liquid cleanser followed by a pad to maintain the same appearance as the rest of the countertop. Deep scratches will probably require professional services, but repairs for cracks or chips can be practically invisible since the color runs throughout the countertop.

The fabricated countertop is not screwed in or nailed down. Instead, it is attached with silicone caulk that will allow it to expand and contract. The drop edge or buildup will typically be created by cutting narrow strips (usually between 1” to 1-1/2” wide) lengthwise from the solid-surface sheet. The next step is stacking, gluing, and clamping two strips together on the underside of the countertop deck to create an edge that is 1-1/2” thick. After the glue dries, the squeezeout—glue that has oozed out of the layered solid-surface sandwich and hardened—is machined off. A profile is routed into the edge and the finish is sanded.

3.9.3 Linoleum over Plywood
Linoleum is a resilient sheet-flooring product made from natural materials, such as oxidized linseed oil and ground cork. It may have a pre-waxed surface, usually a metallic wax. Linoleum can be applied with adhesives over plywood in the same manner as plastic laminates.

3.9.4 Plastic Laminate over Plywood
Laminate is a colorful, moderately durable surface with a fraction of the cost of other countertop options. Laminate countertops can be purchased ready-made with pre-molded backsplash and molded edges or fabricated on site. Laminate is created from layers of

decorative paper and kraft paper—a strong, moisture-resistant product with bonded fiber. These papers are treated with resin and fused using high heat and pressure. To make a fully prefabricated countertop, the laminate is bonded as one piece with the backsplash and edge. Laminate comes in different thicknesses, depending on the intended use. Horizontal grade is the thickest variety of laminate because it is designed for flat, high-impact, and heavy-use countertops. It is the most resilient grade of laminate and can withstand the most impact. For postforming—the process of forming the decorative laminate into simple shapes—a slightly thinner grade of laminate is used. Vertical grade is the thinnest and is typically used for low-impact vertical installations, such as backsplashes. It can be used for horizontal applications if the surface is not expected to withstand heavy use.

Marketed under such trade names as Formica, Wilsonart, and Nevamar, laminate now comes in popular designs that resemble wood, granite, stone, and engineered stone. Combined with a beveled or curved edge, the designs can appear very realistic.

Laminate countertop cleanup is simple, generally by wiping it with a damp cloth or sponge using mild soap or a non-bleach detergent. For stuck-on residue, scrubbing with a nylon bristle brush works well. Abrasive cleaners/powders and metal or abrasive-coated pads should not be used on most laminates because they may permanently dull and scratch the laminate and make it more susceptible to staining.

While a laminate countertop is strong, it can be scratched, cut, or chipped, especially on its edges. Knives or sharp utensils and abrasives can slice or scratch the surface. Certain chemicals can stain a laminate surface, especially inks and dyes. Laminate can also be scorched or separated from its substrate if exposed to temperatures above 150 degrees Farenheit. To protect against damage, laminate should not be exposed to extreme heat. Laminate cannot be repaired. Some third-party seam-fill kits may make damage less noticeable, but they cannot completely repair a piece that is damaged.

3.9.5 Stainless Steel

Stainless steel is stain-resistant and the only surface that can be safely bleached. A cleaner that contains chlorine should not be used. As a rule of thumb, ketchup, mustard, mayonnaise, lemon juice, vinegar, salt, or salad dressings should not be allowed to sit on the surface of stainless steel because they will cause a white stain over time. Newer applications include brushed or textured finishes that help camouflage scratches. If scratched, a nonabrasive pad works well by rubbing in the same direction as the finish. Welded stainless steel sinks create an integrated look, and backsplashes are available with corrugated patterns. Stainless steel, when attached to a wood substrate, becomes more sound-resistant. Regular rolled edges, bullnose, or Marine edges (no drip) are standard.

3.9.6 Quartz

Quartz combines natural quartz with epoxy resin binders to create a virtually indestructible material that does not require sealants. Since it is not 100% stone, it is often referred to as "engineered" quartz. Quartz provides the look of natural stone, with added durability. Its non-porous nature makes it practically stain-free and it has consistent color and hygienic qualities. When cleaning quartz, it is important to follow the manufacturer's specific instructions. A leading quartz countertop producer recommends using warm water and a pH neutral, non-abrasive cleaner to wash the stone.

CHAPTER 4
HEATING, VENTILATING, AND AIR-CONDITIONING (HVAC) SYSTEMS

4.0 INTRODUCTION

This section identifies mechanical heating, ventilating, and air-conditioning (HVAC) system types that may be implemented in educational facilities in Florida. HVAC systems can be complex and require careful design considerations to ensure the building's occupants have a healthy, safe, and comfortable environment. Each project has a unique set of criteria that should be considered during the design phase to select the most appropriate system for the building function. This chapter outlines the criteria that should be considered in the selection of mechanical systems for educational facilities in Florida.

Each section begins with a matrix comparing the selection criteria for each HVAC system in the section. This matrix is not intended to provide a definitive selection for the mechanical system of an educational facility. Its intention is to provide an accurate and practical tool to aid districts in narrowing the choices for the selection of HVAC systems. Section 1013.37(1)(e), Florida Statutes, calls for a Life Cycle Cost (LCC) analysis to be performed for new educational facility construction projects with a total air-conditioning load of 360,000 BTUs per hour (30 tons) or greater. This detailed LCC analysis will better address the unique design aspects of the building under consideration than a general analysis such as this one. The recommendations provided in this chapter should not replace detailed studies performed by mechanical engineers that are specific to each project.

This chapter is divided into sections of similar HVAC systems to better allow for the comparison of the associated Life Cycle Costs. Decentralized systems are discussed first. These types of systems are suitable for smaller projects where no central plant exists. The installation of these systems is also relatively simple. Section 4.1 covers direct expansion systems or DX Systems. Centralized systems are discussed next. These systems are suitable for larger facilities, especially where maximizing equipment service life is important. Section 4.2 discusses chiller systems. Air distribution systems are covered in Section 4.3. These are methods of distributing air throughout the conditioned space and can be used with both decentralized and centralized systems.

A selection criteria matrix is presented to compare the DX and chiller systems. This matrix is divided into two sections of selection criteria: Costs and Other. The Costs section criteria include First Cost, Energy Cost, Maintenance Cost, Replacement Cost, and Life Cycle Cost (LCC). Costs were computed on a cost-per-ton basis, and they were computed only for the unit itself. The costs of any other associated equipment for the system were neglected in this study. The Other section criteria include required space of the system, complexity of the system, life of the unit, and the noise produced by the unit.

The air distribution systems are analyzed separately for this study because they are a means of distributing conditioned air throughout the space. The Costs section criteria include First Cost, Replacement Cost, and Life Cycle Cost (LCC). The costs for this section were computed on a cost per unit basis. The “Other” section criteria include required space of the system, complexity of the system, life of the unit, noise produced by the unit, and temperature control of the system.

Further descriptions on how each of these criteria was calculated and ranked can be found in Appendix C.

Description of Selection Criteria

Cost Criteria

First Cost: The initial capital cost of materials and installation of an HVAC unit.

Energy Cost: The electricity costs associated with running HVAC equipment on a day-to-day basis.

Maintenance Cost: The cost associated with performing preventive maintenance on air-conditioning systems to maintain proper design conditions and prolong service life, which includes activities such as changing filters and making minor repairs.

Replacement Cost: The cost associated with changing out the air-conditioning unit at the end of its useful life. The Replacement Costs will also include any associated costs of replacing major components of the system that fail before the end of the unit’s useful life.

Life Cycle Cost: The total cost of an HVAC system, taking into account First Cost, Energy Cost, Maintenance Cost, and Replacement Cost.

Other Criteria

Required Space: The space needed to house the HVAC system. Along with the footprint of the system, the required space may include required mechanical rooms and any needed space above the ceiling.

Complexity: The difficulty level of installing and maintaining the system.

Life of Unit: The average useful life of an HVAC unit.

Noise: How much noise the system generates during operation and its potential to affect the learning environment.

Temperature Control: The level of control the system has in maintaining the desired air temperature of the conditioned space.

4.1 DIRECT EXPANSION (DX) SYSTEMS

In direct expansion, or DX systems, the evaporator is in direct contact with the air stream. DX systems are primarily used for applications requiring 10 tons or less of air-conditioning capacity. Table 4.1 shows the Life Cycle Cost criteria and system selection criteria for comparing DX systems and chiller systems. Further description on how each of these criteria was calculated and ranked can be found in Appendix C.

Table 4.1 Life Cycle Cost and System Selection Criteria Matrix for DX Systems

Legend: GOOD | FAIR | POOR

Unit Type	First Cost	Energy Cost	Maint. Cost	Replacement Cost	LCC	Required Space	Complexity	Life of Unit	Noise
4.1.1 Wall-Mounted Unit	6	5	4	6	5	1	1	4	3
4.1.2 Package Rooftop	5	5	4	5	5	2	1	4	1
4.1.3 Split Systems	4	4	2	4	4	3	2	4	2
4.1.4 Water-Loop Heat Pump	3	4	3	3	4	4	4	2	1
4.1.5 Geothermal Heat Pump	6	2	3	4	3	3	3	2	1
4.2.1 Air-Cooled Chiller	1	3	1	1	2	5	4	3	1
4.2.2 Water-Cooled Chiller	2	1	1	2	1	6	4	1	1

4.1.1 Wall-Mounted Unit

Wall-mounted units are self-contained HVAC systems mounted on the walls of classrooms. They are designed to provide conditioned air to the room without ducts or with very short ducts. Enhanced wall-mounted units also provide ventilation using outside air. Figure 4.1.1 shows a wall-mounted unit on a portable classroom.

Figure 4.1.1 Wall-Mounted Unit

First Cost
The First Cost of a wall-mounted unit is generally low compared to centralized systems. The unit is self-contained and has a simple installation requiring only an opening in the wall and connection to electrical power. Wall-mounted units are designed to serve single zones. This limits the amount of conditioned space that they will be able to provide. While initial costs are low for individual units, more units will be needed to condition a larger space. First Costs will increase with a more energy-efficient system. Enhanced systems will also cost more than regular units.

Energy Costs
Energy use for wall-mounted units is related to the system's energy efficiency ratio (EER). Systems are available with EERs from 8.9 to 11.8. The higher the system's EER, the more energy-efficient it is, which translates to lower Energy Costs. For this study, an EER of 11 was used to compute the Energy Costs.

Maintenance Costs
Wall-mounted units typically have a higher maintenance cost due to the multiple units needed to serve a large building. Each unit will have a compressor and fan that need to be maintained. Enhanced units will have higher maintenance costs than regular units to ensure that all components are running at optimal performance levels. Regular maintenance must be performed to maintain proper operation. Filters must be changed regularly, and condenser and cooling coils must be cleaned every three to four months. The condensate drains must be cleaned out regularly, or they can lead to water damage in classrooms. Maintenance and repairs can be made by most residential technicians.

Replacement Costs
Replacement Costs for package through-wall units include only the cost to replace the unit itself. They occur every 10 to 15 years, which is the useful life of the unit. Defective units may be replaced quickly and easily.

Life of the Unit
With proper maintenance, wall-mounted units may last up to 15 years, which equates to three replacements of the unit throughout the 50-year life of the building. Wall-mounted units have a high Life Cycle Cost.

Spatial Requirements/Complexity
Ductwork and mechanical rooms are not necessary with wall-mounted units, thus conserving building space. However, these units require direct access to outside air, which limits wall-mounted units' placement to exterior zones. Wall-mounted units have few points of maintenance and can be serviced by most residential technicians. System spare parts are also readily available if any part requires replacement.

Noise
Noise and vibration levels for wall-mounted units vary considerably. Both the compressor and fan noise are located near the occupied space, which can generate considerable noise levels if not properly designed and installed. Units with adjustable fan motor speeds allow for quieter operation. Care must be taken in installing wall-mounted units correctly to avoid vibration in the building structure.

Temperature and Humidity Control
Wall-mounted units allow for the refrigeration of air and its dehumidification. They control the temperature by an adjustable built-in thermostat. As the room temperature reaches the desired temperature, the compressor will cycle off. Depending on the unit, the blower may remain on or run at a lower speed while the compressor cycles off.

Ventilation of the conditioned space may be provided by enhanced units or by a dedicated outside air unit. Enhanced wall-mounted units allow for ventilation of the room, which a normal unit does not provide. Dedicated outside air units bring in fresh air to maintain proper carbon dioxide levels in the building.

4.1.2 Package Rooftop Unit
Package rooftop systems are self-contained HVAC units located on the rooftops of buildings. They may also be mounted on a concrete pad on the ground. They supply cooling through ducts that penetrate the roof or through the wall if mounted on the ground. These units can be used to serve a single zone or to serve multiple zones. When used to serve multiple zones, they are usually used with variable air volume (VAV) boxes (see Section 4.3.2) to control the temperature in the individual zones. Heating is typically provided by using a gas furnace or electrical resistance heat strip located inside the air handler.

Figure 4.1.2 Package Rooftop Unit

First Cost
This system has a low First Cost, depending on the number of zones provided and whether or not each unit will have multiple zones. Ducts are required to move air to and from the classroom, and VAV boxes are required if multiple zones will be incorporated. No pumps, pipes, or other equipment need to be provided for a complete operating system. Other costs to be

considered include the added electrical service that will be run to each rooftop unit (single zone) to power the system. The additional structural requirements to support the unit should be included in the First Costs.

Energy Costs
Energy use for package rooftop units will be related to the system's EER. The EER of Package rooftop units ranges from 8.9 to 12.8. The higher the system's energy efficiency ratio (EER), the more energy-efficient it is, which translates to lower Energy Costs. For this study, an EER of 11 was used to compute the Energy Costs.

Maintenance Costs
All maintenance of a rooftop unit takes place outside the occupied space. A safe means of access to the equipment must be provided. Regular maintenance should be performed approximately every three months to maintain proper capacity. This maintenance should include changing filters, cleaning condensate drain pans, cleaning lines, greasing bearings, and visually inspecting the wiring. The coils should be cleaned every two years.

Replacement Costs
Replacement Costs will include the costs to replace and reinstall the unit itself. Coil life will vary based on the geographical location of the units. Units installed in schools near the ocean will have decreased life due to deterioration from salt water in the air.

Life of the Unit
Outdoor installation can reduce the equipment life due to the unit being subjected to the weather, possibly leading to casing corrosion. The average life for a rooftop unit is 15 years, which equates to three replacements of the unit throughout the 50-year life of a building. A galvanized or vinyl coating may be applied by the manufacturer to help prevent rusting of the unit, which extends the life of the unit to be comparable with indoor units.

Spatial Requirements/Complexity
Package rooftop units do not require a mechanical room inside the building, thus conserving space. Architectural designs may limit the placement of equipment or require special screening to hide the unit from sight.

Noise
Excessive sound and vibration may be transmitted through the building, depending on the building construction. Sound and vibration should be taken into account in the design of the system.

Temperature and Humidity Control
Package rooftop units provide consistent air movement to the conditioned space. The unit should be properly sized to minimize humidity buildup at part load conditions. Ventilation can be provided by a return air/exhaust air fan.

4.1.3 Split Systems

A unitary air conditioner with more than one factory-made assembly is referred to as a split system. Split systems consist of both an indoor air-handling unit and a separate outdoor condensing unit. These systems may be configured as either straight cool or a heat pump. In the straight cool configuration, heating is provided by an electric resistance heating strip or gas. A heat pump is a self-contained air-conditioning unit with a reverse refrigeration cycle so that it may provide both cooling and heating. Only one source of energy is needed to provide both cooling and heating in this configuration.

Smaller systems are considered single zone units, and they can serve one or more individual spaces, depending on the desired control. Larger split systems may use VAV systems (see Section 4.3.2).

(a) (b)

Figure 4.1.3 Split System Units: a) outdoor condensing units of straight cool split systems, and b) condensing units of air-source heat pumps.

First Costs

Straight cool split systems will have a lower Initial Cost than heat pumps due to a simpler design. Piping must be field-installed to transport the refrigerant between the indoor and outdoor units. Ducts are required in both situations to distribute conditioned air to the classroom. A concrete pad needs to be placed under the outdoor condensing unit. The Initial Cost of the units will vary based on efficiency.

Energy Costs

Split system units are available with EER values from 9.0 to 13.4. The higher the EER, the greater the efficiency of the unit, which translates to lower Energy Costs. Straight cool systems with electric resistance heating strips will have greater heating Energy Costs than heat pumps. Air-source heat pumps become much less efficient at low air temperatures, which makes them an unsuitable choice for cold climates. Florida’s relatively mild winter temperatures make heat pumps a cost-effective choice for heating. For this study, an EER of 12 was used to compute the Energy Costs of the split system.

Maintenance Costs

Split systems have relatively inexpensive Maintenance Costs when compared to other DX systems. Regular maintenance should be performed approximately every three months to maintain proper capacity. This maintenance should include changing filters, cleaning condensate drain pans, cleaning lines, greasing bearings, and visually inspecting the wiring. The coils should be cleaned every two years.

Replacement Costs

Replacement Costs include the parts and labor to replace the outdoor condensing unit and the indoor air-handling unit. Coil life will vary based on the geographical location of the units. Units installed in schools near the ocean will have decreased life due to deterioration from salt water in the air.

Life of the Unit

The average life for split system units is 15 years. This equates to three unit replacements during the 50-year life span of the building.

Spatial Requirements/Complexity

The indoor air handler is typically located adjacent to (in a closet) or above the space that it is cooling. The condensing unit is located outside near the classroom or on the roof. Refrigerant piping and exhaust ducting must be run through the building, but this takes up little space. Suction and liquid lines are sized based on type of refrigerant used, tonnage of the unit and effective line length. A suction line accumulator may be required if the line length exceeds 75 feet. Maximum linear length between the indoor and outdoor section may be limited to 100 feet. Check manufacturer's specifications for the maximum distance between the indoor and outdoor section.

Noise

The fan and compressor of the split system unit generate noise and vibration during operation. The noise and vibration levels may vary considerably from unit to unit. This should be taken into consideration during the design phase so that the condensing unit may be located away from the classroom. Larger units should be mounted on concrete pads to reduce vibration.

Temperature and Humidity Control

Split systems provide ample air distribution throughout the conditioned space, but they provide poor filtration. Individual temperature control is provided by a thermostat. Without additional measures, a split system has poor humidity control due to the lack of a dedicated ventilation system. However, the system may be decoupled to provide adequate humidity control.

4.1.4 Water-Loop Heat Pump

A water-loop heat pump system is similar to an air-cooled heat pump in that it has a reverse refrigeration cycle to provide both cooling and heating. It uses a circulating water loop as a heat source and sink. A cooling tower may be used to moderate the water loop temperature if all the heat pumps are in cooling mode. A boiler or water heater may be used to supplement the water loop temperature if all the units are in heating mode.

