THESIS FINAL REPORT

77 K STREET

Washington, DC





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Construction Management

Penn State AE Senior Thesis 2008

Consultant: Dr. Messner

77 K STREET

WASHINGTON, DC

PROJECT TEAM

Owner:	Brookfield Properties
Architect:	Davis, Carter, Scott, Ltd.
Civil Engineer:	Edwards & Kelcey, Inc.
Structural Engineer:	Fernandez & Associates
MEP Engineer:	Girard Engineering, PC
General Contractor:	James G. Davis Construction Corporation

PROJECT FEATURES

Function:	Mixed Office & Retail
Size:	344,000 SF
Levels:	3 Below Grade, 11 Above
Construction Schedule:	Nov. 2006 – Sept. 2008
Construction Cost:	$41,000,000
Delivery Method:	Design-Bid-Build

ARCHITECTURE

Architectural precast, metal panel, and curtainwall glazing facade

View of the Capitol Building to the north

Two-story lobby featuring honed granite floors, white plaster, wood veneer, and granite walls

STRUCTURAL

4'-0" thick mat foundation

10" or 11" reinforced, post-tensioned two-way slab with 4-1/4" drop panels at columns

Structural steel penthouse framing with EIFS exterior

ELECTRICAL & LIGHTING

408/277V and 208/120V system

(3) 4000A switchboards

4000A plug-in feeder busways for distribution

750 KW, 480/277V diesel emergency generator

Outdoor photocell and occupancy sensors to control lighting levels

MECHANICAL

(3) 91,560 CFM rooftop cooling tower units

27,000 CFM air conditioning units at typical levels

VAV boxes in tenant spaces

Wet pipe fire suppression system with a dry pipe system in the garage and loading dock areas

77 K Street

FINAL THESIS REPORT

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Acknowledgements

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Brookfield Properties

James Berkon	Owner's Representative

Davis, Carter, Scott Design

Ernest Ulibarri	Architect

James G. Davis Construction Corporation

Dominic Argentieri	Senior Project Manager
Marybeth Bulgaris	Project Manager
Ron Juban	Senior Project Manager

Pennsylvania State University

Craig Dubler	PhD. Candidate, Construction Management
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Moses Ling	Associate Professor, Mechanical Option
Dr. John Messner	Associate Professor, Construction Management
Professor Kevin Parfitt	Associate Professor, Thesis Course Administrator
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Dr. David Riley	Associate Professor, Construction Management

Sika Sarnafil

Ryan Shaughnessy	Sales Representative

Viracon, Inc.

Alissa Schmidt	Architectural Design Associate

Executive Summary

The 77 K Street project is a class A core and shell office base building project consisting of 11 above grade levels and 3 levels of below grade parking garage. The site is located at the intersection of 1st and K Streets in Washington, DC in the North of Massachusetts development district north of the Capitol Building. The project includes approximately 350,000 gross square feet of above grade office space and an additional 100,000 square feet of below grade parking.

The investigation of the 77 K Street project throughout the fall semester led to the thesis proposal and eventually this final thesis report. One of the most intriguing ideas that emerged from the fall investigation came from conversations with the building's owner, Brookfield Properties. James Berkon, the primary point of contact within Brookfield Properties, had informed me that the project had considered pursuing LEED accreditation. Unfortunately, this thought did not emerge until well into the design process. Making the project LEED accredited at this point was simply too costly. Consequently, the financial feasibility of changing the design hindered the incorporation of measures that would allow the project to achieve LEED certification.

The purpose of this thesis report is to investigate ways in which the 77 K Street project could achieve accreditation. The report uses indepth knowledge learned within the construction management option area as well as information from other architectural engineering disciplines. This thesis report is a culmination of a year long's worth of work in senior thesis coursework. The report draws from investigative studies of the existing building's design as well as research into potential changes to the existing design and scope.

A logical place to start seemed to investigate industry trends in sustainable accreditation to see if indeed LEED accreditation is an accepted and well looked upon sustainable practice. Rather than perform a literary review of prior research, information was collected and analyzed from firsthand sources, building owners themselves. This investigation, which explored owner representative's views on LEED accreditation, helped lay the groundwork as to whether indeed LEED accreditation is viewed as a positive measure within the commercial office building sector.

After investigating industry trends, two key analysis areas were identified that could significantly contribute to the building's sustainable design. These two areas are the incorporation of a green roof in lieu of the existing EPDM roofing membrane and also the use of more efficient solar glazing. Both of these investigation areas required extensive breadth analyses. They pulled from structural, mechanical, and solar knowledge bases. The focus throughout remained on the incorporation of cost effective sustainable design that is not only environmentally conscious but also financially enticing from a developer's perspective. Cost, schedule, value engineering, and constructability were primary concerns in all investigation areas.

The following report outlines in detail the methodology and the results of the three studies listed above. Additionally, the report provides an overview of the project's existing LEED status, as well as the project's potential LEED status if it were to pursue the green roof design and glazing alternative.

Project Overview

The 77 K Street project is a class A core and shell office base building project consisting of 11 above grade levels and 3 levels of below grade parking garage. The site is located at the intersection of 1st and K Streets in Washington, DC in the North of Massachusetts development district north of the Capitol Building. Additionally, the project is located only blocks from Union Station, Washington, D.C.'s primary rail terminal. The project includes approximately 350,000 gross square feet of above grade office space and an additional 100,000 square feet of below grade parking.

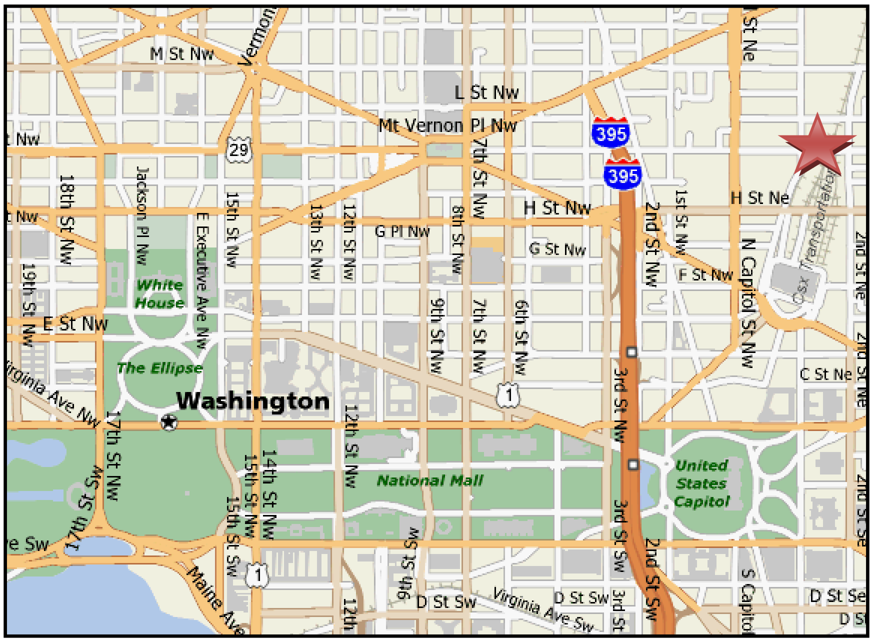


Figure 1.1: District of Columbia Map (Source: Mapquest.com)

Client Information

The owner of this project, 77 K Street LLC, is a joint venture between Brookfield Properties and ING Clarion. The original partnership at project startup was between Cafritz Company and ING Clarion but in July 2006 Brookfield Properties replaced Cafritz Company and the partnership as it is today was born.

Brookfield Properties had a number of goals and expectations that they sought to achieve on the project.

Tenant: Though none have been named to date, the developer is seeking to lease the building to either a government or private sector tenant on a minimum ten year lease.

Cost: The firm is extremely determined to finish the project within budget. Their decision to abandon contract negotiations with a general contractor in favor of opening up the project to a competitive bid in an effort to drive down the costs is a testament to this.

Quality: The building is class A construction. The owner wants high quality finishes and a first class commercial environment.

Schedule: Schedule is important and the contractor must meet the substantial completion date of July 18, 2008 and the final completion date of September 18 or face liquidated damages.

Safety: Above all the project must achieve the above objectives with a superb safety record and no accidents resulting in lost time or injury.

If the project team is able to successfully meet these objectives by providing a high quality end product within budget with a minimal number of change orders and on time, the owner will be a satisfied client. Of primary importance, the owner is targeting the exterior skin enclosure as a sequencing issue of particular importance. They are pushing the general contractor, Davis Construction, to get the facade erected soon after topping out the concrete in order to allow critical interior work to commence.

Project Team

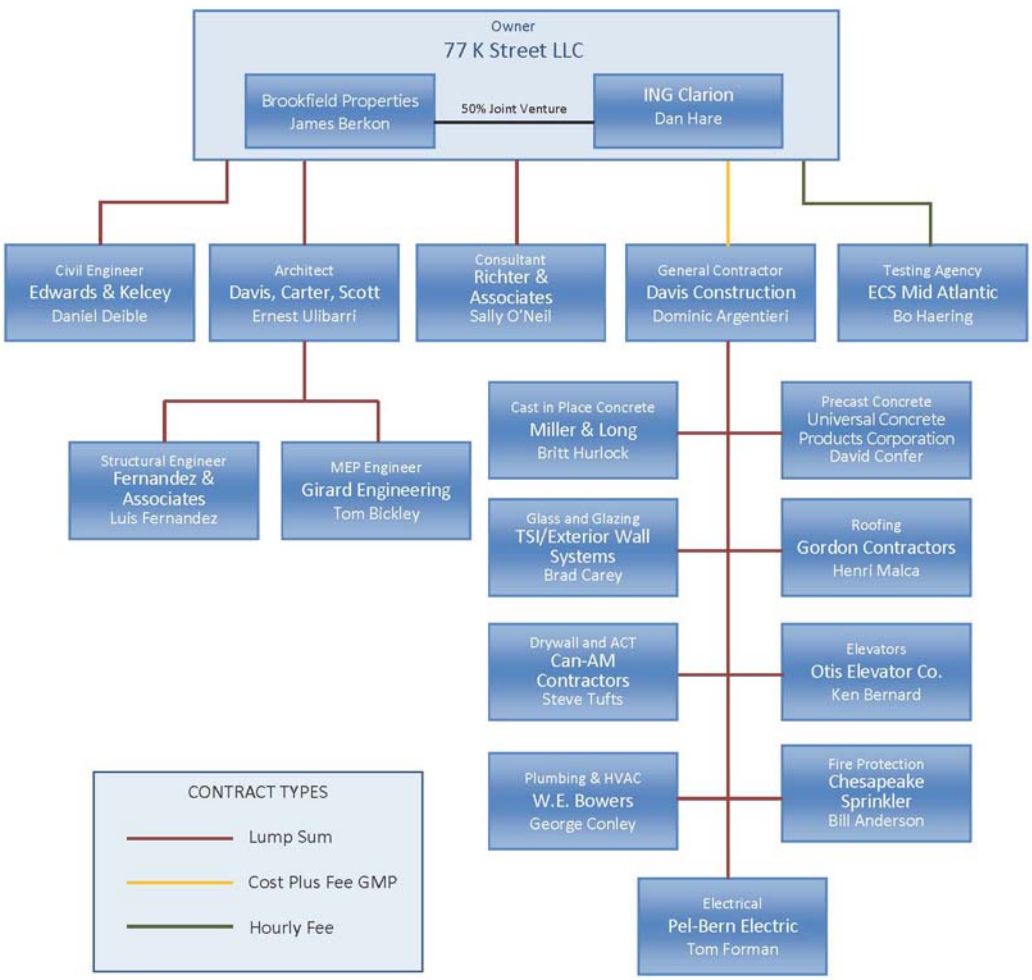


Figure 1.2: Project Team Hierarchy

Project Delivery Method

This project was developed via a design-bid-build delivery system. The ownership entity, 77 K Street LLC, sought to invest in a commercial development project in Washington, DC. After Davis, Carter, Scott developed a design, the project was put out to bid. The initial general contractor selection was based on a negotiated contract but after the owner sought a cheaper bid, the project was put out for competitive bid to a group of three shortlisted contractors. The ultimate decision was based on a number of criteria including cost, schedule, contractor's t eam, reputation, and qualifications with similar sized projects. Davis Construction won the job in November 2006.

The owner-general contractor agreement is AIA A111, a cost plus fee contract with a guaranteed maximum price. The guaranteed maximum price for the project is $41,005,150 with a stipulated, lump sum fee of $1,372,221. The contract includes clauses for increases in the fee based upon approved increases in the cost of construction. Additionally, there are stipulations for liquidated damages starting at $1,000 per day for delays in substantial completion.

Local Conditions

Washington, DC has an ordinance restricting the height of all buildings in order to prevent any structure from standing taller than the nation's capitol building. Consequently, designers have turned to concrete design to maximize their design potential. Cast in place concrete allows for long spans with a decreased floor to floor height as compared to steel construction. When concrete is post tensioned, even longer spans are possible, such is the case in the 77 K Street project. By reducing floor heights and providing open floor plans, developers are able to maximize their rental space square footage in the district. Consequently, nearly every newly constructed building within Washington, DC will have a concrete structural system.

Tipping fees for garbage disposal are approximately $850 per 20 CY dumpster. This includes pickup, disposal, and return of the dumpster. Dumpsters 40 CY in size are approximately double this cost. Recycling efforts were not pursued on this project.

The project is located in what is known as the Coastal Plain Physiographic Province of Washington, DC which contains mostly sedimentary soil materials. Stratum I which extends to a depth of between 13 and 22 feet below site grade consists of old fill predominantly composed of silty, clayey, and gravelly sand with varying amounts of organics, rock fragments, and gravel, as well as soils with stiff consistencies, classified as sandy clay. Stratum II which is first encountered at a depth between 13 and 22 feet below site grade consists of loose to dense silty and clayey sand with varying amounts of gravel and rock fragments. It also consists of cohesive soils classifying as clay with varying amounts of silt and sand. Such soil conditions in combination with groundwater conditions encountered at a depth between 18 and 39 feet below grade warranted the design of a mat foundation system.

Site Layout Plan

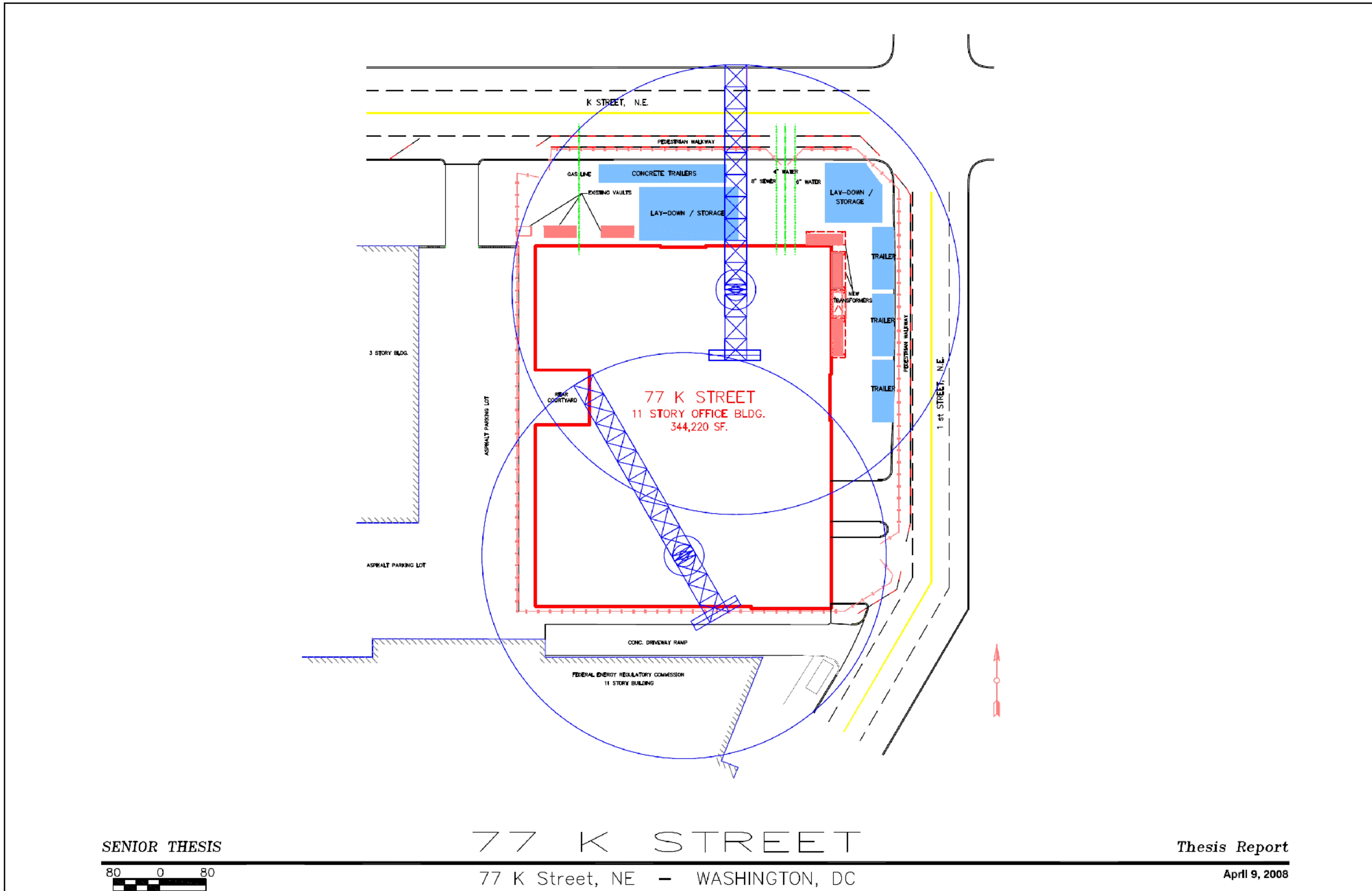
A site layout was developed for the concrete sequence of the project, which extends from April through December 2007. Concrete trucks will enter the site from K Street at the northwestern corner of the site or from the single entrance on 1st street. Their entrance location will depend on which tower crane they will be supplying concrete to.

Also of note, the layout plan has lay down areas for structural steel rebar and formwork awaiting placement within the building. One critical feature of the site plan is the placement of the southern tower crane. The crane's placement intentionally just allowed the crane to reach the southwestern corner of the rear courtyard. At this location, the crane will make a critical precast concrete pick during the façade sequence of the project.

Included on the plan are the locations of Davis Construction's trailer and spaces for subcontractor trailers. During this sequence, Miller & Long, the concrete subcontractor, will occupy one of the two remaining trailer locations. Port-O-Johns and dumpsters are also provided on the site plan. Both can be serviced via the 1st Street entrance.

Additionally, pedestrian safety is of paramount importance so pedestrian walkways have been added to protect from vehicular traffic and site equipment. Additionally, site traffic cannot exit directly at the intersection of 1st and K Street as this would be a danger to pedestrians and other vehicles alike.

The site plan developed by Davis Construction is not only appropriate but highly effective as well. It best utilizes the limited space available in an efficient, safe manner.


K STREET, N.E.
PEDESTRIAN WALKWAY
CONCRETE TRAILERS
LAY-DOWN / STORAGE
LAY-DOWN / STORAGE
TRAILER
TRAILER
TRAILER
1 st STREET, N.E.
77 K STREET
11 STORY OFFICE BLDG.
344,220 SF.
CONC. DRIVEWAY RAMP
FEDERAL ENERGY REGULATORY COMMISSION
11 STORY BUILDING
ASPHALT PARKING LOT
SENIOR THESIS
77 K STREET
Thesis Report
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77 K Street, NE – WASHINGTON, DC
April 9, 2008

Building Overview

Architecture

The 77 K Street base building project contains a variety of spaces including three levels of underground parking. The first floor contains a two-story lobby, retail space, an exercise facility, managerial offices, and a mailroom. The high-end lobby features honed granite floors, white Venetian plaster, wood veneer, and granite stone walls. Beginning at floor two, the building is designed for office tenants. The core of each floor contains the MEP rooms, elevator shafts, restrooms, and stairways.

The building was designed to reach its maximum height potential. It stands just shy of the 130′ limitation, created in the District of Columbia to prevent any building from standing taller than the nation's capitol. The building also contains a rooftop terrace that provides views both east and south towards the Capitol Building, an appealing feature for the building's future tenants.

Zoning

77 K Street is zoned as type C-3-C under District of Columbia Title 11, Zoning 2002. C-3-C is a "high bulk major business and employment" zone. The code states that C-3-C "Permits matter-of-right development for major business and employment centers of medium/high density development, including office, retail, housing, and mixed uses to a maximum lot occupancy of 100%, a maximum FAR of 6.5 for residential and for other permitted uses, and a maximum height of ninety (90) feet." Because 77 K Street sits in the NoMa Development District, north of Massachusetts Avenue, the owner was able to obtain a code variance to increase both the maximum FAR and the building height.

Building Envelope

The exterior façade is predominantly composed of architectural precast concrete panels with punched out windows. Behind the precast panels, which are mounted at each slab level, there are 2″ to 3-5/8″ light gauge metal studs with R-13 batt insulation and either a single or double layer of 1/2″ gypsum wallboard. The precast also has metal mullions attached to the outside to visually extend the lines of the windows both vertically and horizontally throughout the building.

At the entrances to the building on the north and east elevations, there are two story granite entries into the lobby. Proceeding up the building from these entranceways there are minimal amounts of precast but rather a façade predominantly composed of insulating vision glass windows, metal mullions, shadow boxes, and metal slab covers at the floor levels. The top two floors of the entire building have similar features. Elsewhere throughout the building façade, the eye is met for the most part by sets of two or three windows separated both above, below, and to the sides by light colored architectural precast.

The mechanical penthouse on the roof has an engineered insulating finish system mounted to structural steel which is not visible from street level.

The roofing system is composed of a hot fluid-applied roofing membrane directly above the concrete slab. Type VI rigid polystyrene insulation is placed above the roofing membrane. Finally, either a size 4 aggregate ballast ranging in size from 3/4" to 1-1/2" or two foot square roof pavers are placed above.

Building Systems Summary

YES	NO	WORK SCOPE
X		Demolition Required
X		Support Excavation
	X	Structural Steel Frame
X		Cast in Place Concrete
X		Precast Concrete
X		Mechanical System
X		Fire Suppression System
X		Electrical System
	X	Masonry
X		Curtain Wall

Demolition

The project is being constructed on the lot of the former 65 K Street building. 65 K Street was a two story masonry building with a basement. The building sat on 16,486 SF at the northwest corner of the lot. A fifty-two car asphalt parking lot wrapped around the south and east sides of the building. Demolition of the existing building was not included in the scope of work for the 77 K Street contract. The removal of 65 K Street, the asphalt parking lot, select utility lines, and certain site features took place prior to the general contractor selection for the new building.

Support of Excavation

In order to support the excavation of the three level underground parking garage, a system of piles, soldier beams, lagging, and tiebacks was utilized. Testing by ECS Mid Atlantic estimated that groundwater would be found between 18 an 39 feet below site grade, thus a temporary dewatering system was installed during excavation and construction with a discharge on the southeast corner of the building on 1st street. Discharge rates in the range of 50 to 100 gallons per minute were to be expected and additional sump pumps were needed as excavation progressed. A permanent sump pump is to be installed in the building as well.

Cast in Place Concrete

77 K Street utilizes a cast in place concrete structural system. The foundation is a 4'-0" thick, 4,000 psi concrete mat foundation resting on undisturbed soil with a minimum 4,000 psf bearing capacity. Below grade parking levels through the first floor are 9" reinforced

concrete flat slabs with 5-1/2″ drop panels at select column locations. Floors two through the roof are 10″ or 11″ post-tensioned two-way slabs with 4-1/4″ drop panels at all columns and around the slab perimeter. All post tensioned slabs have a force of between 130 and 1290 kips. The upper roof of the mechanical penthouse is framed using a combination of concrete and hollow structural steel members with a 8″ one-way slab roof. Typical columns have a compressive strength of 5,000 psi with select columns having increased capacity up to 10,000 psi. Slab concrete capacities range from 3,000 psi at the lowest garage level to 5,000 psi for above grade slabs. Concrete is placed using two tower cranes, both staged within the footprint of the building.

Precast Concrete

The facade of the structure is a precast and glazing system. Precast panels are either exposed architectural cladding or support units with stone veneer. Precast pieces are being casted by Universal Concrete Products Corporation in Stowe, Pennsylvania and being erected by E.E. Marr Erectors. The southern and western facades will be erected utilizing the tower cranes already mobilized on site by the cast in place concrete contractor, Miller & Long. The precast on the northern and eastern facades will be erected using a mobile crane stationed on the sidewalk within the project worksite. Precast panels will be connected to the structure by embeds cast into the concrete during slab pours.

Mechanical System

In order to meet ventilation requirements, the three levels of underground garage parking each receive just over 49,000 CFMs of fresh air via intake and exhaust shafts and fans. Both the intake and exhaust shafts contain two propeller type fans at each garage level.

The first floor of 77 K Street contains two water cooled air conditioning units. One 7,200 CFM unit supplies air to the lobby of the building with a smaller 1890 CFM unit controlling air quality within the fitness center. The base building project has mechanical rooms located in the core of each floor with the primary mechanical equipment located on the roof of the building. Three 91,560 CFM cooling tower units supply chilled air to the building. One outside air, gas fired supply unit provides 50,000 CFMs to the mechanical rooms on each floor level. Additionally, each floor contains a 27,000 CFM air conditioning unit for distribution to VAV boxes located in the tenant spaces. At this time, only a limited number of variable air volume units will be installed in order to provide temporary heat to the building's tenant spaces. The majority of the VAV boxes will be stockpiled and installed during future tenant build out.

Stair pressurization shafts contain supply register diffusers at every second or third floor. Air volume at such diffusers is between 1,250 and 1,500. The top of stairwell two contains a 7500 CFM in line fan unit supplying outside air to the pressurization shaft. Stairwell one, which services only the above grade levels, contains a smaller 6,000 CFM fan.

Plenum spaces range in size from 29″ in the core of the building to 22″ in the tenant spaces. Typical supply ducts are 16″ in height and reduce to a 12″. Plenums in the tenant spaces also contain the recessed light fixtures, VAV units, and sprinkler pipes. They are concealed with two layers of gypsum drywall.

Fire Suppression System

The building is classified as a type 1-B structure and must adhere to the NFPA 13 standard for fire sprinklers. In order to reduce the fire risk to the building, above grade levels have a wet pipe fire suppression system, whereas the garage and loading dock areas have a typical dry pipe suppression system. A 6" incoming fire protection service is located on the P1 level. After passing through a double backflow preventer this service passes through a jockey and service pump to distribute water throughout the building, via two 1-1/2" standpipes with one located in each stairwell. The first level of the building contains a fire department siamese and pump test connection on the north elevation.

Electrical System

77 K Street contains a standard 408/277V and 208/120V four wire, three phase electrical system. The main switchgear room, located on the P1 level, contains three 4000A switchboards and a single 2000A switchboard. Two of the 4000A switchboards power the normal operations of the building with the third dedicated to emergency systems. The 2000A switchboard is dedicated to the retail space on the first floor. A 750kW diesel powered generator located on the roof powers the emergency systems in case of a power outage. Power is distributed throughout the building by 4000A plug-in feeder busways and panelboards ranging in size from 150 to 400 amps.

Curtain Wall

The exterior of the building is a precast cladding and glass curtain wall system. Precast panels are attached at each slab level and extend both horizontally as well vertically throughout the building. Insulating vision glass windows and shadow boxes contain metal mullions with metal mullions extending through precast elements to create a linear visual appearance. At the lower lobby entrances precast panels support a granite veneer. Precast and glazing system design will be closely coordinated between Universal Concrete Products Corporation and TSI Exterior Wall Systems, Inc. The curtain wall will be constructed using the tower cranes, mobile cranes, and from within the building.

Lighting System

The lighting in the building is a combination of metal halide and fluorescent fixtures. The metal halide lighting systems are located predominantly in the garage levels and loading dock areas. The linear and compact fluorescents are located in the core and tenant spaces. On the roof of the building there is an outdoor photocell facing north to control lighting levels within the building. Additionally, under consideration is the possibility of adding occupancy sensors with fifteen minute time-out delay settings to control lighting levels within the tenant spaces.

Transportation

The building contains two stairwells providing means of egress. Stairwell one, located on the northern side of the building core, services the above grade levels, floors one through the penthouse. Stairwell two extends from the P3 level through the penthouse, though the location of the shaft shifts when the stairwell reaches grade level.

The building also contains nine elevators. Two elevators service the garage, one large service elevator services floors one through eleven, five typical passenger elevators service floors one though eleven, and one additional passenger elevator services floors one through the penthouse. The six passenger elevators located in the core of the building have a rated capacity of 4000 pounds, the service elevator has a capacity of 4500 pounds, and the two garage elevators have a smaller capacity of 3500 pounds. All elevators travel at a rate of 350 feet per minute.