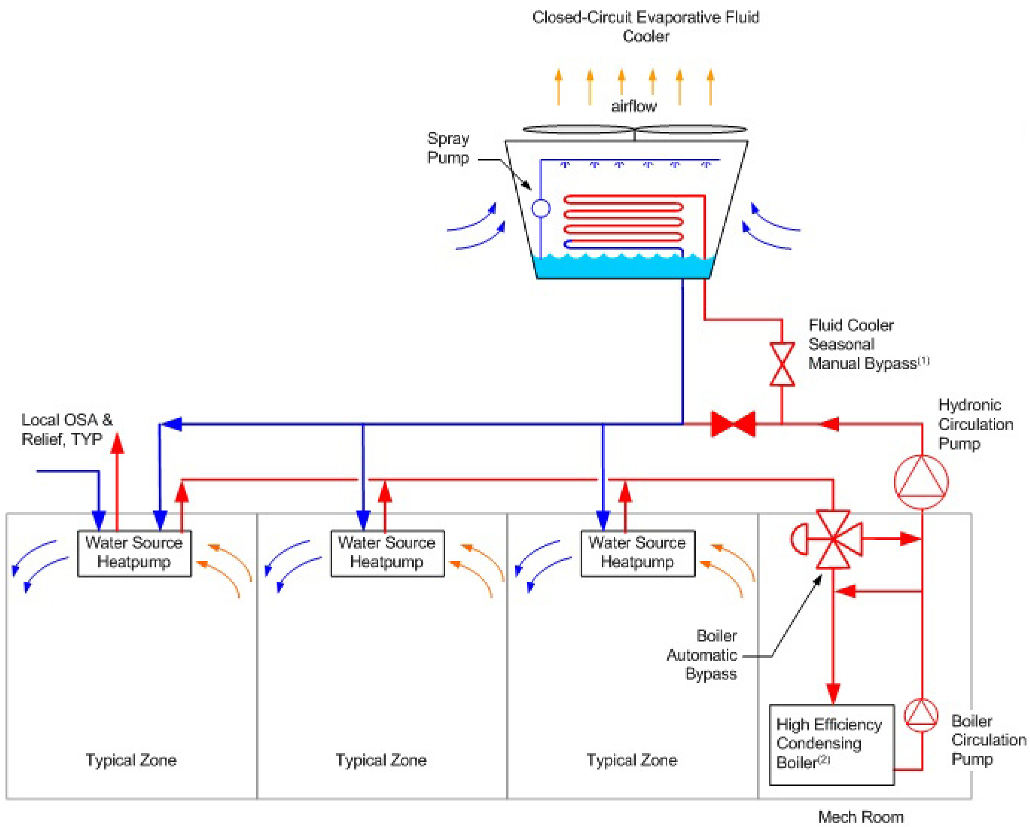


Figure 4.1.4 Water-Loop Heat Pump (Diagram Courtesy of Hargis Engineers Inc. © 2008)

First Costs

Water-loop heat pump systems will have increased First Costs over air-source heat pumps due to all of the associated equipment. First Costs will include the heat pump units, water pump, and the associated piping and ductwork for the system. It will also include the costs for the cooling tower and boiler or water heater.

Energy Costs

These systems have lower energy consumption costs due to greater unit efficiency. For this study, an EER of 12 was used.

Maintenance Costs
Routine maintenance is required for the system to maintain capacity, which includes cleaning and changing filters, replacing belts, and sealing bearings. Condenser coils may also need to be cleaned periodically. The cooling tower, water pumps, and water heaters will also require regular maintenance. Since heat pump units are often installed within the conditioned space, service of the unit may disturb the room occupants. These units also have many points of service that need to be maintained.

Replacement Costs
Replacement Costs for water-loop heat pumps will include the cost to replace the unit itself. The pump and boiler used in the system may also need to be replaced during the life of the building.

Life of the Unit
Water-loop heat pumps have a life expectancy of 24 years, which equates to two replacements during the 50-year life of the building.

Spatial Requirements/Complexity
Water-loop heat pumps are packaged units that can be placed outside of the conditioned space, on the roof, or in a mechanical closet. They require installation and configuration expertise. Adequate space is required above the ceiling to house the ductwork to distribute the conditioned air. Space must also be provided for the cooling tower and water heater. Piping must be run from the heat rejection device and water heater to each of the heat pumps in the system.

Noise
The fan and compressor of the heat pump unit generate noise and vibration during operation. The noise and vibration levels may vary considerably from unit to unit. The cooling tower and water pump will also generate noise during operation. They should be located away from the classroom areas so as not to disrupt the learning environment.

Temperature and Humidity Control
This system is well suited for buildings requiring many zones with individual temperature control. Water-source heat pumps require a dedicated outside air unit to provide ventilation to the space. This ventilation air may be supplied to the space directly or mixed with the return air. Without additional measures, this system has poor humidity control due to the lack of a dedicated ventilation system. However, the system may be decoupled to provide adequate humidity control.

4.1.5 Geothermal Heat Pump
Geothermal heat pumps use the ground, ground water, or surface water as a heat sink to provide cooling. Besides cooling, geothermal heat pumps provide heating and domestic hot water. Geothermal heat pumps may be arranged in either an open-loop or closed-loop configuration. Open-loop geothermal heat pumps use local ground water or surface water as a

direct heat transfer medium. Water is pumped from the supply source, through the unit, and then returned to the water supply. The quality of the water must be suitable for the application so that corrosion of the coils does not occur.

Figure 4.1.5 Geothermal Heat Pump with a Vertical Water Loop (Picture Courtesy of McQuay Corporation)

Closed-loop geothermal heat pumps use the ground's relative constant temperature as a means for a heat sink. The two configurations of closed-loop systems are horizontal and vertical. These systems vary on the placement of piping in the ground. In the horizontal configuration, a series of parallel pipes are laid in 3' to 6' trenches. In the vertical configuration, holes are bored 100' to 400' deep.

First Costs

Closed-loop horizontal heat pumps are the easiest of the closed systems to install. Depending on the land space available, pipes are buried in the ground in either a dense pattern that is connected in series or parallel or in a wide-loop pattern. With the unit installation costs, trenching costs are associated with laying pipes in the ground. Vertical loops are generally more expensive to install than horizontal loops, but they require less piping and less land area.

Energy Costs

Geothermal heat pumps are efficient due to the constant temperature of the ground. They are 20% to 40% more efficient than traditional air-conditioning systems. For this study, an EER of 14.1 was used to compute the Energy Costs. The cost of pumping water through an open-loop system can be higher than through a closed-loop system. These power requirements can be excessive if the pump is oversized or poorly controlled. Open-loop operating costs may be lowered if water is already being pumped for other purposes such as irrigation.

Maintenance Costs

Geothermal heat pumps have lower maintenance costs compared to conventional systems. Units are located indoors with the water pump and piping needed for the system. The tubing placed in the ground has a warranty up to 50 years.

Replacement Costs
Replacement Costs for this system include the material and labor cost to replace the unit at the end of its useful life. The ground water pumps may also need to be replaced over the life of the building.

Life of the Unit
Geothermal heat pumps have an average life of 24 years, which equates to two unit replacements during the 50-year life of the building. The quality of the local ground water source can affect the life of the unit. Contaminants in the water supply can lead to corrosion of coils.

Spatial Requirements/Complexity
The ground area for this type of system can be large; however, the pipe loops for these systems may be buried beneath lawns, landscaping, and parking lots.

Noise
The fan and compressor of the heat pump unit generate noise and vibration during operation. The noise and vibration levels may vary considerably from unit to unit. However, these units are normally located in a mechanical room or closet so they will not disturb the learning environment.

Temperature and Humidity Control
Water-source heat pumps require a dedicated outside air unit to provide ventilation to the space. This ventilation air may be supplied to the space directly or mixed with the return air. Without additional measures, this system has poor humidity control due to the lack of a dedicated ventilation system. However, the system may be decoupled to provide adequate humidity control.

4.2 CHILLER SYSTEMS
Two main types of chiller systems are absorption and vapor compression (refrigeration) chillers. An absorption chiller uses water as the system's refrigerant and lithium bromide as the absorbent. A heat-operated refrigeration machine is used instead of a compressor to condense and compress the refrigerant. Absorption chillers may be classified as single-stage or two-stage, with the latter offering greater efficiency. Few, if any, public schools in Florida use absorption chillers.

In vapor compression chilled water circulating systems, the air is conditioned by using chilled water that is circulated to various cooling coils in air handlers throughout the building. Heat from the conditioned space is absorbed by the circulating chilled water. This heat is then removed from the water by the primary refrigerant system in the water chiller. Four main types of vapor compression chillers may be used: reciprocating, helical rotary (screw), scroll, and centrifugal. Each of these systems uses a different type of compressor. The efficiency of the chiller system depends on the type of chiller that is selected. Discernable cost differences among these four types of vapor compression chillers were not determined for these *Guidelines*.

The chiller systems described in this section provide chilled water to air-handling units located throughout the educational facilities. Table 4.1 presented at the beginning of Section 4.1 shows the Life Cycle Cost criteria and system selection criteria for comparing chiller systems to direct expansion systems. Additional descriptions on how each of these criteria was calculated and ranked can be found in Appendix C.

4.2.1 Air-Cooled Chiller
Air-cooled chillers are used to produce chilled water for air-handling units. The chillers absorb heat from processed water and transfer it to surrounding air. They are completely packaged with air-cooled condensers. Figure 4.2.1 shows an array of air-cooled chillers.

Figure 4.2.1 Air-Cooled Chiller

First Costs
This system, as a whole, has a high First Cost, which includes the chiller, air handling units, pumps, piping, and ductwork. However, the initial cost per ton of the chiller itself is less than the cost per ton of direct expansion (DX) units. The First Costs of the chillers will depend on the type of chiller installed. Scroll compressors are typically used for applications up to 190 tons and screw compressors are used for applications 140 to 500 tons.

Energy Costs
Energy Costs will vary based on the type of chiller installed due to differences in system efficiencies. Air-cooled chillers are not as energy-efficient as water-cooled chillers, but they are more efficient than DX systems. For this study, a unit efficiency of 0.98 kW/ton was used to compute the unit Energy Costs.

Maintenance Costs
Air-cooled chillers have lower maintenance costs than DX systems. Maintenance costs may vary based on the type of chiller used. Once a year, the strainers at the air-handling unit should be cleaned of debris to ensure proper water flow to the unit. The air handlers will also require regular service to maintain proper capacity.

Replacement Costs
Replacement costs for this system include the material and labor to replace the chiller at the end of its useful life. Condensing unit pumps and chilled water pumps will also need to be replaced every three to five years. Coil life will vary based on the geographical location of the units. Units installed in schools near the ocean will have decreased life due to deterioration from salt water in the air.

Life of the Unit
Air-cooled chillers have a life expectancy of 25 years, which equates to one replacement during the 50-year life of a building. The life of the unit can vary based on the type of compressor used in the unit. A chiller with a reciprocating compressor will have a shorter life than chillers with a centrifugal or screw compressor.

Spatial Requirements/Complexity
The chillers themselves have a large footprint, which will vary in size based on the tonnage. They require outdoor installation to reject heat to the surrounding air. The system requires piping to distribute the water to and from the air-handling units, which are normally placed in mechanical rooms located throughout the building.

Noise
Air-cooled chillers produce a considerable amount of noise during operation. However, these units are normally placed in service areas away from classroom buildings. The noise heard in the classroom buildings will depend on the noise of the air distribution system employed. While their noise should not significantly affect the classroom environment, air-cooled chillers may be too loud for the school’s surrounding residents. The placement of these systems should

be carefully considered during the design phase. Noise reduction can be achieved by encapsulation of motors and by noise abatement panels.

Temperature and Humidity Control

The temperature of the chilled water effectively cools and dehumidifies the supply air. Outside air may be mixed with return air to provide ventilation to the space.

4.2.2 Water-Cooled Chiller

Water-cooled chillers absorb heat from processed water and transfer it to another water source, such as a cooling tower with an open water loop. Figure 4.2.2 shows different components of a water-cooled system.

Figure 4.2.2 Water-Cooled Chiller

First Costs

Water-cooled chiller systems require the field installation of a chiller, cooling tower, condenser water pump(s), and piping. The system installation costs are 15% more than that of air-cooled chiller systems. The First Costs also depend on the type of chiller installed. Scroll compressors are typically used for applications up to 190 tons and screw compressors are used for applications 140 to 500 tons. Centrifugal compressors are typically used for applications over 400 tons.

Energy and Operating Costs

Water-cooled chillers have a high efficiency. Centrifugal chillers are available with efficiencies from 0.68 kW per ton to 0.47 kW per ton. For this study, an efficiency of 0.56 kW per ton was used to compute the unit Energy Costs.

Maintenance and Repair Costs

Water-cooled chillers require water treatment to prevent mineral buildup. Mineral deposits on the heat exchanger fins greatly reduce the efficiency of the system. The cooling towers also require maintenance. Once a year they should be drained and cleaned, and twice a year the strainers should be cleaned. The air handlers will also require regular service to maintain proper capacity. Once a year the strainers at the air-handling unit should be cleaned of debris to ensure proper water flow to the unit.

Replacement Costs

Replacement costs for this system include the material and labor to replace the chiller at the end of its useful life. Condensing unit pumps and chilled water pumps will need to be replaced every three to five years.

Life of the Unit

Water-cooled chillers have a life expectancy of 25 years, which equates to one replacement during the 50-year life of the building. The life of the unit can vary based on the type of compressor used in the unit. A chiller with a reciprocating compressor will have a shorter life than a chiller with a centrifugal or screw compressor.

Spatial Requirements/Complexity

A mechanical room is needed to house the chiller and pumps. This room should be properly sized so that enough clearance is available to service the chiller. The system requires piping to distribute the chilled water to and from the air-handling units, which are normally placed in mechanical rooms located throughout the building. Properly trained maintenance personnel are needed to maintain this type of system.

Noise

Water-cooled chillers produce significantly less noise than air-cooled chillers during operation. As with air cooled chillers, these units are normally placed in service areas that are located away from classroom buildings. The noise heard in the classroom buildings will depend on the noise of the air distribution system employed. The noise generated by the chiller system should be taken into consideration during the design of the school so as not to produce too much noise for the school's surrounding residents. Cooling towers typically have high levels of noise generation and their location must be carefully considered so as not to interfere with the academic and administrative operations of the educational facility.

Temperature and Humidity Control

Temperature and humidity control will depend on the method of air distribution used in the building. The temperature of the chilled water effectively cools and dehumidifies the supply air. Outside air may be mixed with return air to provide ventilation to the space.

Chillers with Ice Storage

In this variation, the chillers may be operated during non-peak hours to produce ice. During peak demand hours, water is circulated through the ice to produce chilled water for the air-conditioning units. Figure 4.2.3 shows ice storage units that may be used with both air-cooled or water-cooled chillers.

Figure 4.2.3 Ice Storage Units

The initial cost for a thermal storage system will be greater than just the chiller system due to the equipment needed to produce and store the ice. However, Energy Costs will be reduced in this situation because peak electrical demand charges may be reduced by running the chiller during non-peak hours.

4.3 AIR DISTRIBUTION SYSTEMS

The following systems use varying methods to distribute air to the conditioned space. These methods may be used to distribute air in both direct expansion (DX) systems and chiller systems. Table 4.3 shows the Life Cycle Cost criteria and system selection criteria for comparing air distribution systems.

Table 4.3 Life Cycle Cost and System Selection Criteria Matrix for Air Distribution Systems

Legend: GOOD | FAIR | POOR

Unit Type	First Cost	Replacement Cost	LCC	Required Space	Complexity	Life of Unit	Noise	Temp. Control
4.3.1 Constant Volume	1	1	1	1	1	1	1	2
4.3.2 Variable Air Volume (VAV)	2	2	2	2	2	2	1	1
4.3.3 Variable Volume & Temperature (VVT)	2	2	2	2	2	2	1	1
4.3.4 Fan-Coil Units	3	3	3	3	3	2	2	1

4.3.1 Constant Volume

Constant volume systems deliver a constant volume of air to the conditioned space. Variations in the thermal requirements of a space are achieved by changing the temperature of the constant volume of air delivered to the space.

First Costs

First Costs for constant volume systems include the costs to install the supply and return ductwork needed to move the air to and from the occupied space.

Energy and Operating Costs

The energy consumption for these systems can vary greatly depending on the efficiency of the refrigeration equipment. Constant volume systems are not as energy-efficient as variable air volume (VAV) systems.

Maintenance and Repair Costs

Maintenance will need to be done only on the air-handling unit itself. No maintenance is required for the supply and return ductwork with the exception of duct cleaning.

Replacement Costs

Replacement Costs will include only the cost to replace the air-handling unit. Ductwork is assumed to have a service life of 50 years.

Life Cycle Costing

The Life Cycle Cost of the system will depend on the HVAC unit providing the conditioned air.

Spatial Requirements/Complexity
This system requires sufficient space above the ceiling to house the supply and return ductwork. The size of the ductwork is based on the size (cubic feet per minute) of the air-handling unit providing the conditioned air. Controls for this type of system are not as complicated as those needed for Variable Air Volume (VAV) systems.

Noise
Ductwork should be properly sized to prevent whistling.

Temperature and Humidity Control
This system does not provide as much control over the temperature and air flow in the conditioned space as a VAV system. A constant fraction of outdoor air may be mixed with return air to provide proper ventilation to the space.

4.3.2 Variable Air Volume (VAV)

Variable air volume, or VAV, systems deliver only the amount of cold air to a space that is needed to achieve its cooling load. A direct expansion (DX) or chilled water coil air handling unit provides the conditioned air at a constant temperature for this system. A supply duct delivers the air to the VAV boxes located in the individual zones. The amount of air that flows into the VAV box is regulated by a balancing damper. Heating may be provided by a reheat coil in the VAV box.

First Costs
VAV systems will have an increased cost over constant volume systems due to the need for the VAV boxes and their required electrical hookup.

Energy Costs
According to the U.S. Environmental Protection Agency, VAV systems are more energy-efficient than constant volume systems, consuming 10% to 20% less energy than constant volume systems. The energy consumption for these systems can vary greatly, depending on the efficiency of the refrigeration equipment, the minimum air flow control settings, and the energy-conserving options employed.

Maintenance Costs
Routine maintenance on the air-handling unit for VAV systems takes place within the centralized equipment room. Since these rooms are located in remote zones, building occupants will not be affected. Little maintenance is required for the zone VAV boxes.

Replacement Costs
The VAV boxes have a useful service life of 20 years and will need to be replaced twice during the life of the building.

Life Cycle Costing
Life Cycle Costs associated with this method of air distribution include the First Costs and Replacement Costs of the VAV boxes.

Spatial Requirements/Complexity
Space is needed above the ceiling to house the VAV boxes and associated ductwork. The system also requires controls to operate the VAV boxes.

Noise
VAV systems have quiet operations since the air-handling unit is located away from the conditioned space.

Temperature and Humidity Control
VAV systems offer a high level of temperature control for the individual zones. No separate ventilation or exhaust system is required. However, minimum air flows are required to meet fresh air ventilation rates if a decoupled system is not employed.

4.3.3 Variable Volume and Temperature (VVT)
Variable volume and temperature, or VVT, systems use constant volume air-handling units to supply air for the system. Each room or zone has a VVT terminal box equipped with a volume damper. This damper regulates the amount of air that is provided to the space in response to the zone thermostat. Supply air not used by the system is bypassed to the return air plenum or ducted return. Heating for this system may be provided by a heating coil in the unit or in the supply duct.

First Costs
Packaged rooftop units or split systems may be used to supply air in a VVT system. VVT systems have low to moderate installed costs since they use standard equipment and ductwork.

Energy Costs
While the volume of air supplied to the conditioned spaces is reduced, the fan's total air flow remains constant. Therefore, the fan power and its associated Energy Costs remain constant.

Maintenance Costs
Routine maintenance for VVT systems takes place within the centralized equipment room on the air handler itself. No routine maintenance is required in the conditioned space. Few points of maintenance are required with this air distribution system. The volume dampers may have to be greased if they get stuck.

Replacement Costs
The VVT boxes have a useful service life of 20 years and will need to be replaced twice during the 50-year life of the building.

Life Cycle Cost
Life Cycle Costs associated with this method of air distribution include the First Costs and Replacement Costs of the VVT boxes.

Spatial Requirements/Complexity
VVT systems require space above the ceiling to house the VVT terminal boxes and the supply and return ductwork. The air-handling unit is placed either on the roof or in a mechanical room. Controls will have to be installed to regulate the volume dampers for the system.

Noise
VVT systems provide quiet operation since the air-handling unit is placed on the roof or in a centralized mechanical room. Rooftop rumble should be taken into account with packaged rooftop units.

Temperature and Humidity Control
VVT systems provide good indoor air quality. No separate ventilation system or exhaust system are required for zones.

4.3.4 Fan-Coil Units

Fan-coil units are single zone air conditioners with either chilled water or direct expansion (DX) cooling coils. They are located at or within the conditioned space. They are available in either a two-pipe or four-pipe arrangement. The two-pipe fan-coil is the most common arrangement. A separate ventilation and exhaust system is needed in this distribution system. Heating for this system is provided either by an electric heating element (DX coils) or hot water coils.

First Costs
The fan-coil units will need to be connected to the chilled water supply and return. The two-pipe arrangement carries a lower First Cost than the four-pipe system.

Energy Costs
The fan-coil units themselves consume a low amount of energy since the air friction losses are low. The system energy consumption depends on the efficiency of the chilled water system.