Estimate Summary

BUILDING CONSTRUCTION	
Construction Cost	$41,005,150
Cost Per Square Foot	$91.30

TOTAL PROJECT *Including Land Acquisition and Design Fees*	
Project Cost	$125,000,000
Cost Per Square Foot	$278.32

BUILDING SYSTEM TOTAL AND SYSTEM PER SQUARE FOOT COSTS			
02000	Site Utilities	$244,800	$0.54
02300	General Excavation	$1,287,500	$2.87
03300	Cast in Place Concrete	$11,296,000	$25.15
03450	Precast Concrete	$2,950,000	$6.57
05000	Miscellaneous Metals	$617,788	$1.37
07100	Waterproofing	$201,432	$0.45
07500	Roofing	$313,595	$0.70
08800	Curtainwall	$3,734,000	$8.31
09250	Drywall	$1,482,000	$3.30
14200	Elevators	$2,334,000	$5.20
15000	Mechanical & Plumbing	$4,764,000	$10.61
15300	Fire Protection	$605,000	$1.35
16000	Electrical System	$3,588,000	$7.99

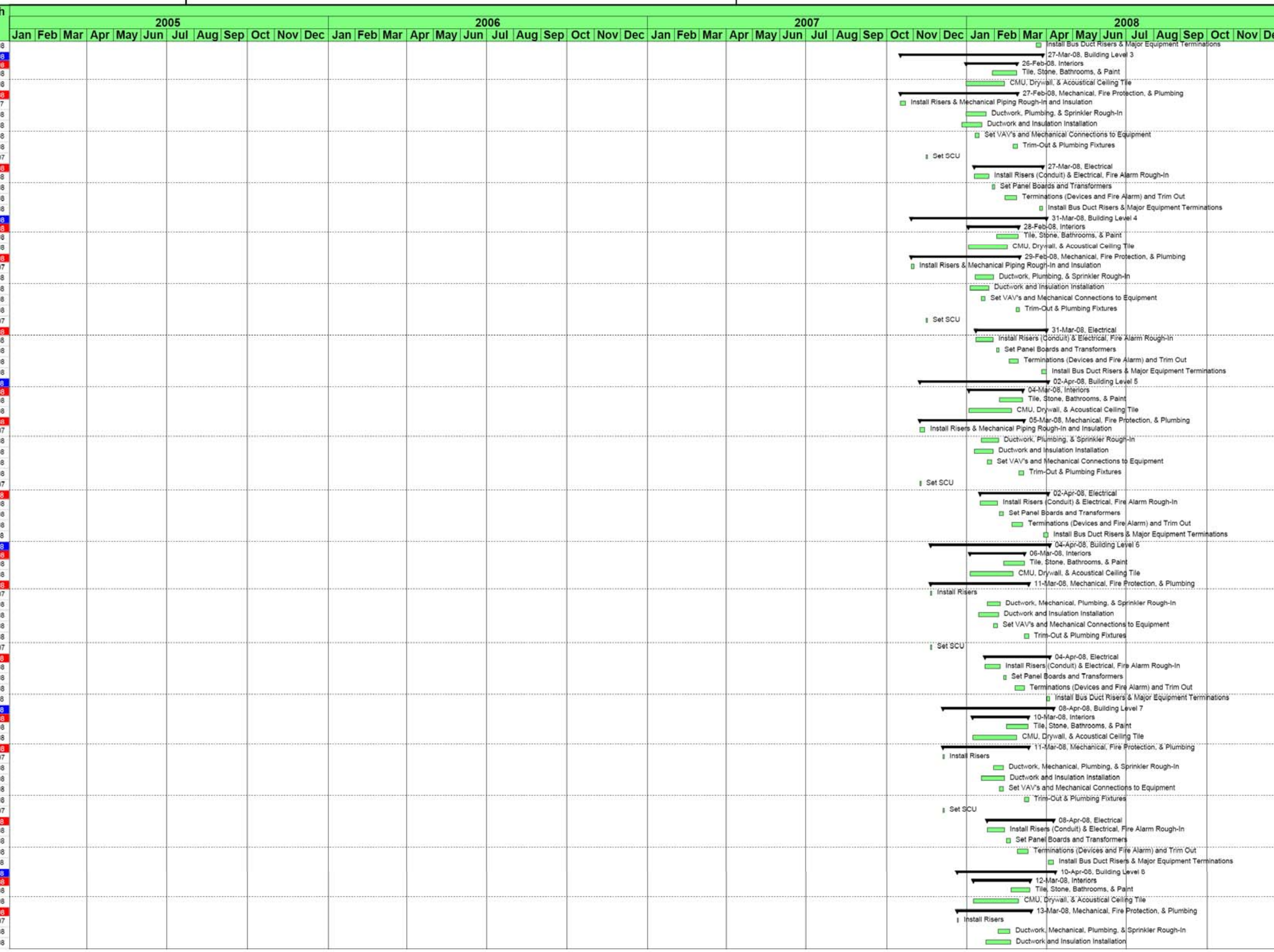
Summary Schedule

A summary schedule outlining key project activities can be found on the following four pages. Activities are arranged by floor.

77 K Street | Classic WBS Layout | 31-Oct-07 19:55

Activity ID	Activity Name	Du...	Start	Finish
77 K Street		952	03-Jan-05	18-Sep-08
Pre-Construction		470	03-Jan-05	03-Nov-06
A1000	Initial Planning through Construction Documents	293	03-Jan-05	24-Feb-06
A1010	General Contractor Selection	33	20-Sep-06	03-Nov-06
Construction		468	28-Nov-06	18-Sep-08
Excavation		126	28-Nov-06	24-May-07
A1020	Excavation	126	28-Nov-06	24-May-07
A1030	Dewatering: Installation & Set-Up	32	12-Dec-06	26-Jan-07
A1040	Sheeting & Shoring	107	19-Dec-06	18-May-07
Substructure		92	23-Mar-07	01-Aug-07
Garage Level P3		55	23-Mar-07	08-Jun-07
A1050	F/R/P Mat Foundation	51	23-Mar-07	01-Jun-07
A1060	Slab Waterproofing	40	02-Apr-07	25-May-07
A1070	In Slab Plumbing	43	03-Apr-07	31-May-07
A1280	Erect Northern Tower Crane	1	16-Apr-07	16-Apr-07
A1290	Erect Southern Tower Crane	1	08-Jun-07	08-Jun-07
Garage Level P2		45	17-Apr-07	19-Jun-07
A1080	F/R/P Walls, Columns, Slabs	35	02-May-07	19-Jun-07
A1090	Exterior Wall Waterproofing	34	17-Apr-07	01-Jun-07
Garage Level P1		21	07-Jun-07	06-Jul-07
A1100	F/R/P Walls, Columns, Slabs	22	07-Jun-07	06-Jul-07
A1110	Exterior Wall Waterproofing	20	08-Jun-07	05-Jul-07
Building Level 1		26	26-Jun-07	01-Aug-07
A1120	F/R/P Walls, Columns, Slabs	18	09-Jul-07	01-Aug-07
A1130	Exterior Wall Waterproofing	16	26-Jun-07	17-Jul-07
Superstructure Concrete		166	03-Aug-07	24-Mar-08
A1140	Level 2	10	03-Aug-07	16-Aug-07
A1150	Level 3	10	17-Aug-07	30-Aug-07
A1160	Level 4	11	29-Aug-07	12-Sep-07
A1170	Level 5	10	11-Sep-07	24-Sep-07
A1180	Level 6	10	21-Sep-07	04-Oct-07
A1190	Level 7	10	03-Oct-07	16-Oct-07
A1200	Level 8	16	15-Oct-07	05-Nov-07
A1210	Level 9	20	25-Oct-07	21-Nov-07
A1220	Level 10	10	06-Nov-07	19-Nov-07
A1230	Level 11	12	16-Nov-07	03-Dec-07
A1240	Main Roof	12	04-Dec-07	19-Dec-07
A1250	Penthouse Roof	6	20-Dec-07	27-Dec-07
A1260	Remove Southern Tower Crane	1	11-Feb-08	11-Feb-08
A1270	Infill Slab Openings at Southern Tower Crane	10	12-Feb-08	25-Feb-08
A1300	Remove Northern Tower Crane	1	10-Mar-08	10-Mar-08
A1310	Infill Slab Openings at Southern Tower Crane	10	11-Mar-08	24-Mar-08
Exterior Facade & Roof		140	20-Nov-07	02-Jun-08
A1400	Substantially Watertight	0		09-Apr-08
East Elevation		140	20-Nov-07	02-Jun-08
A1320	Precast Using Mobile Crane	68	20-Nov-07	21-Feb-08
A1330	Windows	124	12-Dec-07	02-Jun-08
North Elevation		110	12-Dec-07	13-May-08
A1340	Precast Using Mobile Crane	32	12-Dec-07	24-Jan-08
A1350	Windows	87	14-Jan-08	13-May-08
South Elevation		98	28-Dec-07	13-May-08
A1360	Precast Using Tower Crane	21	28-Dec-07	25-Jan-08
A1370	Windows	77	28-Jan-08	13-May-08
West Elevation		77	28-Jan-08	13-May-08
A1380	Precast Using Tower Crane	30	28-Jan-08	07-Mar-08
A1390	Windows	67	11-Feb-08	13-May-08
Main Roof & Penthouse		83	14-Jan-08	07-May-08
A1410	Main Roof Installation	83	14-Jan-08	07-May-08
A1420	Penthouse Steel, Framing, and EIFS Installation	48	14-Jan-08	19-Mar-08
A1430	Penthouse Roofing Installation	15	28-Feb-08	19-Mar-08
Core		177	05-Oct-07	09-Jun-08
A1440	Elevator Installation	100	22-Jan-08	09-Jun-08
A2930	PEPCO Work	40	14-Jan-08	07-Mar-08
A2940	Energize Permanent Power	0		07-Mar-08
A2950	Pull MCC Feeder Cable and Terminate	15	27-Mar-08	16-Apr-08
A2960	MEP System Start-Up	15	21-Apr-08	09-May-08
Building Level 2		123	05-Oct-07	25-Mar-08
Interiors		39	28-Dec-07	20-Feb-08
A1450	CMU, Drywall, & Acoustical Ceiling Tile	30	28-Dec-07	07-Feb-08
A1460	Tile, Stone, Bathrooms, & Paint	19	25-Jan-08	20-Feb-08
Mechanical, Fire Protection, & Plumbing		100	05-Oct-07	21-Feb-08
A1470	Install Risers	2	05-Oct-07	08-Oct-07
A1480	Set SCU	2	15-Nov-07	16-Nov-07
A1490	Ductwork and Insulation Installation	17	26-Dec-07	17-Jan-08
A1500	Ductwork, Mechanical, Plumbing, & Sprinkler Rough-In	21	26-Dec-07	23-Jan-08
A1510	Set VAV's and Mechanical Connections to Equipment	3	03-Jan-08	07-Jan-08
A1520	Trim-Out & Plumbing Fixtures	4	18-Feb-08	21-Feb-08
Electrical		56	08-Jan-08	25-Mar-08
A1530	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	11	08-Jan-08	22-Jan-08
A1540	Set Panel Boards and Transformers	3	25-Jan-08	29-Jan-08
A1550	Terminations (Devices and Fire Alarm) and Trim Out	9	08-Feb-08	20-Feb-08

Activity ID	Activity Name	Du...	Start	Finish
A1560	Install Bus Duct Risers & Major Equipment Terminations	4	20-Mar-08	25-Mar-08
Building Level 3		117	17-Oct-07	27-Mar-08
Interiors		42	31-Dec-07	26-Feb-08
A1570	Tile, Stone, Bathrooms, & Paint	20	30-Jan-08	26-Feb-08
A1580	CMU, Drywall, & Acoustical Ceiling Tile	32	31-Dec-07	12-Feb-08
Mechanical, Fire Protection, & Plumbing		96	17-Oct-07	27-Feb-08
A1590	Install Risers & Mechanical Piping Rough-In and Insulat...	4	17-Oct-07	22-Oct-07
A1600	Ductwork, Plumbing, & Sprinkler Rough-In	17	31-Dec-07	22-Jan-08
A1610	Ductwork and Insulation Installation	17	26-Dec-07	17-Jan-08
A1620	Set VAV's and Mechanical Connections to Equipment	3	10-Jan-08	14-Jan-08
A1630	Trim-Out & Plumbing Fixtures	4	22-Feb-08	27-Feb-08
A1640	Set SCU	2	15-Nov-07	16-Nov-07
Electrical		57	09-Jan-08	27-Mar-08
A1650	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	13	09-Jan-08	25-Jan-08
A1660	Set Panel Boards and Transformers	3	30-Jan-08	01-Feb-08
A1670	Terminations (Devices and Fire Alarm) and Trim Out	10	13-Feb-08	26-Feb-08
A1680	Install Bus Duct Risers & Major Equipment Terminations	4	24-Mar-08	27-Mar-08
Building Level 4		111	29-Oct-07	31-Mar-08
Interiors		42	02-Jan-08	28-Feb-08
A1690	Tile, Stone, Bathrooms, & Paint	19	04-Feb-08	28-Feb-08
A1700	CMU, Drywall, & Acoustical Ceiling Tile	33	02-Jan-08	15-Feb-08
Mechanical, Fire Protection, & Plumbing		90	29-Oct-07	29-Feb-08
A1710	Install Risers & Mechanical Piping Rough-In and Insulat...	4	29-Oct-07	01-Nov-07
A1720	Ductwork, Plumbing, & Sprinkler Rough-In	16	10-Jan-08	31-Jan-08
A1730	Ductwork and Insulation Installation	16	04-Jan-08	25-Jan-08
A1740	Set VAV's and Mechanical Connections to Equipment	3	17-Jan-08	21-Jan-08
A1750	Trim-Out & Plumbing Fixtures	4	26-Feb-08	29-Feb-08
A1760	Set SCU	2	15-Nov-07	16-Nov-07
Electrical		57	11-Jan-08	31-Mar-08
A1770	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	14	11-Jan-08	30-Jan-08
A1780	Set Panel Boards and Transformers	3	04-Feb-08	06-Feb-08
A1790	Terminations (Devices and Fire Alarm) and Trim Out	9	18-Feb-08	28-Feb-08
A1800	Install Bus Duct Risers & Major Equipment Terminations	4	26-Mar-08	31-Mar-08
Building Level 5		105	08-Nov-07	02-Apr-08
Interiors		44	03-Jan-08	04-Mar-08
A1810	Tile, Stone, Bathrooms, & Paint	19	07-Feb-08	04-Mar-08
A1820	CMU, Drywall, & Acoustical Ceiling Tile	35	03-Jan-08	20-Feb-08
Mechanical, Fire Protection, & Plumbing		85	08-Nov-07	05-Mar-08
A1830	Install Risers & Mechanical Piping Rough-In and Insulat...	4	08-Nov-07	13-Nov-07
A1840	Ductwork, Plumbing, & Sprinkler Rough-In	14	17-Jan-08	05-Feb-08
A1850	Ductwork and Insulation Installation	16	09-Jan-08	30-Jan-08
A1860	Set VAV's and Mechanical Connections to Equipment	3	24-Jan-08	28-Jan-08
A1870	Trim-Out & Plumbing Fixtures	4	29-Feb-08	05-Mar-08
A1880	Set SCU	2	08-Nov-07	09-Nov-07
Electrical		56	16-Jan-08	02-Apr-08
A1890	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	14	16-Jan-08	04-Feb-08
A1900	Set Panel Boards and Transformers	3	07-Feb-08	11-Feb-08
A1910	Terminations (Devices and Fire Alarm) and Trim Out	9	21-Feb-08	04-Mar-08
A1920	Install Bus Duct Risers & Major Equipment Terminations	4	28-Mar-08	02-Apr-08
Building Level 6		99	20-Nov-07	04-Apr-08
Interiors		45	04-Jan-08	06-Mar-08
A1930	Tile, Stone, Bathrooms, & Paint	18	12-Feb-08	06-Mar-08
A1940	CMU, Drywall, & Acoustical Ceiling Tile	36	04-Jan-08	22-Feb-08
Mechanical, Fire Protection, & Plumbing		81	20-Nov-07	11-Mar-08
A1950	Install Risers	2	20-Nov-07	21-Nov-07
A1960	Ductwork, Mechanical, Plumbing, & Sprinkler Rough-In	11	24-Jan-08	07-Feb-08
A1970	Ductwork and Insulation Installation	17	14-Jan-08	05-Feb-08
A1980	Set VAV's and Mechanical Connections to Equipment	3	31-Jan-08	04-Feb-08
A1990	Trim-Out & Plumbing Fixtures	4	06-Mar-08	11-Mar-08
A2000	Set SCU	2	20-Nov-07	21-Nov-07
Electrical		55	21-Jan-08	04-Apr-08
A2010	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	14	21-Jan-08	07-Feb-08
A2020	Set Panel Boards and Transformers	3	12-Feb-08	14-Feb-08
A2030	Terminations (Devices and Fire Alarm) and Trim Out	9	25-Feb-08	06-Mar-08
A2040	Install Bus Duct Risers & Major Equipment Terminations	4	01-Apr-08	04-Apr-08
Building Level 7		91	04-Dec-07	08-Apr-08
Interiors		46	07-Jan-08	10-Mar-08
A2050	Tile, Stone, Bathrooms, & Paint	17	15-Feb-08	10-Mar-08
A2060	CMU, Drywall, & Acoustical Ceiling Tile	37	07-Jan-08	26-Feb-08
Mechanical, Fire Protection, & Plumbing		71	04-Dec-07	11-Mar-08
A2070	Install Risers	2	04-Dec-07	05-Dec-07
A2080	Ductwork, Mechanical, Plumbing, & Sprinkler Rough-In	8	31-Jan-08	11-Feb-08
A2090	Ductwork and Insulation Installation	19	17-Jan-08	12-Feb-08
A2100	Set VAV's and Mechanical Connections to Equipment	3	07-Feb-08	11-Feb-08
A2110	Trim-Out & Plumbing Fixtures	4	06-Mar-08	11-Mar-08
A2120	Set SCU	2	04-Dec-07	05-Dec-07
Electrical		54	24-Jan-08	08-Apr-08
A2130	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	14	24-Jan-08	12-Feb-08
A2140	Set Panel Boards and Transformers	3	15-Feb-08	19-Feb-08
A2150	Terminations (Devices and Fire Alarm) and Trim Out	9	27-Feb-08	10-Mar-08
A2160	Install Bus Duct Risers & Major Equipment Terminations	4	03-Apr-08	08-Apr-08
Building Level 8		81	20-Dec-07	10-Apr-08
Interiors		47	08-Jan-08	12-Mar-08
A2170	Tile, Stone, Bathrooms, & Paint	16	20-Feb-08	12-Mar-08
A2180	CMU, Drywall, & Acoustical Ceiling Tile	38	08-Jan-08	28-Feb-08
Mechanical, Fire Protection, & Plumbing		61	20-Dec-07	13-Mar-08
A2190	Install Risers	2	20-Dec-07	21-Dec-07
A2200	Ductwork, Mechanical, Plumbing, & Sprinkler Rough-In	10	05-Feb-08	18-Feb-08
A2210	Ductwork and Insulation Installation	21	22-Jan-08	19-Feb-08



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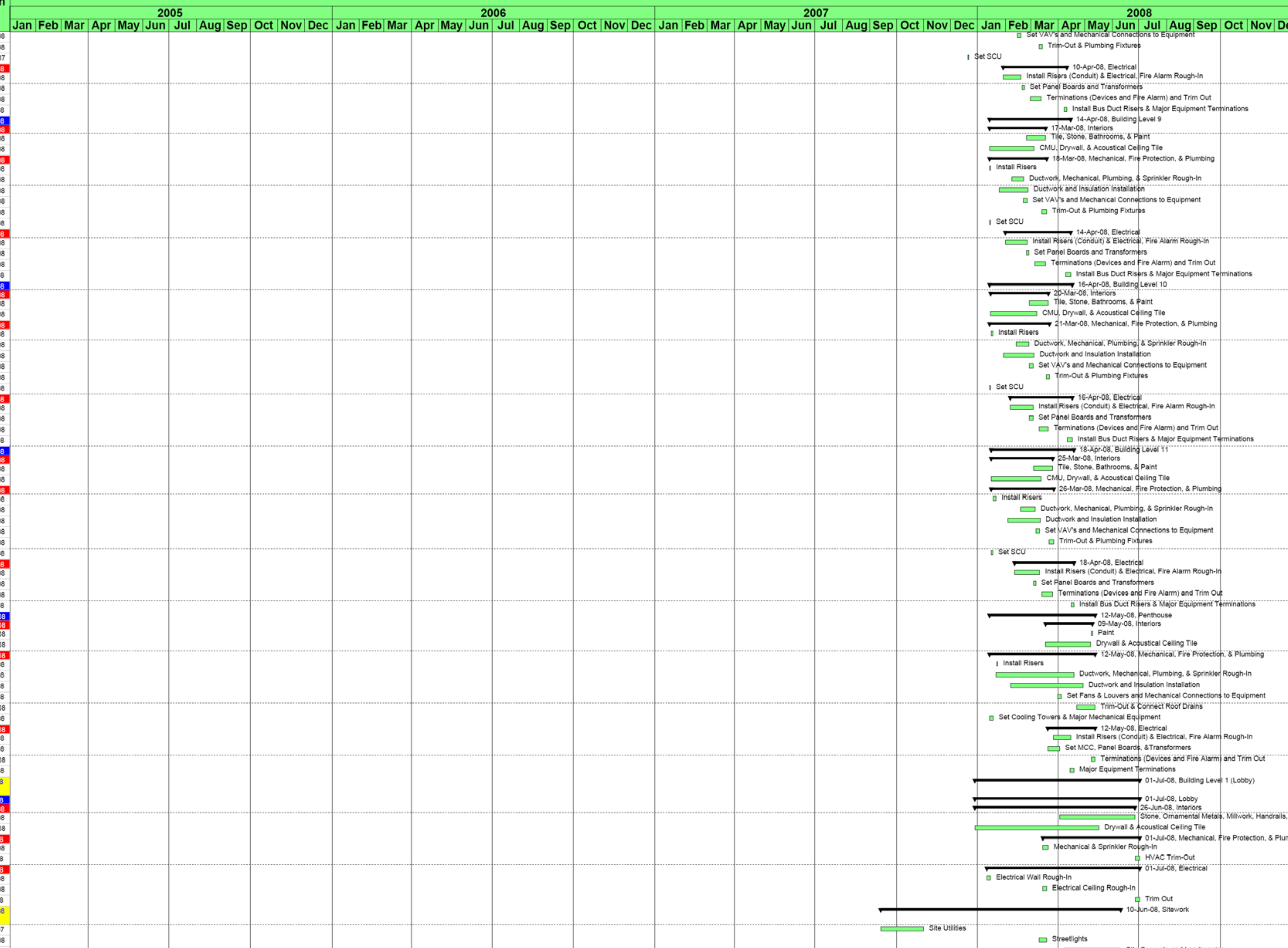
Activity ID	Activity Name	Du...	Start	Finish
A2220	Set VAV's and Mechanical Connections to Equipment	3	14-Feb-08	18-Feb-08
A2230	Trim-Out & Plumbing Fixtures	4	10-Mar-08	13-Mar-08
A2240	Set SCU	2	20-Dec-07	21-Dec-07
Electrical		53	29-Jan-08	10-Apr-08
A2250	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	15	29-Jan-08	18-Feb-08
A2260	Set Panel Boards and Transformers	3	20-Feb-08	22-Feb-08
A2270	Terminations (Devices and Fire Alarm) and Trim Out	9	29-Feb-08	12-Mar-08
A2280	Install Bus Duct Risers & Major Equipment Terminations	4	07-Apr-08	10-Apr-08
Building Level 9		66	14-Jan-08	14-Apr-08
Interiors		46	14-Jan-08	17-Mar-08
A2290	Tile, Stone, Bathrooms, & Paint	16	25-Feb-08	17-Mar-08
A2300	CMU, Drywall, & Acoustical Ceiling Tile	37	14-Jan-08	04-Mar-08
Mechanical, Fire Protection, & Plumbing		47	14-Jan-08	18-Mar-08
A2310	Install Risers	2	14-Jan-08	15-Jan-08
A2320	Ductwork, Mechanical, Plumbing, & Sprinkler Rough-In	10	08-Feb-08	21-Feb-08
A2330	Ductwork and Insulation Installation	23	25-Jan-08	26-Feb-08
A2340	Set VAV's and Mechanical Connections to Equipment	3	21-Feb-08	25-Feb-08
A2350	Trim-Out & Plumbing Fixtures	4	13-Mar-08	18-Mar-08
A2360	Set SCU	2	14-Jan-08	15-Jan-08
Electrical		52	01-Feb-08	14-Apr-08
A2370	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	17	01-Feb-08	25-Feb-08
A2380	Set Panel Boards and Transformers	3	25-Feb-08	27-Feb-08
A2390	Terminations (Devices and Fire Alarm) and Trim Out	9	05-Mar-08	17-Mar-08
A2400	Install Bus Duct Risers & Major Equipment Terminations	4	09-Apr-08	14-Apr-08
Building Level 10		68	14-Jan-08	16-Apr-08
Interiors		48	15-Jan-08	20-Mar-08
A2410	Tile, Stone, Bathrooms, & Paint	16	28-Feb-08	20-Mar-08
A2420	CMU, Drywall, & Acoustical Ceiling Tile	39	15-Jan-08	07-Mar-08
Mechanical, Fire Protection, & Plumbing		50	14-Jan-08	21-Mar-08
A2430	Install Risers	2	16-Jan-08	17-Jan-08
A2440	Ductwork, Mechanical, Plumbing, & Sprinkler Rough-In	11	13-Feb-08	27-Feb-08
A2450	Ductwork and Insulation Installation	25	30-Jan-08	04-Mar-08
A2460	Set VAV's and Mechanical Connections to Equipment	3	28-Feb-08	03-Mar-08
A2470	Trim-Out & Plumbing Fixtures	4	18-Mar-08	21-Mar-08
A2480	Set SCU	2	14-Jan-08	15-Jan-08
Electrical		51	06-Feb-08	16-Apr-08
A2490	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	19	06-Feb-08	03-Mar-08
A2500	Set Panel Boards and Transformers	3	28-Feb-08	03-Mar-08
A2510	Terminations (Devices and Fire Alarm) and Trim Out	9	10-Mar-08	20-Mar-08
A2520	Install Bus Duct Risers & Major Equipment Terminations	4	11-Apr-08	16-Apr-08
Building Level 11		68	16-Jan-08	18-Apr-08
Interiors		50	16-Jan-08	25-Mar-08
A2530	Tile, Stone, Bathrooms, & Paint	16	04-Mar-08	25-Mar-08
A2540	CMU, Drywall, & Acoustical Ceiling Tile	41	16-Jan-08	12-Mar-08
Mechanical, Fire Protection, & Plumbing		51	16-Jan-08	26-Mar-08
A2550	Install Risers	2	18-Jan-08	21-Jan-08
A2560	Ductwork, Mechanical, Plumbing, & Sprinkler Rough-In	13	18-Feb-08	05-Mar-08
A2570	Ductwork and Insulation Installation	27	04-Feb-08	11-Mar-08
A2580	Set VAV's and Mechanical Connections to Equipment	3	06-Mar-08	10-Mar-08
A2590	Trim-Out & Plumbing Fixtures	4	21-Mar-08	26-Mar-08
A2600	Set SCU	2	16-Jan-08	17-Jan-08
Electrical		50	11-Feb-08	18-Apr-08
A2610	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	21	11-Feb-08	10-Mar-08
A2620	Set Panel Boards and Transformers	3	04-Mar-08	06-Mar-08
A2630	Terminations (Devices and Fire Alarm) and Trim Out	9	13-Mar-08	25-Mar-08
A2640	Install Bus Duct Risers & Major Equipment Terminations	4	15-Apr-08	18-Apr-08
Penthouse		86	14-Jan-08	12-May-08
Interiors		40	17-Mar-08	09-May-08
A2650	Paint	2	08-May-08	09-May-08
A2660	Drywall & Acoustical Ceiling Tile	38	17-Mar-08	07-May-08
Mechanical, Fire Protection, & Plumbing		86	14-Jan-08	12-May-08
A2670	Install Risers	2	22-Jan-08	23-Jan-08
A2680	Ductwork, Mechanical, Plumbing, & Sprinkler Rough-In	65	21-Jan-08	18-Apr-08
A2690	Ductwork and Insulation Installation	58	07-Feb-08	28-Apr-08
A2700	Set Fans & Louvers and Mechanical Connections to Eq...	5	31-Mar-08	04-Apr-08
A2710	Trim-Out & Connect Roof Drains	16	21-Apr-08	12-May-08
A2720	Set Cooling Towers & Major Mechanical Equipment	5	14-Jan-08	18-Jan-08
Electrical		38	20-Mar-08	12-May-08
A2730	Install Risers (Conduit) & Electrical, Fire Alarm Rough-In	14	26-Mar-08	14-Apr-08
A2740	Set MCC, Panel Boards, &Transformers	10	20-Mar-08	02-Apr-08
A2750	Terminations (Devices and Fire Alarm) and Trim Out	3	08-May-08	12-May-08
A2760	Major Equipment Terminations	5	14-Apr-08	18-Apr-08
Building Level 1 (Lobby)		133	28-Dec-07	01-Jul-08
Lobby		133	28-Dec-07	01-Jul-08
Interiors		130	28-Dec-07	26-Jun-08
A2770	Stone, Ornamental Metals, Millwork, Handrails, Floorin...	62	02-Apr-08	26-Jun-08
A2780	Drywall & Acoustical Ceiling Tile	101	28-Dec-07	16-May-08
Mechanical, Fire Protection, & Plumbing		78	14-Mar-08	01-Jul-08
A2790	Mechanical & Sprinkler Rough-In	5	14-Mar-08	20-Mar-08
A2800	HVAC Trim-Out	3	27-Jun-08	01-Jul-08
Electrical		123	11-Jan-08	01-Jul-08
A2810	Electrical Wall Rough-In	3	11-Jan-08	15-Jan-08
A2820	Electrical Ceiling Rough-In	3	14-Mar-08	18-Mar-08
A2830	Trim Out	3	27-Jun-08	01-Jul-08
Sitework		194	13-Sep-07	10-Jun-08
A2840	Site Utilities	35	13-Sep-07	31-Oct-07
A2850	Streetlights	7	10-Mar-08	18-Mar-08
A2860	Site Concrete and Landscaping	46	08-Apr-08	10-Jun-08



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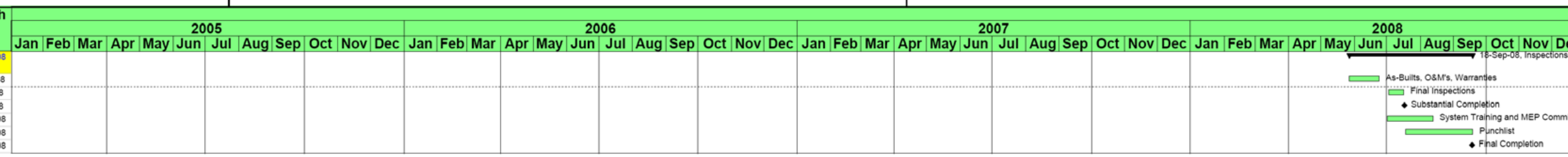
Activity ID	Activity Name	Du...	Start	Finish
	Inspections and Close-Out	83	27-May-08	18-Sep-08
A2870	As-Builts, O&M's, Warranties	20	27-May-08	23-Jun-08
A2880	Final Inspections	11	02-Jul-08	16-Jul-08
A2890	Substantial Completion	0		17-Jul-08
A2900	System Training and MEP Commissioning	31	01-Jul-08	12-Aug-08
A2910	Punchlist	45	18-Jul-08	18-Sep-08
A2920	Final Completion	0		18-Sep-08



LEED for Core & Shell Development: Current Status

The 77 K Street project is not pursuing LEED accreditation though the idea was considered but not until well into the design and planning process. After conducting a LEED benchmark survey, the design team realized that the building only achieved a 4.8% energy savings compared to a baseline model. This is significantly shy of the 14% minimum LEED prerequisite requirement for *Energy & Atmosphere Credit 1: Optimize Energy Performance*. Because the idea of LEED accreditation was first considered late in the project and significant time and cost implications would be incurred, the project team opted not to pursue accreditation though minor LEED items are being pursued for the sake of sustainability and efficiency.