Maintenance Costs
The difficulty of maintenance depends on the location of the unit. Repairs must be made within the conditioned space, which can disrupt occupants. Many points of maintenance are required in this type of system.

Replacement Costs
Fan-coil units have a life expectancy of 20 years, which equates to two replacements during the 50-year life of the building.

Life of the Unit
Life Cycle Costs associated with this method of air distribution include the First Costs and Replacement Costs of the fan-coil units.

Spatial Requirements/Complexity
Fan-coil units may be placed above the ceiling or within the conditioned space. Placement above the ceiling will provide better room aesthetics.

Noise
Fan-coils units can be noisy since their fan is located in the unit.

Temperature and Humidity Control
Fan-coil units provide consistent air circulation in the room. Ventilation requirements are satisfied by an independent system.

4.4 EMERGING SYSTEMS AND TECHNOLOGIES

The following systems are emerging technologies that have the potential for use in educational facilities. At the time of this study, few of these emerging systems, if any, are currently being used in schools; however, they are on the verge of gaining more use.

4.4.1 Heat Pipe

A heat pipe is a thermal transfer device. When employed in an air-handling unit, it provides an economical and reliable means of recovering both heating and cooling. Heat pipes have two sections: pre-cool and reheat. The pre-cool portion is located in the incoming air stream. As the hot and humid air passes over the pre-cool section, some of the heat is transferred from the air to the refrigerant in the heat pipe. This heat vaporizes the refrigerant, which causes it to travel to the reheat section of the heat pipe.

The reheat portion of the heat pipe is located after the cooling coil and acts as a reheat coil. The reheat portion uses the heat transferred from the pre-cool portion to warm the overcooled and dehumidified air to a comfortable temperature. This pre-cooling and reheat process is all done without any additional energy use.

Heat pipes are capable of removing a greater amount of moisture from the conditioned air than traditional systems, which helps to improve indoor air quality of the building. Heat pipe systems have lower Energy Costs than conventional systems that use active reheat.

4.4.2 Magnetic-Bearing Compressors

Magnetic-bearing compressors use magnetic levitation to suspend the rotor shaft and impellers in the compressors of chillers, which allows for frictionless operation that greatly increases the reliability of the system. The frictionless operation also eliminates the need for oil handling equipment, which is found in conventional compressors. The service life of the compressors is greatly increased since no mechanical wear occurs with the frictionless technology, which also reduces the maintenance cost of the system.

Magnetic-bearing compressors are compact in size and weigh less than traditional compressors, which reduces the overall footprint of the chiller itself, thus saving building space. Magnetic-bearing compressors are more energy-efficient than traditional compressors, which decreases system operating costs. These compressors produce much lower sound levels during operation than normal compressors. They also have reduced vibration levels, which minimize the vibration that may be transferred to the structure.

4.4.3 Variable Refrigerant Flow Systems

Variable refrigerant flow systems consist of multiple air-handling units connected to a single external condensing unit. The air-handling units supply air at a constant volume, but vary the flow of refrigerant through the coils using an electronic expansion valve. This expansion valve reacts to several temperature sensing devices, and it modulates to maintain the desired temperature.

Variable refrigerant systems can offer increased energy efficiency. This system allows for many zones, each with its own thermostat. Maintenance for this system is similar to other DX systems.

4.5 SUMMARY

HVAC systems can be very complex and the design and selection of these systems must be accomplished while considering a wide range of criteria. Since systems are uniquely designed to condition specific buildings, it is difficult to precisely predict their cost over the building's useful life. The life cycle parameters presented in this chapter represent economic conditions at the time of publication. A detailed Life Cycle Cost analysis should be performed for the specific design of the building to provide the school or institution with a better estimate of the costs of an HVAC system. The recommendations provided in this chapter should not replace detailed studies performed by mechanical engineers, which are specific to each project.

CHAPTER 5
LIGHTING SYSTEMS

5.0 INTRODUCTION

Excellence in the design of lighting systems is important for new educational facilities for two major reasons: (1) lighting quality affects student performance, and (2) the operational costs of lighting systems can be significant. Because the quality of lighting is an important factor in student performance, the designer must optimize lighting quality along with life cycle cost. Energy costs are very important and are becoming more so over time. The cost of electricity has risen more than 40% in the past 40 years and lighting now accounts for 25% of a typical school's electricity costs. Choosing energy-efficient designs will enable a school to have more resources to invest in education. This chapter will present an overview of lighting design goals for educational facilities. Metrics used to measure energy consumption are presented in addition to the American Society of Heating, Refrigeration, and Air Conditioning Engineering (ASHRAE) recommendations for energy-efficient educational facility lighting in Florida. Different types of lights and their Life Cycle Costs are presented. In summary, by making good choices in lighting, school districts can achieve the design goal of providing high quality lighting in an energy-efficient manner.

5.1 LIGHTING PRINCIPLES

The quantity of light emitted by a lamp is measured in lumens, a useful unit for comparing different lighting technologies. For example, a premium 32-watt lamp emitting 3,100 lumens is superior to a standard 32-watt lamp emitting 2,800 lumens. Lighting levels in a room are measured in footcandles, which is the quantity of light per unit area or the number of lumens per square foot. For the purposes of lighting design, the footcandle measurement is determined for the work surface, a horizontal plane at the height of a desk top. This measurement is useful because a student needs a certain amount of light on the desk top to enable him or her to work. The Illumination Engineering Society of North America (IESNA) publishes guidelines with recommended footcandle levels for many spaces included in educational facility classrooms. For classroom activities, a horizontal illumination of 40 footcandles provides adequate illumination for students to perform reading and writing tasks. Although this design approach provides adequate lighting, good visual comfort, which impacts occupant performance, requires a more holistic approach. A good design should follow IESNA's recommendations, which include horizontal illumination, vertical illumination, uniformity, glare, and color rendering.

If only horizontal illumination is considered, then the optimum solution is to use direct lighting, which directs all light to the desk top. However, the result of this strategy would be dark walls and dark ceilings. This creates problems because the occupant's perception of the lighting is that the room is dark, and the contrast of bright lights and dark ceiling increases visual discomfort, which negatively impacts occupant performance. Wall spaces are often used for displays that require high levels of vertical illumination. The front wall is often used for video projection, which requires low levels of vertical illumination. This difference is shown in Figures 5.1 and 5.2, which depict the differences between an efficient direct luminaire (see Figure 5.1) and a volumetric luminaire (see Figure 5.2). Both systems effectively illuminate the desk tops, but the volumetric system also illuminates the ceiling and walls.

Figure 5.1 Direct Lighting

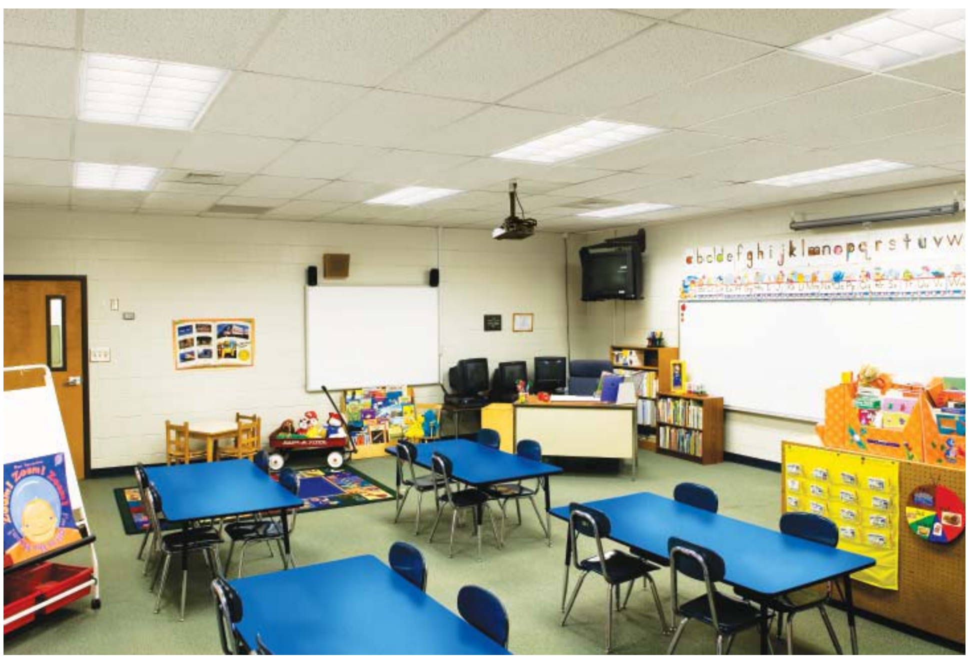


Figure 5.2 Volumetric Lighting Retrofit

Lighting uniformity is also important. The 40 footcandle recommendation also stipulates that the lowest illumination of any area more than 3’ from the walls should be at least 20 footcandles. Indirect lighting is more effective at providing uniformity of illumination and vertical illumination; direct lighting is effective only for horizontal illumination. For this reason, using a direct/indirect lighting system (see Figure 5.3) works well for classroom illumination where ceiling heights are at least 9’ high. Daylight harvesting also adds to lighting quality by providing good vertical illumination. Although the level of lighting can significantly vary when using daylight, humans are not very sensitive to this variance. Studies have found that people can read text at lighting levels between 20 and 250 footcandles without any differences in reading speed and comprehension.

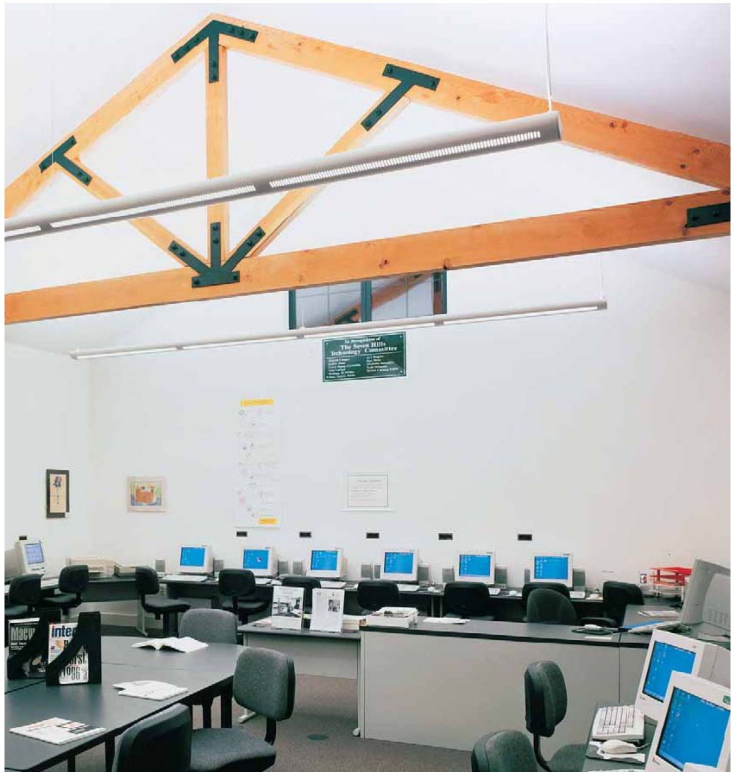


Figure 5.3 Direct/Indirect Lighting

Both daylight harvesting and electric illumination present challenges in controlling glare. When doing desk work, vertical glare is distracting, and glare will reduce contrast on whiteboards and for video projection.

Color rendering impacts how colors are perceived. Color rendering can be improved by choosing lamps with a color rendering index (CRI) of at least 80 and by harvesting daylight. Incandescent lamps have a CRI of 100, but are not often used because they have a much lower efficacy (lumens/watt) than fluorescent and high intensity discharge (HID) lamps. Fluorescent lamps continue to improve, and the designer can achieve good color rendering by specifying high CRI lamps (see Table 5.1).

5.2 DAYLIGHTING

Daylight harvesting can provide adequate illumination for classroom tasks, with good uniformity and vertical illumination. For daylighting, windows are placed high on the walls and shaded to block direct sunlight. This strategy results in high quality ambient lighting without the solar heat gains associated with direct sunlight. This approach can reduce lighting energy consumption and reduce interior heat gain from lighting, which helps reduce cooling loads. In addition to the energy benefits, a study by the National Renewable Energy Laboratory (NREL) showed that students working in a daylit classroom progressed 20% faster on math tests and 26% faster on reading tests in one year when compared to classrooms with the least amount of daylighting.

5.3 CHOOSING AN ENERGY-EFFICIENT LUMINAIRE

The efficiency of lighting also depends on a particular light fixture's effectiveness at directing the lamp lumens to the desired location. Comparing different lighting systems requires the use of software that calculates lighting levels on both horizontal and vertical surfaces. Once the goals of horizontal/vertical illumination, uniformity, glare, and color rendering have been achieved, the power density of that lighting layout can be calculated and compared to recommended levels and competing lighting layouts. This power density measurement is calculated in watts per square foot (w/ft^2). The ASHRAE Standard 90.1-2007 limits power density to 1.35 w/ft^2; however, ASHRAE's guide for energy-efficient K-12 facilities recommends a maximum of 1.1 w/ft^2 for classroom lighting (1.2 w/ft^2 when daylighting is used).

Another efficiency measurement for lighting is efficacy, which is the ratio of lumens produced to watts consumed. Efficacy numbers must be carefully compared. For example, Table 5.1 shows the lumen output for four different 4' long T8 fluorescent lamps. The lumen output is given in both the initial output for a new lamp and the average output during the life of the lamp. In this study, the average lumen output is used when computing efficacy. This method is consistent with the method used by ASHRAE in its K-12 guidelines. ASHRAE recommended for efficacy is 85 mean lumens per watt (MLPW) for linear fluorescent lamps. For daylit spaces, the recommendation is 75 MLPW. All other light sources have a recommended 50 MLPW.

5.3.1 Linear Fluorescent Lamps

For linear fluorescent lighting, lamps are available in standard, efficient, and premium versions. Table 5.1 shows typical technical and cost data for T8 fluorescent lamps.

Table 5.1 Typical Lamp Data for T8 Fluorescent Lamps

Lamp Type	Sylvania Cat. #	Nominal Watts	Average Life (hrs)	CRI	Initial Lumens	Mean Lumens	Cost (2010)
Premium	F032/830/XPS/ECO	32	36000	85	3100	2945	$5.50
Efficient	F032/730/XP/ECO	32	36000	78	2850	2705	$2.50
Standard	F032/730/ECO	32	25000	78	2800	2520	$1.75
Super Saver	F028/830/XP/SS/ECO	28	36000	85	2475	2350	$5.00

Fluorescent lamps require an electrical device called a ballast to power the lamps. With improvements in lamp technology, ballast efficiency has dramatically improved over the years. Ballasts are available using older magnetic technology or current electronic versions. School energy regulations now limit schools to using only the more efficient electronic ballasts. As with lamps, standard and premium efficiency ballasts are available. Fluorescent lamps cannot be dimmed unless a special dimming ballast is specified for the light fixtures. Table 5.2 shows the costs for instant start, programmed start, and dimming ballasts for a 2-lamp linear fluorescent fixture. The programmed start ballast follows a precise startup sequence that first heats the cathode on the fluorescent lamp before raising the voltage to illuminate the fluorescent tube. This operation extends the life of the lamp compared to the instant start ballast, which quickly ignites the lamp using a large startup current. Instantly starting the lamp slightly damages the cathode in the fluorescent tube. Programmed start ballasts may increase lamp life by 50% in situations where lamps are cycled on and off frequently, for example, when occupancy sensors are used to control lighting. Programmed start ballasts do not make financial sense if cycling is infrequent. Lamp life data published by lamp manufacturers (see Table 5.1) assume that lamps are left on 12 hours per start. A rapid start ballast heats the cathode of the lamp in a manner similar to the programmed start ballast. The difference is that the rapid start ballast continues to heat the cathode after the lamp is lit, which decreases the luminaire efficiency. Rapid start ballasts cost about the same as instant start ballasts and are used when lamps are cycled on and off frequently. Dimming systems have proven economical for use in conjunction with daylight harvesting systems. In this configuration, classroom lighting is kept constant by adjusting the electrical lighting as the amount of daylighting varies during the day.

Table 5.2 Cost of T8 Electronic Ballasts

Type of Electronic T8 Ballast, 2 Lamp	Cost (2010)
Instant Start	$25
Rapid Start	$25
Programmed Start	$50
Dimming	$100

5.3.2 LED Lighting

Light Emitting Diodes (LEDs) are solid-state light bulbs that are very energy-efficient. LEDs are relatively new for commercial lighting due to advances in LED technology. Recently LEDs have been developed that can produce a bright, white light. LEDs have a useful life of 50,000 hours, and they have been used in applications where maintenance-free reliability is important. An example of a common commercial use for LEDs is in lighted exit signs. LEDs contain no mercury, making them more environmentally friendly than fluorescent bulbs. The lumen level is lower than that available from a fluorescent troffer, making the LED version suitable where low to medium lighting levels are needed. At present LEDs cost three to four times more than corresponding fluorescent fixtures, and the efficacy of the LED fixture is lower than that of a quality linear fluorescent fixture. LED highbay fixtures currently cost five to six times more than corresponding metal halide fixtures, and have a slightly better efficacy. LED commercial lighting systems are relatively new and prices will likely drop as more products become available. Florida regulations for school construction now make LED lighting a priority consideration in the selection and design of lighting systems.

5.3.3 Compact Fluorescent Lighting

Compact fluorescent lighting is well suited for down-lighting in areas that require low to medium levels of light, for example, a lobby. Compact fluorescents are not suitable for classroom lighting because a large number of compact fluorescent lights would be required to achieve the same lighting as a lower number of linear fluorescent luminaires, increasing the labor cost for the installation. Compact fluorescent lights are also used for architectural effects, such as wall wash lighting. The luminaire below is a common 6” diameter recessed can light. This luminaire is available in a dimmable version, making this an energy-efficient replacement for incandescent down-lighting. As with the linear fluorescent lamps, compact fluorescent lamps can have good color rendering qualities.

Figure 5.4 6” Compact Fluorescent (CFL), (1) 32-Watt CFL, Clear Diffuser

5.4 CLASSROOM LIGHTING SYSTEMS

Classrooms have shifted from using blackboards with chalk to whiteboards with markers, and now to interactive smartboards with content projected onto screens. Blackboards work more effectively with high illumination and are not susceptible to glare. Glare must be controlled when whiteboards are being used in a classroom. When showing a video, whether with a large screen LCD, rear projection, or front projection, rooms need to be darkened and vertical illumination on the instruction wall must be carefully limited. New technology will inevitably continue to result in challenging lighting scenarios, and, as a result, lighting systems need to be adaptable. The current recommendation for classroom lighting is to provide a two-level illumination system with which a teacher can easily adjust the illumination level when using video equipment. Daylight harvesting improves lighting quality, reduces energy consumption, and has been shown to positively affect student progress. Therefore, daylight harvesting should be considered whenever possible. The Florida Building Code requires that occupancy sensors be installed to turn lights off in unoccupied rooms. If daylight is being harvested, then controls should be installed to automatically dim the electric lights in response to the amount of daylight being harvested. Fixtures within 15’ of windows and 10’ of skylights should have these automatic controls. Figures 5.4 through 5.6 show a 30’ x 30’ x 9’ classroom illuminated in instruction mode, A/V presentation mode, and daylight mode.