The overarching theme of my thesis research will be analyzing ways in which the 77 K Street project could begin to take steps towards gaining accreditation. Key areas that will be explored include glazing selection and the incorporation of a green roof. Design changes are merely suggestions that could have been incorporated early in the design process. Estimates of cost implications are based on this assumption that they were incorporated in early design.

The applicable LEED rating system for the 77 K Street project would be LEED for Core & Shell Development, Version 2.0. This rating system contains a total of 61 points as detailed in Figure 2.1. The 61 point system requires a minimum of 23 points for the minimum accreditation level of LEED certified.

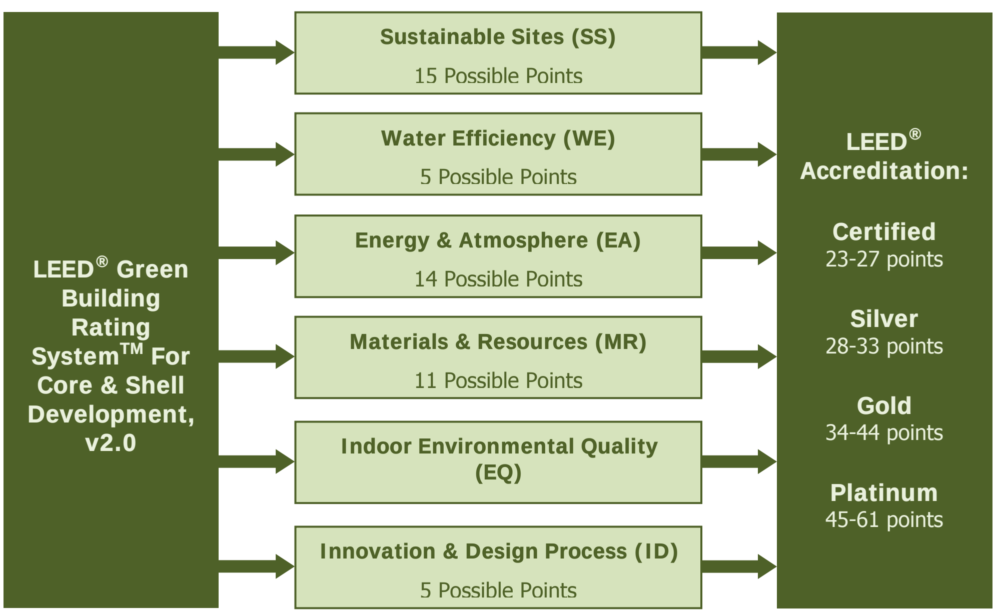


Figure 2.1: LEED for Core and Shell Development

The current building design would obtain four credits in the Sustainable Sites (SS) category and potentially two additional credits in the Indoor Environmental Quality (EQ) category.

Sustainable Sites Credit 1.0,
Avoid development of inappropriate sites and reduce the environmental impact from the location of a building on a site.

The site on which the 77 K project sits abides by all environmental criteria listed within the credit description.

Sustainable Sites Credit 2.0,
Channel development to urban areas with existing infrastructure, protect greenfields and preserve habitat and natural resources.

The building is located on a previous development and within a community exceeding a density of 60,000 square feet per acre. Therefore, the credit is obtained.

Sustainable Sites Credit 4.1,
Reduce pollution and land development impacts from automobile use.

The building is located within a ¼ mile from multiple public bus stops and and obtains one credit.

Sustainable Sites Credit 7.1,
Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.

This credit is achieved with the use of Portland cement sidewalks which have a surface reflectance index of 0.4 to 0.5 which surpasses the credit requirement of 0.29 SRI.

Indoor Environment Quality Credit 8.1,
Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

Illumination levels must be modeled to determine whether or not 75% of all occupied spaces achieve a daylight illumination level of 25 footcandles. According to their product data, glass types VE 1-85 and VE 1-2M, the two types of glazing used on 77 K Street, both exceed this requirement.

Indoor Environment Quality Credit 8.2,
Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

A tenant space layout must be developed to determine whether 90% of occupied spaces have direct lines of sight to the outdoors via vision glass. With an open floor layout, this credit will be achieved.

The two key analysis areas, the incorporation of a green roof and the selection of an alternative glazing system, were chosen for their ability to contribute a significant number of points towards ultimately reaching the minimum accreditation level. It is not suggested that adding these two design changes alone would allow the 77 K Street project to gain accreditation. Additional changes to the current project's scope and design would be required as well.

Commercial Office Building LEED Accreditation: An Owner's Perspective

Background / Goals

As the popularity and acceptance of the green building concept continues to grow, many owners and developers of commercial office projects are struggling to come to terms with whether or not it is advantageous for them to pursue LEED accreditation.

Leadership in Energy and Environmental Design, more commonly known as LEED, is a nationally recognized accreditation procedure and benchmark for the design, construction, and operation of green buildings. Since its founding in 1993 the U.S. Green Building Council has continued to develop and improve its rating system for the energy and environmental performance of buildings. It is now commonly accepted that green buildings certified by the LEED system have the following benefits:

- Lower Operating Costs
- Improved Occupant Health
- Enhanced Occupant Physical Comfort
- Improved Occupant Productivity
- Reduced Pollution and Landfill Waste
- Reduced Fossil Fuel Dependence
- Reduced Water Waste
- Decreased Ecological Impact

Research will focus on assessing owners' views of green buildings and their willingness to accept higher upfront costs in order to achieve life cycle savings and the additional benefits listed above. Do owners believe that tenants are willing to pay for the increased up-front construction costs knowing the long term benefits? Do owners believe that a building being green is an important criterion for tenants when deciding on which commercial office space to rent? Are LEED accredited buildings easier or more difficult to rent? Industry research will attempt to assess these questions and more.

By assessing owner's and developer's views on LEED accreditation, one can begin to develop an understanding of why LEED buildings are or are not growing in popularity within the commercial office sector. By beginning to understand the answers to the questions listed above, one can begin to develop assumptions on industry trends.

Resources and Tools

An online survey was developed in order to create a less time intensive means for participants to complete the questionnaire. The survey was developed using SurveyMonkey, an online survey creation and analysis website. A copy of the survey can be found in Appendix A.1. The survey was specifically designed to be provoking for both owners who are experienced with LEED accreditation as well as owners who have yet to participate in the construction of a LEED accredited project.

The survey was broken down as follows:

- Page 1 of the survey was used as a means of evaluating the survey participant's experience with the LEED process.
- Page 2 was directed towards industry members who do have LEED experience. It evaluated what levels of accreditation their past projects had pursued as well as assessed their views on LEED rental rates and their ability to find tenants relative to similar, non-accredited office buildings. The survey sought to explore specifically how accreditation has benefitted their past projects. Finally, owners were asked to elaborate on how they go about determining whether or not a project should pursue accreditation.
- Page 3 was directed towards industry members who do not have LEED experience. It assessed what factors have kept their firm from pursuing accreditation as well as whether or not they would be interested in pursuing LEED accredited projects in the future.
- Page 4 was applicable to all participants and included questions that evaluated typical utility agreements and how, if it all, this affected the decision to pursue accreditation. This page also began to explore how owners felt tenants were going to respond to the industry trend of LEED accreditation.

The survey was distributed via email to a list of contacts. Many of the development company contacts were obtained with the help of members from within the general contracting community. It is estimated that the survey was distributed directly through myself and indirectly through industry members to approximately twenty owner and development company representatives. Thirteen responses were collected. Survey results can be found in Appendix A.2.

The Experienced Owner's Perspective

How to decide whether or not to pursue accreditation?

Based on the responses collected from the survey participants with prior LEED experience, the decision on whether or not to pursue LEED objectives fell into two primary categories and two secondary categories.

PRIMARY CRITERIA	SECONDARY CRITERIA
Financial Analysis	Market Trends
Corporate Policy	Target Tenant Profile

Corporate Policy: A number of respondents noted that their corporate policy dictates that all development projects are required to obtain LEED accreditation. One company required a minimum silver rating in all projects, even including buildings previously occupied and now being repositioned on the marketplace. This is a bold company strategy that can be extremely costly in terms of retrofitting and upgrading an existing structure. As was indicated though, LEED is becoming the norm, and it is simply "the right thing to do." For some firms, cost is not of primary importance.

Financial Analysis: The most common means for determining whether or not to pursue accreditation is to complete a cost/building performa assessment or a rate of return analysis. Most companies decide on whether or not to pursue accreditation on a project by project by basis. Though there are environmental benefits, ultimately most companies are only willing to pursue LEED if it is financially more profitable than a non-accredited equivalent. If the project is profitable and it makes sense to pursue LEED objectives, the company is very willing and eager to pursue accreditation.

Market Trends: Firms want to stay competitive. If other companies are pursuing LEED, they too want to stay competitive and likewise pursue similar, if not more aggressive, accreditation levels. As much as LEED is a means of helping the environment, reducing the impact of buildings, and reducing energy demand, from an owner's point-of-view, it also a strong marketing tool to set their building apart from another.

Target Tenant Profile: The decision to pursue LEED is sometimes evaluated based on the known or anticipated tenants. If the tenant demands a LEED space, the decision is clear. Similar to some owners only developing LEED buildings, some tenants also will only occupy LEED spaces. This is often the case when working with governmental agencies or contractors. One survey participant responded that many "tenants have a corporate awareness; even a corporate directive about occupying LEED certified buildings, at a minimum. It's a corporate iconic statement about meeting energy and environmental obligations." If the tenant does not have such a policy though, the decision is a bit more convoluted. Will the anticipated tenant be cognizant of the LEED designation? From the tenant's perspective, will it differentiate their firm from another? Again, marketability is a strong consideration not only from a developer's perspective but from an individual tenant's perspective as well.

> *"Tenants have a corporate awareness; even a corporate directive about occupying LEED certified buildings, at a minimum. It's a corporate iconic statement about meeting energy and environmental obligations."*
>
> *--Survey Response # 11*

The Current Rental Environment

It was intriguing to discover that the vast majority of LEED accredited rental properties were not more expensive than their non-accredited equivalents. This can be seen in Figure 3.1. In fact, the rental agreements are typically equivalent in price. This was true

regardless of the rental utility agreement. If the utility was paid by the landlord, the owner would see the cost savings to offset the higher construction costs and thus have no need to increase rental rates. On the other hand, if the utility was paid for by the tenant, which is often the case, LEED accreditation was seen as a marketing tool to set one building apart from another. LEED accreditation is a way of making a property more competitive and enticing for a prospective tenant. Increasing rental rates to offset construction costs is generally not done, regardless of the utility structure.

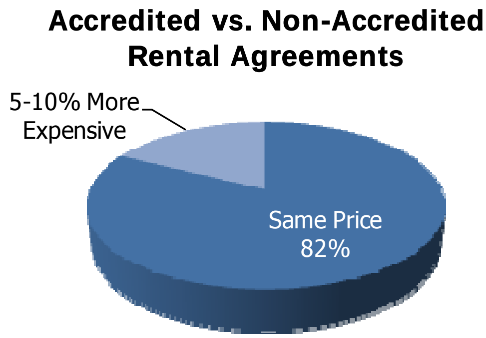


Figure 3.1: Rental Agreement Analysis

Going along with the concept of marketability, it was seen that LEED accredited projects were generally quicker to get off of the rental market. As was mentioned, LEED provides a means of gaining a competitive advantage in an increasingly competitive commercial office building market. Therefore, projects that are accredited and offer the same rental agreement can be expected to lease sooner than their traditional counterparts. This can be seen below in Figure 3.2.

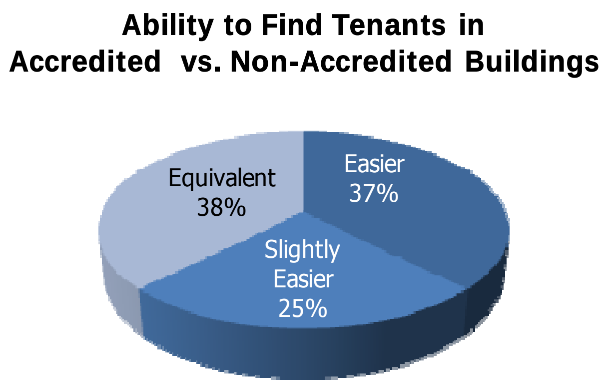


Figure 3.2: Leasing Difficulty Analysis

The Benefits of LEED Accreditation: Real World Experiences

Much has been said in the industry about the benefits of LEED accredited buildings: lower operating costs, better working environments, reduced impact on the earth, etc. Hearing reports from individuals who have worked closely on LEED projects and have seen the

results firsthand was of interest. As was anticipated, development company representatives had only positive things to say about their decision to go green and pursue LEED accreditation.

Overall, respondents noted the overall improvement in building efficiency and operation. Indeed, many have seen reduced utility consumption. This has in term lead to lower operating costs. Representatives have also noted that occupants are in fact benefitting from the improved indoor environment. Productivity is increasing, as is employee attitude. All of this can be attributed to the higher quality of space within green buildings. The improved mechanical systems are a large contributor to occupant happiness within their LEED building. All of this has been accomplished without a negative impact on the architecture of a building. Indeed, owners and tenants are seeing the benefits that have been promised within their LEED accredited office buildings.

The Inexperienced Owner's Perspective

When discussing the issue of accreditation with owner's who have never completed a LEED project, the number one concern that was mentioned amongst these individuals was cost. Every one of the survey respondents noted that cost was a primary issue that has prevented their firm from pursuing such a project. Though other preventative criteria were mentioned as well, cost was the number one item on everyone's list. There is a concern that increased first costs cannot be overcome. Numerous survey participants mentioned that if higher first costs are not offset in a relatively short payback period, the idea of LEED accreditation is discarded. The only other criterion that was mentioned as an initial hurdle to entering the LEED market is the effort to document.

There is a bit of a catch twenty-two within the thought process in that on one hand the owner seeks to stay financially competitive within the rental sector by not increasing its upfront costs and having to pass them on to the tenant; yet on the other hand, they acknowledge that the industry is adopting LEED and LEED projects are seen as competitively advantageous from a marketing perspective. In other words, the owner wants to stay competitive without increasing its costs; yet the only way of staying competitive is to pursue LEED and indeed spend more upfront.

Despite current hesitation, all of the respondents were interested in pursuing a LEED project in the future if the conditions were right. Many see that in order to stay competitive they indeed must look into pursuing LEED. Many tenants are demanding LEED accredited spaces and as long as the rental market is capable of accepting the added upfront costs, these development firms would be very interested in entering the market to construct LEED accredited projects.

Also of note, some companies acknowledge the benefits associated with sustainably designed buildings and incorporate green features into their projects without getting the project accredited. The reason they choose not to have them accredited by LEED or another accreditation agency is because of the added costs and effort associated with the accreditation process.

Tenant Evaluation

It was common among survey participants to believe that tenants are unwilling to pay higher rental rates to occupy LEED accredited spaces. Given the current market conditions, LEED is a differentiator and a means of setting one building apart from another. Most tenants are not willing to pay more for a LEED accredited space, at least one that is only certified or LEED silver. It's almost as if LEED accreditation is viewed as a building feature that is weighed along with other building components to create an entire building package.

Respondents did note though that a tenant's willingness to pay more to occupy a LEED space is somewhat dependent on the client's size. Government tenants and large firms with a corporate directive or policy may be more inclined to pay more for a LEED space. Just as owners can use LEED as a marketing tool, tenants as well may be willing to pay more for a LEED space knowing that it will improve their public image with their own clients and potential employees. On the other hand, smaller cost sensitive tenants that are more bottom-line driven will be less inclined to pay more for LEED space. As the market progresses even further into accrediting more LEED buildings, market conditions may change that will warrant firms paying more for LEED space, but as of now, overall, rental rates are remaining the same as non-accredited equivalent projects.

Conclusion

Based on the survey results, it is clear that LEED accreditation has been, and will only continue becoming, an increasingly important trend in the commercial office sector. From an experienced owner's perspective, seeking LEED accreditation is either an important company policy or a project by project evaluation. Regardless, owner and development company representatives agree, LEED buildings are extremely marketable. The continued growth of the commercial development sector will follow trends of global environmental awareness. Though LEED has been an ever growing topic of conversation, it appears as though the industry is just at the cusp of accepting the U.S. Green Building Council's rating system. LEED accredited projects will only continue to grow popularity not only from an owner's perspective but for a tenant's point-of-view as well.

For inexperienced owner's, they realize as well that the industry is only continuing to gain acceptance of the accreditation system. They realize that the future will demand green design initiatives and in order to remain competitive, they too will need to accept the changes taking place within the industry. Nonetheless, at present, many companies still are hesitant to accept higher construction costs even knowing that lifecycle savings are a strong possibility.

As the world continues to face more and more pressing environmental concerns and as the dependence on dwindling international fuel sources continues to drive fossil fuel prices upward, the day of environmental conscience sustainable design has arrived. Sustainable designs are becoming more and more attractive from a tenant's and from an owner's perspective. The idea of LEED accreditation is just beginning and will not fade anytime soon. The market demands it and the popularity of LEED accredited building will only continue to increase.

Green Roof Design

Background / Goals

In their initial investigation into pursuing LEED accreditation, Brookfield Properties considered incorporating a green roof into the 77 K Street project. After realizing that the building would not be able to achieve certain LEED benchmark requirements, the idea of adding a green roof was abandoned. Incorporating a green roof into the existing building would improve the facility in the following ways:

- Reduce storm water runoff into Washington, D.C.'s sewer system
- Reduce peak energy demands by decreasing heating and cooling loads
- Decrease the urban heat island effect
- Protect the waterproofing membrane from UV exposure and freeze-thaw cycles, thus extending its lifespan
- Help the environment through oxygen filtration and production
- Improve sound insulation
- Contribute a significant number of LEED points to help achieve accreditation
- Add recreational space for tenants to enjoy
- Increase property value

The following analysis will investigate the structural implications of adding a green roof to the project. A rudimentary energy study is performed as well in order to assess potential energy savings achieved through the green roof addition. Finally, a LEED assessment will be performed to evaluate contributions the green roof design would add towards LEED accreditation.

Analysis Methodology

1. Investigate various green roof alternatives.
2. Select an appropriate roofing system and components.
3. Assess cost impacts of the new roofing system.
4. Assess schedule impacts of the new roofing system.
5. Determine new roof loads.
6. Design new roof structural system based on the Concrete Reinforcing Steel Design Handbook (2002).
7. Assess plenum space implications of the one-way slab design.
8. Assess energy savings of the new roofing system.
9. Evaluate impact on LEED accreditation.

Resources and Tools

In order to perform the green roof analysis, a number of resources were utilized. After investing various green roof systems, it was decided that the Sika Sarnafil system would be utilized. Ryan Shaughnessy, a representative from Sika Sarnafil Inc., was an integral contact that helped guide my green roof design.

Once an appropriate system was selected and the new roof loads were calculated, the 2002 edition of the Concrete Reinforcing Steel Institute Design Handbook was used to

design the new structural system. Of note, the current roofing system uses a two-way post-tensioned slab. The redesigned system is based on a one-way slab system. The primary reason why a two-way post-tensioned system was not used was because of the complexity of post-tension design. Following discussions with Professor Parfitt, it was determined that a one-way slab would be the most appropriate design alternative for a construction management student. Results of this decision are further discussed later in the analysis.

Green Roof System Selection

Intensive vs. Extensive System

When determining what type of green roof system would be most appropriate for the 77 K Street project, the various benefits of a green roof design were assessed. What features does the owner want to incorporate? What components would the future tenants most value?

From the owner's perspective, the benefits of adding a green roof include large energy savings, more usable space, increased property value, prolonged roof lifespan, and valuable marketing. If the green roof was able to be used as a recreational, leisure space, the roof would be an attractive feature that could set the 77 K Street building apart from other similar commercial office buildings in the Washington, DC metro area.

Based on the following chart from the organization Green Roofs for Health Cities, a green roof type was selected.

EXTENSIVE	SEMI-INTENSIVE	INTENSIVE
Lightweight	Combines best features of extensive and intensive	Greater diversity of plants
Suitable for large areas	Utilizes roof areas with greater loading capacity	Best insulation and storm water management
Low maintenance costs and no irrigation required after fully established	Greater coverage at less cost than intensive	Greater range of design
Suitable for retrofit projects	Average maintenance	Usually accessible
Lower capital costs	Greater plant diversity than extensive	Greater variety of human uses
Easier to replace	Greater opportunities for aesthetic design than extensive	Greater biodiversity potential

Figure 4.1: Green Roof System Summary
(Source: *Green Roofs for Healthy Cities*)

Extensive Roof | Semi-Intensive Roof | Intensive Roof

(Source: *Sika Sarnifil*)

A semi-intensive system seemed to be the most appropriate for this commercial setting. The building would benefit from many of the advantages of an intensive roof without many of the added costs.

- The lighter loads would have a smaller impact on the existing structural system.
- The system still contributes significant energy savings to the building.
- The design would have fewer maintenance concerns in terms of irrigation and landscaping.
- The roofing system could incorporate areas for pedestrian access, thus allowing tenants of the building to enjoy the green space.
- The mid-range media depth allows for a wider range of small plant diversity as compared to an extensive design.
- The owner achieves a strong cost-benefit relationship.

After investigating various manufacturers of green roof systems, Sika Sarnafil Inc. was selected as the roofing system of choice. Other manufacturers that were considered include Hydrotech and Icopal.

Select System Components

As seen on the next page in Figure 4.2, the Sarnafil green roof system includes a waterproofing membrane, protection and drainage layer, insulation layer, drainage composite, growth medium, and vegetation. Based on the proposed design parameters, the system could support grasses and small plant species.

Sarnafil Waterproofing Membrane (Sarnafil G476-15):

The Sarnafil G476 waterproofing membrane is a PVC based fiberglass mat system. The membrane comes in a variety of thicknesses ranging from 60 mil to 120 mil. The 60 mil (1.5 mm) system was chosen in this design as an alternative to the 1.5 mm EPDM waterproofing membrane in the current roofing design. The G476 system is applied directly to the concrete surface and attaches by means of a pressure sensitive adhesive as well as fasteners. Edges of the membrane are heat-welded together to create a

single waterproofing membrane. Sections of the roof can be compartmentalized as well as a maintenance precaution in case of water penetration below the membrane.

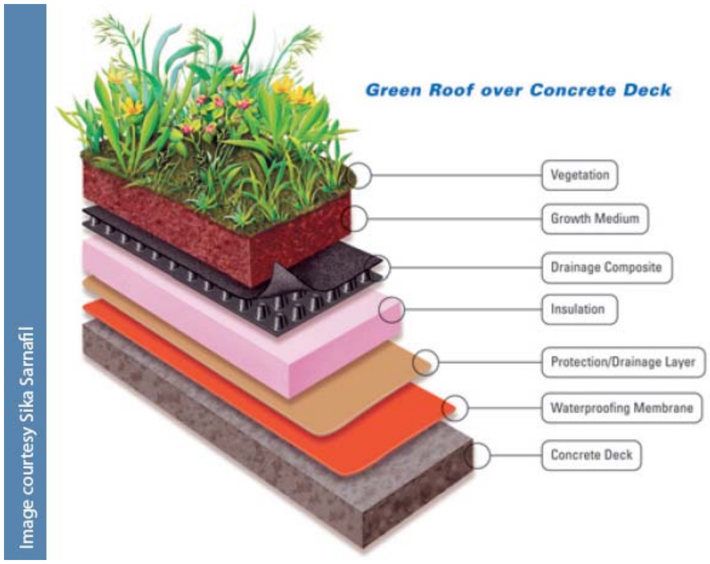


Figure 4.2: Green Roof Components
(Source: *Sika Sarnafil*)

Insulation (4" Sarnatherm XPS-400):

The extruded polystyrene (XPS) insulation board is installed above the waterproofing membrane. The XPS system is specifically designed for moist, buried environments. As a result, it need not be protected by an air or vapor barrier. The insulation does not lose thermal performance when exposed to moisture because of its closed cell design.

Drainage Panel 900:

The drainage panel has a three-dimensional core with a fabric covering that allows large amounts of water to pass freely out of the roofing system. The purpose of the panel is to allow water that flows through the soil medium to drain out of the system, thus protecting the waterproofing membrane from ponding and hydrostatic uplift. The panels also have pockets to store some water as well for the plant medium to absorb after it begins to lose some of its current moisture.

Growth Medium and Plant Vegetation:

It was decided that a semi-intensive green roof system would be incorporated into the building. Eight inches of soil medium will support small shrubberies and plant growth. This wider diversity of plant species will be more attractive than an extensive system that can only support grasses.

Cost and Schedule Comparison

In order to determine an accurate cost estimate for the green roof system, a number of sources were utilized. An attempt was made to receive an estimate from Sika Sarnafil but the company was unable to provide such a cost estimate. A supplier from the Philadelphia area was also contacted but again, they were unable to provide a cost estimate for the system. At which point it was decided to develop a cost estimate based on case studies and design guidelines. The cost estimate was developed from green roof systems of comparable size and scope. Additionally, the system breakdown was developed from the "Design Guidelines for Green Roofs" developed by the Ontario Association of Architects. The estimate of $22.50 falls within the anticipated cost range for a semi-intensive roofing system and the general guideline of being roughly twice the construction cost of a standard built-up roofing system.

	Component	Cost / SF
Green Roof	Green Roof System (curbing, drainage layer, filter cloth, growing medium, pavers, etc.)	$11.00
	Plants	$3.50
	Installation / Labor	$8.00
	Total	**$22.50**

The green roof design would cover approximately 24,000 square feet of the 32,000 square foot roof. The penthouse and second floor roofs will still be covered by the ballasted EPDM roof system. The primary factor governing the use of the EPDM system in these two areas is the difficulty of access. The green roof system does have additional landscaping and upkeep issues that require more extensive maintenance access.

Material and Installation Cost Summary:

Existing EPDM Roof System

32,000 SF @ $9.80/SF = $313,600

Total Cost = $313,600

Average Cost = $9.80/SF

Green Roof Redesign

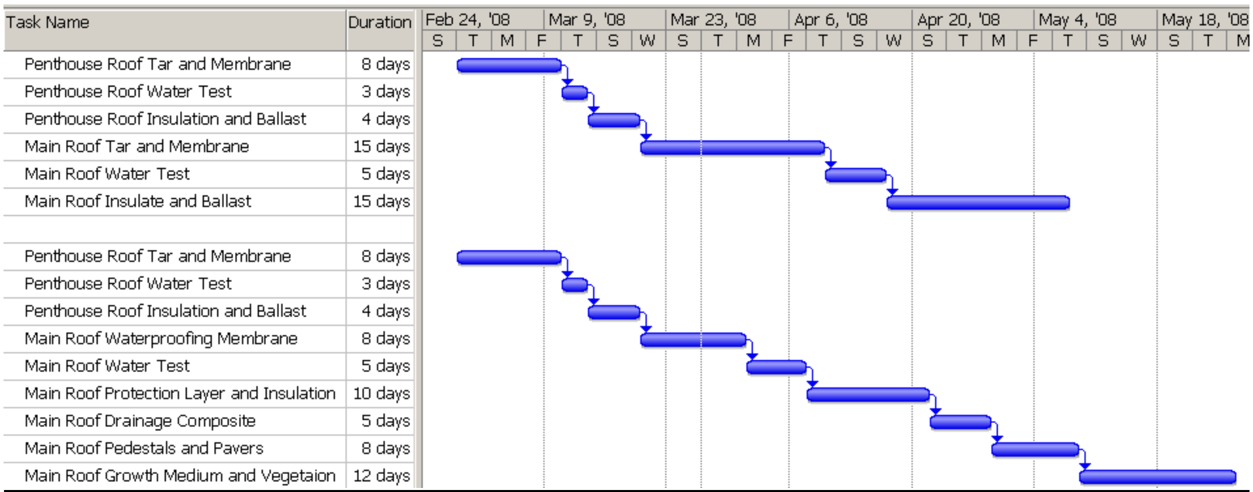
8,000 SF @ $9.80/SF = $78,400

24,000 SF @ $22.50/SF = $540,000

Total Cost = $618,400

Average Cost = $19.32/SF

Based on the proposed schedule below, the green roof system would add thirteen days to the existing roofing schedule. Though this adds duration to the roofing activities, it does not push back the overall construction schedule. The substantial completion date is not affected in any way.



Green Roof Structural Design

Description

To accommodate the increased load on the roof structure, the existing structural system was redesigned to accommodate the additional dead loads associated with the green roof. Additionally, live loads were increased to 100 PSF on all portions of the roof to accommodate pedestrian access. A one-way concrete slab system with beams and girders was designed for a typical 30'-0" x 30'-0" bay with typical 24" x 24" columns. Both interior and end span bays were designed. Members were sized using *Concrete Reinforcing Steel Institute Design Handbook, 2002*. Detailed calculations for the design of the roofing system can be found in Appendix B. For this breadth study, torsional moments induced on end span spandrel beams were not considered. Additionally, the tributary area for a typical interior span was used in the calculation of end spans as well. A typical interior bay is shown in Figure 4.3.