Figure 5.5 Instruction Mode

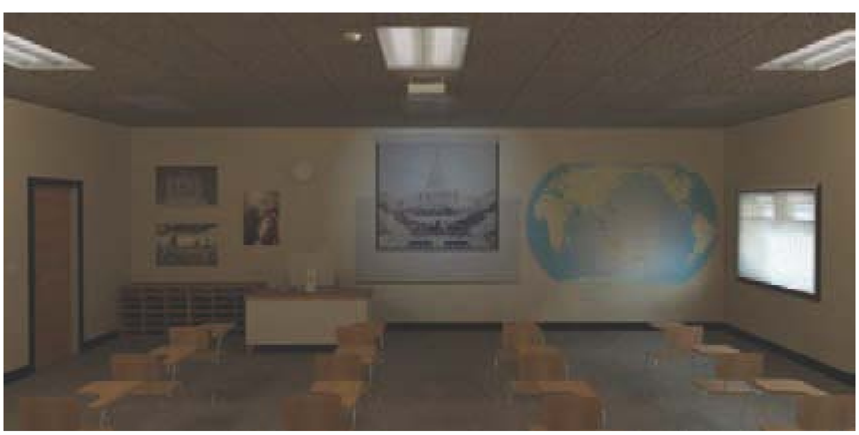


Figure 5.6 A/V Presentation Mode


Figure 5.7 Daylight Mode

5.5 ECONOMICS
Lighting quality depends on many factors, such as the reflectance of the ceiling/wall finishes and the dimensions of the room. In this section, the economics of classroom lighting are analyzed using a classroom with the same interior finishes as shown in Figure 5.4. The classroom dimensions are 30' x 30' x 9'. The ceiling reflectance is 80%, the wall reflectance is 50%, and the floor reflectance is 20%. The horizontal illumination was calculated at 2.5' above the floor, and the vertical illumination was calculated for the north and west walls. Power consumption is then calculated without the effects of daylight. Using this approach, the efficiency of different types of lighting systems can be compared. Adding daylight will reduce the need for the electric lighting equally for all the configurations. Seven types of luminaires that are suitable for classroom lighting were used to compare energy consumption, maintenance, and life cycle costs. Pictures of these lighting systems are provided below.

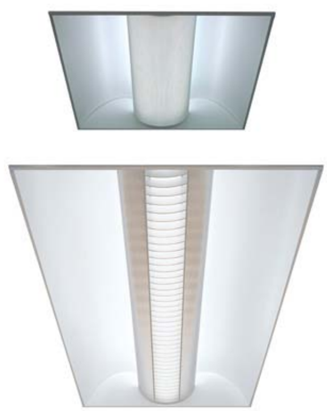
5.5.1 Recessed Lensed Troffer, (2) 32-Watt T8 lamps, Electronic Ballast

5.5.2 Recessed Parabolic Troffer, (2) 32-Watt T8 lamps, Electronic Ballast

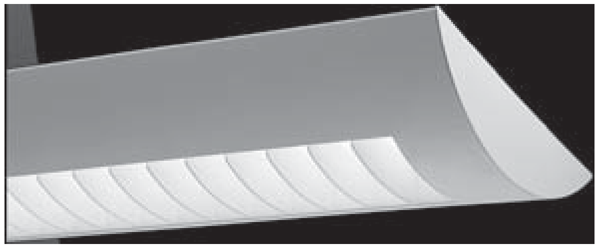
5.5.3 Recessed Volumetric Troffer, (2) 32-Watt T8, Electronic Ballast

5.5.4 Recessed Volumetric Troffer, (2) 28-Watt T5, Electronic Ballast

5.5.5 Recessed Direct/Indirect Troffer, (2) 32-Watt T8, Electronic Ballast



5.5.6 Suspended Direct/Indirect, (3) 32 Watt T8, Electronic Ballast



5.5.7 Recessed Volumetric, LED, 45 Watts

Table 5.3 summarizes the performance of each lighting system. The results are from lighting simulation software that was used to calculate the lighting levels employing both direct and reflected components. The number of lights and placement of the lights was chosen to achieve good illumination and uniformity without excessive glare. Based on the simulation, the power consumption was calculated in w/ft^2, and the efficacy was calculated by dividing horizontal footcandles by the power consumption in w/ft^2. The calculated efficacy can be used to compare and rank the various lighting systems.

Table 5.3 Efficacy of Classroom Luminaires

Legend: GOOD | FAIR | POOR

Fixture	Mounting	Lamp	Type	Lumens	Horiz FC	N FC	W FC	w/ft^2	Efficacy
5.5.1 Recessed Lensed Troffer (T8)	Recessed	(2) 32 W T8	Fluorescent	2850	38	14	25	0.58	66
5.5.2 Recessed Parabolic Troffer (T8)	Recessed	(2) 32 W T8	Fluorescent	3100	34	15	26	0.48	71
5.5.3 Recessed Volumetric Troffer (T8)	Recessed	(2) 32 W T8	Fluorescent	3100	46	32	30	0.72	64
5.5.4 Recessed Volumetric Troffer (T5)	Recessed	(2) 32 W T5	Fluorescent	2730	38	17	29	0.58	66
5.5.5 Recessed Direct/Indirect (T8)	Recessed	(2) 32 W T8	Fluorescent	3100	47	21	21	0.95	49
5.5.6 Suspended Direct/Indirect (T8)	Suspended	(3) 32 W T8	Fluorescent	2850	27	14	22	0.58	47
5.5.7 Recessed Volumetric (LED)	Recessed	45 W LED	LED	3300	45	21	24	0.8	56

Notes: Horizontal illumination (Horiz FC) was calculated in footcandles at 2.5' above the floor. Vertical illumination was calculated in footcandles on the north wall (N FC) and west wall (W FC). The power consumption in w/ft^2 was calculated based on the 30' x 30' x 9' room previously described, and includes both direct and interreflective components. The efficacy value (lumens/watt) is for the horizontal illumination, calculated by dividing the horizontal illumination (Horz FC) by the w/ft^2 .

Table 5.3 shows that the highest efficacy for horizontal illumination is achieved by using recessed parabolic luminaires (ID2), which are an efficient form of direct lighting. These fixtures are generally not used for classroom lighting because they perform poorly for vertical illumination. This difference can be seen by comparing Figures 5.1 and 5.2. The room in Figure 5.1 appears poorly illuminated despite having adequate horizontal illumination because the walls and ceilings are dark. The dark walls and ceilings affect the perception of brightness and they also reduce the legibility of posters or pictures placed on the walls. For this reason, the preferred lighting for a classroom is volumetric or lensed troffers (ID 1 and IDs 3-5). Of these two, the volumetric luminaires are generally considered more aesthetically appealing.

5.5.1 Life Cycle Costs

The following assumptions are used for a Life Cycle Cost analysis of the systems in the previous section. The analysis is based on the overall efficiency of each light fixture type for a 30’ x 30’ x 9’ classroom. The analysis period is 50 years and the life of the lighting system is assumed to be 25 years. The analysis also assumes that, after 20 years, the needs of the space will change based on changes in student populations, teaching styles, and technology. The First Cost and Replacement Cost are based on the material and labor required to install the light fixtures. These costs do not include the cost of the underlying electrical distribution system since this cost is similar for each fixture type. The cost of energy was assumed to be $0.12/kWh, the average cost of electricity for Florida municipalities in January 2010. The Maintenance Cost assumes relamping all lights once and replacing one fixture in the classroom. The resulting Life Cycle Cost analysis is shown in Table 5.4, where the ID column corresponds to the seven types of fixtures described above.

Table 5.4 Life Cycle Cost per Square Foot Based on 2010 Dollars

Legend: GOOD | FAIR | POOR

Fixture	First Cost	Energy Cost	Maint. Cost	Replacement Cost	LCC
5.5.1 Recessed Lensed Troffer (T8)	1	1	1	1	1
5.5.2 Recessed Parabolic Troffer (T8)	1	1	1	1	1
5.5.3 Recessed Volumetric Troffer (T8)	2	2	2	2	2
5.5.4 Recessed Volumetric Troffer (T5)	2	1	2	2	2
5.5.5 Recessed Direct/Indirect (T8)	2	1	2	2	2
5.5.6 Suspended Direct/Indirect (T8)	3	3	3	3	3
5.5.7 Recessed Volumetric (LED)	3	2	1	3	3

Although Table 5.4 shows that the recessed parabolic (ID 1) has the lowest Life Cycle Cost, it should be noted that this fixture is designed to illuminate only the horizontal work plane. However, the volumetric and recessed direct/indirect luminaires (IDs 3-5) are designed to illuminate the walls and ceilings in addition to the horizontal work plane.

5.5.2 Life Cycle Costs for Daylighting Systems

Daylight harvesting requires a holistic design approach to strategically place windows and shading devices to increase daylight penetration into the classroom while controlling glare. The cost/benefit of daylighting is difficult to determine because most published studies give only the total energy savings for a project. The total energy savings include improvements to the building envelope, the HVAC system, and the additional cost of windows and lighting controls. In a one-year test by the Iowa Energy Center at a facility in Ankeny, Iowa, it was found that lighting energy was reduced by 32% and cooling energy by 25% for daylit rooms. Table 5.5 shows the Life Cycle Costs for a daylit space. The First Cost and Replacement Cost are adjusted to include the dimming ballasts and lighting controls, which are required to adjust the electric light levels in response to the amount of daylight present. In Table 5.5, reductions in the cost of cooling to account for the differences in the Iowa and Florida climates were not calculated. As a result, the savings presented in Table 5.5 are conservative.

Table 5.5 Life Cycle Cost per Square Foot for Daylit Spaces Based on 2010 Dollars

Legend:	GOOD	FAIR	POOR

Fixture	First Cost	Energy Cost	Maint. Cost	Replacement Cost	LCC	Savings
5.5.1 Recessed Lensed Troffer (T8)	1	2	1	1	1	2
5.5.2 Recessed Parabolic Troffer (T8)	1	1	1	1	1	1
5.5.3 Recessed Volumetric Troffer (T8)	2	2	2	2	2	5
5.5.4 Recessed Volumetric Troffer (T5)	2	2	2	2	2	2
5.5.5 Recessed Direct/Indirect (T8)	2	2	2	2	2	2
5.5.6 Suspended Direct/Indirect (T8)	3	3	3	3	3	4
5.5.7 Recessed Volumetric (LED)	3	2	1	3	3	4

The addition of daylighting reduces Life Cycle Costs, except for the recessed parabolic (ID 2), due to the relatively low cost of the fixture and its high efficiency. However, the designer should consider that the quality of lighting from the recessed parabolic is lower than from the other luminaires, and that the addition of daylighting will improve the overall lighting quality by illuminating the walls.

5.6 HIGHBAY LIGHTING

Spaces that have high ceilings of 20’ or more, and which require high horizontal illumination, can be most economically illuminated using highbay lighting. Highbay luminaries are commercially available in both high intensity discharge (HID) lighting and in high output T5 fluorescents. Some emerging highbay lights use LED lighting and these may be more readily available and economical in the near future. The two most commonly used HID lamps are the metal halide (MH) and the high pressure sodium (HPS) lamps. The HPS lamp has a higher efficacy for indoor applications that require reasonable color rendering such as a gymnasium. But only the MH lamp is used due to the poor color rendering capability of the HPS lamp. HPS lamps are typically used in areas that do not require reasonable color rendering, such as storage, parking lots, and exterior security lighting. Fluorescent highbay luminaires are also available. Pictures of MH highbay and fluorescent highbay lamps are provided below. Highbay luminaires are also available with LED lamps. The LED highbay does have the highest efficiency of the fixtures, but the price of these fixtures in 2010 was 5-6 times higher than a comparable MH highbay, making the Life Cycle Cost unfavorable. A Life Cycle Cost analysis comparing these three fixtures is provided in Table 5.6.

Figure 5.8 Highbay Lighting in a Gymnasium

5.6.1 Highbay, 400-Watt metal hydride (MH) lamp

5.6.2 Highbay, (6) 54-Watt T5 Fluorescent lamps

5.6.3 Highbay, 324-Watt LED

Table 5.6 Life Cycle Cost per Square Foot for Highbay Lighting Based on 2010 Dollars

Legend:	GOOD	FAIR	POOR

Fixture	First Cost	Energy Cost	Maint. Cost	Replacement Cost	LCC
5.6.1 Highbay (Metal Halide)	1	2	1	1	1
5.6.2 Highbay (T5)	2	1	3	2	2
5.6.3 Highbay (LED)	3	1	1	3	3

5.7 SUMMARY

This chapter presented an objective overview of lighting technology used in educational facility lighting. This overview included information and data to aid in selecting the best luminaire, lamp, and ballast to achieve the facility's lighting goals in a cost-effective manner. Table 5.7 summarizes the luminaires and their Life Cycle Costs. As with all other analyses, using Life Cycle Costing approaches, rather than making decisions based on First Cost, will yield the greatest overall benefit.

Table 5.7 Summary of Lighting Life Cycle Cost per Square Foot Based on 2010 Dollars

Legend:	GOOD	FAIR	POOR

Fixture	First Cost	Energy Cost	Maint. Cost	Replacement Cost	LCC
5.5.1 Recessed Lensed Troffer (T8)	1	1	1	1	1
5.5.2 Recessed Parabolic Troffer (T8)	1	1	1	1	1
5.5.3 Recessed Volumetric Troffer (T8)	2	2	2	2	2
5.5.4 Recessed Volumetric Troffer (T5)	2	1	2	2	2
5.5.5 Recessed Direct/Indirect (T8)	2	1	2	2	2
5.5.6 Suspended Direct/Indirect (T8)	3	3	3	3	3
5.5.7 Recessed Volumetric (LED)	3	2	1	3	3
5.6.1 Highbay (Metal Halide)	1	2	1	1	1
5.6.2 Highbay (T5)	2	2	3	2	2
5.6.3 Highbay (LED)	3	1	1	3	3

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%

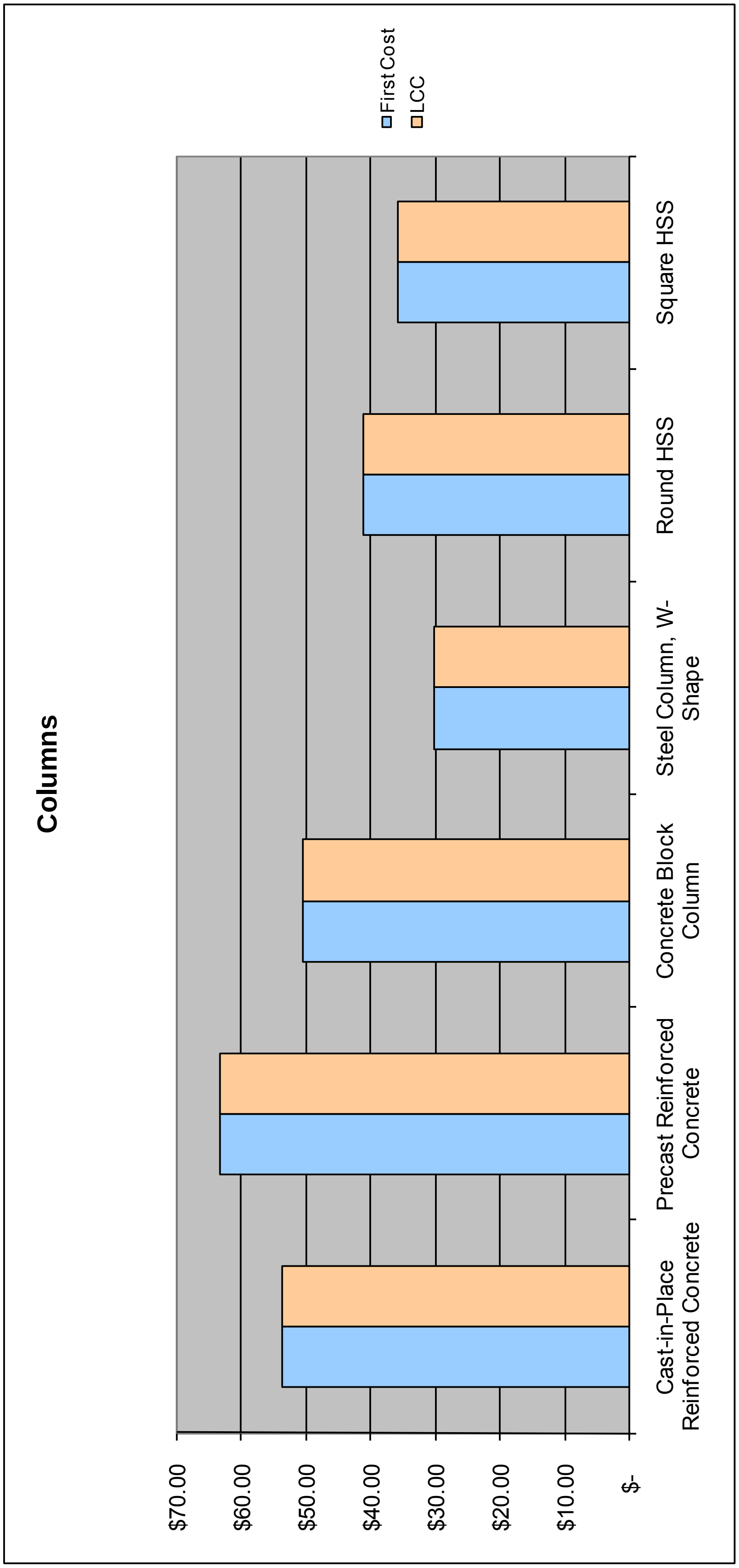
Floors 30'-40' span	Unit	First Cost	LCC	O&M
Steel Deck 1-1/2" Deep + 4” Thick Concrete	SF	$ 10.23	$ 10.23	0.00%
Cast-in-Place Flat Concrete Plate, 4” Thick	SF	$ 13.26	$ 13.26	0.00%
Precast Plank with Concrete Topping	SF	$ 11.79	$ 11.79	0.00%