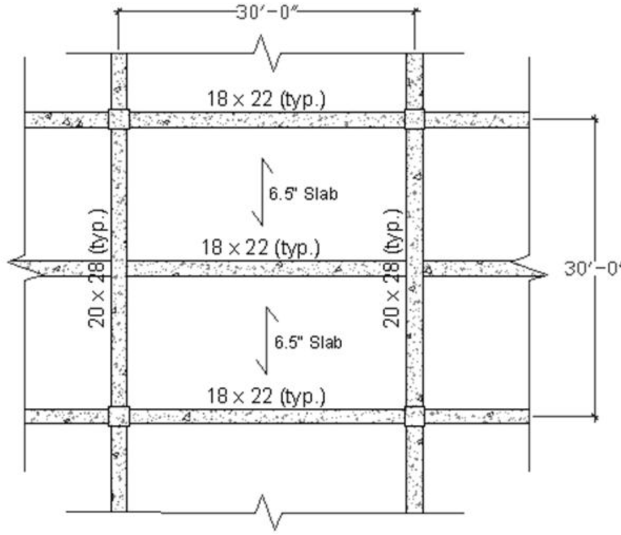


Figure 4.3:
Typical Interior Bay Design

Slab Design Procedure

1. Calculate live and dead loads being induced on the slab.
2. Calculate factored load, w_u.
3. Determine clear span, ℓ_n, between the column and beam.
4. Determine minimum allowable slab thickness based on $\ell/28$.
5. Determine slab thickness and ρ value based on minimum slab thickness, clear span, and factored loading. Use tables in chapter 7 of the CRSI Design Handbook.
6. Compare allowable interior span and end span slab thicknesses and use the greater of the two values. End span thickness will always control.
7. Check deflection and crack control.

The slab thickness for a typical bay was calculated to be 6.5".

Beam Design Procedure

1. Calculate live and dead loads being induced on the slab.
2. Calculate factored load, w_u, per square foot.
3. Calculate load per linear foot of beam stem.
4. Convert factored load into a line load on the beam and add to stem load.
5. Determine minimum beam size based on clear span and factored loading. Use tables in chapter 12 of the CRSI Design Handbook.
6. Adjust beam stem loading in step 3 and repeat steps 4 and 5 as necessary.
7. Compare allowable interior span and end span beam sizes and determine whether it is appropriate to use different sizes. End span size will always be greater given the same loading.

8. Determine stirrup requirements given in beam design based on tables provided on page 12-13 of the design handbook.

The design conditions dictated a beam size of 18” x 22”. It is possible that interior span beams be reduced to 16” x 22” but for ease of construction, all beams were maintained at a 18” x 22” size. By keeping a uniform beam size throughout, the concrete contractor is able to use the same formwork throughout the slab system. Though interior and exterior spans have the same size beams, the reinforcing within the beams varies. Figures 4.4 and 4.5 show typical interior span beam sections.

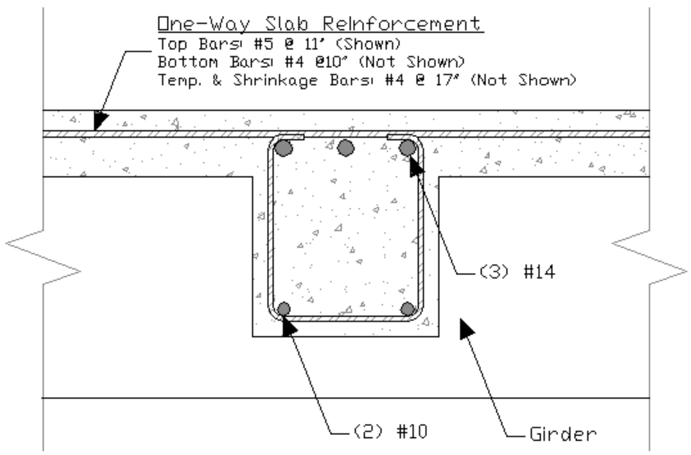


Figure 4.4:
Interior Span, Beam Section

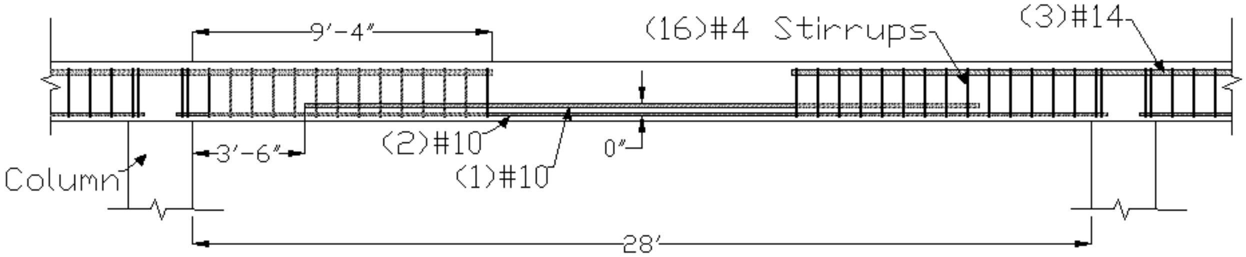


Figure 4.5:
Interior Span, Beam Section

Girder Design Procedure

1 Convert concentrated mid-span beam load to a point load.
2. Calculate load per linear foot of beam stem.
4. Calculate factored moment from concentrated load at mid-span, M.
5. Calculate equivalent uniform load based on factored moment, w.

6. Calculate total uniform factored load, w_u, for negative moment by adding w and girder stem load.
7. Calculate factored positive moment, $+M_u$.
8. Calculate total uniform factored load, w_u, for positive moment.
9. Determine minimum girder size based on clear span and total uniform factored load, w_u, for negative moment. Use tables in chapter 12 of the CRSI Design Handbook.
10. Adjust beam stem loading in step 2 and repeat the above steps as necessary.
11. Compare allowable interior span and end span beam sizes and determine whether it is appropriate to use different sizes. End span size will always be greater given the same loading.
12. Determine stirrup requirements given in girder design based on tables provided on page 12-13 of the design handbook.
13. Check that torsion requirements are met.
14. Check that shear requirements are met.
15. Check bottom bar positive moment capacity based on data in design tables.
16. Adjust initial stirrup spacing based on shear requirements.

The design conditions dictated a girder size of 20" x 28". It is possible that interior span girders be reduced to 18" x 28" but for ease of construction, all beams were maintained at a 20" x 28" size. By keeping a uniform beam size throughout, the concrete contractor is able to use the same girder framing formwork throughout the slab system. Though interior and exterior spans have the same size girders, the reinforcing within the girders varies. Figures 4.6 and 4.7 show typical interior span girder sections. Figure 4.8 illustrates a typical interior span intersection of a column, beam, and girder.

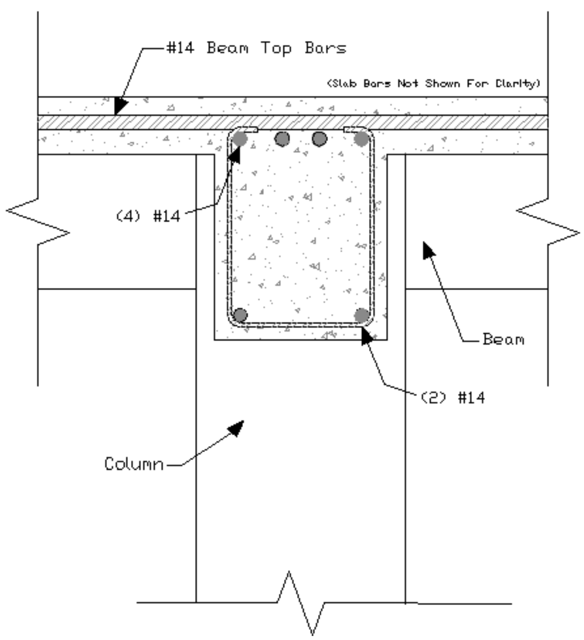


Figure 4.6:
Interior Span, Girder Section

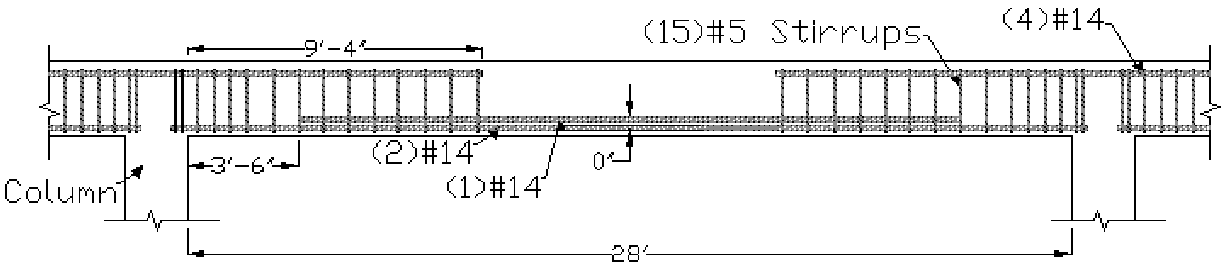


Figure 4.7:
Interior Span, Girder Section

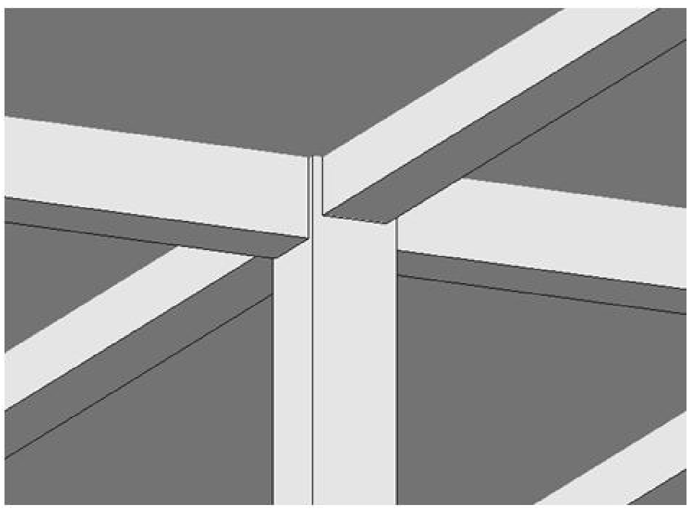


Figure 4.8:
Structural Element Intersection

Plenum Space Implications

The decision to design a one-way reinforced slab system rather than a two-way traditional or post-tensioned system creates a construction coordination concern in terms of mechanical and plumbing coordination within the plenum space. The girders running in the north-south direction have a depth of 28", 17" deeper than the existing 11" slab. In the east-west direction, the beams have a depth of 22", again deeper than the existing conditions.

The existing finished floor to finished ceiling height on all typical floors, except for the eleventh floor, is 8'-7". The eleventh floor has a floor to ceiling height of 9'-1". By lowering the finished ceiling height to 8'-7" on the eleventh floor, an additional 4" is gained to account for some of the reduced plenum space.

As shown in the typical tenant space drawings in Figure 4.9, even with lowering the finished ceiling height, the reduced plenum space still poses a problem for installing the mechanical duct work. Additionally, raising the roof height is not an option. District of Columbia code mandates that the building not exceed a height of 130'-0". The building currently stands at 129'-11-1/2" and therefore it is not a feasible solution to add plenum space on the eleventh floor by raising the roof slab.

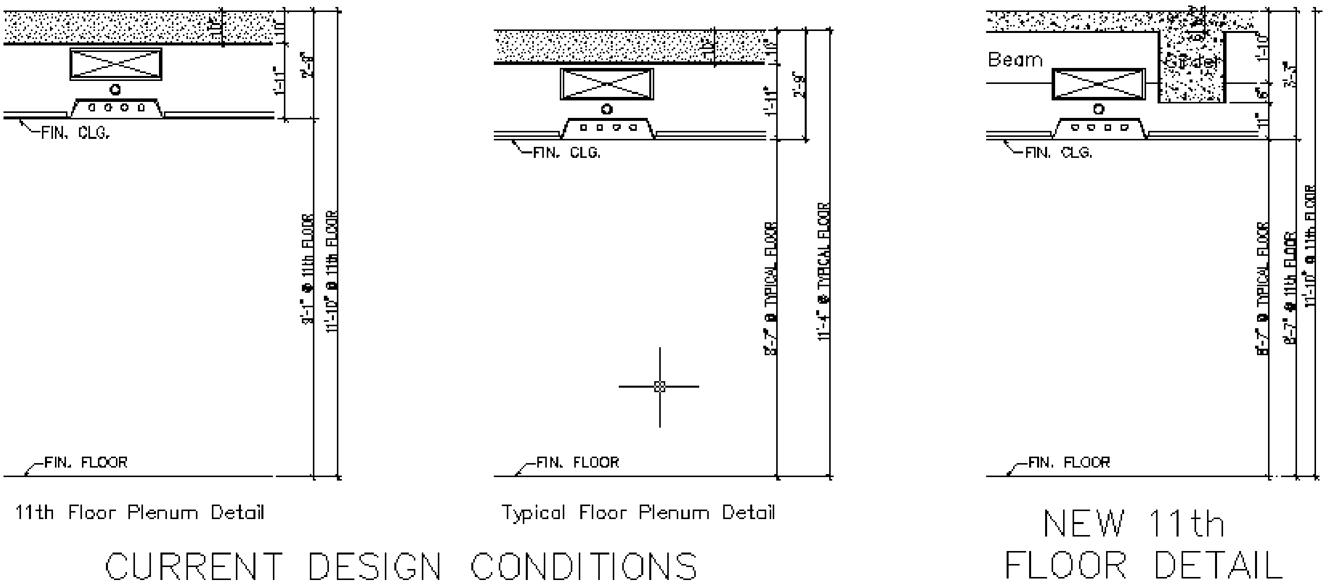


Figure 4.9:
Existing and Proposed Plenum Space Conditions

The current system has a plenum space of 1'-11". The redesigned roof slab system provides for a clearance of 1'-5" beneath the beams running in the east-west direction and only 11" beneath the girders in the north-south direction. From the core of the building, ducts are currently 16" deep extending 20' from the self contained air conditioning units. The 16" ducts are only located in the core of the building where the plenum space is 2'-5", 7" larger than in the tenant space. In the tenant space duct size is reduced to 12" maximum. Consequently, the major concern is fitting the ducts beneath the girders. The beam design does not have a hindering impact on the current duct design.

Possible solutions to the plenum space issue:

1. Resize ducts and minimize duct depth so as to fit beneath the girder and above the current finished ceiling height.
2. Lower the finished ceiling height.
3. Provide cutouts in the girders to accommodate ducts. Provide additional reinforcement at cutout locations to provide adequate load capacity at these locations.

Energy Analysis

Green roof systems have been proven to reduce heat transfer compared to a conventional roofing system. This in turn reduces heating and cooling loads induced on the building. In order to determine the energy savings of the green roof design, the heat transfer was first calculated for the existing roof. Heat transfer through a flat roofing system can be estimated using the equation:

$$Q = UA(\Delta T)$$

To begin, the thermal transmittance (U value) for the existing roofing system was tabulated and is shown in Figure 4.10.

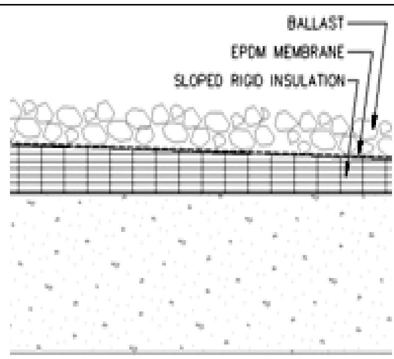
		Unit Resistance (R)
	Inside surface (still air)	0.61
	Concrete slab, 11 in.	0.88
	Rigid roof deck insulation, 4"	20.00
	EPDM, 1.5 mm	0.05
	Ballast, 2"	1.70
	Outside surface (15 mph wind)	0.17
	Total Thermal Resistance (R)	23.41
U = 1/R	*Coefficient of Transmission (U)*	0.0427

Figure 4.10:
Roof Thermal Conductivity Analysis

The calculation of an effective U value for a green roof system is a bit more complex due to the changing thermal properties of the roof with fluctuations in temperature and moisture content. As a result, a study performed at the National Research Center in Toronto, Canada was used as a reference. Their research found that over the two year study, green roofs had a 95% heat gain reduction and a 26% heat loss reduction compared to a reference roof of conventional roofing construction.

In the analysis below in Figure 4.11, a conservative value of 75% of each of these reductions was used (71.25% heat gain reduction and 19.5% heat loss reduction). Their research concluded that green roofs experienced larger heat transfer savings in the warmer, summer months. Being that Washington, DC is a more temperate climate than Toronto, the potential energy savings may be even greater than those estimated.

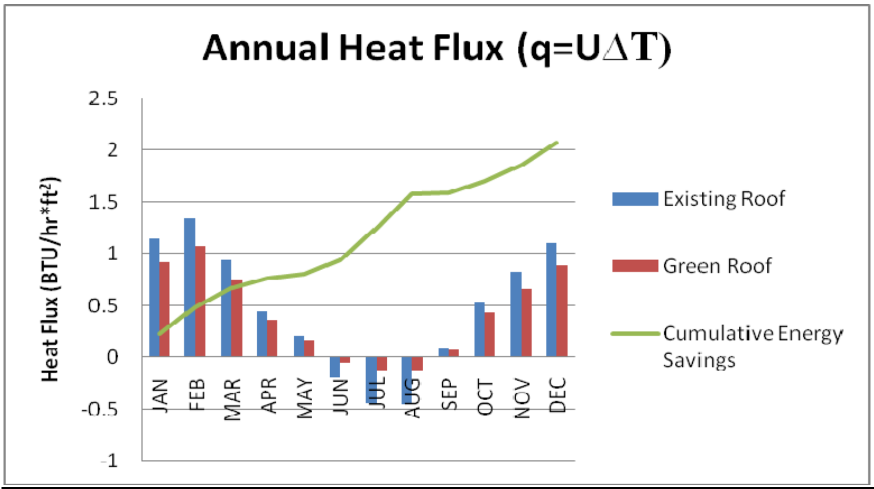


Figure 4.11:
Annual Heat Flux

Based on the above graph, the greatest energy savings will be achieved in August when the system will have a 7.5525 BTU/hr*ft^2 reduction in cooling load between the existing and green roof systems.

Existing Roofing System:

Q_e = UA(ΔT)
Q_e = (0.0427 BTU / (hr*ft^2*°F))*(32,000 ft^2)*(80.6 °F – 70 °F)
Q_e = 14,484 BTU / hr
Q_e for 24,000 SF = 10,863 BTU / hr
Q_e for 8,000 SF = 3,621 BTU / hr

Green Roof Design:

Q_g = (10,863 BTU / hr)*(1-(0.75*0.95)) + 3,621 BTU / hr
Q_g = 6,744 BTU / hr

Savings = (14,484 BTU / hr – 6,744 BTU / hr) / (12,000 BTU / ton)
= 0.645 ton/hr savings

Because the reduction in the maximum cooling load is less than a ton, the possibility of reducing the size of the self-contained air handling unit that cools the eleventh floor is not practical. Nonetheless, there is still a reduction in demand on the system. The McQuay SWP-080 system used in the building has an efficiency of SEER 14.

Annual Energy Savings:
Q = Area * Cum. Annual Savings * Hours Per Day * Days Per Year
Q = (24,000 ft^2) * (2.073 BTU / Hr. * ft^2) * 24 Hrs/Day * 365.25 Days/Year
Q = 436,126,032 BTUs/Year

$$\$/yr = \frac{(BTU/yr)(\$/kWh)}{(SEER)(1{,}000\ \text{W/kW})}$$

$$\$/yr = \frac{(436{,}126{,}032\ \text{BTUs/Year})(\$0.0672/\text{kWh})}{(14\ \text{BTUs/W})(1{,}000\ \text{W/kW})}$$

$$\$/yr = \$2{,}093/yr.$$

Life Cycle Cost Analysis

According to published data, the average expected life expectancy of the waterproofing membrane in an EPDM and ballast roofing system as is currently installed on the 77 K Street project is 17.7 years. Because the waterproofing in a green roof design is protected from UV exposure and more extreme surface temperatures, the life span is greatly extended. Estimates are that green roof systems can last between 35 and 50 years before the waterproofing membrane must be replaced.

The forty year cost analysis below shows that over the life span of the building, the green roof system is a slightly more cost effective solution as the roofing system has a lifespan of approximately twice that of the EPDM system. Replacement of the EPDM system is assumed to take place at year 20 and in year 40, both systems would need replacement. 8,000 square feet of roof will require replacement in the redesigned system as well because 100% of the roof was not redesigned to be green. The owner will realize an equivalent cost at approximately year 20 and from that point forward will begin to realize a cost savings from the green roof design.

The rudimentary analysis below includes initial costs, replacement costs, and annual energy expenses associated with heat loss through the roofing system. Interest rates and changes of the dollar value over time are ignored. A more in depth cost assessment can be found in the final section of this report entitled "LEED for Core & Shell Development: Potential Status." As shown above, the green roof system has an operating savings of $2,903 as compared to the existing system. Maintenance costs are not included in the analysis below but are relatively comparable between the two systems if an appropriate green roof design is incorporated.

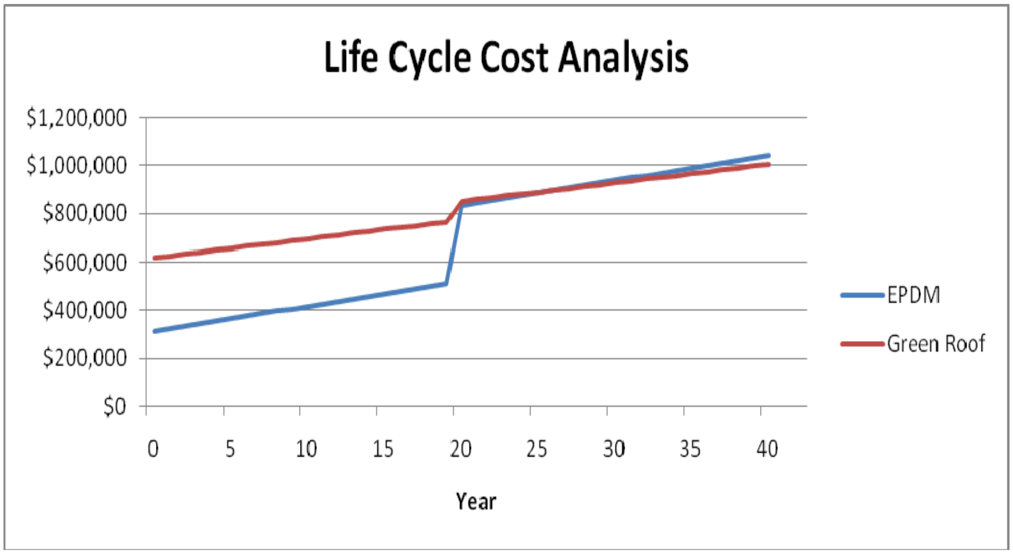


Figure 4.12:
Roofing Life Cycle Analysis

LEED Impact

The incorporation of a green roof into the 77 K Street project has the potential to contribute to four categories of the LEED rating system as outlined below.

# of Credits	LEED Credit	Likely	Possibly	Contributor
1	Sustainable Sites 6.1 *Stormwater Design: Quantity Control*	X		
1	Sustainable Sites 7.2 *Heat Island Effect: Roof*	X		
1	Water Efficiency 1.1 *Water-Efficient Landscaping*		X	
2-8	Energy and Atmosphere 1.0 *Optimizing Energy Performance*			X
1-2	Materials and Resources 4.1, 4.2 *Recycled Content*			X
1-2	Materials and Resources 5.1, 5.2 *Local and Regional Materials*			X

Sustainable Sites Credit 6.1,
Limit disruption of natural hydrology by reducing impervious cover, increasing on-site infiltration, and managing stormwater runoff.

In order to meet the requirements for this credit, one must reduce stormwater runoff by a minimum of 25% for a given two-year 24-hour design storm. The incorporation of a green roof will most certainly meet this criterion.

Sustainable Sites Credit 7.2,
Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.

Installing a green roof on at least 50% of the roof area meets the credit requirement.

Water Efficiency Credit 1.1,
Limit or eliminate the use of potable water, or other natural surface or subsurface water resources available on or near the project site, for landscape irrigation.

Irrigation requirements for landscaping must be reduced by 50%. By selecting appropriate, indigenous plants for the roof, irrigation needs can be reduced or even completely eliminated.

Energy and Atmosphere Credit 1.0,
Achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use.

Total building energy cost savings must equal 14% at minimum to receive the required 2 credits for certification. Incremental increases in building performance will lead to accruing more credits. The green roof will undoubtedly help contribute to this overall energy savings as shown in the energy analysis portion of this report.

Materials and Resources Credits 4.1, 4.2
Increase demand for building products that incorporate recycled content materials, thereby reducing impacts resulting from extraction and processing of virgin materials.

Post-consumer content plus one-half pre-consumer content constitutes at least 10% of the total material value of the project to receive credit 4.1. By adding an additional 10% of the material value, the project will receive an additional credit under credit 4.2. Many green roof materials contain recycled content and thus can contribute to these credits.

Materials and Resources Credits 5.1, 5.2
Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the use of indigenous resources and reducing the environmental impacts resulting from transportation.

10% of all building materials, based on cost, must be produced within a 500 mile radius of the jobsite to receive credit 5.1. By purchasing an additional 10% of local materials, the project will receive an additional credit under credit 5.2. Many green roof materials are produced locally. Plants and medium, for example, are almost always indigenous to the project region.

Glazing Alternatives

Background / Goals

When initially investigating the current glazing system used in the building, it became apparent that for sustainability purposes, the most efficient glazing type was not being utilized. The glazing manufacturer, Viracon, Inc., recommends specific glass types to help achieve Energy and Atmosphere Credit 1.0, *Optimize Energy Performance*. U-value and solar heat gain coefficients (SHGC) are maximized within these recommended glass types to help achieve a minimum 14% energy savings compared to an ASHRAE/IESNA Standard 90.1-2004 baseline building performance model. The manufacturer does not suggest that by solely incorporating these glazing types Energy and Atmosphere Credit 1.0 will be achieved. It will help contribute significant savings to the building though.

The purpose of this breadth study is to perform a value engineering assessment to determine the implications of changing the exterior glazing within the building envelope. Of note, the study focuses on the glass on floors three through eleven.

Analysis Methodology

1. Select Viracon glazing alternatives.
2. Investigate an appropriate methodology for fenestration analysis using ASHRAE Handbook of Fundamentals 2005.
3. Determine daily temperature gradients for the Washington, DC area for calculating conductive heat transfer.
4. Calculate total solar irradiance on each building face throughout the year.
5. Perform energy analysis to compare total energy transfer savings through each glazing type compared to the existing condition.
6. Investigate initial cost implications and life-cycle savings of incorporating each glass type.
7. Evaluate impact on LEED accreditation.

Resources and Tools

To begin this study, a consultation meeting was set up with Andreas Phelps. His extensive knowledge of building envelope design was able to direct me to an appropriate methodology for calculating energy transfer through a fenestration system. After researching methods to estimate solar energy transfer, a meeting was made with Moses Ling to confirm that indeed I was approaching the design problem correctly. Moses was also able to assist in determining the appropriate means for estimating energy savings that would occur as a result of reduced heating and cooling loads.

Alissa Schmidt, a design associate at Viracon, was helpful in providing cost estimates of various glazing types. The 2005 edition of ASHRAE Handbook of Fundamentals was also extensively used to perform necessary heating and cooling load calculations.

Viracon Glazing Options

Glass Type	Transmittance			Reflectance			U-Value		SHGC	$/SF
	Visible	Solar	U-V	Vis-Out	Vis-In	Solar	Winter	Summer		
VE 1-85	76%	47%	26%	12%	13%	21%	0.31	0.29	0.54	$13.30
VRE 1-67	60%	32%	20%	29%	25%	35%	0.30	0.27	0.37	$13.30
VNE 1-63	62%	23%	4%	10%	11%	36%	0.29	0.25	0.28	$14.80

Figure 5.1: Glazing Properties

Existing Glazing (VE 1-85)

The existing glazing on floors three through eleven is a low-emissivity insulating glass unit which is composed of two ¼" lites of glass with a ½" air space between. The low-e coating applied to the number two surface, as seen in Figure 5.2, provides an effective balance between reducing solar transfer and maximizing light transmittance. When short-wave solar energy , as shown in Figure 5.3, strikes the exterior ply it is absorbed and converted into long-wave infrared energy. The low-e coating on the interior side of the exterior ply then serves to reflect the long-wave radiation back outdoors.

Brown Center: Baltimore, MD
Glass Type: VE 1-85
(Source: Viracon)

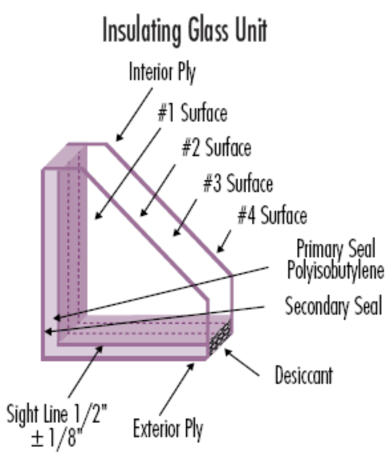


Figure 5.2: IGU Detail
(Source: Viracon)

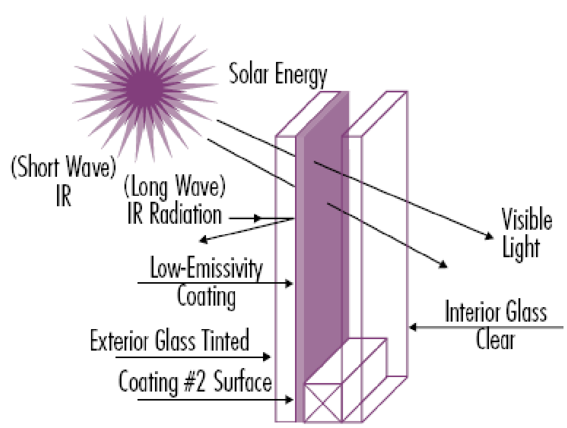


Figure 5.3: Glazing Detail
(Source: Viracon)

It is important to note that the current design incorporates a clear exterior ply with relatively high visible transmittance. This leads to more day lighting within the interior space. It was important to be mindful of the architect's desire to use clear vision glass with high visible transmittance. These two criteria were considered in the selection of alternative insulating glass unit. By using a tinted glass or a clear glass with less visible transmittance, additional energy savings could be achieved.