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
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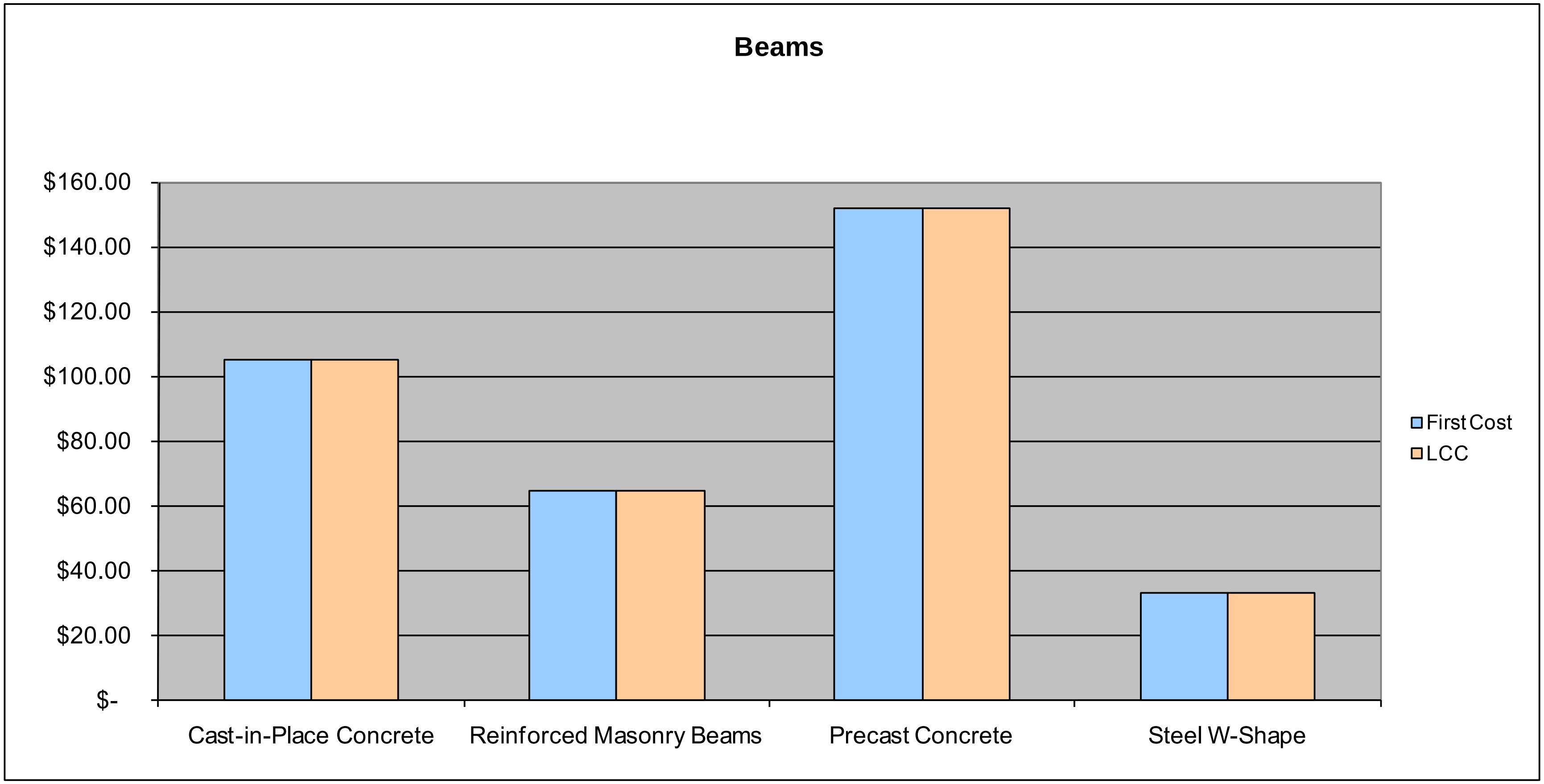
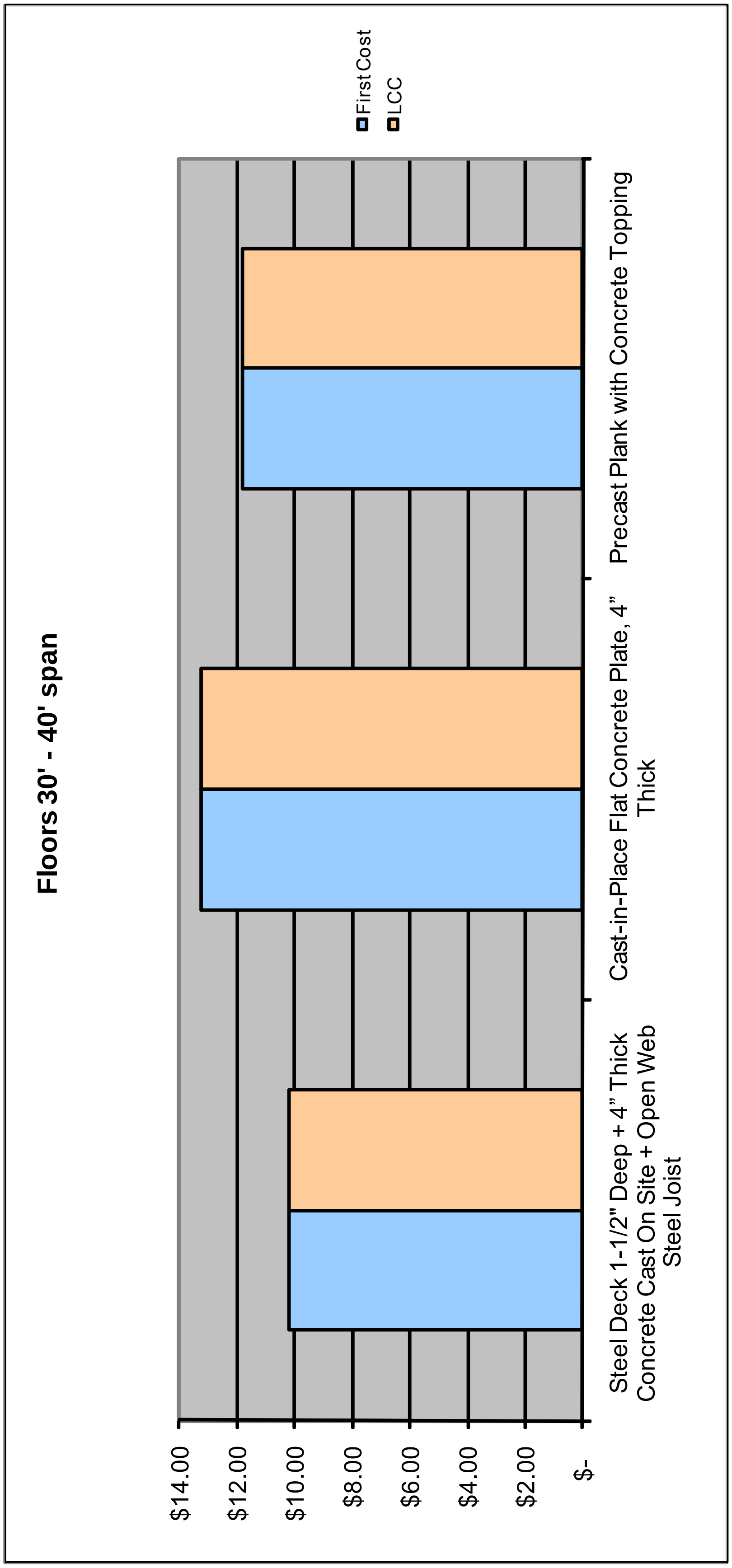
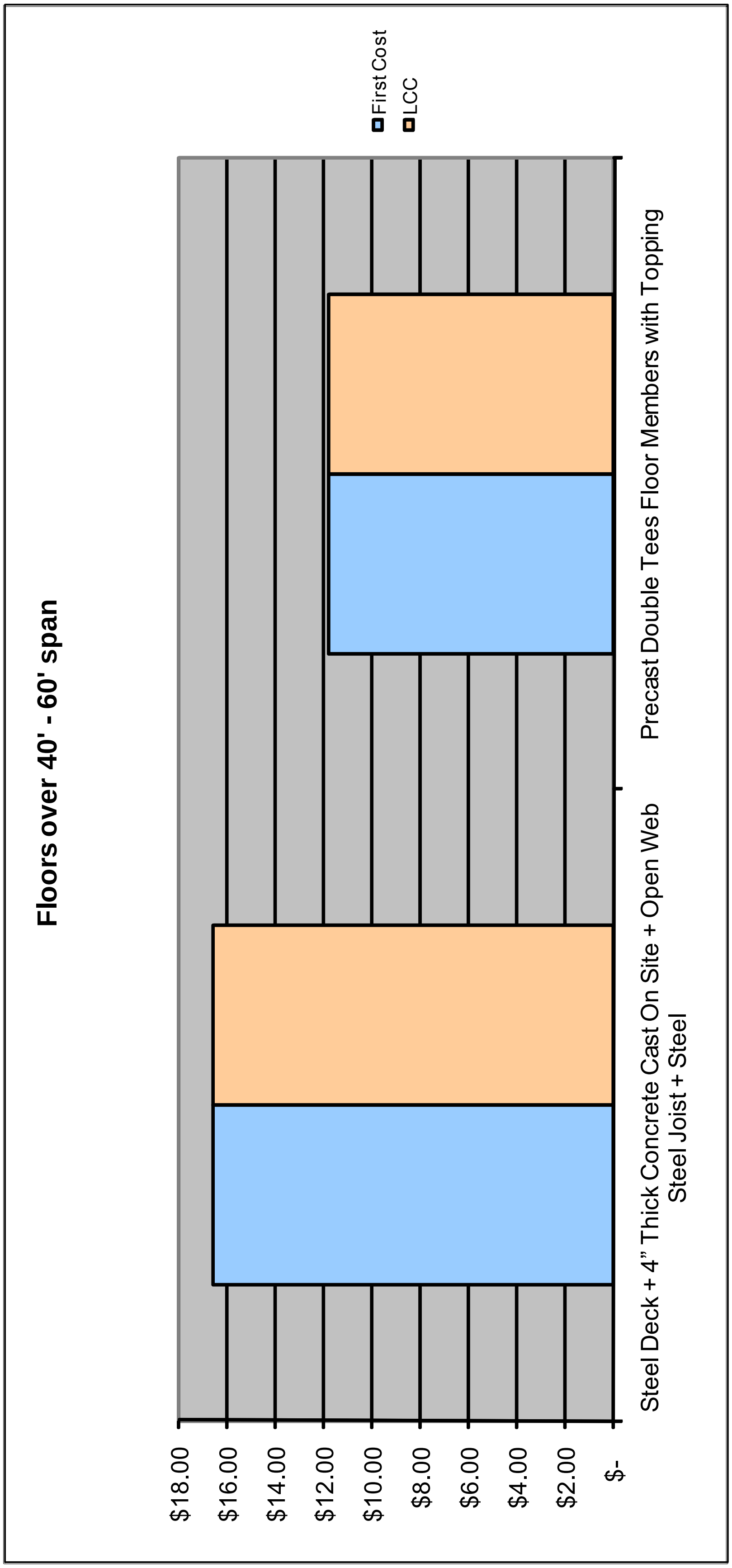
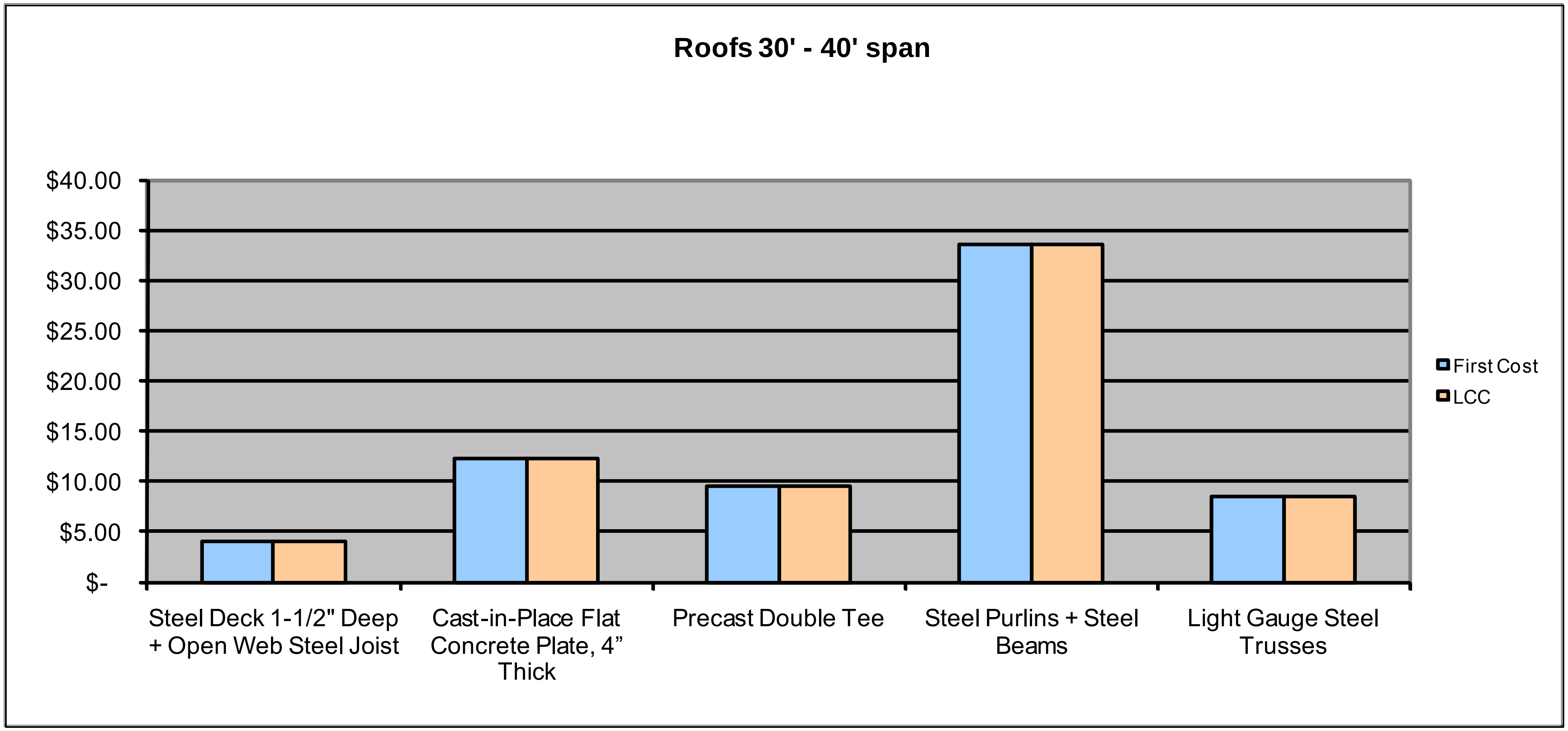
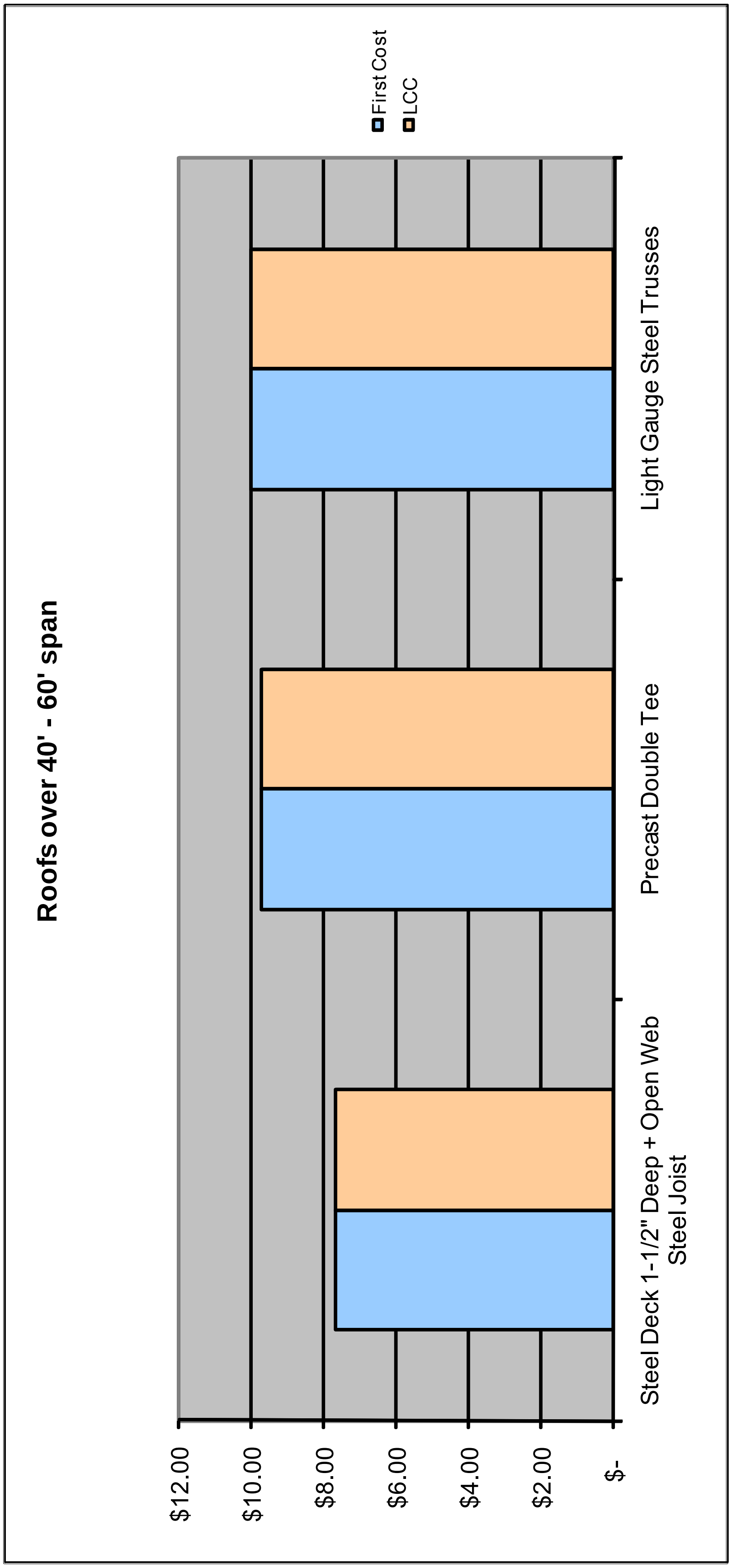
Cast-in-Place Reinforced Concrete
Precast Reinforced Concrete
Concrete Block Column
Steel Column, W-Shape
Round HSS
Square HSS
First Cost
LCC

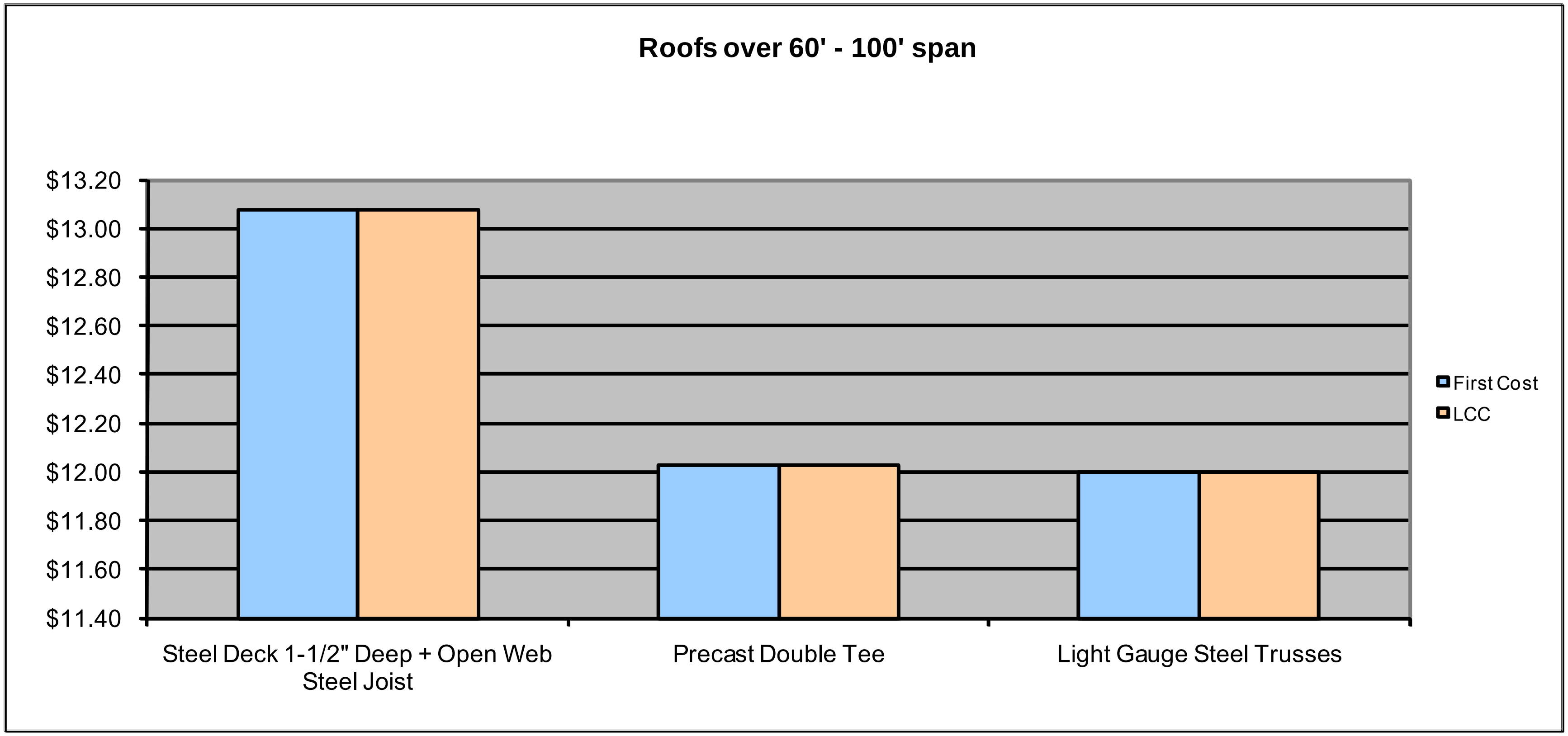

Beams
$160.00
$140.00
$120.00
$100.00
$80.00
$60.00
$40.00
$20.00
$-
Cast-in-Place Concrete
Reinforced Masonry Beams
Precast Concrete
Steel W-Shape
First Cost
LCC


Floors 30' - 40' span
First Cost
LCC
$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


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
$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
First Cost
LCC