Design Alternative #1 (VRE 1-67)

Viracon's radiant low-emissivity coating, also applied to the number 2 surface, is a hybrid coating that combines the performance of traditional low-emissivity glass with reduced solar heat gain. Though conductance is reduced, the primary advantage is achieved through a reduction in the solar heat gain coefficient. The glazing type that was selected has clear interior and exterior lites and also the highest visible transmittance of any of the VRE glazing types.

WSFS Bank Center: Wilmington, DE
Glass Type: VRE 1-67
(Source: Viracon)

Design Alternative #2 (VNE 1-63)

Viracon's VNE coating combines the solar performance of their hybrid, radiant low-e glass (VRE) with the low reflectance experienced with traditional low-emissivity glass (VE). Low interior and exterior reflectance correlates to high visible light transmittance. The VNE coating system is recommended for buildings incorporating sustainable design practices. Therefore, the VNE glazing is ideal for the 77 K Street project if it were to seek LEED accreditation. Though this glazing type alone will not allow the building to achieve Energy and Atmosphere Credit 1.0, it will significantly contribute to a reduction in energy demands. If the architect were willing to accept a tinted glazing system or reduce the visible transmittance, the glazing system chosen could potentially account for a 14% reduction in total building demand.

Fenestration Heat Gain Analysis

The governing equation for instantaneous heat transfer through a fenestration system as outlined on page 31.3, equation 1 of the 2005 ASHRAE Handbook of Fundamentals is:

$$Q = Q_{cond} + Q_{sol}$$

$$Q = UA(t_{out} - t_{in}) + SHGC(A)(E_t)$$

where,

Q = Instantaneous Energy Transfer, BTU/hr
U = Overall Coefficient of Heat Transfer (U-Factor), BTU / (hr*ft^2*°F)
A = Area of Fenestration
t_{out}, t_{in} = Exterior and Interior Temperatures, °F
SHGC = Solar Heat Gain Factor
E_t = Incident Total Irradiance, BTU / (hr*ft^2)

Area, u-value, and solar heat gain coefficient are properties of the glazing in question and have a constant, or relatively constant, value. t_{out} and t_{in} are environmental properties that vary throughout the year. Incident total irradiance also is an environmental property that is dependent on the incident angle of the sun against a given surface, as shown in figure 5.4.

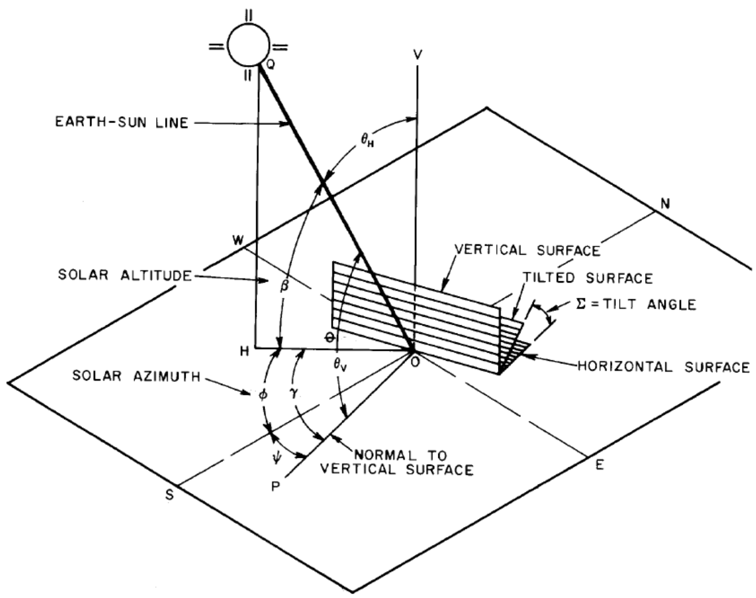


Figure 5.4: Solar Angles
(Source: ASHRAE 2005 Handbook of Fundamentals)

Estimation of Exterior Temperature

In order to calculate the conductive heat transfer, the outdoor air temperature had to be estimated as well. In order to estimate the exterior temperature at each hour of the day of each month, sunrise and sunset data was collected from the United States Naval Observatory's (USNO) Astronomical Application Department. Additionally maximum, minimum, and mean temperatures were collected for each month from the National Oceanic and Atmospheric Administration (NOAA). These two sets of data were used to produce monthly temperature gradients knowing that the maximum daily temperature occurs approximately four hours before sunset and the minimum temperature occurs one hour before sunrise. Figure 5.5, shows the daily temperature gradients for the Washington, DC area.

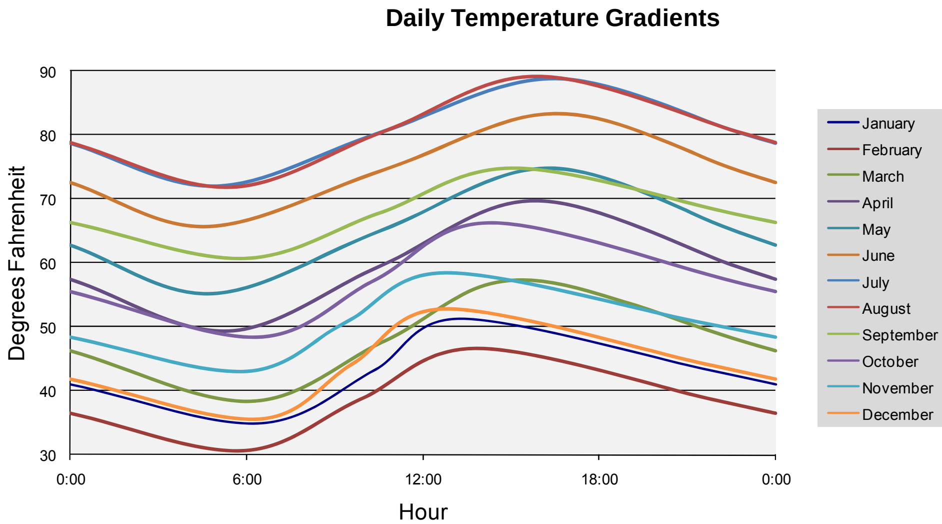


Figure 5.5: Daily Temperature Gradients

Calculation of Total Surface Irradiance

As a result of the continuous change in incident angle, the value of incident total irradiance (E_t) changes throughout the year and also varies based on the orientation of a surface. For the purpose of this study, the value of E_t was calculated hourly for one day per month and for each of the four orientations of the building (north, south, east, and west). The calculation of E_t is governed by the equations listed in Table 14 of the AHRAE handbook in Appendix C.1. The hourly tabulation of total direct irradiance per square foot for each month and each surface orientation can be found in Appendix C.2 but a daily summary graph can be seen below in Figure 5.6.

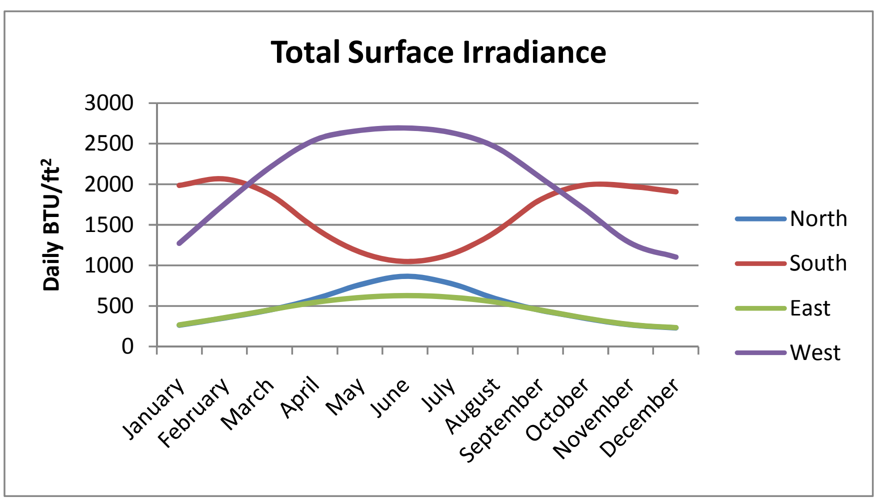


Figure 5.6: Annual Total Surface Irradiance

Cooling Load Analysis

Once the exterior temperature and total surface irradiance is calculated, all variables are known and the heat transfer analysis can be performed. A number of assumptions were made to complete the analysis.

1. Only heat gain, cooling load is considered in the energy transfer analysis. Net heat loss, heating load is ignored as there are other variables within the building that can potentially counter the effect of heat loss. These include heat gain from computers and other equipment, people, etc. This only occurs in the nighttime hours when conductive transfer dominates and solar transfer is not present. Additionally, the glazing alternatives offer only minor incremental improvements in conductive energy transfer so such savings would be relatively insignificant anyway. Solar heat gain is the dominant form of energy transfer and the most important area to consider when selecting glazing for its thermal performance.
2. Indoor temperature is assumed to be set at 70°F between the working hours of 6:00 a.m. and 10:00 p.m. each day. There is an evening setback temperature of 60°F during the heating months of September through May and 78°F during the cooling summer months.
3. Only vision glass is considered in the calculation.

Appendix C.3 contains a detailed month by month analysis that includes both conductive and solar heat transfer through the glazing. Figure 5.7 below shows a summary of the energy loads and energy savings of the three glazing systems. Each glazing type is color coated and corresponds with color coding in the detailed analysis in the appendix. Cooling savings are relative to the existing VE 1-85 glazing system. Figures 5.8 and 5.9 graphically illustrate the monthly cooling loads and expected savings in cooling load compared to the baseline, existing VE 1-85 glazing type.

Energy Analysis Summary Table

	Days	Daily Cooling Load (BTU)			Monthly Cooling Load (BTU)			Cumulative Cooling Savings (BTU)	
		VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
January	31	8296813	4958938	2547364	257201206	153727091	78968269	103474115	178232937
February	28.25	9978682	5985312	3099639	281897754	169085071	87564801	216286797.6	372565889
March	31	13141832	8679506	5447523	407396784	269064695	168873221	354618887	611089452
April	30	15808048	11194399	7816540	474241447	335831966	234496201	493028367	850834698
May	31	16770005	12046713	8584296	519870149	373448104	266113185	639450412	1104591661
June	30	17948427	13114045	9555507	538452796	393421357	286665222	784481851	1356379235
July	31	18428671	13602049	10040575	571288790	421663532	311257820	934107109	1616410206
August	31	17963971	13266104	9799110	556883092	411249214	303772420	1079740988	1869520878
September	30	15757874	11370395	8153816	472736223	341111845	244614494	1211365366	2097642607
October	31	12857872	8892437	5998249	398594044	275665550	185945711	1334293860	2310290939
November	30	9692017	6315484	3863335	290760498	189464508	115900053	1435589850	2485151385
December	31	7503122	4445222	2236877	232596786	137801884	69343187	1530384753	2648404984

Figure 5.7: Annual Cooling Analysis

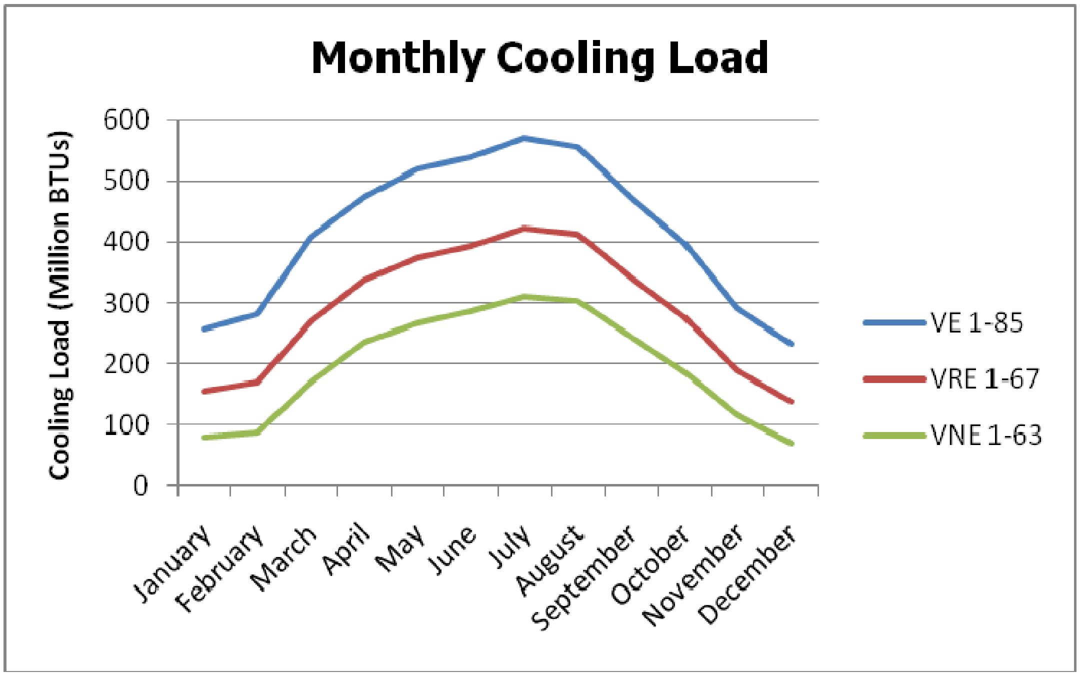


Figure 5.8: Monthly Cooling Loads

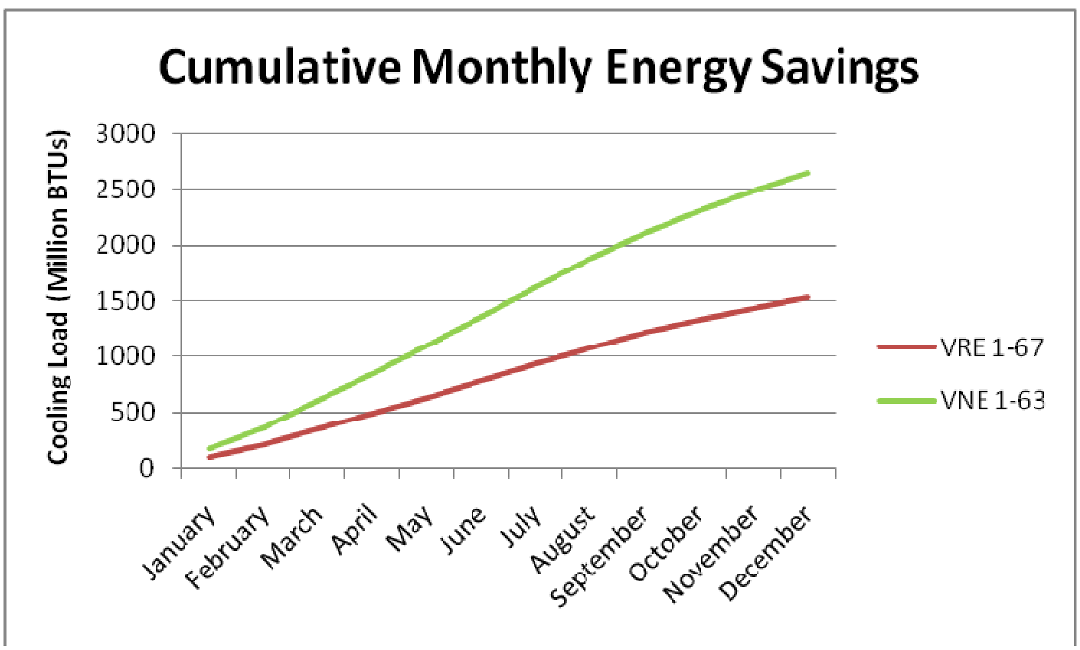


Figure 5.9: Cumulative Energy Savings

Cooling Load Cost Savings Calculation

Once it has been determined how much energy will be saved each year by each of the glazing alternatives, one can determine the financial savings. The financial savings will include both the initial glazing system cost as well as the operational cost.

The cost of cooling can be calculated using the following equation:

$$\$/yr = \frac{(BTU/yr)(\$/kWh)}{(SEER)(1,000\ \text{W/kW})}$$

The Seasonal Energy Efficiency Rating, or SEER value, is a rating of the efficiency of the equipment being used to cool a space. The SEER units are BTUs per watt. The higher the SEER rating, the more efficient the cooling operation and the cheaper the cooling cost will be. The McQuay self-contained air handling units that cool the air on floors three through eleven have a SEER rating of approximately 14.

Glass Type	$/SF	Initial Cost	Annual Cooling Cost	Annual Cooling Savings
VE 1-85	$13.30	$322,924	$24,009.21	----
VRE 1-67	$13.30	$322,924	$16,663.37	$7,346
VNE 1-63	$14.80	$359,344	$11,296.87	$12,712

Figure 5.10: Glazing Cost Evaluation

As shown in Figure 5.10, the square foot cost for both glass types VE 1-85 and VRE 1-67 is $13.30. The cost for glass type VNE 1-63 is more expensive with a cost of $14.80/SF. A rudimentary ten year cost analysis considering both the initial material cost and cooling load costs is shown in Figure 5.11.

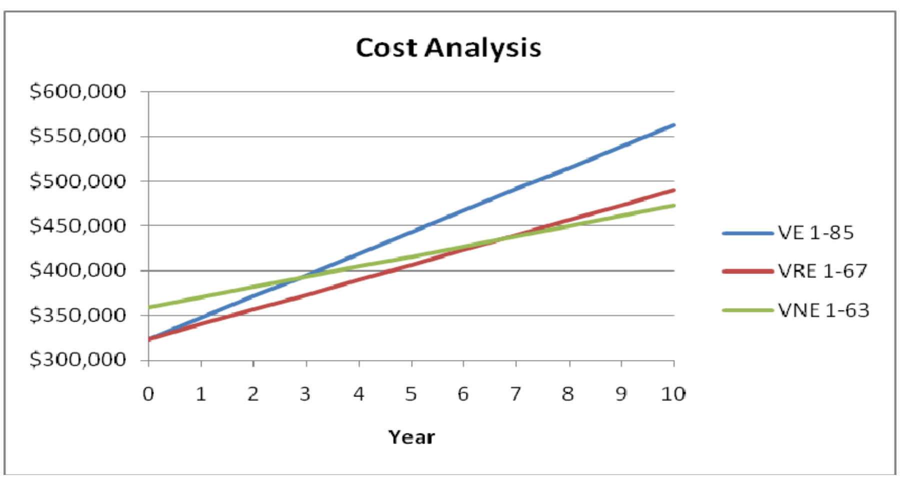


Figure 5.11: Ten Year Cost Analysis

Recommendation

Based on the above analysis, the radiant low-emissivity glazing type VRE 1-67 (alternative #1) has an instantaneous payback period because it has the same upfront cost as the existing glazing type. The hybrid low-emissivity glazing type VNE 1-63 (alternative # 2) has a payback period of just over two years, eleven months as compared to the existing glazing. It takes this period of time for the owner to reach a utility savings that would offset the initial higher material cost. In comparison to the VRE 1-67 glazing, the VNE 1-63 glass has a payback period of six years, ten months.

It is clear that it seems to be a wise investment to change the glazing to at least the radiant low-e glass type. The owner still pays the same upfront cost and receives a utility energy savings. Based on the theme of this report, I would recommend that the owner change the glazing to design alternative #2 though. If the owner wishes to maintain and operate the facility for at least seven years, then the decision is quite clear. Even if the owner wishes to sell the building, I would still encourage them to consider accepting the slightly higher construction cost. The energy savings from the hybrid glass is quite substantial and will help contribute significantly to the overall energy savings of the building and thus help the building achieve Energy and Atmosphere Credit 1.0, *Optimize Energy Performance*.

LEED Impact

The improved glazing system has the potential to contribute to four categories of the LEED rating system as outlined below.

# of Credits	LEED Credit	Likely	Possibly	Contributor
2-8	Energy and Atmosphere 1.0 *Optimizing Energy Performance*			X
1-2	Materials and Resources 4.1, 4.2 *Recycled Content*			X
1	Indoor Environmental Quality 8.1 *Daylight and Views*	X		
1	Indoor Environmental Quality 8.2 *Daylight and Views*	X		
1-4	Innovation & Design Process 1.1-1.4 *Innovation in Design*		X	

Energy and Atmosphere Credit 1.0,
Achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use.

Total building energy cost savings must equal 14% at minimum to receive the required 2 credits for certification. Incremental increases in building performance will lead to accruing more credits. The improved glazing system will undoubtedly help contribute to this overall energy savings as shown in the energy analysis

portion of this report. The VNE 1-63 glazing has a 53% reduction in heat gain as compared to the existing VE 1-83 glass.

Materials and Resources Credits 4.1, 4.2

Increase demand for building products that incorporate recycled content materials, thereby reducing impacts resulting from extraction and processing of virgin materials.

Post-consumer content plus one-half pre-consumer content constitutes at least 10% of the total material value of the project to receive credit 4.1. By adding an additional 10% of the material value, the project will receive an additional credit under credit 4.2. According to their product data, Viracon float glass contains approximately 20% pre-consumer and 0% post-consumer recycled content.

Indoor Environment Quality Credit 8.1,

Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

Illumination levels must be modeled to determine whether or not 75% of all occupied spaces achieve a daylight illumination level of 25 footcandles. According to their product data, glass types VRE 1-67 and VNE 1-63, will far exceed the minimum requirements based on the calculation methodology for achieving this credit.

Indoor Environment Quality Credit 8.2,

Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.

A tenant space layout must be developed to determine whether 90% of occupied spaces have direct lines of sight to the outdoors via vision glass. With an open floor layout, this credit will be achieved using the selected glazing type.

Innovation and Design Process Credits 1.1-1.4,

To provide design teams and projects the opportunity to be awarded points for exceptional performance above the requirements set by the LEED for Core & Shell Green Building Rating System and/or innovative performance in Green Building categories not specifically addressed by the LEED for Core & Shell Green Building Rating System.

It is quite possible that through the use of the hybrid low-emissivity glazing, energy models will far exceed required ASHRAE levels. This opens the opportunity for achieving innovation credits for "exceptional performance above the requirements set by the LEED for Core & Shell Green Building Rating System."

LEED for Core & Shell Development: Potential Status

With the incorporation of a green roof and exchanging the current glazing to a more energy efficient low-emissivity glazing, the 77 K Street project would be well on its way to achieving LEED accreditation. The existing building has the potential for achieving four credits in the sustainable sites category and an additional two credits in the indoor environmental quality category. Incorporating the two design changes proposed in this report, the project would likely achieve ten credits, possibly achieve three additional, and help contribute to another four credits at a minimum. Consequently, the green roof and glazing alternative increased the project's point accrual from a possible six points to a possible seventeen. The breakdown of the current LEED status is outlined on the following two pages in the LEED for Core and Shell, Version 2.0 Project Checklist.

Also, of note, the project would be able to receive a number of additional credits by incorporating a number of simple and cost saving changes. These include reducing the size of the parking garage to the District of Columbia code minimum, adding parking spaces for hybrid vehicles, adding bicycle racks, requiring a LEED professional to work on the project, etc.

Equivalent Uniform Annual Cost Analysis

Below is an equivalent uniform annual cost (EUAC) analysis to determine the equivalent annualized cost of the existing 77 K Street conditions in comparison to the proposed design changes. The roofing system analysis includes anticipated annual maintenance costs. The glazing analysis includes only initial costs. Maintenance costs are minimal in comparison to the construction cost and would also be very similar, if not identical, for the two glazing types. An assumption is made that the interest rate the owner receives is 7%.

	ROOFING		GLAZING	
	Existing	Proposed	Existing	Proposed
Type	Ballasted EPDM	Green Roof	VE 1-85	VNE 1-63
Life	20 years	40 years	25 years	25 years
Initial Cost	$313,600	$618,400	$322,924	$359,344
Annual Maintenance	$8,000	$14,000	----	----
Annual Energy Savings	----	-$2,903	----	-$12,712

$$\begin{aligned} EUAC_{Existing} &= \$313,600(A/P,7\%,20) + \$8,000 + \$322,924(A/P,7\%,25) \\ &= \$313,600(0.0944) + \$8,000 + \$322,924(0.0858) \\ &= \$65,310 \end{aligned}$$

$$\begin{aligned} EUAC_{Proposed} &= \$618,400(A/P,7\%,40) + \$14,000 - \$2,903 + \$359,344(A/P,7\%,25) - \$12,712 \\ &= \$618,400(0.0750) + \$10,400 - \$2,903 + \$359,344(0.0858) - \$12,712 \\ &= \$72,000 \end{aligned}$$

The equivalent uniform annual cost analysis indicates that the existing system is just under $7,000 cheaper per year with a fixed interest rate of 7%. Though the glazing systems has a large energy savings with a minimal initial cost increase, the large discrepancy between the existing and proposed green roof is not able to be offset by the roughly $3,000 annual energy savings through the roofing system. Nonetheless, the proposed system is still highly encouraged as it would greatly reduce energy demands, is more environmentally friendly, and would help the building achieve LEED accreditation. The slightly more expensive redesigned building could be offset by in an increase of only $0.01 per square foot per month. Consequently, it can be ruled that the additional annualized cost is relatively inconsequential.

LEED Project Checklist

LEED for Core and Shell v2.0
Registered Project Checklist

Project Address:

Likely	Poss.	Contr.			
6			**Sustainable Sites**		**15** Points
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required
1			Credit 1	**Site Selection**	1
1			Credit 2	**Development Density & Community Connectivity**	1
			Credit 3	**Brownfield Redevelopment**	1
1			Credit 4.1	**Alternative Transportation:** Public Transportation Access	1
			Credit 4.2	**Alternative Transportation:** Bicycle Storage & Changing Rooms	1
			Credit 4.3	**Alternative Transportation:** Low-Emitting and Fuel-Efficient Vehicles	1
			Credit 4.4	**Alternative Transportation:** Parking Capacity	1
			Credit 5.1	**Site Development:** Protect of Restore Habitat	1
			Credit 5.2	**Site Development:** Maximize Open Space	1
1			Credit 6.1	**Stormwater Design:** Quantity Control	1
			Credit 6.2	**Stormwater Design:** Quality Control	1
1			Credit 7.1	**Heat Island Effect,** Non-Roof	1
1			Credit 7.2	**Heat Island Effect,** Roof	1
			Credit 8	**Light Pollution Reduction**	1
			Credit 9	**Tenant Design & Construction Guidelines**	1

Likely	Poss.	Contr.			
	1		**Water Efficiency**		**5** Points
	1		Credit 1.1	**Water Efficient Landscaping:** Reduce by 50%	1
			Credit 1.2	**Water Efficient Landscaping:** No Potable Use or No Irrigation	1
			Credit 2	**Innovative Wastewater Technologies**	1
			Credit 3.1	**Water Use Reduction:** 20% Reduction	1
			Credit 3.2	**Water Use Reduction:** 30% Reduction	1

Likely	Poss.	Contr.			
2	1		**Energy & Atmosphere**		**14** Points
Y			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**Fundamental Refrigerant Management**	Required

***Note for EAc1:** All LEED for Core and Shell projects registered after June 26th, 2007 are required to achieve at least two (2) points under EAc1.

Likely	Poss.	Contr.			
2	1		Credit 1	**Optimize Energy Performance**	1 to 8
				[ ] 10.5% New Buildings or 3.5% Existing Building Renovations	1
				[2] 14% New Buildings or 7% Existing Building Renovations	2
				[ ] 17.5% New Buildings or 10.5% Existing Building Renovations	3
				[ ] 21% New Buildings or 14% Existing Building Renovations	4
				[ ] 24.5% New Buildings or 17.5% Existing Building Renovations	5
				[ ] 28% New Buildings or 21% Existing Building Renovations	6
				[ ] 31.5% New Buildings or 24.5% Existing Building Renovations	7
				[ ] 35% New Buildings or 28% Existing Building Renovations	8
			Credit 2	**On-Site Renewable Energy**	1
			Credit 3	**Enhanced Commissioning**	1
			Credit 4	**Enhanced Refrigerant Management**	1
			Credit 5.1	**Measurement & Verification** - Base Building	1
			Credit 5.2	**Measurement & Verification** - Tenant Sub-metering	1
			Credit 6	**Green Power**	1

Likely	Poss.	Contr.			
		4	**Materials & Resources**		**11** Points
Y			Prereq 1	**Storage & Collection of Recyclables**	Required
			Credit 1.1	**Building Reuse:** Maintain 25% of Existing Walls, Floors & Roof	1
			Credit 1.2	**Building Reuse:** Maintain 50% of Existing Walls, Floors & Roof	1
			Credit 1.3	**Building Reuse:** Maintain 75% of Interior Non-Structural Elements	1
			Credit 2.1	**Construction Waste Management:** Divert 50% from Disposal	1
			Credit 2.2	**Construction Waste Management:** Divert 75% from Disposal	1
			Credit 3	**Materials Reuse:** 1%	1
		1	Credit 4.1	**Recycled Content:** 10% (post-consumer + ½ pre-consumer)	1
		1	Credit 4.2	**Recycled Content:** 20% (post-consumer + ½ pre-consumer)	1
		1	Credit 5.1	**Regional Materials:** 10% Extracted, Processed & Manufactured Regionally	1
		1	Credit 5.2	**Regional Materials:** 20% Extracted, Processed & Manufactured Regionally	1
			Credit 6	**Certified Wood**	1
Likely	**Poss.**	**Contr.**			
2			**Indoor Environmental Quality**		**11** Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
			Credit 1	**Outdoor Air Delivery Monitoring**	1
			Credit 2	**Increased Ventilation**	1
			Credit 3	**Construction IAQ Management Plan:** During Construction	1
			Credit 4.1	**Low-Emitting Materials:** Adhesives & Sealants	1
			Credit 4.2	**Low-Emitting Materials:** Paints & Coatings	1
			Credit 4.3	**Low-Emitting Materials:** Carpet Systems	1
			Credit 4.4	**Low-Emitting Materials:** Composite Wood & Agrifiber Products	1
			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
			Credit 6	**Controllability of Systems:** Thermal Comfort	1
			Credit 7	**Thermal Comfort:** Design	1
1			Credit 8.1	**Daylight & Views:** Daylight 75% of Spaces	1
1			Credit 8.2	**Daylight & Views:** Views for 90% of Spaces	1
Likely	**Poss.**	**Contr.**			
	1		**Innovation & Design Process**		**5** Points
	1		Credit 1.1	**Innovation in Design**: Provide Specific Title	1
			Credit 1.2	**Innovation in Design**: Provide Specific Title	1
			Credit 1.3	**Innovation in Design**: Provide Specific Title	1
			Credit 1.4	**Innovation in Design**: Provide Specific Title	1
			Credit 2	**LEED® Accredited Professional**	1
Likely	**Poss.**	**Contr.**			
10	3	4	**Totals (pre-certification estimates)**		**61**

Certified: 23 to 27 points, **Silver:** 28 to 33 points, **Gold:** 34 to 44 points, **Platinum:** 45 to 61 points

Conclusion

As a development company, Brookfield Properties is seeking to construct a financially, aesthetically attractive office building that is at the forefront of the commercial office building market. 77 K Street must be a unique project that is enticing to a potential tenant. One such way of differentiating the project from other similar office buildings is to pursue LEED accreditation with a minimum accreditation level of certified.