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%

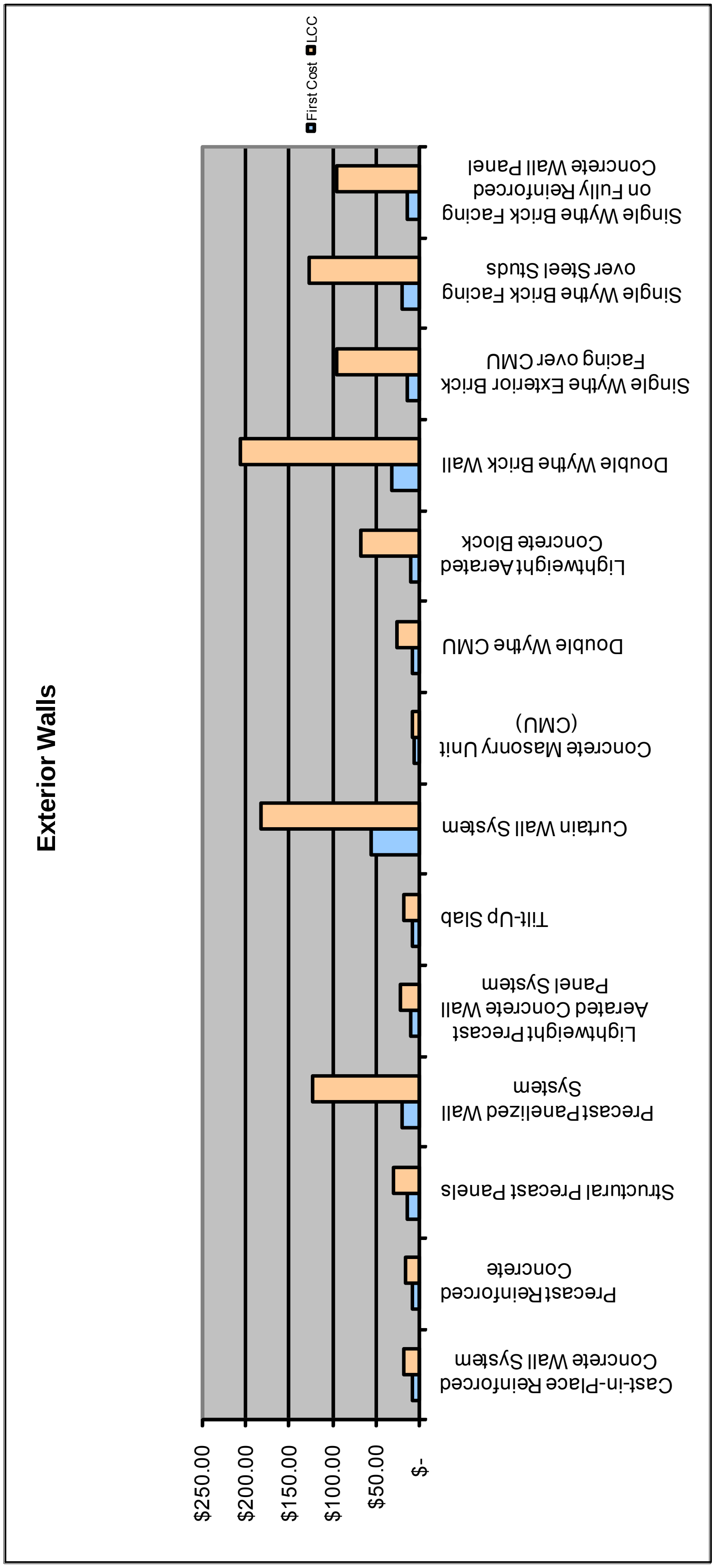
Pitched and Curved Roof Systems	Unit	First Cost	LCC	O&M
Steel, Flat Profile, 1-3/4" Standing Seam, 10" Wide, Zn/Al	SF	$ 4.71	$ 25.98	2.00%
Copper, Standing Seam, 20 oz., 150lb/square	SF	$ 12.40	$ 26.39	1.00%
Zinc-Copper Alloy, Standing Seam, 0.32" Thick	SF	$ 15.80	$ 24.71	0.50%
Asphalt Shingles, Class 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%

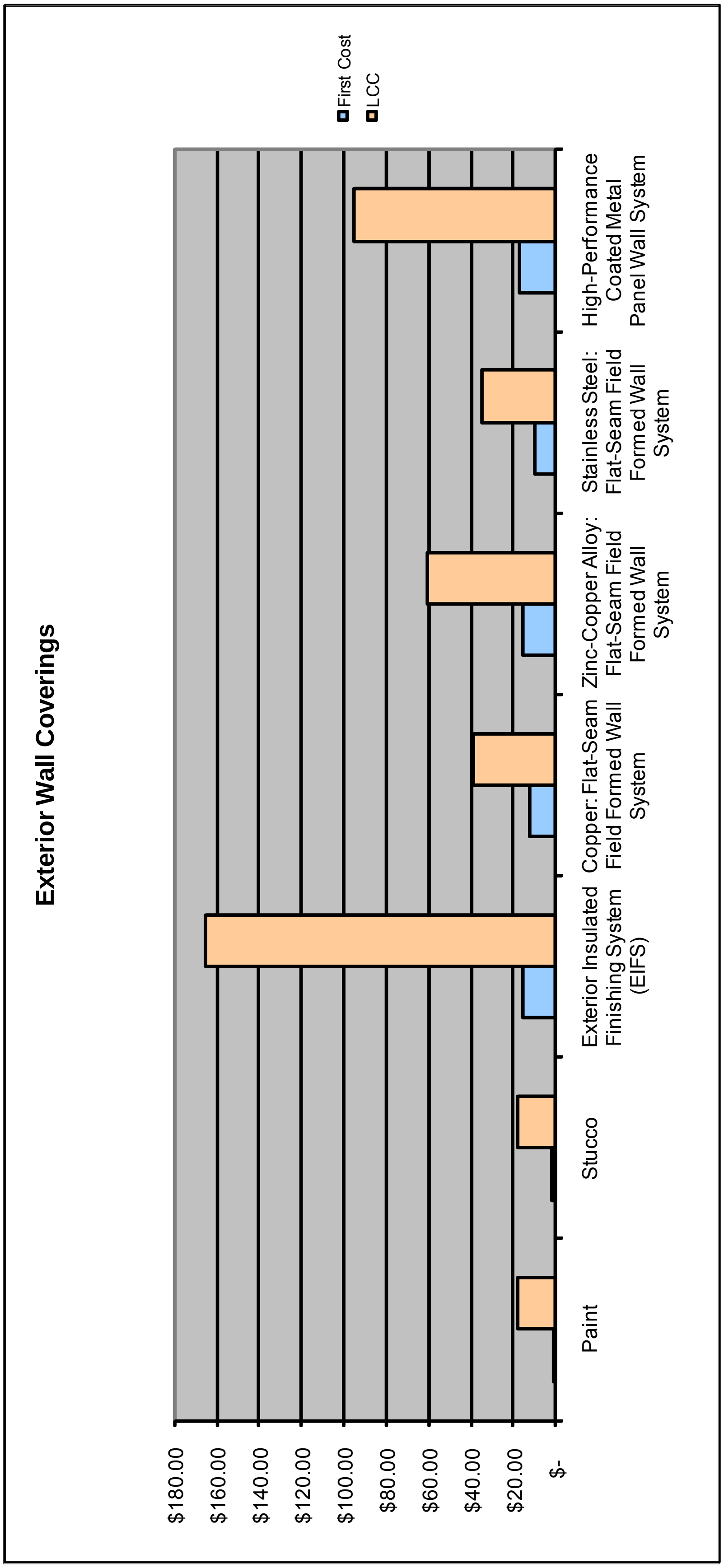
Low Slope Roof Systems	Unit	First Cost	LCC	O&M
Built-Up Roofing, 4 plies #15 Asphalt Felt	SF	$ 2.34	$ 57.73	15.00%
SBS Modified Bitumen, Hot Mopped	SF	$ 2.26	$ 55.78	15.00%
Coal-Tar Pitch	SF	$ 2.52	$ 22.45	1.00%
Polyurethane Spray-Foam (SPF)	SF	$ 1.29	$ 11.47	1.00%
SBS Modified Bitumen, Cold Applied	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%

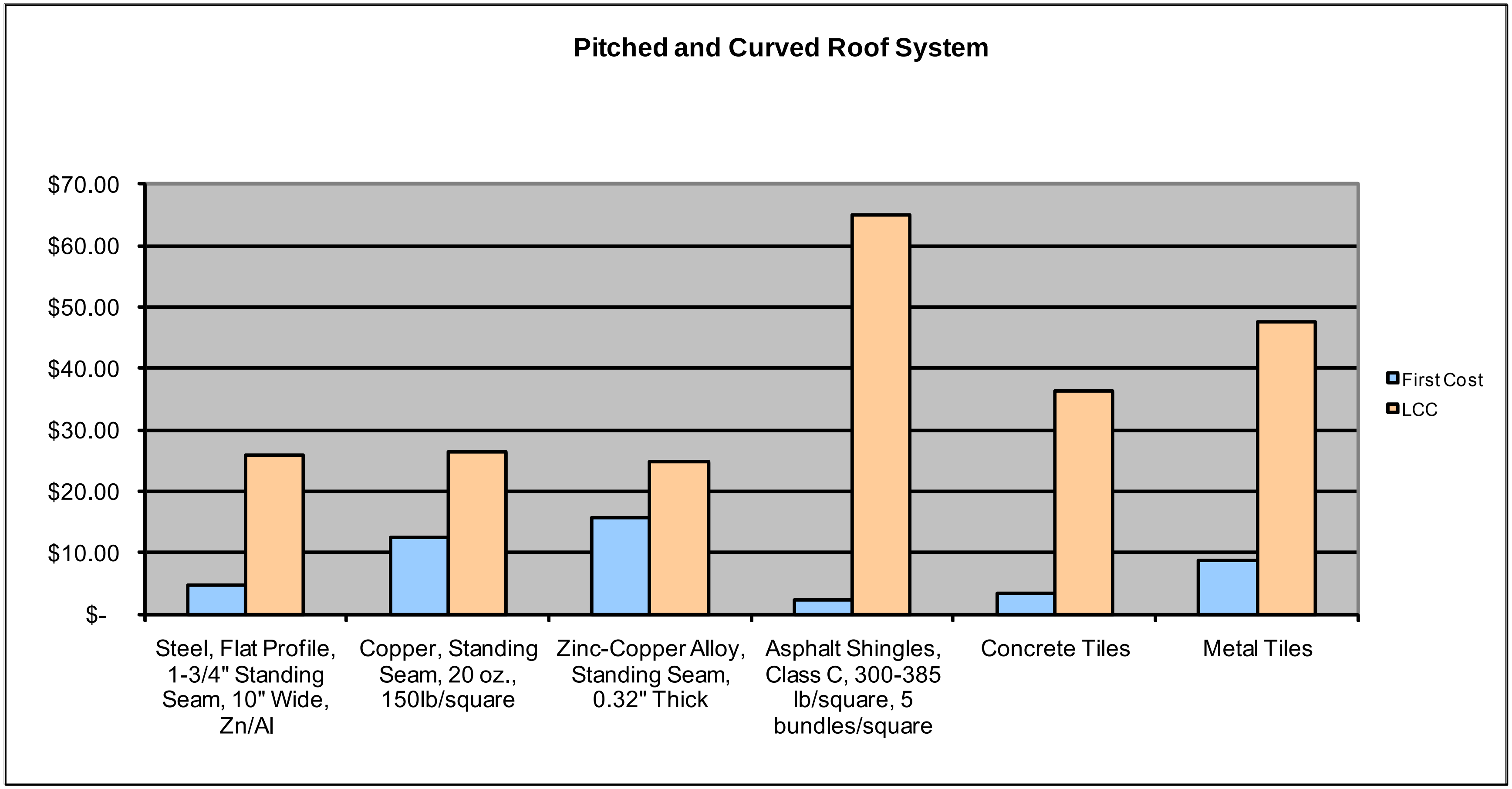
Doors	Unit	First Cost	LCC	O&M
Glazed Entry, Aluminum Frame	EA	$ 707.23	$ 5,705.30	5.00%
Glazed Entry, Aluminum Frame, Thermally Broken	EA	$ 707.23	$ 5,705.30	5.00%
Hollow Metal, Painted	EA	$ 309.52	$ 2,755.31	5.00%
Roll-Up Overhead Service	EA	$ 2,179.83	$ 7,749.78	1.00%

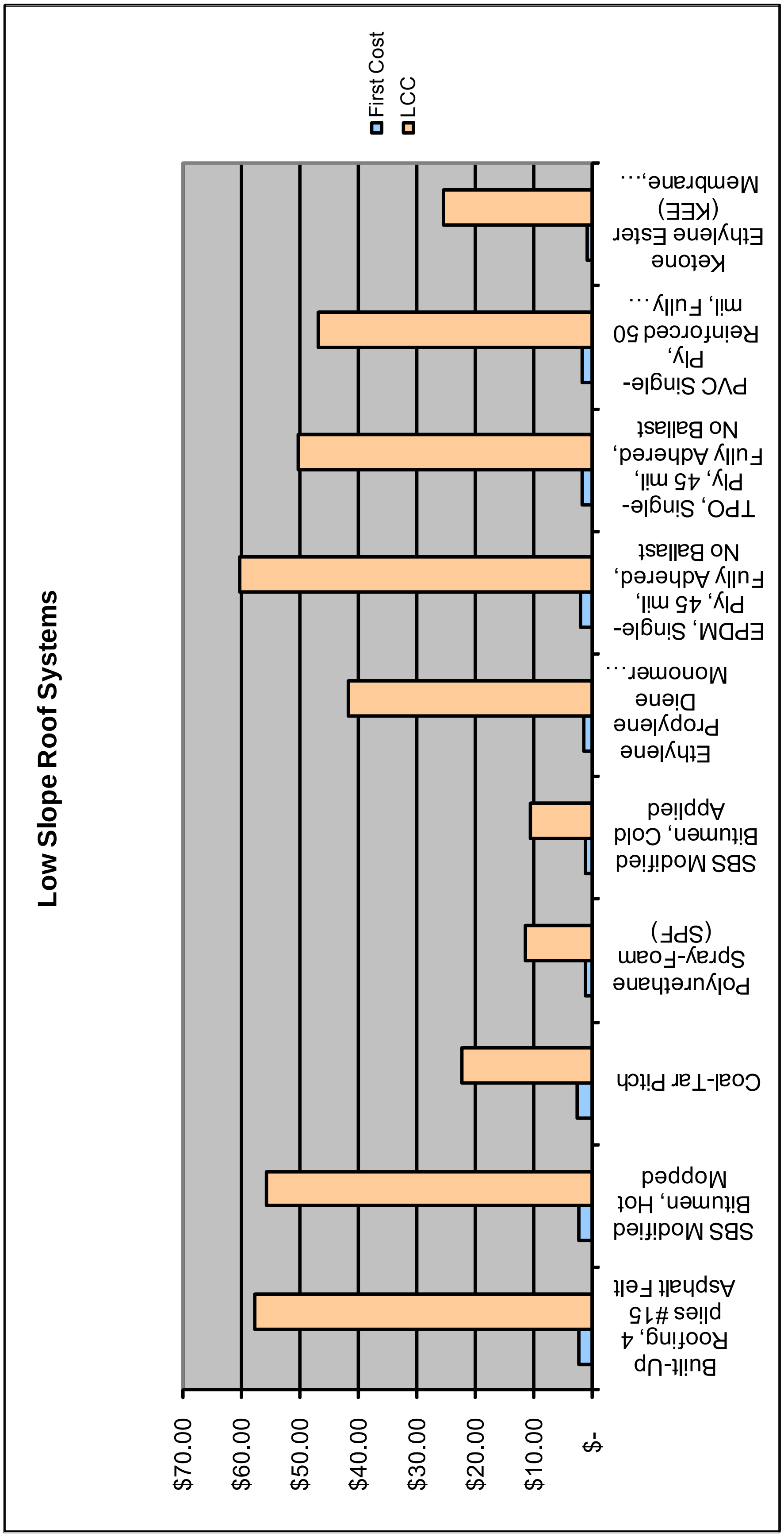
Glazing	Unit	First Cost	LCC	O&M
Float Glass (1/4") with Low Emissivity Coating	SF	$ 10.99	$ 72.94	5.00%
Float Glass (1/4"), Tinted	SF	$ 12.26	$ 81.40	5.00%
Tempered Float Glass (1/4"), Clear	SF	$ 12.33	$ 81.87	5.00%
Tempered Float Glass (1/4"), Tinted	SF	$ 15.32	$ 101.72	5.00%
Laminated Float Glass, 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%

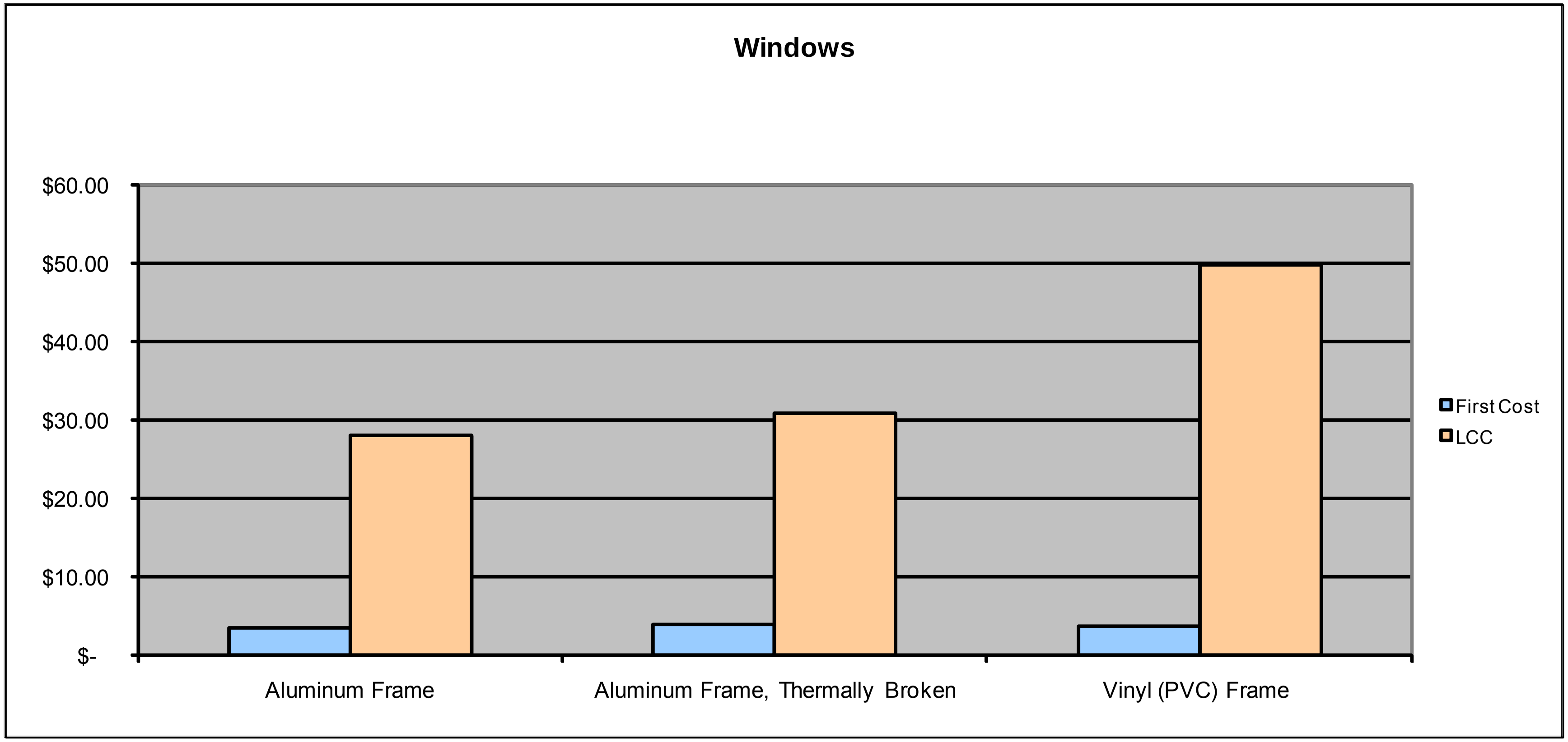

Exterior Walls
First Cost
LCC
$250.00
$200.00
$150.00
$100.00
$50.00
$-
Cast-in-Place Reinforced Concrete Wall System
Precast Reinforced Concrete
Structural Precast Panels
Precast Panelized Wall System
Lightweight Precast Aerated Concrete Wall Panel System
Tilt-Up Slab
Curtain Wall System
Concrete Masonry 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