This thesis report helped assess the feasibility of such a business decision. Is seeking accreditation a wise investment? Will it help make the building more attractive to a potential tenant? Will it cost more in the long run? What steps must be taken to go about earning accreditation? These questions and more were all addressed within the content of this thesis report.

The first analysis was a survey of industry representatives from the owner's side of the business. The research concluded that indeed LEED accreditation is seen as a worthwhile business venture and many projects are choosing to pursue such accreditation. Not only are LEED buildings reaping the benefits of improved occupant health and productivity, decreased energy dependence, and lower operating costs, LEED projects are moving off of the market faster than their non-accredited equivalent buildings. LEED accreditation is a strong marketing tool that many companies are pursuing. Some even have a corporate policy requiring all projects to pursue LEED accreditation.

Once it was established that accrediting 77 K Street was based on solid industry trends, the next question was how exactly to go about gaining LEED points in the most cost effective and environmentally beneficial manner. The first analysis of adding a green roof showed that indeed the owner would experience reduced energy loss through the roof of the structure. The additional cost of the green roof system may not necessarily be offset by the utility savings associated with the addition but the system would significantly contribute to the sustainable design that the project is seeking to achieve. It was also ruled that the scheduling and plenum implication of the redesign were not severe and could be overcome through prior planning and coordination amongst trades.

The glazing alternative analysis provided the project with a means of reducing solar transfer through the glazing system without adding significant cost to the project. The cost to benefit ratio for this design change was advantageous as the energy savings far outweighed the additional cost of the better performing glass. Higher initial material costs could be offset by utility savings from reduced cooling loads within only a matter of a few years.

Upon completion of the two design analyses, a potential LEED status analysis was performed. It was determined that the two changes could potentially bring the project to a total of 17 LEED points, only six shy of LEED Certified. With only minor changes to the project's scope and design, it is very reasonable to assume that the project could indeed achieve accreditation with only limited impacts to the project's cost and schedule. This report provided a means for assessing how incorporating only a limited number of design changes could significantly impact the 77 K Street project's potential for achieving LEED accreditation.

APPENDIX A

LEED Owner Assessment

A.1 LEED Accreditation Survey

A.2 Participant Responses

A.1 LEED Accreditation Survey

Owner/Developer Assessment of Commercial Office Building LEED Accreditation Exit this survey >>

1.

1. Has your company constructed a LEED accreditated building in the past?

If you answer 'YES' to question 1, please proceed to Page 2 and continue.

If you answer 'NO' to question 1, please proceed to Page 3 and continue.

- Yes
- No

1 / 5 20%

Next >>

Page 1

Page 2

Owner/Developer Assessment of Commercial Office Building LEED Accreditation Exit this survey >>

2. Page 2: To Be Completed By Individuals With Prior LEED Accreditation Experience

Please answer the questions on this page only if your company has previously constructed a LEED accredited building.

1. What level of accreditation did those projects achieve? Please select multiple answers if level varies between multiple projects.

- Certified
- Silver
- Gold
- Platinum

Additional Comments:

2. Were tenant rental rates more expensive than to be expected if the project had not pursued sustainable options?

	Cheaper	Same Price	0-5% More Expensive	5-10% More Expensive	10-15% More Expensive	15-20% More Expensive	>20% More Expensive
Tenant Rental Rates							

Additional Comments:

3. Was it easier or more difficult to find tenants to occupy the LEED accredited projects as compared to a similar building that did not pursue sustainable options?

	Much Easier	Easier	Slightly Easier	The Same	Slightly More Difficult	More Difficult	Much More Difficult
Ability to Find Tenants	○	○	○	○	○	○	○

Additional Comments:

4. What benefits have you seen in your LEED accredited projects? Is your company pleased with your decision to pursue LEED accreditation? Why or why not?

5. What criteria are used to determine whether or not a specific project should pursue LEED accreditation?

Please proceed to page 4 after answering this question to complete the survey.

2 / 5 — 40%

<< Prev Next >>

Page 2

Page 3

Owner/Developer Assessment of Commercial Office Building LEED Accreditation

Exit this survey >>

3. Page 3: To Be Completed By Individuals With NO Prior LEED Accreditation Experience

Please answer the questions on this page only if your company has not previously constructed a LEED accredited building.

1. Would your company be interested in pursuing LEED projects in the future even if construction costs are more expensive than a traditional building of the same type? Why or why not?

2. What factors have prevented your company from pursuing a LEED building in the past or will prevent you from pursuing a LEED building in the future?

3 / 5 — 60%

<< Prev Next >>

Owner/Developer Assessment of Commercial Office Building LEED Accreditation Exit this survey >>

4. All Survey Participants

1. In a typical rental agreement, who pays for utility expenses?

- Owner / Developer
- Tenant

It has been accepted that sustainable buildings provide operational savings over the life of a facility. How does the utility agreement between your company and the tenant(s) on a particular project affect your decision to pursue LEED accreditation?

2. It has been commonly accepted that LEED accredited buildings provide the following benefits: lower operating costs, improved occupant health, enhanced occupant physical comfort, and improved occupant productivity.

Do you believe most tenants are willing to pay higher rental rates to work in a green building? Why or why not?

4 / 5 — 80%

<< Prev Next >>

Page 4

Page 5

Owner/Developer Assessment of Commercial Office Building LEED Accreditation Exit this survey >>

5.

Thank you for your time and your input. Your participaion in my senior thesis research is greatly appreciated.

5 / 5 — 100%

<< Prev Done >>

A.2 Participant Responses

Question 1.1:

1. Has your company constructed a LEED accreditated building in the past? If you answer 'YES' to question 1, please proceed to Page 2 and continue. If you answer 'NO' to question 1, please proceed to Page 3 and continue.	Response Percent	Response Count
Yes	**61.5%**	8
No	38.5%	5
answered question		**13**
skipped question		**0**

Question 2.1:

1. What level of accreditation did those projects achieve? Please select multiple answers if level varies between multiple projects.	Response Percent	Response Count
Certified	37.5%	3
Silver	**75.0%**	6
Gold	25.0%	2
Platinum	37.5%	3

Question 2.2:

2. Were tenant rental rates more expensive than to be expected if the project had not pursued sustainable options?

	Cheaper	Same Price	0-5% More Expensive	5-10% More Expensive	10-15% More Expensive	15-20% More Expensive	>20% More Expensive	Rating Average	Response Count
Tenant Rental Rates	0.0% (0)	**83.3% (5)**	0.0% (0)	16.7% (1)	0.0% (0)	0.0% (0)	0.0% (0)	2.33	6

Comments:

- Rental rates were the same but the facility still remained vacant six months after project completion.
- The cost to perform the leed work was more expensive. This did not translate to an increase in the rental rate. It simply made the building more competitive in the market place.

Question 2.3:

3. Was it easier or more difficult to find tenants to occupy the LEED accredited projects as compared to a similar building that did not pursue sustainable options?									
	Much Easier	Easier	Slightly Easier	The Same	Slightly More Difficult	More Difficult	Much More Difficult	Rating Average	Response Count
Ability to Find Tenants	0.0% (0)	**37.5% (3)**	25.0% (2)	**37.5% (3)**	0.0% (0)	0.0% (0)	0.0% (0)	3.00	8

Comments:

- Most tenants have a corporate awareness, even a corporate directive about occupying LEED certified buildings, at a minimum. It's a corporate iconic statement about meeting energy and environmental obligations. More often, tenants value the comfort factor which is achieved through the LEED elements.
- Tenants are now demanding LEED buildings but are not yet ready to pay the extra rental dollars. If we are competing for tenants and the rental rates are the same the tenant will select the LEED building.

Question 2.4 **What benefits have you seen in your LEED accredited projects? Is your company pleased with your decision to pursue LEED accreditation? Why or why not?**

- Lower operating cost. Higher quality of space. No negative impact on architecture. Responsibility to future generations. Company is pleased with decision to pursue LEED rating for project.
- People enjoy the creature comforts and have experienced operational excellence, lower energy costs, lifted attitudes in employees.
- It is good business and leads to a more effective building for the owner and end users.
- Many tenants, especially governmental agencies or contractors, expect LEED accreditation as part of a newly constructed building specification. Our company is highly committed to pursuing LEED accreditation and pursuing sustainable design options in new as well as existing facilities.
- Ahead of the trend toward LEED related projects. No short term payback, but hopefully energy efficiency helps afford minor payback on first costs.
- There has been a lower rate of consumption with the utility. MITRE is a not-for-profit that works with the government and we are dedicated to sustainability where it makes financial sense. We have a vigorus recycling program at both locations and when making building decisions we incorporate sustainable design where we can even if it does not lead to LEED accreditation.

Question 2.5 **What criteria are used to determine whether or not a specific project should pursue LEED accreditation? Please proceed to page 4 after answering this question to complete the survey.**

- Our company policy is that every building we now develop will be LEED Silver or greater. This also includes any existing buildings we reposition in the market place if possible.
- All future developments will strive to be achieve LEED rating.
- Costs/building performa, target tenant audience, expected rents and payback periods.
- Whether or not the additional cost of LEED accreditation can be passed through to tenants on a spec. office project.
- Rate of return for the LEED Certification.
- In the current marketplace, LEED certification is becoming the norm for most new projects (unless budget restrictions do not allow for these upgrades.) It is seen as a marketable advantage, as well as the "right thing to do."
- Target tenant profile. Will they be conscious of the LEED designation? Will it differentiate you in a positive way from the competition?
- Basically it is a financial review.

Question 3.1 **Would your company be interested in pursuing LEED projects in the future even if construction costs are more expensive than a traditional building of the same type? Why or why not?**

- Yes because many tenants are now demanding LEED certified space. However, if the target audience isn't sensitive to LEED than perhaps not.
- Yes - we have a new awareness of sustainability and are looking to build LEED's buildings and get existing buildings certified.
- Only is the rental market will sustain the added cost or if the project is build for a signed tenant.
- Yes
- If everyone else is doing it, then yes. If the operating costs are sufficiently lower to offset the higher first costs, then yes.
- Yes
- The LEED process is more expensive than regular construction as a general rule. While we strive to include sustainable elements in the design of each project we don't typically pursue LEED accreditation because of the cost.
- Educating Owners regarding the benefits vs cost of LEED certification is very important. Some Jurisdictions are requiring that LEED certification be part of future projects, so this will likely become less of a problem. Previous projects have evaluated LEED, but the cost vs benefit was not accepted by the Owner.

Question 3.2 **What factors have prevented your company from pursuing a LEED building in the past or will prevent you from pursuing a LEED building in the future?**

- Cost but what we have learned is that today's building design gets you to a LEED certified space anyway, with incremental costs to go to silver. The more important question is converting a building into LEED EB and if the existing/new prospective tenants will value that costly conversion.
- Cost - Effort to document
- Costs and the ability to recover in the current rental market.
- Cost

- Higher first costs. For the record, these are coming down as more suppliers respond to sustainable design.
- Timing
- Basically cost, if first cost is not offset by a relatively short pay back for the additional costs then we wouldn't pursue the accreditation.
- Cost vs. benefit. Return on investment is the biggest issue, not just the fact that you can advertise LEED certification. More time evaluating the benefits will make the case easier, especially with the "Green" trend that our country is pursuing.

Question 4.1

1. In a typical rental agreement, who pays for utility expenses?

	Response Percent	Response Count
Owner / Developer	18.2%	2
Tenant	**81.8%**	9

Question 4.1.2 **It has been accepted that sustainable buildings provide operational savings over the life of a facility. How does the utility agreement between your company and the tenant(s) on a particular project affect your decision to pursue LEED accreditation?**

- None - We will only develop LEED Silver buildings or greater.
- This varies and is packaged in many different ways-but ultimately, tenant pays
- If a commercial full service lease the electricity is paid by the landlord.
- In some facets, it is more an issue of marketing to political correctness, though sustainable approaches have a proven return on investment, where LEED as a certification often does not.
- Depends on the lease agreement --operating expenses are typically passed on to the tenants. On specific buildings, LEED certification is seen as a marketing advantage. On build-to-suit projects, many tenants request LEED certification.
- Obviously, if the Landlord is responsible for utilities or increases above a base amount, we are more motivated to control them. In a typical commercial lease, tenants pay these costs, so the Landlord is more interested in being competitive from a building operations standpoint in attracting the tenant upfront.
- Does not.

Question 4.2 **It has been commonly accepted that LEED accredited buildings provide the following benefits: lower operating costs, improved occupant health, enhanced occupant physical comfort, and improved occupant productivity. Do you believe most tenants are willing to pay higher rental rates to work in a green building? Why or why not?**

- Not yet. The market is not there that a tenant will not agree to pay extra for a LEED building.
- Lower operating costs, improved employee well being and employee retention.
- Maybe not higher rates, but it could be a differentiator

- I do not. Most of our tenants are small business that is owned not corporate entities. They are bottom line driven--how much profit do I deliver to the bottom line.
- No....it is just like an office building. They love love the grand lobby and then they ask how much is the rent. It only goes so far.
- Yes
- Some tenants are willing to pay a slight upcharge for green buildings. It may help their image with the public, with their clients & with employees/recruiting.
- Maybe if they believe the evidence of improved employee efficiency studies; although we haven't experienced this yet.
- Yes, marketing and operations.
- if we were to lease a building we probably would not pay higher than the prevailing rate for for space in a LEED building do to our relationship with the government and their concern about our rate structure.
- I would think from a Government Tenant perspective this could be a selling point and current project is basing the redevelopment model on that. Private tenants (large in scale) will likely be more inclined to entertain the potential, smaller cost sensitive tenants may look for a different building in the near future. Overall, the trend will be to be Green.

APPENDIX B

Structural Slab Design

Design calculations and tables are derived from Concrete Reinforcing Steel Institute Design Handbook, 2002.

Slab Design

Typical Bay Size: 30' x 30'
Average Column Size: 24" x 24"

Live Load: 100 PSF
Dead Load:

Ceiling………………………………………………………………….. 10 PSF
Sarnatherm XPS Insulation………………………………… 0.69 PSF
Sarnafelt NWP-HD Separation Layer…………………... 0.13 PSF
Sarnafil G476-15 Waterproofing Membrane………... 0.33 PSF
Drainage Panel 900…………………………………………... 0.23 PSF
Saturated Growth Media and Plants…………………… 48 PSF
59.38 PSF ≈ 60 PSF

Strength Design

w_u = 1.4 Dead Load x 1.7 Live Load
w_u = 1.4 (60 PSF) x 1.7 (100 PSF)
w_u = 254 PSF

Clear span between the column and interior beam is conservatively estimated to be 13'-6". Clear span between columns is 28'-0". Therefore the clear span between column line and interior beam is likely even smaller than 13'-6" given that the beam design will likely yield a beam width of greater than 1'-0". Assuming a larger clear span value is a conservative estimate for the slab thickness design.

The minimum allowable slab thickness is ℓ/28 = 15'/28 = 6.4". Therefore, a minimum slab thickness of 6.5" will be used.

Based on the Solid One-Way Slab tables in Chapter 7 of the CRSI Handbook, the minimum amount of reinforcement that can be used in a 6.5" slab based on a factored load of 254 PSF is $\rho \approx 0.0050$. End span and interior span tables located on pages 7-12 and 7-17, respectively, are used. End span loading is most critical in determining slab thickness because of the increased shear in these regions.

End Spans: See Table 1.

w_u = 312 PSF capacity > 254 PSF

Top Bars, #5 @ 11"
Bottom Bars, #5 @ 12"
Top Bars at Free End, #4 @ 12"
Temperature Bars, #4 @ 17"

Interior Spans: See Table 2.

w_u = 355 PSF capacity > 254 PSF

Top Bars, #5 @ 11”
Bottom Bars, #4 @ 10”
Temperature Bars, #4 @ 17”

Serviceability Check

1. Deflection - Maximum deflection occurs in the end span.

$$\text{Service Load} = \left(\frac{1}{1.7}\right) w_u = \left(\frac{1}{1.7}\right)(232 \text{ PSF}) = 136.5 \text{ PSF}$$

$$\text{Live Load Deflection} = \left(\frac{L}{\text{Service}}\right)\left(\frac{l_n \times 12 \ ^{in}/_{ft}}{360}\right) < \frac{l}{360}$$

$$= \left(\frac{100 \text{ PSF}}{136.5 \text{ PSF}}\right)\left(\frac{13.5' \times 12 \ ^{in}/_{ft}}{360}\right) < \frac{15'}{360}$$

$$= 0.33'' < 0.50'' \qquad \text{OK!}$$

2. Crack Control – Based on ACI 10.6.4, for ¾” concrete cover, bar spacing is limited to 12”. Bar spacing in design is satisfactory.

Beam Design

Live Load: 100 PSF
Dead Load:

Ceiling……………………………………………………………..	10 PSF
6-1/2” Concrete Slab…………………………………..…….	81 PSF
Sarnatherm XPS Insulation……………………………………	0.69 PSF
Sarnafelt NWP-HD Separation Layer……………………...	0.13 PSF
Sarnafil G476-15 Waterproofing Membrane…………...	0.33 PSF
Drainage Panel 900……………………………………….......	0.23 PSF
Saturated Growth Media and Plants………….……….	48 PSF
	140.38 PSF ≈ 141 PSF

Strength Design

w_u = 1.4 Dead Load x 1.7 Live Load
w_u = 1.4 (141 PSF) x 1.7 (100 PSF)
w_u = 368 PSF

Estimate end and interior span beam stem to be b=18”, h=22”. It was later determined that the interior spans could be designed with a beam width of 16” and larger reinforcing steel but for consistency in formwork and constructability, the interior span beams were left with a depth of 22” and a width of 18”

$$\text{Beam Stem Estimate:} \quad [18'' \times (22''\text{-}6.5'')]\left(\frac{150 \text{ PCF}}{144 \text{ in}^2/\text{ft}^2}\right)(1.4) = \quad 407 \text{ PLF}$$

Area Factored Load:	368 PSF x 15’ = 5,520 PLF
Total Factored Load, w_u:	5,927 PLF

Determine load capacity of beams. See Tables 3 and 4 for end span and interior span load capacities.

End Spans: See Table 3.
w_u = 6.1 k/ft capacity > 5.9 k/ft

Bottom Bars, (2) #14 [ℓ_n + 12"]
(1) #14 [0.875 ℓ_n]
Top Bars, (3) #14
Open Stirrups: Max Spacing at Exterior End, 195G: (19)#5: 1@2", 18@9"
Open Stirrups: Max Spacing at Interior End, 164G: (16)#4: 1@2", 15@9"

Interior Spans: See Table 4.
w_u = 6.1 k/ft capacity > 5.9 k/ft

Bottom Bars, (2) #10 [ℓ_n + 12"]
(1) #10 [0.875 ℓ_n]
Top Bars, (3) #14
Open Stirrups: Max Spacing at Each End, 164G: (16)#4: 1@2", 15@9"

Girder Design

Convert to uniform loads.

Concentrated load at center = 5.93 kips/ft (30 ft) = 177.9 kips

Estimate stem to be b=20", h=28".

$$[20" \times (28"\text{-}6.5")]\left(\frac{150\ \text{PCF}}{144\ \text{in}^2/\text{ft}^2}\right)(1.4) = \quad 627\ \text{PLF}$$

Concentrated load factored moment, $M = \dfrac{(177.9\ \text{k} \times 28')}{8} = 622.65$ ft-kips

Equivalent uniform load, $w = \dfrac{11M}{l_n^2} = \dfrac{11(622.65'\ \text{kips})}{(28')^2} = 8.74$ kips/ft

Total factored uniform load (for $-M_u$), $w_u = 8.74\ \frac{kips}{ft} + 0.63\ \frac{kips}{ft} = 9.37\ \frac{kips}{ft}$

Factored positive moment, $+M_u = 622.5\ \text{ft-kips} + \dfrac{0.63\ \text{PLF}\ (28')^2}{16} = 653.4$ ft-kips

Equivalent uniform load (for $+M_u$), $w_u = \dfrac{16(622.65'\ \text{kips})}{(28')^2} + 0.63\ \frac{kips}{ft} = 13.3\ \frac{kips}{ft}$

Determine load capacity of girders. See Tables 5 and 6 for end span and interior span load capacities.

End Spans: See Table 5.
w_u = 9.8 k/ft capacity > 9.37 k/ft

Bottom Bars, (3) #11 [ℓ_n + 12″]
(2) #11 [0.875 ℓ_n]
Top Bars, (4) #12
Open Stirrups: Max Spacing at Exterior End, 175FfI: (17)#5: 1@2″, 6@8″, 10@11″
Open Stirrups: Max Spacing at Interior End, 155FeI: (15)#5: 1@2″, 5@8″, 9@11″

Interior Spans: See Table 6.
w_u = 10.9 k/ft capacity > 9.37 k/ft

Bottom Bars, (2) #14 [ℓ_n + 12″]
(1) #14 [0.875 ℓ_n]
Top Bars, (4) #14
Open Stirrups: Max Spacing at Each End, 155FeI: (15)#5: 1@2″, 5@8″, 9@11″

Check Torsion.
Torsional moment capacity (with open stirrups) = 15 ft-kips.

Estimate T_u for the girder with live load on one side only.
w_u (live load) = 0.17 KLF (15′) = 2.55 kips/ft
$T_u = 1/11 \times (2.55 \text{ kips/ft})(30' - 1.67')^2 = 186.1$ ft-kips

T_u in girder = (60/1820)(186.1 ft-kips) = 6.13 ft-kips < 15
Closed stirrups and additional longitudinal bars are not required.

Check Shear.
Max V = (177.9 kips/2)+(0.63 KLF x 14′) = 97.8 kips
Equivalent w_u for shear = 97.8 kips / 14′ = 7.0 kips/ft
Initial stirrup spacing is ok.

Bottom Bar Check.
Equivalent w_u = 13.3 kips/ft
$+M_u$ = 653.4 ft-kips

For a 20″ x 28″ girder with a clear span of 28′-0″ and (5)#11 bars, $+M_u$ = 696 ft-kips. OK!

Initial Stirrup Adjustment.
Adjust for equivalent w_u of 7.0 kips/ft over the full span. Based on Table 5, use stirrup spacing 155I, (15)#5′s: 1@2″, 14@11″ at each end.

SOLID ONE-WAY SLABS—END SPAN — Top Steel for $-M_u$
$f'_c = 3{,}000$ psi — Grade 60 Bars — $\rho \approx 0.0050$

Thickness (in.)	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10
Top Bars	#4	#4	#4	#4	#5	#5	#5	#5	#5	#6	#6	#6	#6
Spacing (in.)	12	12	11	9	12	11	10	10	9	12	11	10	10
Bottom Bars	#4	#4	#4	#4	#4	#5	#5	#5	#5	#5	#6	#6	#6
Spacing (in.)	12	11	10	8	8	12	11	11	10	9	12	11	11
Top Bars Free End	#4	#4	#4	#4	#4	#4	#4	#4	#4	#4	#4	#4	#4
Spacing (in.)	12	12	12	12	12	12	12	12	12	12	12	12	12
T-S Bars	#3	#3	#3	#3	#4	#4	#4	#4	#4	#4	#4	#5	#5
Spacing (in.)	15	13	12	11	18	17	15	14	13	13	12	18	17
Areas of Steel ($in.^2/ft$) Top Interior	.200	.200	.218	.267	.310	.338	.372	.377	.413	.440	.480	.528	.528
Bottom	.200	.218	.240	.300	.300	.310	.338	.338	.372	.413	.440	.480	.480
Slab Wt. (psf)	50	56	63	69	75	81	88	94	100	106	113	119	125
CLEAR SPAN	FACTORED USABLE SUPERIMPOSED LOAD (psf)												
6′-0″	700	906											
6′-6″	586	761	967										
7′-0″	496	645	821										
7′-6″	423	552	704	988									
8′-0″	363	475	608	856	986								
8′-6″	314	412	528	747	861	976							
9′-0″	272	359	462	656	757	858							
9′-6″	237	314	405	579	669	759	916						
10′-0″	207	276	357	513	593	674	814	890					
10′-6″	158	191	248	364	481	591	722	790	957				
11′-0″	138	167	218	323	429	528	647	708	859	987			
11′-6″	120	146	192	287	383	473	582	636	774	890			
12′-0″	105	127	169	256	343	426	524	574	700	806	952		
12′-6″	91	111	149	228	308	383	473	518	634	731	865		
13′-0″	79	97	131	204	277	346	428	469	575	664	787	937	999
13′-6″	68	84	115	182	249	312	388	426	523	605	719	857	914
14′-0″	58	73	101	162	224	282	352	386	477	552	657	785	837
14′-6″	49	62	88	145	202	256	320	351	435	505	602	721	769
15′-0″	42	53	76	129	182	231	291	320	397	462	552	662	707
15′-6″		45	66	115	163	209	264	291	363	423	507	610	651
16′-0″			56	102	147	190	241	265	332	388	466	562	600
16′-6″			48	90	132	171	219	241	304	356	429	519	554
17′-0″			40	79	118	155	199	220	278	327	395	479	511
17′-6″				69	105	140	181	200	255	300	363	442	473
18′-0″				60	94	126	164	182	233	275	335	409	437
18′-6″				51	83	113	149	165	213	253	309	378	405
19′-0″				44	73	101	135	149	195	232	284	350	374
19′-6″					64	90	122	135	178	213	262	324	347
20′-0″					56	80	109	122	162	195	241	300	321

Table 1. End Span, Slab
CRSI, Page 7-12

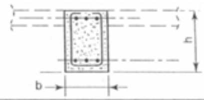
SOLID ONE-WAY SLABS—INTERIOR SPAN — Top Steel for $-M_u$
$f'_c = 3{,}000$ psi — Grade 60 Bars — $\rho \approx 0.0050$

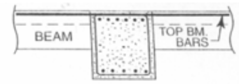
Thickness (in.)	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10
Top Bars	#4	#4	#4	#4	#5	#5	#5	#5	#5	#6	#6	#6	#6
Spacing (in.)	12	11	10	9	12	11	10	10	9	12	11	10	10
Bottom Bars	#3	#3	#3	#4	#4	#4	#4	#4	#4	#5	#5	#5	#5
Spacing (in.)	10	9	7	12	11	10	10	9	8	12	11	10	10
T-S Bars	#3	#3	#3	#3	#4	#4	#4	#4	#4	#4	#4	#5	#5
Spacing (in.)	15	13	12	11	18	17	15	14	13	13	12	18	17
Areas of Steel ($in.^2/ft$) Top Interior	.200	.218	.240	.267	.310	.338	.372	.372	.413	.440	.480	.528	.528
Bottom	.132	.147	.189	.200	.218	.240	.240	.267	.300	.310	.338	.372	.372
Slab Wt. (psf)	50	56	63	69	75	81	88	94	100	106	113	119	125
CLEAR SPAN	FACTORED USABLE SUPERIMPOSED LOAD (psf)												
6′-0″	703	923											
6′-6″	589	775											
7′-0″	498	657	907										
7′-6″	425	562	778	988									
8′-0″	365	485	673	856									
8′-6″	315	420	586	747	935								
9′-0″	273	367	513	656	822								
9′-6″	238	321	452	579	727	894	980						
10′-0″	208	282	399	513	646	795	872						
10′-6″	181	243	317	410	539	661	779	882					
11′-0″	159	214	281	365	482	592	699	792	964				
11′-6″	139	189	249	326	432	532	629	713	870	994			
12′-0″	122	167	222	291	388	479	568	644	787	901			
12′-6″	107	148	197	261	349	433	514	583	715	819	967		
13′-0″	94	131	176	234	315	392	465	529	650	746	882		
13′-6″	82	116	157	210	285	355	423	481	593	681	806	959	
14′-0″	71	102	139	188	257	322	384	438	541	623	739	880	939
14′-6″	61	90	124	169	233	293	350	400	495	570	678	809	863
15′-0″	53	79	110	151	210	266	319	365	453	523	623	745	795
15′-6″	45	69	97	136	190	242	291	333	416	480	573	688	733
16′-0″		60	86	121	172	220	265	305	381	442	528	635	678
16′-6″		51	76	108	156	200	242	279	350	406	487	587	627
17′-0″		44	66	96	140	182	221	255	322	374	450	543	580
17′-6″			57	86	127	165	201	233	296	345	416	503	538
18′-0″			49	76	114	150	184	213	272	318	384	467	499
18′-6″			42	66	102	136	167	195	250	293	355	433	463
19′-0″				58	91	123	152	178	230	270	329	402	429
19′-6″				50	81	111	138	162	211	249	304	373	399
20′-0″				43	72	100	125	147	194	229	281	346	370