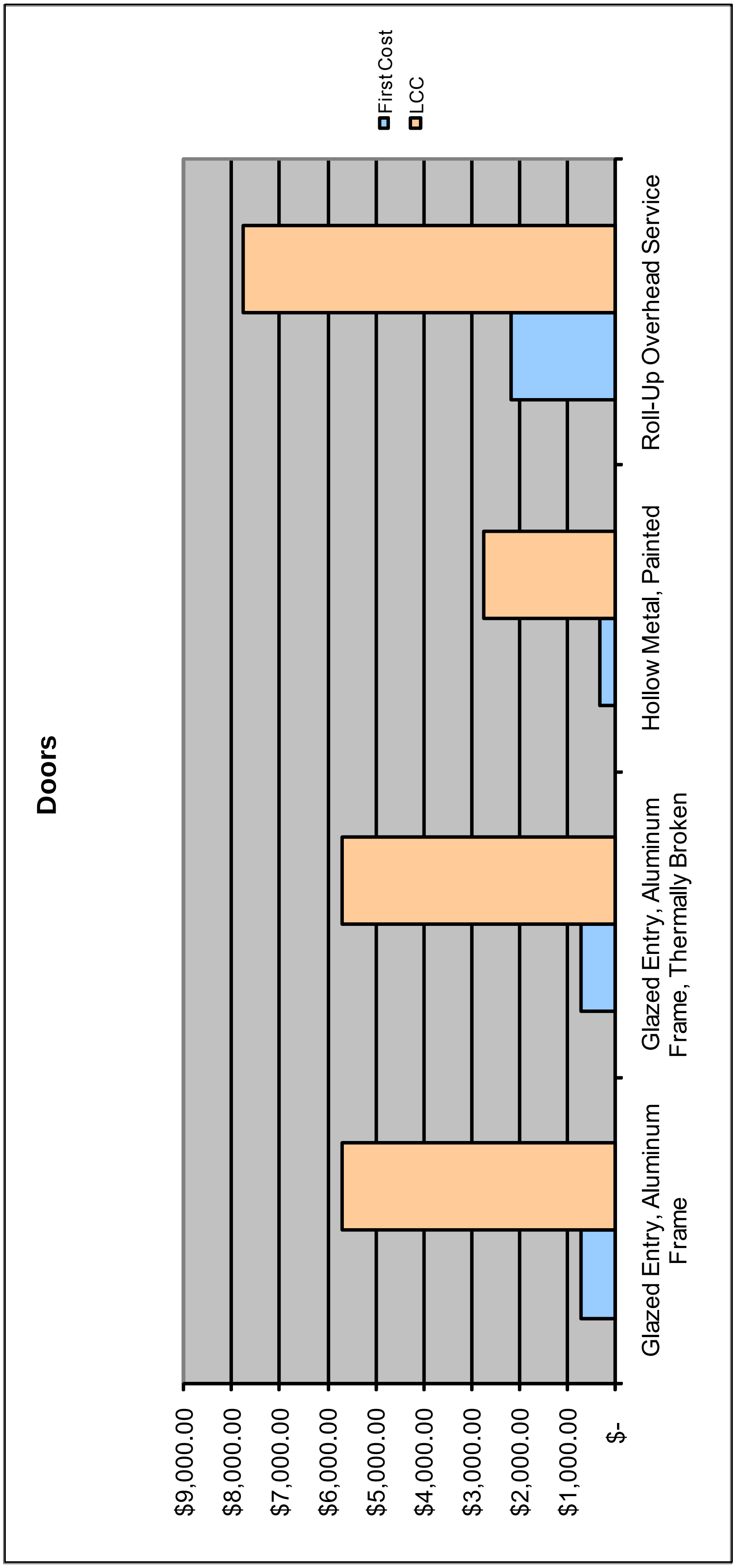


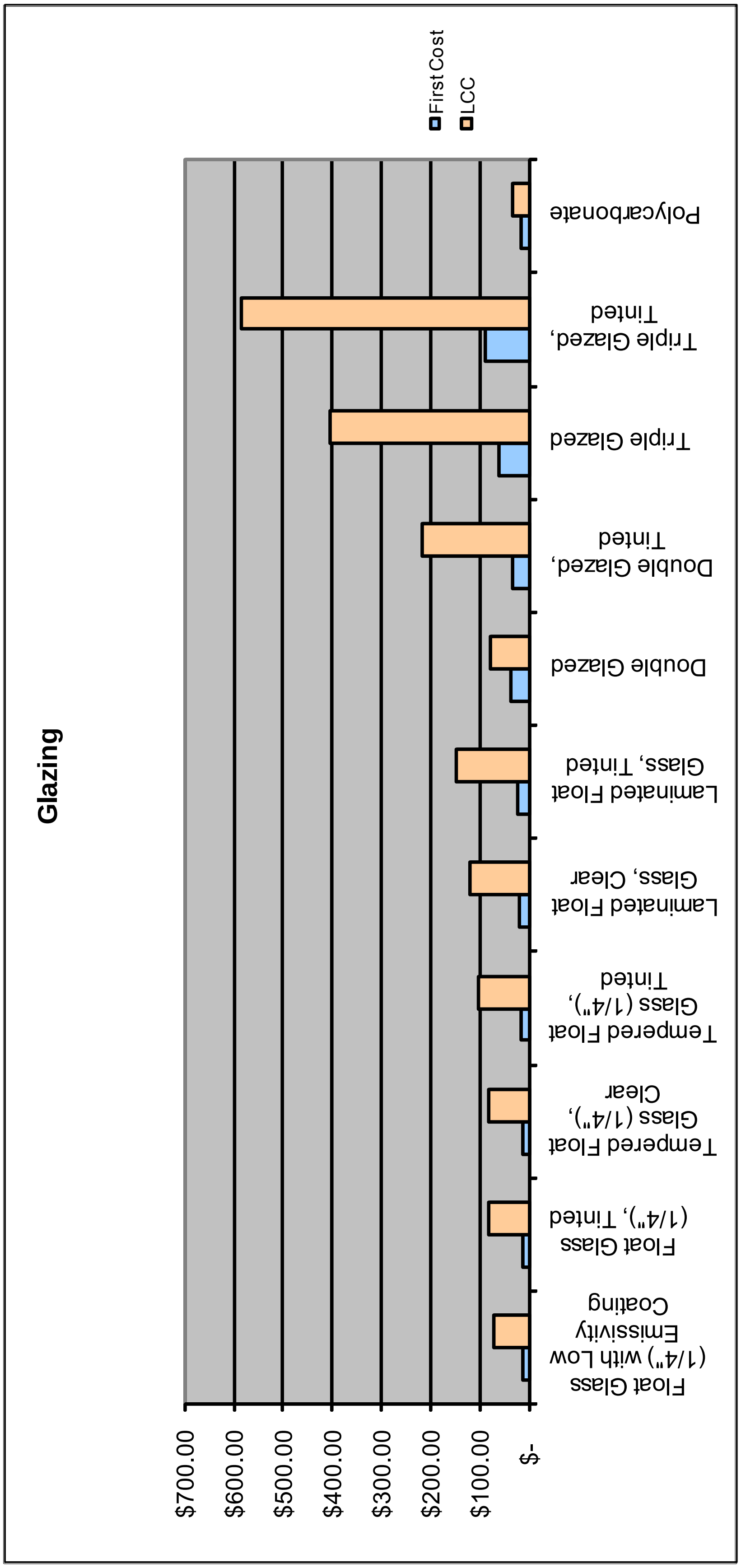
Exterior Wall Coverings
First Cost
LCC
$180.00
$160.00
$140.00
$120.00
$100.00
$80.00
$60.00
$40.00
$20.00
$-
Paint
Stucco
Exterior Insulated Finishing System (EIFS)
Copper: Flat-Seam Field Formed Wall System
Zinc-Copper Alloy: Flat-Seam Field Formed Wall System
Stainless Steel: Flat-Seam Field Formed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


Pitched and Curved Roof System
$70.00
$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
$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
First Cost
LCC

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%

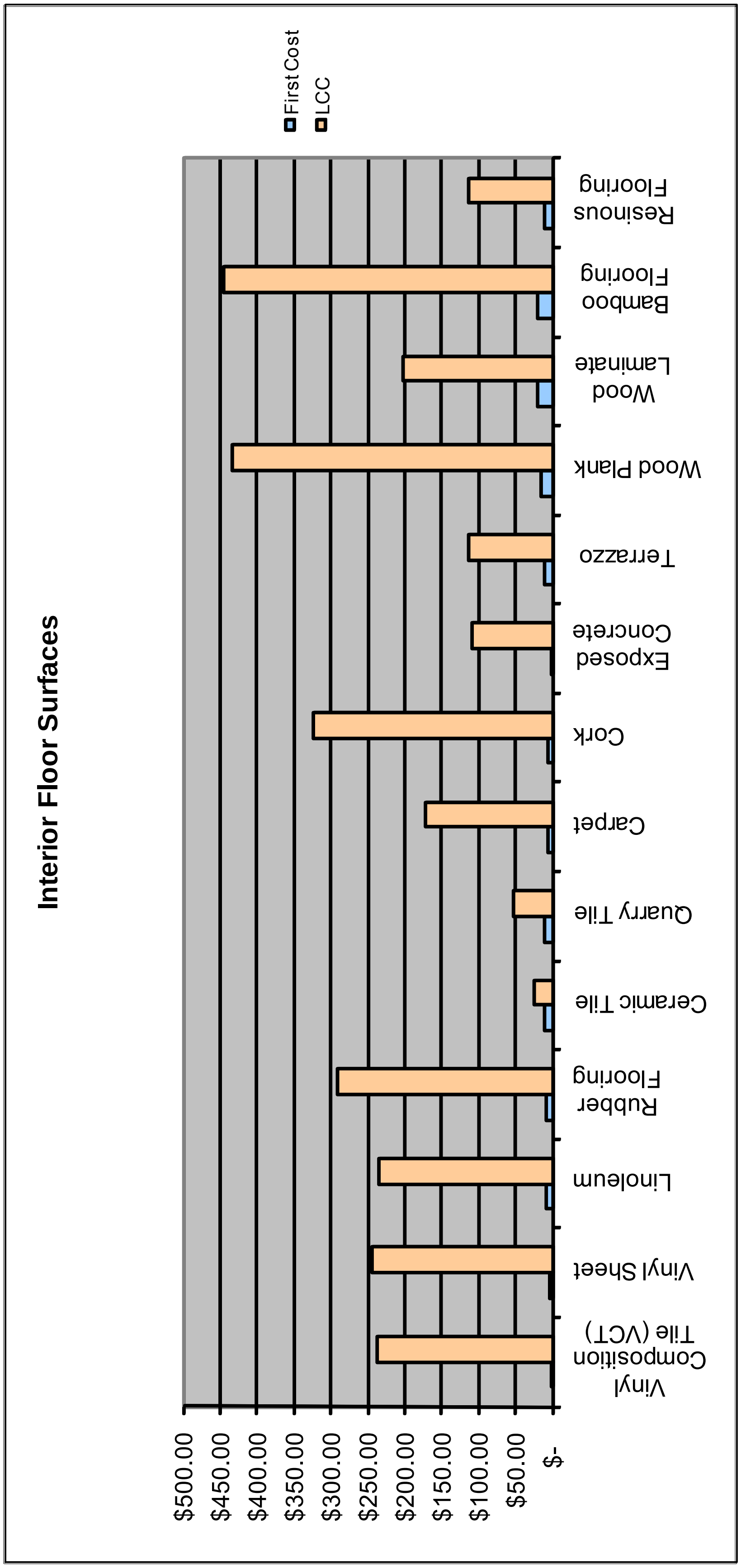
Interior Door Assemblies	Unit	First Cost	LCC	O&M
Steel Door	EA	$ 521.40	$ 7,582.06	10.00%
Hollow Core Wood Door	EA	$ 134.40	$ 1,893.95	8.00%
Solid Core Wood Door	EA	$ 173.60	$ 2,446.35	8.00%
Aluminum Door	EA	$ 932.04	$ 12,775.45	10.00%
Fiberglass Door	EA	$ 463.68	$ 2,558.57	2.00%

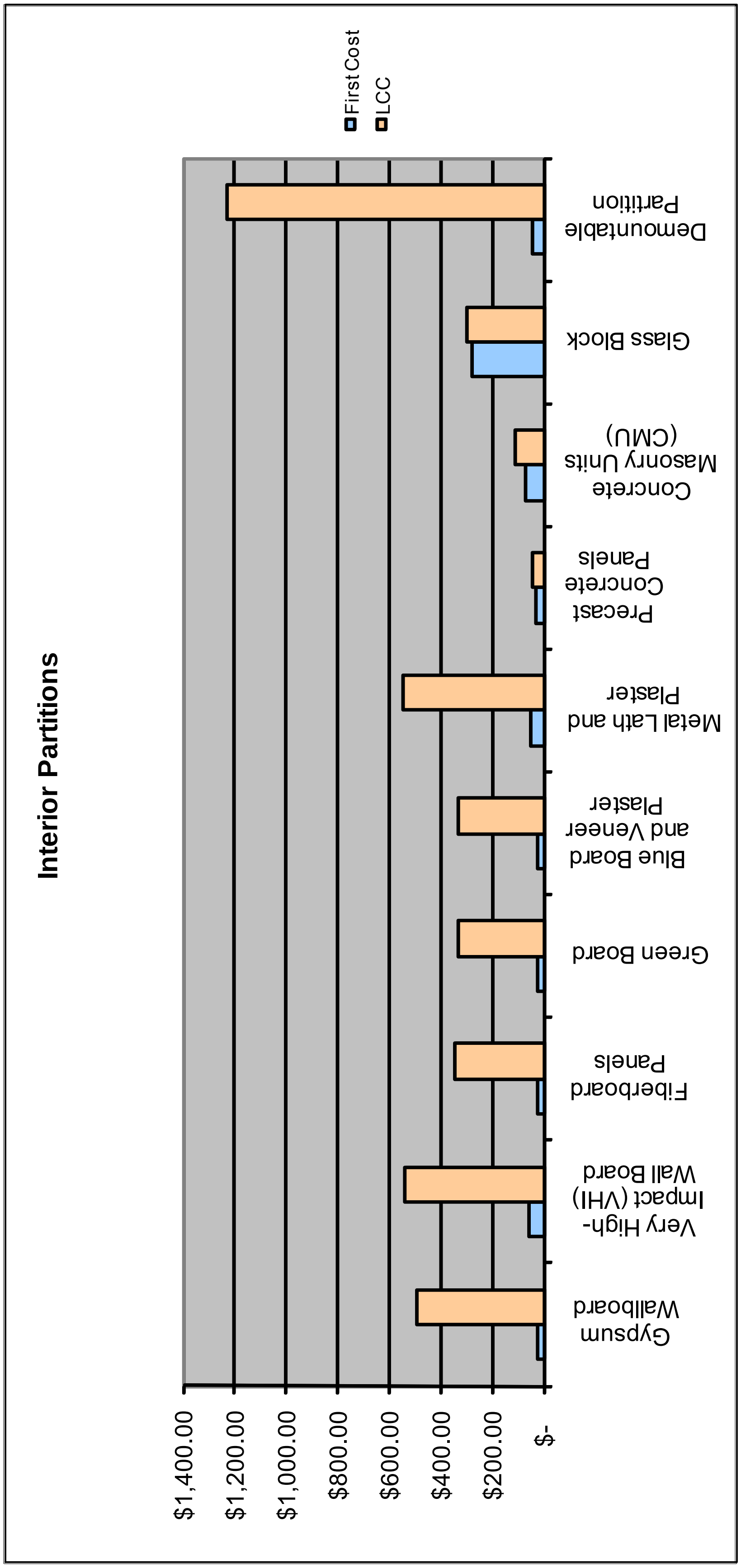
Interior Window Assemblies	Unit	First Cost	LCC	O&M
Aluminum Frame Window	SF	$ 45.28	$ 365.30	5.00%
Steel Frame Window	SF	$ 44.87	$ 298.22	3.00%
Vinyl Frame Window	SF	$ 44.24	$ 692.91	7.00%

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%

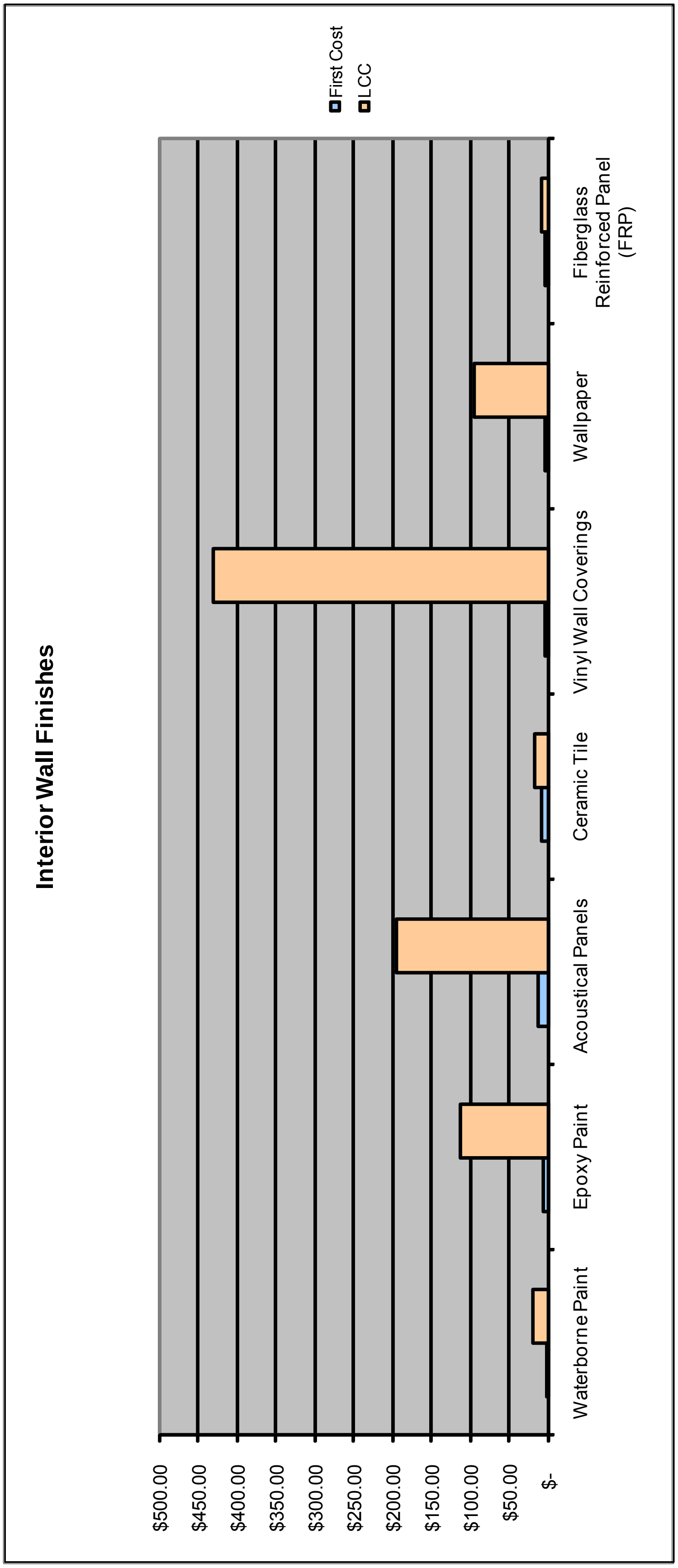
Interior Specialty Items: Millwork - Built-in Cabinetry	Unit	First Cost	LCC	O&M
Plywood	LF	$ 260.70	$ 2,907.00	3.00%
Medium Density Fiberboard (MDF)	LF	$ 260.70	$ 4,204.81	5.00%
Particle Board	LF	$ 221.20	$ 7,032.65	15.00%
Melamine board	LF	$ 205.40	$ 6,530.32	15.00%

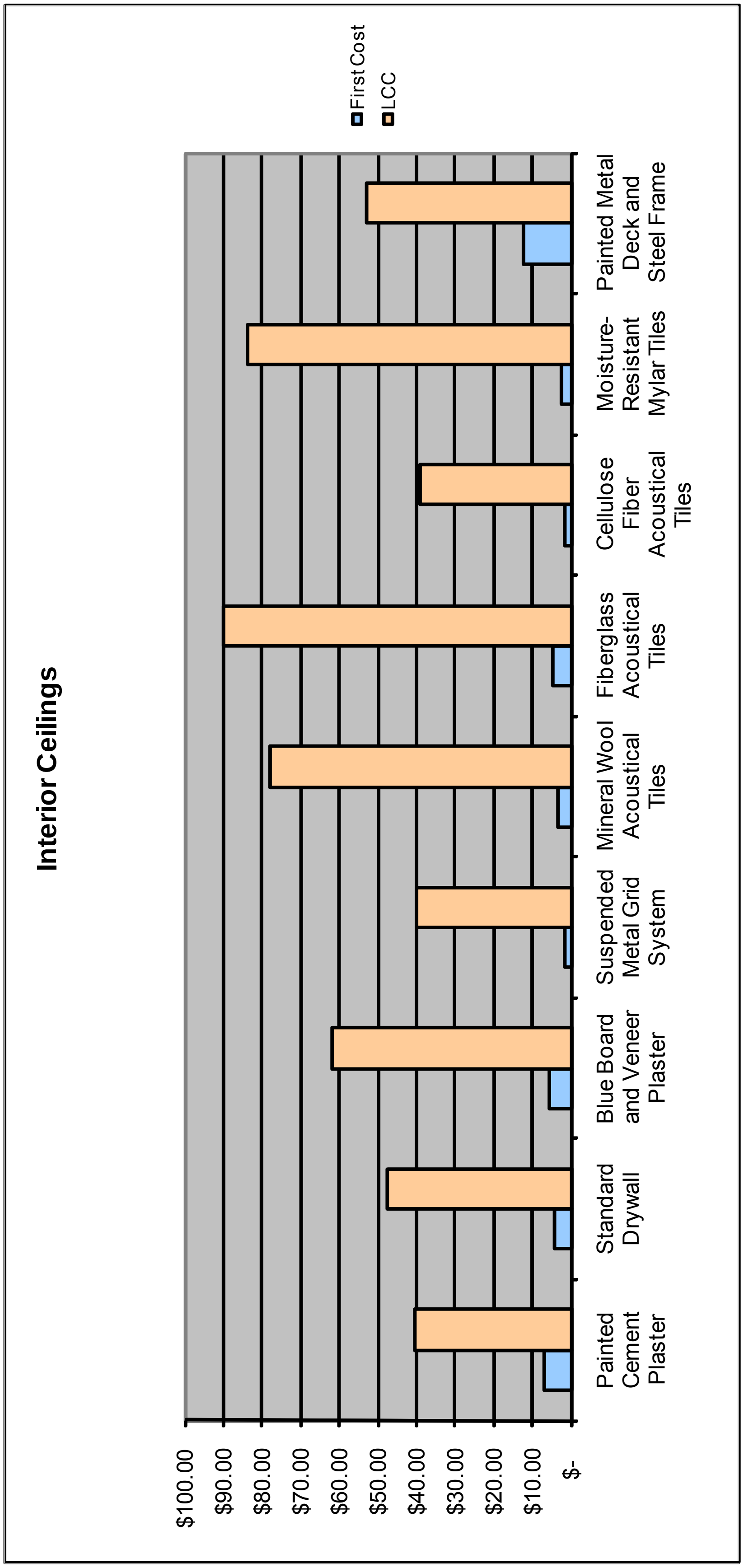
Interior Specialty Items: Countertops	Unit	First Cost	LCC	O&M
Granite	LF	$ 161.16	$ 252.05	0.50%
Chemical-Resistant Solid Surfacing	LF	$ 118.50	$ 467.11	1.00%
Linoleum Over Plywood	LF	$ 33.18	$ 674.48	12.00%
Plastic Laminate Over Plywood	LF	$ 91.64	$ 1,745.42	10.00%
Stainless Steel	LF	$ 172.22	$ 366.48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

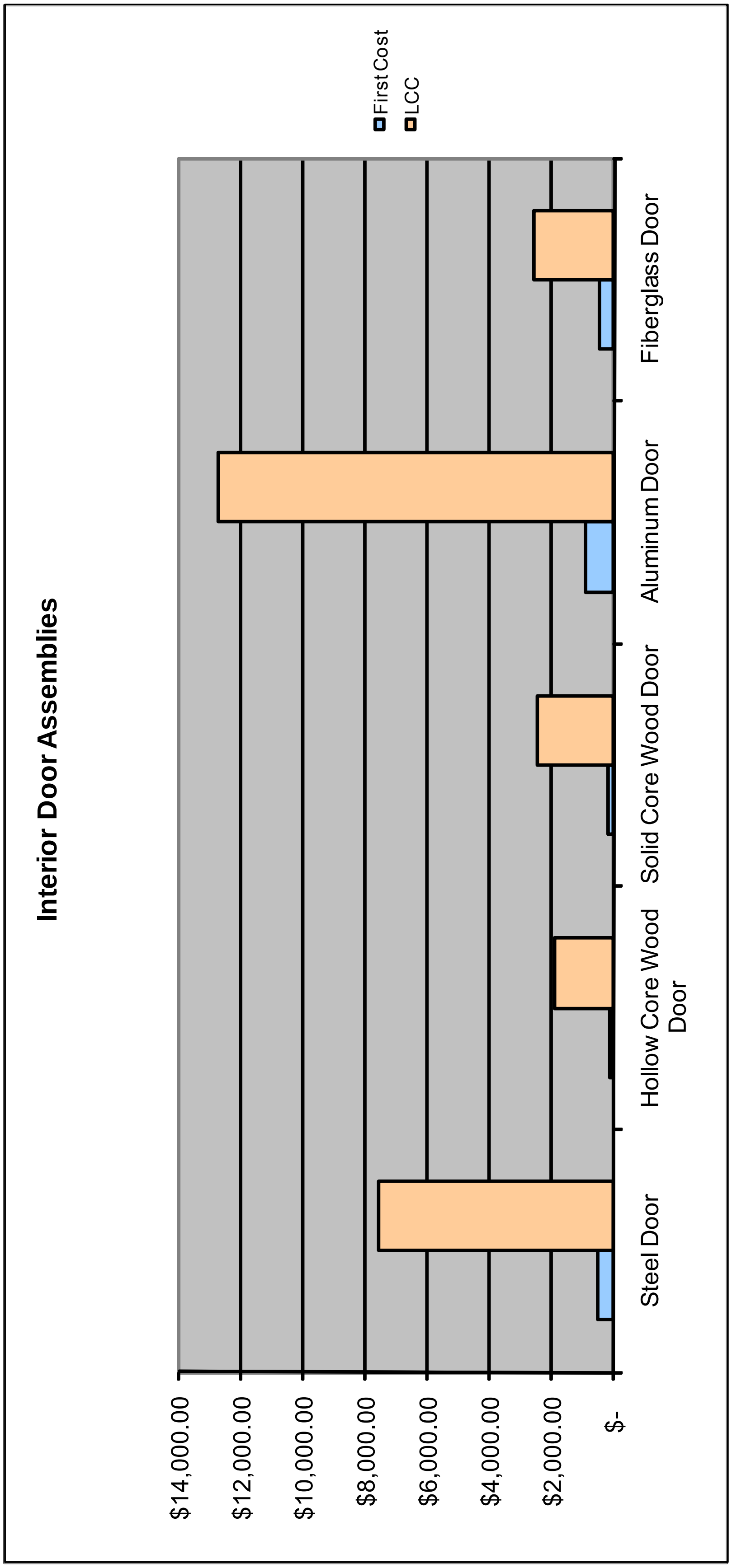


Interior Partitions
$1,400.00
$1,200.00
$1,000.00
$800.00
$600.00
$400.00
$200.00
$-
Gypsum Wallboard
Very High-Impact (VHI) Wall Board
Fiberboard Panels
Green Board
Blue Board and Veneer Plaster
Metal Lath and Plaster
Precast Concrete Panels
Concrete Masonry Units (CMU)
Glass Block
Demountable Partition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

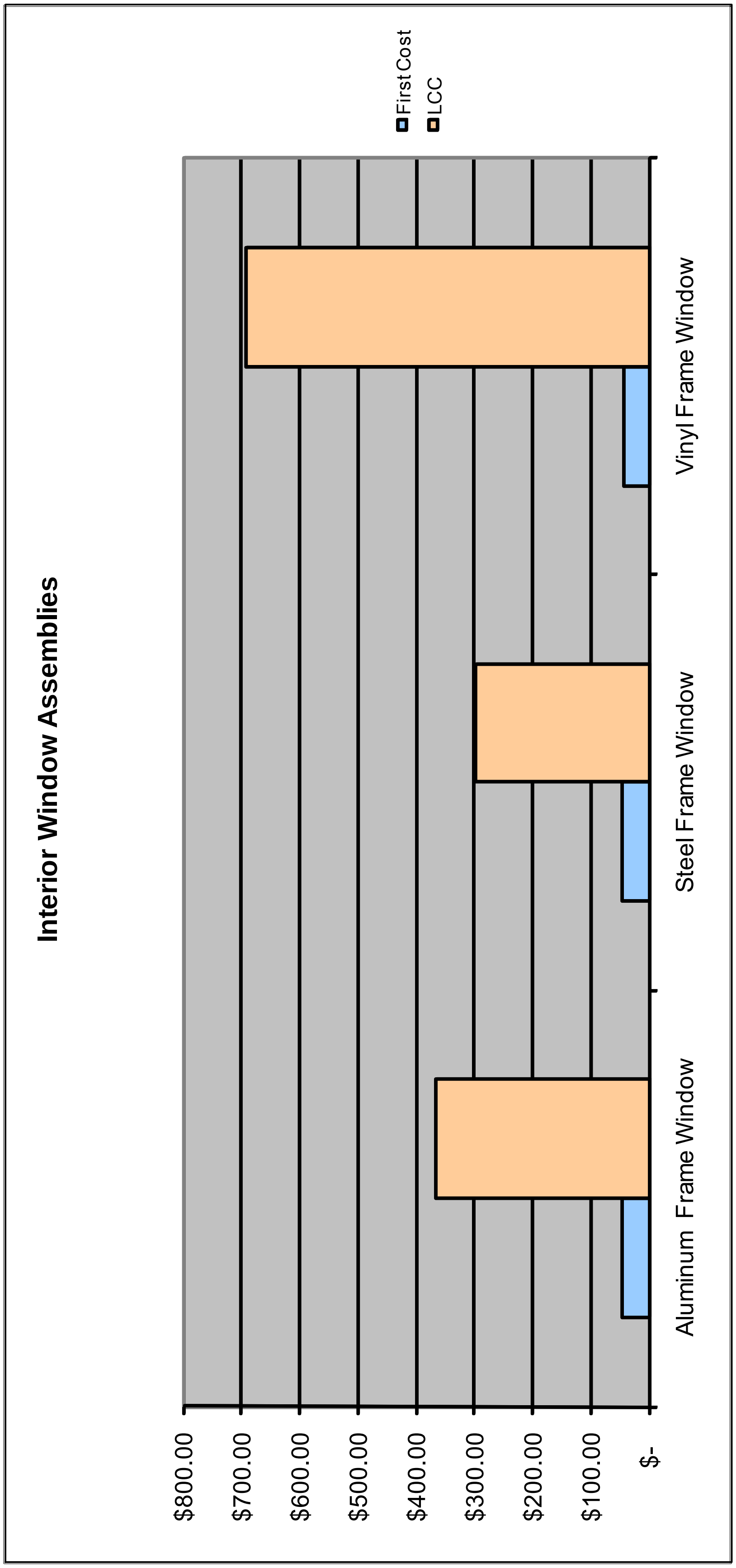

Interior Wall Finishes
First Cost
LCC
$500.00
$450.00
$400.00
$350.00
$300.00
$250.00
$200.00
$150.00
$100.00
$50.00
$-
Waterborne Paint
Epoxy Paint
Acoustical Panels
Ceramic Tile
Vinyl Wall Coverings
Wallpaper
Fiberglass Reinforced Panel (FRP)



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

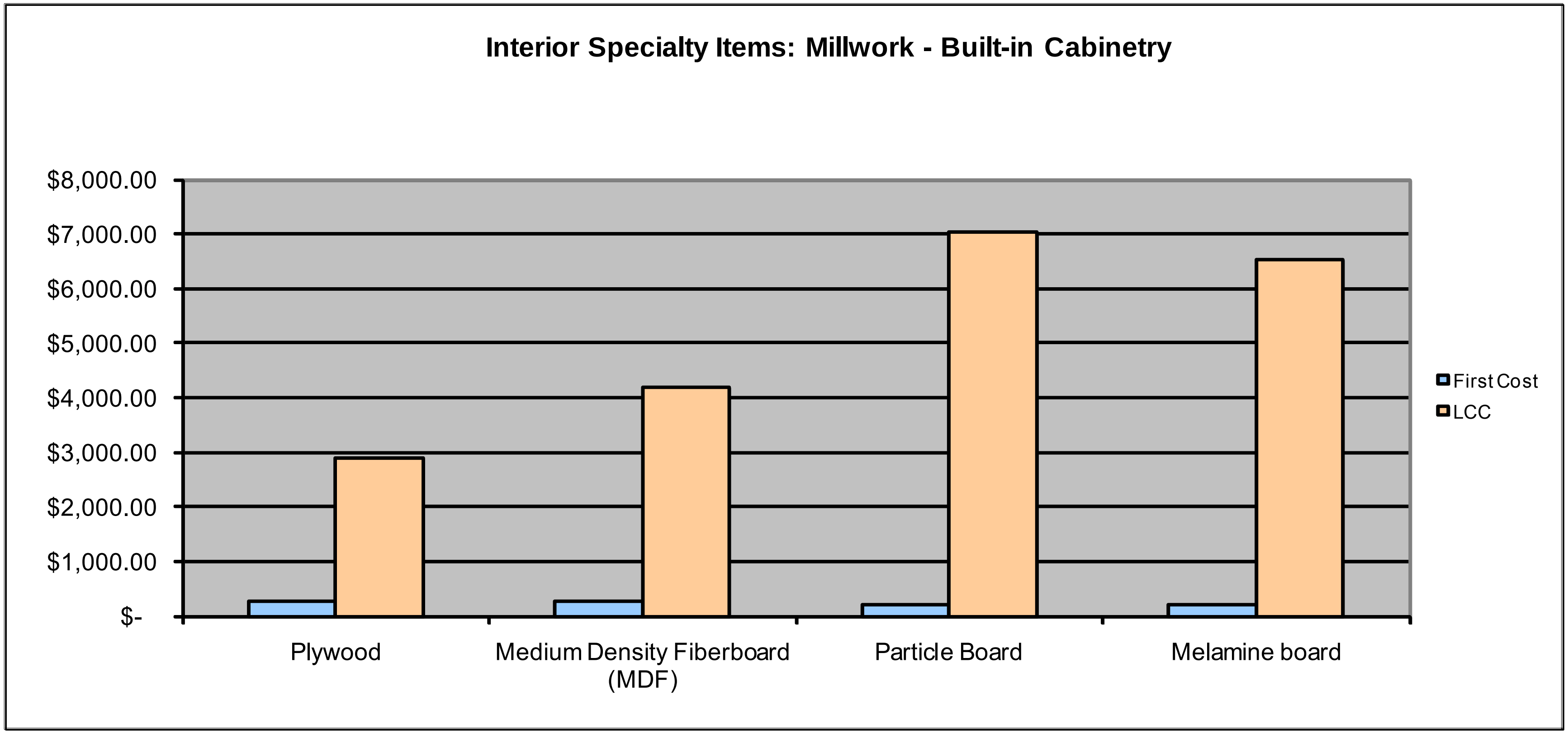


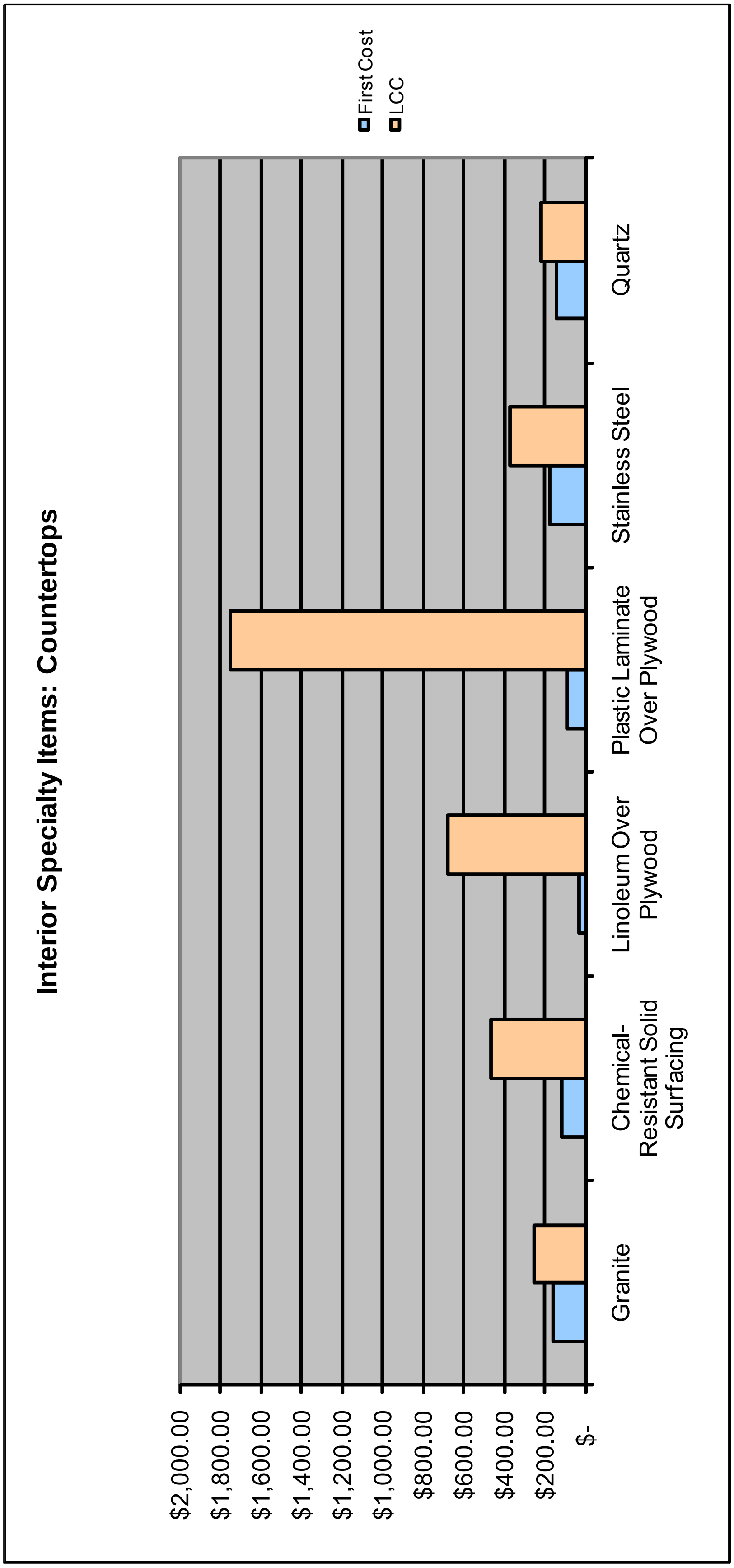
Interior Door Assemblies
$14,000.00
$12,000.00
$10,000.00
$8,000.00
$6,000.00
$4,000.00
$2,000.00
$-
Steel Door
Hollow Core Wood Door
Solid Core Wood Door
Aluminum Door
Fiberglass Door
First Cost
LCC



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
$8,000.00
$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 Replacement 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.