Table 2. Interior Span, Slab
CRSI, Page 7-17

$f'_c = 4,000$ psi
$f_y = 60,000$ psi

RECTANGULAR BEAMS, END SPANS





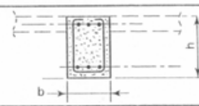
TOTAL CAPACITY $U = 1.4D + 1.7L$ (3)

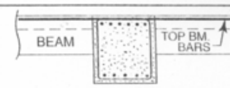
STEM h in.	STEM b in.	BARS(1) BOTTOM ℓ_n + 12 in.	BOTTOM 0.875 ℓ_n	Layers (2)	TOP	SPAN ℓ_n = 28 ft LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	SPAN ℓ_n = 30 ft LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	SPAN ℓ_n = 32 ft LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	SPAN ℓ_n = 34 ft LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	$+\phi M_n$ $-\phi M_n$ (6) ft-kip	DEFL (C) (7) $\times 10^{-9}$ in.
22	12	2#8		1	2#8	1.7	133G	5	-	303	1.4	133G	5	-	320	1.3	133G	5	-	336	1.1	123G	5	-	350	130	968
				1			243E	20	0.9	375		263E	20	0.9	402		283E	20	0.9	429		293E	20	0.9	451	130	
		2#9		1	2#10	2.3	153G	5	-	416	2.0	163G	5	-	444	1.7	163G	5	-	467	1.5*	163G	5	-	491	161	905
				1			244E	20	0.9	603		264E	20	0.9	647		284E	20	0.9	691		294E	20	0.9	724	199	
		2#11		1	3#10	3.3	183G	5	-	620	2.9*	193G	5	-	660	2.6*	193G	5	-	697	2.3*	203G	5	-	737	238	716
				1			244E	20	0.9	796		264E	20	0.9	852		284E	20	0.9	909		294E	20	0.9	955	283	
		2#14		1	2#14	4.1*	194G	5	-	881	3.6*	204G	5	-	936	3.1*	214G	5	-	992	2.8*	214G	5	-	1040	320	615
				1			424B	20	0.9	1167		454B	20	0.9	1246		484B	20	0.9	1325		294E	20	0.9	1181	320	
	14	2#9		1	3#7	1.9	133G	7	-	360	1.7	133G	7	-	381	1.5	123G	6	-	398	1.3	123G	6	-	419	163	806
				1			243E	26	1.0	437		263E	26	1.0	468		283E	26	1.0	500		293E	26	1.0	526	149	
		2#10		1	3#9	2.8	163G	7	-	503	2.5	163G	7	-	532	2.2*	173G	6	-	565	1.9*	173G	6	-	594	203	764
				1			244E	26	1.0	695		264E	26	1.0	745		284E	26	1.0	795		294E	26	1.0	835	236	
		2#10	1#10	1	3#11	4.1	184G	7	-	798	3.6*	194G	7	-	848	3.1*	203G	6	-	827	2.8*	203G	6	-	870	290	595
				1			245E	26	1.0	1081		265E	26	1.0	1159		284E	26	1.0	1045		294E	26	1.0	1099	344	
		2#14		1	4#10	4.6*	194G	7	-	913	4.0*	204G	7	-	971	3.5*	204G	6	-	1022	3.1*	214G	6	-	1080	330	553
				1			245E	26	1.0	1188		265E	26	1.0	1274		285E	26	1.0	1359		295E	26	1.0	1427	369	
	16	2#9		1	3#8	2.3	133G	8	-	398	2.0	133G	8	-	421	1.8	133G	8	-	444	1.6	133G	8	-	467	164	736
				1			214F	32	1.1	578		234F	32	1.1	623		244F	32	1.1	657		264F	32	1.1	702	194	
		2#11		1	3#9	3.1	163G	8	-	563	2.7	163G	8	-	597	2.3	163G	8	-	630	2.1*	173G	8	-	667	246	677
				1			214F	32	1.1	731		234F	32	1.1	787		244F	32	1.1	831		264F	32	1.1	886	240	
		2#14		1	3#11	4.5*	184G	8	-	888	3.9*	194G	8	-	945	3.4*	194G	8	-	994	3.0*	203G	8	-	976	337	545
				1			215F	32	1.1	1130		235F	32	1.1	1215		245F	32	1.1	1282		265F	32	1.1	1368	351	
		2#10	2#10	1	3#14	5.3*	194G	8	-	1060	4.6*	194G	8	-	1119	4.1*	204G	8	-	1186	3.6*	214G	8	-	1253	378	462
				1			345C	32	1.1	1529		235F	32	1.1	1389		245F	32	1.1	1466		265F	32	1.1	1562	468	
	18	2#8	1#8	1	3#8	2.5	133G	10	-	424	2.2	133G	10	-	449	1.9	133G	10	-	473	1.7	123G	10	-	494	195	645
				1			244E	39		646		264E	39	1.3	694		283E	39	1.2	582		293E	38	1.2	612	195	
		2#9	1#9	1	3#10	3.4	153G	10	-	589	3.0	163G	10	-	628	2.6	163G	10	-	662	2.3*	163G	10	-	697	242	603
				1			214F	39	1.3	769		264E	39	1.3	861		284E	39	1.2	918		294E	38	1.2	964	299	
		2#11	1#11	1	4#11	5.0	184G	10	-	992	4.4*	194G	10	-	1055	3.8*	194G	10	-	1110	3.4*	203G	10	-	1097	358	464
				1			215F	39	1.2	1244		235F	39	1.2	1336		245F	38	1.2	1411		265F	38	1.2	1503	455	
		2#14	1#14	1	3#14	6.1*	195G	10	-	1326	5.3*	205G	10	-	1409	4.7*	214G	10	-	1392	4.2*	214G	10	-	1463	481	410
				1			345C	39	1.2	1723		365C	39	1.2	1831		385C	38	1.2	1939		265F	38	1.2	1785	481	

Table 3. End Span, Beams
CRSI, Page 12-31

$f'_c = 4,000$ psi
$f_y = 60,000$ psi

RECTANGULAR BEAMS, INTERIOR SPANS





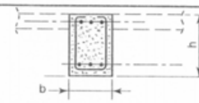
TOTAL CAPACITY $U = 1.4D + 1.7L$ (3)

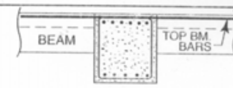
STEM h in.	STEM b in.	BARS(1) BOTTOM ℓ_n + 12 in.	BOTTOM 0.875 ℓ_n	Layers (2)	TOP	SPAN ℓ_n = 28 ft LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	SPAN ℓ_n = 30 ft LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	SPAN ℓ_n = 32 ft LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	SPAN ℓ_n = 34 ft LOAD (4) k/ft	STIR. TIES (5)	ϕT_n ft-kips	$A\ell$ sq. in.	STEEL WGT lb.	$+\phi M_n$ $-\phi M_n$ (6) ft-kip	DEFL (C) (7) $\times 10^{-9}$ in.
22	12	2#7		1	2#9	2.1	123G	5	-	290	1.8	123G	5	-	307	1.6	123G	5	-	324	1.4	123G	5	-	342	100	516
				1			244E	21	0.9	488		263E	21	0.9	393		273E	20	0.9	415		283E	20	0.9	438	161	
		2#8		1	2#10	2.7	143G	5	-	367	2.3	143G	5	-	389	2.0	143G	5	-	412	1.8	153G	5	-	437	130	551
				1			244E	21	0.9	558		264E	21	0.9	600		274E	20	0.9	632		284E	20	0.9	665	199	
		2#10		1	2#14	4.1	164G	5	-	651	3.6	173G	5	-	636	3.1	173G	5	-	673	2.8	183G	5	-	715	199	440
				1			244E	21	0.9	777		264E	21	0.9	835		274E	20	0.9	883		284E	20	0.9	931	320	
		2#11		1	2#14	4.5	164G	5	-	709	3.9	174G	5	-	758	3.4	184G	5	-	807	3.1	193G	5	-	789	238	418
				1			424B	21	0.9	1018		444B	21	0.9	1079		274E	20	0.9	950		284E	20	0.9	1001	320	
	14	2#8		1	3#8	2.7	133G	7	-	354	2.3	133G	7	-	375	2.1	133G	7	-	397	1.8	133G	7	-	418	131	476
				1			244E	27	1.0	558		264E	26	1.0	600		274E	26	1.0	632		293E	26	1.0	521	192	
		2#9		1	3#9	3.3	143G	7	-	441	2.9	153G	7	-	472	2.5	153G	7	-	499	2.3	153G	7	-	527	163	473
				1			244E	27	1.0	641		264E	26	1.0	689		274E	26	1.0	727		294E	26	1.0	775	236	
		2#11		1	3#11	4.8	164G	7	-	725	4.2	174G	7	-	775	3.7	174G	7	-	817	3.3	183G	7	-	802	243	386
				1			245E	27	1.0	1023		265E	26	1.0	1100		274E	26	1.0	976		294E	26	1.0	1039	344	
		2#10	1#10	1	4#10	5.2	164G	7	-	780	4.5	174G	7	-	835	4.0	184G	7	-	889	3.5	184G	7	-	935	290	351
				1			245E	27	1.0	1078		265E	26	1.0	1160		275E	26	1.0	1224		295E	26	1.0	1305	369	
	16	2#8		1	3#8	2.7	123G	8	-	352	2.4	123G	8	-	373	2.1	123G	8	-	394	1.8	123G	8	-	416	132	391
				1			214F	33	1.2	536		234F	33	1.1	579		244F	33	1.1	611		254F	32	1.1	644	194	
		2#10		1	3#10	4.2	153G	8	-	550	3.6	153G	8	-	584	3.2	163G	8	-	623	2.8	163G	8	-	657	205	402
				1			215F	33	1.1	870		234F	33	1.1	778		244F	32	1.1	824		254F	32	1.1	869	295	
		2#11		1	3#11	4.9	154G	8	-	721	4.3	164G	8	-	771	3.8	173G	8	-	758	3.3	173G	8	-	800	246	365
				1			215F	33	1.1	985		235F	33	1.1	1064		245F	32	1.1	1125		255F	32	1.1	1185	351	
		2#14		1	3#14	6.6	175G	8	-	1082	5.7	175G	8	-	1143	5.0	184G	8	-	1133	4.5	194G	8	-	1202	337	297
				1			345C	33	1.1	1487		365C	33	1.1	1584		245F	32	1.1	1428		255F	32	1.1	1508	468	
	18	2#7	1#7	1	3#9	3.1	123G	10	-	401	2.7	123G	10	-	426	2.4	123G	10	-	450	2.1	123G	10	-	475	151	344
				1			244E	40	1.3	627		264E	39	1.3	675		284E	39	1.3	723		293E	39	1.3	594	242	
		2#8	1#8	1	3#10	4.0	143G	10	-	509	3.5	143G	10	-	541	3.1	143G	10	-	573	2.7	153G	10	-	609	195	367
				1			214F	40	1.3	693		234F	39	1.3	748		284E	39	1.3	837		294E	39	1.3	880	299	
		2#10	1#10	1	3#14	6.1	164G	10	-	895	5.3	174G	10	-	957	4.7	174G	10	-	1011	4.2	184G	10	-	1074	299	293
				1			215F	40	1.3	1163		235F	39	1.3	1254		245F	39	1.3	1327		265F	39	1.2	1419	481	
		2#11	1#11	1	3#14	6.8	165G	10	-	1051	5.9	174G	10	-	1042	5.2	184G	10	-	1110	4.6	194G	10	-	1178	358	279
				1			345C	40	1.3	1486		365C	39	1.3	1584		245F	39	1.2	1418		265F	39	1.2	1516	481	

Table 4. Interior Span, Beams
CRSI, Page 12-61

f'_c = 4,000 psi
f_y = 60,000 psi

RECTANGULAR BEAMS, END SPANS





TOTAL CAPACITY $U = 1.4D + 1.7L$[3]

STEM h (in.)	STEM b (in.)	BARS[1] BOTTOM ℓ_n + 12 in.	BARS BOTTOM 0.875 ℓ_n	Layers (2)	TOP	24 ft LOAD (4) k/ft	24 ft STIR. TIES (5)	24 ft ϕT_n ft-kips	24 ft $A\ell$ sq. in.	24 ft STEEL WGT lb.	26 ft LOAD (4) k/ft	26 ft STIR. TIES (5)	26 ft ϕT_n ft-kips	26 ft $A\ell$ sq. in.	26 ft STEEL WGT lb.	28 ft LOAD (4) k/ft	28 ft STIR. TIES (5)	28 ft ϕT_n ft-kips	28 ft $A\ell$ sq. in.	28 ft STEEL WGT lb.	30 ft LOAD (4) k/ft	30 ft STIR. TIES (5)	30 ft ϕT_n ft-kips	30 ft $A\ell$ sq. in.	30 ft STEEL WGT lb.	$+\phi M_n$ $-\phi M_n$ (6) ft-kip	DEFL (C) (7) $\times 10^{-9}$ in.
26	14	2#9		1	3#8	3.8	113I	9	-	348	3.2	123I	9	-	376	2.8	123I	8	-	399	2.4	123I	8	-	422	199	500
				1			184F	35	1.3	507		204F	34	1.2	553		214F	34	1.2	588		234F	33	1.2	633	234	
		2#11		1	3#9	5.0	134I	9	-	543	4.3	133I	9	-	523	3.7	143I	8	-	561	3.2	143I	8	-	594	299	459
				1			185F	35	1.2	772		205F	34	1.2	843		214F	34	1.2	741		234F	33	1.2	797	290	
		2#11	1#11	1	3#11	7.4	135I	9	-	823	6.3	145I	9	-	885	5.5	154I	8	-	873	4.8	164I	8	-	930	428	360
				1			295C	35	1.2	1193		205F	34	1.2	1074		215F	34	1.2	1141		235F	33	1.2	1228	428	
		2#11	1#11	1	4#11	8.2	135I	9	-	913	7.0	145I	9	-	981	6.0	165I	8	-	1063	5.2	165I	8	-	1119	428	352
				2			295C	35	1.2	1283		315C	34	1.2	1376		215F	34	1.2	1244		235F	33	1.2	1336	504	
	16	2#10		1	3#8	4.1	113I	11	-	395	3.5	113I	11	-	421	3.0	123I	10	-	452	2.6	123I	10	-	479	251	424
				1			165G	43	1.4	657		184G	42	1.4	587		214F	42	1.4	650		234F	42	1.4	700	236	
		2#11		1	3#10	5.8	134I	11	-	593	4.9	134I	11	-	629	4.2	143I	10	-	616	3.7	143I	10	-	652	302	406
				1			165G	43	1.4	793		185G	42	1.4	868		195G	42	1.4	924		205G	42	1.3	979	364	
		2#11	1#11	1	3#11	7.6	135I	11	-	827	6.5	145I	11	-	890	5.6	154I	10	-	876	4.8	164I	10	-	934	436	343
				1			245D	43	1.4	1116		265D	42	1.4	1204		195G	42	1.3	1117		205G	42	1.3	1186	436	
		6#6	6#6	2	3#14	9.0	145FdI	11	-	1007	7.7	145I	11	-	1068	6.6	165I	10	-	1156	5.8	165I	10	-	1217	471	301
				1			245D	43	1.4	1282		265D	42	1.4	1382		285D	42	1.3	1481		305D	41	1.3	1581	590	
	18	2#8	1#8	1	3#9	4.5	113I	13	-	410	3.9	113I	13	-	437	3.3	113I	13	-	464	2.9	123I	13	-	496	238	377
				1			165G	52	1.5	682		184G	51	1.5	609		194G	51	1.5	649		264E	50	1.5	763	296	
		2#10	1#10	1	3#10	6.4	134I	13	-	638	5.5	134I	13	-	678	4.7	143I	13	-	667	4.1	143I	13	-	707	368	363
				1			165G	-52	1.5	846		185G	51	1.5	926		195G	51	1.5	986		205G	50	1.5	1046	368	
		2#11	1#11	1	3#14	8.4	135I	13	-	959	7.2	145I	13	-	1030	6.2	154I	13	-	1023	5.4	164I	13	-	1089	442	292
				1			245D	52	1.5	1260		265D	51	1.5	1358		285D	51	1.5	1455		305D	50	1.5	1553	602	
		2#11	2#11	1	3#14	10.5	155FeI	13	-	1101	8.9	165FdI	13	-	1182	7.7	165I	13	-	1249	6.7	165I	13	-	1315	568	268
				1			295C	52	1.5	1475		265D	51	1.5	1481		285D	51	1.5	1588		305D	50	1.5	1695	602	
	20	2#9	1#9	1	3#9	5.2	113I	15	-	463	4.4	113I	15	-	495	3.8	123I	15	-	531	3.3	123I	15	-	562	298	345
				1			155H	61	1.7	724		165H	61	1.7	777		175H	60	1.7	829		185H	59	1.6	881	298	
		2#10	1#10	1	3#11	7.1	134I	15	-	694	6.0	134I	15	-	738	5.2	143I	15	-	729	4.5	143I	15	-	773	371	328
				1			215E	61	1.7	1015		225E	61	1.7	1079		175H	60	1.6	1018		185H	59	1.6	1082	447	
		2#11	2#11	1	3#14	10.6	145FdI	15	-	1092	9.1	155FcI	15	-	1173	7.8	155I	15	-	1240	6.8	165I	15	-	1321	576	259
				1			295C	61	1.7	1495		265D	61	1.7	1499		285D	60	1.6	1607		265E	59	1.6	1632	612	
		3#11	2#11	1	4#14	13.3	295C	15	-	1573	11.3	175EhI	15	-	1486	9.8	175FII	15	-	1573	8.5	185FII	15	-	1673	696	219
				1			485A	61	1.7	2156		315C	61	1.7	1888		345C	60	1.6	2037		365C	59	1.6	2164	776	

Table 5. End Span, Girder
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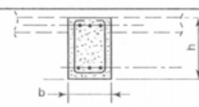
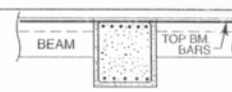
f'_c = 4,000 psi
f_y = 60,000 psi

RECTANGULAR BEAMS, INTERIOR SPANS





TOTAL CAPACITY $U = 1.4D + 1.7L$[3]

STEM h (in.)	STEM b (in.)	BARS[1] BOTTOM ℓ_n + 12 in.	BARS BOTTOM 0.875 ℓ_n	Layers (2)	TOP	24 ft LOAD (4) k/ft	24 ft STIR. TIES (5)	24 ft ϕT_n ft-kips	24 ft $A\ell$ sq. in.	24 ft STEEL WGT lb.	26 ft LOAD (4) k/ft	26 ft STIR. TIES (5)	26 ft ϕT_n ft-kips	26 ft $A\ell$ sq. in.	26 ft STEEL WGT lb.	28 ft LOAD (4) k/ft	28 ft STIR. TIES (5)	28 ft ϕT_n ft-kips	28 ft $A\ell$ sq. in.	28 ft STEEL WGT lb.	30 ft LOAD (4) k/ft	30 ft STIR. TIES (5)	30 ft ϕT_n ft-kips	30 ft $A\ell$ sq. in.	30 ft STEEL WGT lb.	$+\phi M_n$ $-\phi M_n$ (6) ft-kip	DEFL (C) (7) $\times 10^{-9}$ in.
26	14	2#9		1	3#9	5.5	113I	9	-	381	4.7	113I	9	-	408	4.1	123I	9	-	439	3.5	123I	9	-	467	199	287
				1			185F	35	1.3	671		204F	35	1.3	590		214F	34	1.2	628		234F	34	1.2	679	290	
		2#10		1	3#10	6.9	124I	9	-	522	5.8	124I	9	-	557	5.0	134I	9	-	599	4.4	133I	9	-	581	248	272
				1			185F	35	1.3	760		205F	35	1.3	832		215F	34	1.2	885		235F	34	1.2	957	359	
		2#10	1#10	1	4#10	8.8	125I	9	-	729	7.5	135I	9	-	789	6.5	144I	9	-	778	5.6	144I	9	-	825	359	226
				1			295C	35	1.3	1112		205F	35	1.2	990		215F	34	1.2	1055		235F	34	1.2	1140	460	
		2#14		1	3#14	11.0	264C	9	-	967	9.3	145FcI	9	-	998	8.1	145I	9	-	1059	7.0	155I	9	-	1134	411	200
				1			295C	35	1.3	1294		315C	35	1.2	1393		345C	34	1.2	1510		365C	34	1.2	1609	574	
	16	2#9		1	3#9	5.6	103I	11	-	378	4.8	113I	11	-	409	4.1	113I	11	-	437	3.6	123I	11	-	468	200	245
				1			165G	44	1.4	645		185G	43	1.4	711		195G	43	1.4	758		204G	42	1.4	653	294	
		2#11		1	3#11	8.3	125I	11	-	685	7.1	124I	11	-	666	6.1	134I	11	-	717	5.3	144I	11	-	769	302	232
				1			245D	44	1.4	988		265D	43	1.4	1069		195G	43	1.4	976		205G	42	1.4	1038	436	
		2#14		1	3#14	11.3	145FdI	11	-	942	9.6	135I	11	-	989	8.3	145I	11	-	1064	7.2	155I	11	-	1139	418	190
				1			245D	44	1.4	1217		265D	43	1.4	1317		285D	43	1.4	1417		305D	42	1.4	1517	590	
		2#14		1	5#11	11.6	145FeI	11	-	1000	9.9	145FdI	11	-	1066	8.5	145I	11	-	1132	7.4	155I	11	-	1212	418	191
				2			245D	44	1.4	1275		265D	43	1.4	1380		285D	43	1.4	1485		305D	42	1.4	1590	627	
	18	2#8	1#8	1	3#10	6.6	113I	13	-	438	5.6	113I	13	-	470	4.9	113I	13	-	502	4.2	123I	13	-	539	238	218
				1			165G	53	1.6	711		185G	53	1.6	783		195G	52	1.5	835		205G	51	1.5	887	368	
		2#9	1#9	1	3#11	8.2	114I	13	-	583	7.0	124I	13	-	632	6.1	134I	13	-	681	5.3	133I	13	-	666	296	216
				1			245D	53	1.6	970		185G	52	1.5	889		195G	52	1.5	949		205G	51	1.5	1009	442	
		2#11	1#11	1	3#14	11.5	135FdI	13	-	912	9.8	135I	13	-	971	8.5	145I	13	-	1045	7.4	145I	13	-	1105	442	179
				1			245D	53	1.6	1212		265D	52	1.5	1313		285D	52	1.5	1413		305D	51	1.5	1513	602	
		2#10	2#10	1	4#14	13.3	145FII	13	-	1057	11.3	155FeI	13	-	1142	9.7	155FdI	13	-	1213	8.5	155I	13	-	1284	477	157
				1			295C	53	1.6	1444		315C	52	1.5	1556		285D	52	1.5	1566		305D	51	1.5	1677	759	
	20	2#8	1#8	1	3#10	6.7	103I	16	-	435	5.7	113I	16	-	472	4.9	113I	15	-	504	4.3	113I	15	-	535	239	189
				1			155H	63	1.7	701		165H	62	1.7	754		175H	61	1.7	807		185H	61	1.7	859	371	
		2#10	1#10	1	3#11	8.5	114I	16	-	647	7.3	124I	15	-	701	6.3	124I	15	-	746	5.5	133I	15	-	743	371	190
				1			215E	63	1.7	986		225E	62	1.7	1051		175H	61	1.7	992		185H	61	1.7	1056	447	
		2#11	1#11	1	4#14	12.4	135FdI	16	-	1038	10.6	135I	15	-	1108	9.1	145I	15	-	1193	7.9	145I	15	-	1263	447	154
				1			295C	63	1.7	1456		265D	62	1.7	1463		285D	61	1.7	1575		265E	60	1.7	1603	776	
		2#14	1#14	1	4#14	14.8	265C	16	-	1385	12.6	155FII	15	-	1309	10.9	155FeI	15	-	1392	9.5	165FdI	15	-	1489	612	141
				1			485A	63	1.7	2011		315C	62	1.7	1739		345C	61	1.7	1885		305D	60	1.7	1884	776	

Table 6. Interior Span, Girder
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APPENDIX C

Window Glazing Design Calculations

C.1 ASHRAE 2005 Handbook of Fundamentals Solar Angles and Total Irradiance Formulas

C.2 Monthly Total Surface Irradiance Calculations

C.3 Monthly Fenestration Heat Transfer Analysis

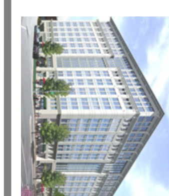

Table 14 Solar Equations

Solar Angles

All angles are in degrees. The solar azimuth ϕ and the surface azimuth ψ are measured in degrees from south; angles to the east of south are negative, and angles to the west of south are positive. Calculate solar altitude, azimuth, and surface incident angles as follows:

Apparent solar time AST, in decimal hours:

$$AST = LST + ET/60 + (LSM - LON)/15$$

Hour angle H, degrees:

$$H = 15(\text{hours of time from local solar noon}) = 15(AST - 12)$$

Solar altitude β:

$$\sin\beta = \cos L \cos\delta \cos H + \sin L \sin\delta$$

Solar azimuth ϕ:

$$\cos\phi = (\sin\beta \sin L - \sin\delta)/(\cos\beta \cos L)$$

Surface-solar azimuth γ:

$$\gamma = \phi - \psi$$

Incident angle θ:

$$\cos\theta = \cos\beta \cos\gamma \sin\Sigma + \sin\beta \cos\Sigma$$

where

ET = equation of time, decimal minutes
L = latitude
LON = local longitude, decimal degrees of arc
LSM = local standard time meridian, decimal degrees of arc
= 60° for Atlantic Standard Time
= 75° for Eastern Standard Time
= 90° for Central Standard Time
= 105° for Mountain Standard Time
= 120° for Pacific Standard Time
= 135° for Alaska Standard Time
= 150° for Hawaii-Aleutian Standard Time
LST = local standard time, decimal hours
δ = solar declination, °
ψ = surface azimuth, °
Σ = surface tilt from horizontal, horizontal = 0°

Values of ET and δ are given in Table 7 of Chapter 31 for the 21st day of each month.

Direct, Diffuse, and Total Solar Irradiance

Direct normal irradiance E_{DN}

If $\beta > 0$ $\quad E_{DN} = \left[\frac{A}{\exp(B/\sin\beta)}\right]CN$

Otherwise, $\quad E_{DN} = 0$

Surface direct irradiance E_D

If $\cos\theta > 0$ $\quad E_D = E_{DN}\cos\theta$

Otherwise, $\quad E_D = 0$

Ratio Y of sky diffuse on vertical surface to sky diffuse on horizontal surface

If $\cos\theta > -0.2$ $\quad Y = 0.55 + 0.437\cos\theta + 0.313\cos^2\theta$

Otherwise, $\quad Y = 0.45$

Diffuse irradiance E_d

Vertical surfaces $\quad E_d = CYE_{DN}$

Surfaces other than vertical $\quad E_d = CE_{DN}(1 + \cos\Sigma)/2$

Ground-reflected irradiance $\quad E_r = E_{DN}(C + \sin\beta)\rho_g(1 - \cos\Sigma)/2$

Total surface irradiance $\quad E_t = E_D + E_d + E_r$

where

A = apparent solar constant
B = atmospheric extinction coefficient
C = sky diffuse factor
CN = clearness number multiplier for clear/dry or hazy/humid locations. See Figure 5 in Chapter 33 of the 2003 *ASHRAE Handbook—HVAC Applications* for CN values.
E_d = diffuse sky irradiance
E_r = diffuse ground-reflected irradiance
ρ_g = ground reflectivity

Values of A, B, and C are given in Table 7 of Chapter 31 for the 21st day of each month. Values of ground reflectivity ρ_g are given in Table 10 of Chapter 31.

January Total Surface Irradiance

LST Local Standard Time	AST Apparent Solar Time	H Hour Angle	β Solar Altitude	φ Solar Azimuth	EDN Direct Normal Irradiance	Er Diffuse Ground-Reflected Ir	North γ Surface-Solar Azimuth	North θ Incident Angle	North ED Surface Direct Irradiance	North Y Sky Diffuse Ratio	North Ed Diffuse Irradiance	North Et Total Surface Irradiance	South γ Surface-Solar Azimuth	South θ Incident Angle	South ED Surface Direct Irradiance	South Y Sky Diffuse Ratio	South Ed Diffuse Irradiance	South Et Total Surface Irradiance	East γ Surface-Solar Azimuth	East θ Incident Angle	East ED Surface Direct Irradiance	East Y Sky Diffuse Ratio	East Ed Diffuse Irradiance	East Et Total Surface Irradiance	West γ Surface-Solar Azimuth	West θ Incident Angle	West ED Surface Direct Irradiance	West Y Sky Diffuse Ratio	West Ed Diffuse Irradiance	West Et Total Surface Irradiance
0	-0.32	-184.83	-70.66	166.18	0.00	0.00	-13.82	71.24	0.00	0.72	0.00	0.00	166.18	108.76	0.00	0.45	0.00	0.00	256.18	94.54	0.00	0.52	0.00	0.00	76.18	85.46	0.00	0.59	0.00	0.00
1	0.68	-169.83	-69.17	152.18	0.00	0.00	-27.82	71.67	0.00	0.72	0.00	0.00	152.18	108.33	0.00	0.45	0.00	0.00	242.18	99.55	0.00	0.49	0.00	0.00	62.18	80.45	0.00	0.63	0.00	0.00
2	1.68	-154.83	-61.25	123.82	0.00	0.00	-56.18	74.47	0.00	0.69	0.00	0.00	123.82	105.53	0.00	0.45	0.00	0.00	213.82	113.56	0.00	0.45	0.00	0.00	33.82	66.44	0.00	0.77	0.00	0.00
3	2.68	-139.83	-50.68	106.94	0.00	0.00	-73.06	79.36	0.00	0.64	0.00	0.00	106.94	100.64	0.00	0.48	0.00	0.00	196.94	127.31	0.00	0.45	0.00	0.00	16.94	52.69	0.00	0.93	0.00	0.00
4	3.68	-124.83	-39.23	95.24	0.00	0.00	-84.76	85.94	0.00	0.58	0.00	0.00	95.24	94.06	0.00	0.52	0.00	0.00	185.24	140.47	0.00	0.45	0.00	0.00	5.24	39.53	0.00	1.07	0.00	0.00
5	4.68	-109.83	-27.57	85.72	0.00	0.00	-94.28	93.79	0.00	0.52	0.00	0.00	85.72	86.21	0.00	0.58	0.00	0.00	175.72	152.13	0.00	0.45	0.00	0.00	-4.28	27.87	0.00	1.18	0.00	0.00
6	5.68	-94.83	-16.04	76.98	0.00	0.00	-103.02	102.51	0.00	0.45	0.00	0.00	76.98	77.49	0.00	0.66	0.00	0.00	166.98	159.45	0.00	0.45	0.00	0.00	-13.02	20.55	0.00	1.23	0.00	0.00
7	6.68	-79.83	-4.91	68.18	0.00	0.00	-111.82	111.74	0.00	0.45	0.00	0.00	68.18	68.26	0.00	0.75	0.00	0.00	158.18	157.66	0.00	0.45	0.00	0.00	-21.82	22.34	0.00	1.22	0.00	0.00
8	7.68	-64.83	5.53	58.70	85.97	2.74	-121.30	121.14	0.00	0.45	3.98	6.73	58.70	58.86	44.46	0.86	7.61	54.81	148.70	148.26	0.00	0.45	3.98	6.73	-31.30	31.74	73.11	1.15	10.17	86.02
9	8.68	-49.83	14.90	47.99	214.65	12.37	-132.01	130.30	0.00	0.45	9.95	22.32	47.99	49.70	138.83	0.96	21.30	172.50	137.99	135.89	0.00	0.45	9.95	22.32	-42.01	44.11	154.13	1.03	22.67	189.16
10	9.68	-34.83	22.68	35.57	257.72	20.15	-144.43	138.63	0.00	0.45	11.95	32.09	35.57	41.37	193.41	1.05	27.99	241.55	125.57	122.46	0.00	0.45	11.95	32.09	-54.43	57.54	138.32	0.87	23.22	181.69
11	10.68	-19.83	28.25	21.22	275.77	25.43	-158.78	145.20	0.00	0.45	12.78	38.21	21.22	34.80	226.46	1.12	31.81	283.70	111.22	108.59	0.00	0.45	12.78	38.21	-68.78	71.41	87.91	0.72	20.48	133.82
12	11.68	-4.83	30.94	5.29	282.37	27.88	-174.71	148.66	0.00	0.45	13.09	40.97	5.29	31.34	241.16	1.15	33.49	302.54	95.29	94.54	0.00	0.52	15.05	42.93	-84.71	85.46	22.34	0.59	17.06	67.28
13	12.68	10.17	30.34	11.08	281.01	27.34	-168.92	147.88	0.00	0.45	13.02	40.37	11.08	32.12	237.99	1.14	33.13	298.46	101.08	99.55	0.00	0.49	14.07	41.41	-78.92	80.45	46.62	0.63	18.27	92.24
14	13.68	25.17	26.57	26.54	271.03	23.86	-153.46	143.15	0.00	0.45	12.56	36.42	26.54	36.85	216.86	1.10	30.71	271.43	116.54	113.56	0.00	0.45	12.56	36.42	-63.46	66.44	108.32	0.77	21.62	153.80
15	14.68	40.17	20.13	40.21	246.61	17.64	-139.79	135.81	0.00	0.45	11.43	29.07	40.21	44.19	176.82	1.02	26.02	220.48	130.21	127.31	0.00	0.45	11.43	29.07	-49.79	52.69	149.48	0.93	23.62	190.75
16	15.68	55.17	11.71	51.98	185.48	9.08	-128.02	127.10	0.00	0.45	8.60	17.68	51.98	52.90	111.87	0.93	17.72	138.67	141.98	140.47	0.00	0.45	8.60	17.68	-38.02	39.53	143.07	1.07	20.50	172.65
17	16.68	70.17	1.91	62.19	5.44	0.12	-117.81	117.80	0.00	0.45	0.25	0.37	62.19	62.20	2.54	0.82	0.46	3.12	152.19	152.13	0.00	0.45	0.25	0.37	-27.81	27.87	4.81	1.18	0.66	5.59
18	17.68	85.17	-8.81	71.36	0.00	0.00	-108.64	108.41	0.00	0.45	0.00	0.00	71.36	71.59	0.00	0.72	0.00	0.00	161.36	159.45	0.00	0.45	0.00	0.00	-18.64	20.55	0.00	1.23	0.00	0.00
19	18.68	100.17	-20.11	80.06	0.00	0.00	-99.94	99.33	0.00	0.49	0.00	0.00	80.06	80.67	0.00	0.63	0.00	0.00	170.06	157.66	0.00	0.45	0.00	0.00	-9.94	22.34	0.00	1.22	0.00	0.00
20	19.68	115.17	-31.72	88.97	0.00	0.00	-91.03	90.88	0.00	0.54	0.00	0.00	88.97	89.12	0.00	0.56	0.00	0.00	178.97	148.26	0.00	0.45	0.00	0.00	-1.03	31.74	0.00	1.15	0.00	0.00
21	20.68	130.17	-43.36	99.05	0.00	0.00	-80.95	83.43	0.00	0.60	0.00	0.00	99.05	96.57	0.00	0.50	0.00	0.00	189.05	135.89	0.00	0.45	0.00	0.00	9.05	44.11	0.00	1.03	0.00	0.00
22	21.68	145.17	-54.60	112.11	0.00	0.00	-67.89	77.40	0.00	0.66	0.00	0.00	112.11	102.60	0.00	0.45	0.00	0.00	202.11	122.46	0.00	0.45	0.00	0.00	22.11	57.54	0.00	0.87	0.00	0.00
23	22.68	160.17	-64.52	132.17	0.00	0.00	-47.83	73.22	0.00	0.70	0.00	0.00	132.17	106.78	0.00	0.45	0.00	0.00	222.17	108.59	0.00	0.45	0.00	0.00	42.17	71.41	0.00	0.72	0.00	0.00

February Total Surface Irradiance

LST Local Standard Time	AST Apparent Solar Time	H Hour Angle	β Solar Altitude	φ Solar Azimuth	EDN Direct Normal Irradiance	Er Diffuse Ground-Reflected Ir	North γ Surface-Solar Azimuth	North θ Incident Angle	North ED Surface Direct Irradiance	North Y Sky Diffuse Ratio	North Ed Diffuse Irradiance	North Et Total Surface Irradiance	South γ Surface-Solar Azimuth	South θ Incident Angle	South ED Surface Direct Irradiance	South Y Sky Diffuse Ratio	South Ed Diffuse Irradiance	South Et Total Surface Irradiance	East γ Surface-Solar Azimuth	East θ Incident Angle	East ED Surface Direct Irradiance	East Y Sky Diffuse Ratio	East Ed Diffuse Irradiance	East Et Total Surface Irradiance	West γ Surface-Solar Azimuth	West θ Incident Angle	West ED Surface Direct Irradiance	West Y Sky Diffuse Ratio	West Ed Diffuse Irradiance	West Et Total Surface Irradiance
0	-0.37	-185.51	-61.48	168.62	0.00	0.00	-11.38	62.09	0.00	0.82	0.00	0.00	168.62	117.91	0.00	0.45	0.00	0.00	258.62	95.41	0.00	0.51	0.00	0.00	78.62	84.59	0.00	0.59	0.00	0.00
1	0.63	-170.51	-60.66	160.69	0.00	0.00	-19.31	62.46	0.00	0.82	0.00	0.00	160.69	117.54	0.00	0.45	0.00	0.00	250.69	99.33	0.00	0.49	0.00	0.00	70.69	80.67	0.00	0.63	0.00	0.00
2	1.63	-155.51	-54.43	135.56	0.00	0.00	-44.44	65.46	0.00	0.79	0.00	0.00	135.56	114.54	0.00	0.45	0.00	0.00	225.56	114.03	0.00	0.45	0.00	0.00	45.56	65.97	0.00	0.78	0.00	0.00
3	2.63	-140.51	-45.04	117.85	0.00	0.00	-62.15	70.73	0.00	0.73	0.00	0.00	117.85	109.27	0.00	0.45	0.00	0.00	207.85	128.66	0.00	0.45	0.00	0.00	27.85	51.34	0.00	0.95	0.00	0.00
4	3.63	-125.51	-34.17	104.87	0.00	0.00	-75.13	77.74	0.00	0.66	0.00	0.00	104.87	102.26	0.00	0.45	0.00	0.00	194.87	143.10	0.00	0.45	0.00	0.00	14.87	36.90	0.00	1.10	0.00	0.00
5	4.63	-110.51	-22.67	94.36	0.00	0.00	-85.64	85.98	0.00	0.58	0.00	0.00	94.36	94.02	0.00	0.52	0.00	0.00	184.36	156.93	0.00	0.45	0.00	0.00	4.36	23.07	0.00	1.22	0.00	0.00
6	5.63	-95.51	-11.01	84.93	0.00	0.00	-95.07	94.97	0.00	0.51	0.00	0.00	84.93	85.03	0.00	0.59	0.00	0.00	174.93	167.89	0.00	0.45	0.00	0.00	-5.07	12.11	0.00	1.28	0.00	0.00
7	6.63	-80.51	0.49	75.67	0.00	0.00	-104.33	104.33	0.00	0.45	0.00	0.00	75.67	75.67	0.00	0.68	0.00	0.00	165.67	165.66	0.00	0.45	0.00	0.00	-14.33	14.34	0.00	1.27	0.00	0.00
8	7.63	-65.51	11.50	65.81	179.82	8.73	-114.19	113.67	0.00	0.45	8.42	17.14	65.81	66.33	72.21	0.78	14.51	95.45	155.81	153.36	0.00	0.45	8.42	17.14	-24.19	26.64	160.74	1.19	22.27	191.74
9	8.63	-50.51	21.63	54.63	249.40	18.86	-125.37	122.55	0.00	0.45	11.67	30.53	54.63	57.45	134.20	0.88	22.72	175.77	144.63	139.29	0.00	0.45	11.67	30.53	-35.37	40.71	189.05	1.06	27.52	235.43
10	9.63	-35.51	30.32	41.36	276.70	26.95	-138.64	130.38	0.00	0.45	12.95	39.90	41.36	49.62	179.27	0.96	27.76	233.98	131.36	124.78	0.00	0.45	12.95	39.90	-48.64	55.22	157.86	0.90	25.93	210.74
11	10.63	-20.51	36.76	25.44	289.17	32.50	-154.56	136.34	0.00	0.45	13.53	46.03	25.44	43.66	209.21	1.03	30.98	272.68	115.44	110.13	0.00	0.45	13.53	46.03	-64.56	69.87	99.50	0.74	22.18	154.18
12	11.63	-5.51	40.05	7.07	294.00	35.16	-172.93	139.44	0.00	0.45	13.76	48.92	7.07	40.56	223.35	1.06	32.49	291.00	97.07	95.41	0.00	0.51	15.64	50.80	-82.93	84.59	27.70	0.59	18.16	81.02
13	12.63	9.49	39.53	12.13	293.29	34.75	-167.87	138.95	0.00	0.45	13.73	48.47	12.13	41.05	221.17	1.06	32.26	288.17	102.13	99.33	0.00	0.49	14.87	49.61	-77.87	80.67	47.52	0.63	19.19	101.46
14	13.63	24.50	35.32	29.94	286.76	31.30	-150.06	135.00	0.00	0.45	13.42	44.72	29.94	45.00	202.75	1.02	30.28	264.33	119.94	114.03	0.00	0.45	13.42	44.72	-60.06	65.97	116.79	0.78	23.26	171.34
15	14.63	39.50	28.19	45.14	271.42	25.03	-134.86	128.44	0.00	0.45	12.70	37.73	45.14	51.56	168.75	0.94	26.61	220.39	135.14	128.66	0.00	0.45	12.70	37.73	-44.86	51.34	169.57	0.95	26.68	221.27
16	15.63	54.50	19.05	57.78	237.27	16.34	-122.22	120.27	0.00	0.45	11.10	27.44	57.78	59.73	119.59	0.85	20.97	156.90	147.78	143.10	0.00	0.45	11.10	27.44	-32.22	36.90	189.74	1.10	27.13	233.21
17	16.63	69.50	8.64	68.53	142.41	5.79	-111.47	111.22	0.00	0.45	6.66	12.46	68.53	68.78	51.53	0.75	11.10	68.42	158.53	156.93	0.00	0.45	6.66	12.46	-21.47	23.07	131.03	1.22	18.02	154.84
18	17.63	84.50	-2.54	78.16	0.00	0.00	-101.84	101.83	0.00	0.45	0.00	0.00	78.16	78.17	0.00	0.65	0.00	0.00	168.16	167.89	0.00	0.45	0.00	0.00	-11.84	12.11	0.00	1.28	0.00	0.00
19	18.63	99.50	-14.11	87.39	0.00	0.00	-92.61	92.53	0.00	0.53	0.00	0.00	87.39	87.47	0.00	0.57	0.00	0.00	177.39	165.66	0.00	0.45	0.00	0.00	-2.61	14.34	0.00	1.27	0.00	0.00
20	19.63	114.50	-25.76	97.01	0.00	0.00	-82.99	83.69	0.00	0.60	0.00	0.00	97.01	96.31	0.00	0.51	0.00	0.00	187.01	153.36	0.00	0.45	0.00	0.00	7.01	26.64	0.00	1.19	0.00	0.00
21	20.63	129.50	-37.15	108.01	0.00	0.00	-71.99	75.74	0.00	0.68	0.00	0.00	108.01	104.26	0.00	0.45	0.00	0.00	198.01	139.29	0.00	0.45	0.00	0.00	18.01	40.71	0.00	1.06	0.00	0.00
22	21.63	144.50	-47.74	121.98	0.00	0.00	-58.02	69.13	0.00	0.75	0.00	0.00	121.98	110.87	0.00	0.45	0.00	0.00	211.98	124.78	0.00	0.45	0.00	0.00	31.98	55.22	0.00	0.90	0.00	0.00
23	22.63	159.50	-56.49	141.45	0.00	0.00	-38.55	64.42	0.00	0.80	0.00	0.00	141.45	115.58	0.00	0.45	0.00	0.00	231.45	110.13	0.00	0.45	0.00	0.00	51.45	69.87	0.00	0.74	0.00	0.00

March Total Surface Irradiance

LST Local Standard Time	AST Apparent Solar Time	H Hour Angle	β Solar Altitude	φ Solar Azimuth	EDN Direct Normal Irradiance	Er Diffuse Ground-Reflected Ir	North γ Surface-Solar Azimuth	North θ Incident Angle	North ED Surface Direct Irradiance	North Y Sky Diffuse Ratio	North Ed Diffuse Irradiance	North Et Total Surface Irradiance	South γ Surface-Solar Azimuth	South θ Incident Angle	South ED Surface Direct Irradiance	South Y Sky Diffuse Ratio	South Ed Diffuse Irradiance	South Et Total Surface Irradiance	East γ Surface-Solar Azimuth	East θ Incident Angle	East ED Surface Direct Irradiance	East Y Sky Diffuse Ratio	East Ed Diffuse Irradiance	East Et Total Surface Irradiance	West γ Surface-Solar Azimuth	West θ Incident Angle	West ED Surface Direct Irradiance	West Y Sky Diffuse Ratio	West Ed Diffuse Irradiance	West Et Total Surface Irradiance
0	-0.26	-183.91	-50.95	173.79	0.00	0.00	-6.21	51.22	0.00	0.95	0.00	0.00	173.79	128.78	0.00	0.45	0.00	0.00	263.79	93.91	0.00	0.52	0.00	0.00	83.79	86.09	0.00	0.58	0.00	0.00
1	0.74	-168.91	-49.80	162.65	0.00	0.00	-17.35	51.97	0.00	0.94	0.00	0.00	162.65	128.03	0.00	0.45	0.00	0.00	252.65	101.10	0.00	0.48	0.00	0.00	72.65	78.91	0.00	0.65	0.00	0.00
2	1.74	-153.91	-44.35	142.04	0.00	0.00	-37.96	55.68	0.00	0.90	0.00	0.00	142.04	124.32	0.00	0.45	0.00	0.00	232.04	116.10	0.00	0.45	0.00	0.00	52.04	63.91	0.00	0.80	0.00	0.00
3	2.74	-138.91	-35.91	125.75	0.00	0.00	-54.25	61.76	0.00	0.83	0.00	0.00	125.75	118.24	0.00	0.45	0.00	0.00	215.75	131.10	0.00	0.45	0.00	0.00	35.75	48.91	0.00	0.97	0.00	0.00
4	3.74	-123.91	-25.73	112.88	0.00	0.00	-67.12	69.50	0.00	0.74	0.00	0.00	112.88	110.50	0.00	0.45	0.00	0.00	202.88	146.10	0.00	0.45	0.00	0.00	22.88	33.91	0.00	1.13	0.00	0.00
5	4.74	-108.91	-14.61	102.13	0.00	0.00	-77.87	78.26	0.00	0.65	0.00	0.00	102.13	101.74	0.00	0.45	0.00	0.00	192.13	161.10	0.00	0.45	0.00	0.00	12.13	18.91	0.00	1.24	0.00	0.00
6	5.74	-93.91	-3.04	92.45	0.00	0.00	-87.55	87.55	0.00	0.57	0.00	0.00	92.45	92.45	0.00	0.53	0.00	0.00	182.45	176.10	0.00	0.45	0.00	0.00	2.45	3.91	0.00	1.30	0.00	0.00
7	6.74	-78.91	8.61	82.98	133.05	5.51	-97.02	96.94	0.00	0.50	7.28	12.79	82.98	83.06	16.07	0.61	8.81	30.39	172.98	168.91	0.00	0.45	6.53	12.03	-7.02	11.10	130.56	1.28	18.57	154.64
8	7.74	-63.91	20.02	72.91	232.82	16.81	-107.09	106.03	0.00	0.45	11.42	28.23	72.91	73.97	64.30	0.69	17.63	98.74	162.91	153.91	0.00	0.45	11.42	28.23	-17.09	26.10	209.09	1.19	30.32	256.23
9	8.74	-48.91	30.77	61.30	268.87	26.70	-118.70	114.37	0.00	0.45	13.19	39.89	61.30	65.63	110.96	0.78	22.97	160.62	151.30	138.91	0.00	0.45	13.19	39.89	-28.70	41.10	202.63	1.06	30.98	260.31
10	9.74	-33.91	40.24	46.95	285.67	34.51	-133.05	121.40	0.00	0.45	14.01	48.52	46.95	58.60	148.85	0.86	26.86	210.23	136.95	123.91	0.00	0.45	14.01	48.52	-43.05	56.10	159.35	0.89	27.75	221.61
11	10.74	-18.91	47.42	28.61	293.87	39.75	-151.39	126.44	0.00	0.45	14.41	54.16	28.61	53.56	174.55	0.92	29.47	243.76	118.61	108.91	0.00	0.45	14.41	54.16	-61.39	71.10	95.21	0.72	23.21	158.17
12	11.74	-3.91	50.95	6.21	296.96	42.08	-173.79	128.78	0.00	0.45	14.57	56.64	6.21	51.22	186.01	0.95	30.64	258.72	96.21	93.91	0.00	0.52	16.89	58.96	-83.79	86.09	20.22	0.58	18.81	81.11
13	12.74	11.10	49.80	17.35	296.01	41.34	-162.65	128.03	0.00	0.45	14.52	55.86	17.35	51.97	182.37	0.94	30.27	253.98	107.35	101.10	0.00	0.48	15.41	56.74	-72.65	78.91	56.96	0.65	20.83	119.13
14	13.74	26.10	44.35	37.96	290.71	37.58	-142.04	124.32	0.00	0.45	14.26	51.84	37.96	55.68	163.91	0.90	28.39	229.88	127.96	116.10	0.00	0.45	14.26	51.84	-52.04	63.91	127.87	0.80	25.44	190.89
15	14.74	41.10	35.91	54.25	279.07	31.06	-125.75	118.24	0.00	0.45	13.69	44.75	54.25	61.76	132.04	0.83	25.15	188.25	144.25	131.10	0.00	0.45	13.69	44.75	-35.75	48.91	183.44	0.97	29.58	244.08
16	15.74	56.10	25.73	67.12	255.27	22.18	-112.88	110.50	0.00	0.45	12.52	34.71	67.12	69.50	89.40	0.74	20.63	132.21	157.12	146.10	0.00	0.45	12.52	34.71	-22.88	33.91	211.86	1.13	31.39	265.44
17	16.74	71.10	14.61	77.87	199.27	11.52	-102.13	101.74	0.00	0.45	9.77	21.29	77.87	78.26	40.53	0.65	14.16	66.21	167.87	161.10	0.00	0.45	9.77	21.29	-12.13	18.91	188.52	1.24	27.01	227.04
18	17.74	86.10	3.04	87.55	21.64	0.56	-92.45	92.45	0.00	0.53	1.25	1.82	87.55	87.55	0.93	0.57	1.34	2.83	177.55	176.10	0.00	0.45	1.06	1.62	-2.45	3.91	21.59	1.30	3.06	25.21
19	18.74	101.10	-8.61	97.02	0.00	0.00	-82.98	83.06	0.00	0.61	0.00	0.00	97.02	96.94	0.00	0.50	0.00	0.00	187.02	168.91	0.00	0.45	0.00	0.00	7.02	11.10	0.00	1.28	0.00	0.00
20	19.74	116.10	-20.02	107.09	0.00	0.00	-72.91	73.97	0.00	0.69	0.00	0.00	107.09	106.03	0.00	0.45	0.00	0.00	197.09	153.91	0.00	0.45	0.00	0.00	17.09	26.10	0.00	1.19	0.00	0.00
21	20.74	131.10	-30.77	118.70	0.00	0.00	-61.30	65.63	0.00	0.78	0.00	0.00	118.70	114.37	0.00	0.45	0.00	0.00	208.70	138.91	0.00	0.45	0.00	0.00	28.70	41.10	0.00	1.06	0.00	0.00
22	21.74	146.10	-40.24	133.05	0.00	0.00	-46.95	58.60	0.00	0.86	0.00	0.00	133.05	121.40	0.00	0.45	0.00	0.00	223.05	123.91	0.00	0.45	0.00	0.00	43.05	56.10	0.00	0.89	0.00	0.00
23	22.74	161.10	-47.42	151.39	0.00	0.00	-28.61	53.56	0.00	0.92	0.00	0.00	151.39	126.44	0.00	0.45	0.00	0.00	241.39	108.91	0.00	0.45	0.00	0.00	61.39	71.10	0.00	0.72	0.00	0.00

April Total Surface Irradiance

LST Local Standard Time	AST Apparent Solar Time	H Hour Angle	β Solar Altitude	φ Solar Azimuth	EDN Direct Normal Irradiance	Er Diffuse Ground-Reflected Ir	North γ Surface-Solar Azimuth	North θ Incident Angle	North ED Surface Direct Irradiance	North Y Sky Diffuse Ratio	North Ed Diffuse Irradiance	North Et Total Surface Irradiance	South γ Surface-Solar Azimuth	South θ Incident Angle	South ED Surface Direct Irradiance	South Y Sky Diffuse Ratio	South Ed Diffuse Irradiance	South Et Total Surface Irradiance	East γ Surface-Solar Azimuth	East θ Incident Angle	East ED Surface Direct Irradiance	East Y Sky Diffuse Ratio	East Ed Diffuse Irradiance	East Et Total Surface Irradiance	West γ Surface-Solar Azimuth	West θ Incident Angle	West ED Surface Direct Irradiance	West Y Sky Diffuse Ratio	West Ed Diffuse Irradiance	West Et Total Surface Irradiance
0	-0.12	-181.76	-39.48	177.77	0.00	0.00	-2.23	39.54	0.00	1.07	0.00	0.00	177.77	140.46	0.00	0.45	0.00	0.00	267.77	91.72	0.00	0.54	0.00	0.00	87.77	88.28	0.00	0.56	0.00	0.00
1	0.88	-166.76	-38.02	163.45	0.00	0.00	-16.55	40.96	0.00	1.06	0.00	0.00	163.45	139.04	0.00	0.45	0.00	0.00	253.45	102.97	0.00	0.45	0.00	0.00	73.45	77.03	0.00	0.66	0.00	0.00
2	1.88	-151.76	-33.05	146.42	0.00	0.00	-33.58	45.71	0.00	1.01	0.00	0.00	146.42	134.29	0.00	0.45	0.00	0.00	236.42	117.62	0.00	0.45	0.00	0.00	56.42	62.38	0.00	0.82	0.00	0.00
3	2.88	-136.76	-25.41	132.01	0.00	0.00	-47.99	52.81	0.00	0.93	0.00	0.00	132.01	127.19	0.00	0.45	0.00	0.00	222.01	132.15	0.00	0.45	0.00	0.00	42.01	47.85	0.00	0.98	0.00	0.00
4	3.88	-121.76	-15.96	119.96	0.00	0.00	-60.04	61.30	0.00	0.83	0.00	0.00	119.96	118.70	0.00	0.45	0.00	0.00	209.96	146.40	0.00	0.45	0.00	0.00	29.96	33.60	0.00	1.13	0.00	0.00
5	4.88	-106.76	-5.37	109.59	0.00	0.00	-70.41	70.50	0.00	0.73	0.00	0.00	109.59	109.50	0.00	0.45	0.00	0.00	199.59	159.72	0.00	0.45	0.00	0.00	19.59	20.28	0.00	1.24	0.00	0.00
6	5.88	-91.76	5.91	100.15	70.90	2.53	-79.85	79.90	12.43	0.64	5.41	20.37	100.15	100.10	0.00	0.48	4.11	6.64	190.15	168.27	0.00	0.45	3.83	6.36	10.15	11.73	69.42	1.28	10.87	82.82
7	6.88	-76.76	17.51	90.94	202.40	13.63	-89.06	89.11	3.16	0.56	13.53	30.32	90.94	90.89	0.00	0.54	13.19	26.83	180.94	162.46	0.00	0.45	10.93	24.56	0.94	17.54	192.99	1.25	30.39	237.01
8	7.88	-61.76	29.15	81.14	249.26	24.21	-98.86	97.73	0.00	0.50	14.86	39.07	81.14	82.27	33.53	0.61	18.38	76.13	171.14	149.65	0.00	0.45	13.46	37.67	-8.86	30.35	215.10	1.16	34.70	274.01
9	8.88	-46.76	40.44	69.64	271.07	33.34	-110.36	105.36	0.00	0.45	14.64	47.97	69.64	74.64	71.79	0.69	22.37	127.49	159.64	135.52	0.00	0.45	14.64	47.97	-20.36	44.48	193.42	1.02	33.22	259.97
10	9.88	-31.76	50.77	54.60	282.44	40.43	-125.40	111.50	0.00	0.45	15.25	55.68	54.60	68.50	103.50	0.75	25.49	169.42	144.60	121.03	0.00	0.45	15.25	55.68	-35.40	58.97	145.61	0.86	29.10	215.13
11	10.88	-16.76	58.91	33.15	288.21	45.02	-146.85	115.62	0.00	0.45	15.56	60.59	33.15	64.38	124.62	0.80	27.58	197.22	123.15	106.40	0.00	0.45	15.56	60.59	-56.85	73.60	81.39	0.70	24.15	150.56
12	11.88	-1.76	62.67	3.75	290.21	46.82	-176.25	117.27	0.00	0.45	15.67	62.49	3.75	62.73	132.98	0.82	28.42	208.21	93.75	91.72	0.00	0.54	18.71	65.53	-86.25	88.28	8.71	0.56	19.62	75.15
13	12.88	13.25	60.28	26.91	288.98	45.70	-153.09	116.24	0.00	0.45	15.61	61.31	26.91	63.76	127.77	0.80	27.89	201.37	116.91	102.97	0.00	0.45	15.61	61.31	-63.09	77.03	64.86	0.66	23.02	133.58
14	13.88	28.25	52.93	50.27	284.20	41.74	-129.73	112.66	0.00	0.45	15.35	57.09	50.27	67.34	109.49	0.76	26.08	177.32	140.27	117.62	0.00	0.45	15.35	57.09	-39.73	62.38	131.75	0.82	27.96	201.45
15	14.88	43.25	42.97	66.52	274.41	35.20	-113.48	106.95	0.00	0.45	14.82	50.01	66.52	73.05	79.98	0.70	23.18	138.36	156.52	132.15	0.00	0.45	14.82	50.01	-23.48	47.85	184.16	0.98	32.41	251.77
16	15.88	58.25	31.84	78.65	255.78	26.50	-101.35	99.62	0.00	0.49	14.91	41.41	78.65	80.38	42.76	0.63	19.39	88.65	168.65	146.40	0.00	0.45	13.81	40.31	-11.35	33.60	213.05	1.13	34.72	274.27
17	16.88	73.25	20.25	88.73	217.30	16.20	-91.27	91.19	0.00	0.54	14.11	30.31	88.73	88.81	4.52	0.56	14.58	35.30	178.73	159.72	0.00	0.45	11.73	27.94	-1.27	20.28	203.83	1.24	32.21	252.24
18	17.88	88.25	8.60	98.00	116.62	5.03	-82.00	82.09	16.06	0.62	8.62	29.71	98.00	97.91	0.00	0.50	6.94	11.97	188.00	168.27	0.00	0.45	6.30	11.33	8.00	11.73	114.18	1.28	17.88	137.10
19	18.88	103.25	-2.78	107.32	0.00	0.00	-72.68	72.70	0.00	0.71	0.00	0.00	107.32	107.30	0.00	0.45	0.00	0.00	197.32	162.46	0.00	0.45	0.00	0.00	17.32	17.54	0.00	1.25	0.00	0.00
20	19.88	118.25	-13.57	117.41	0.00	0.00	-62.59	63.41	0.00	0.81	0.00	0.00	117.41	116.59	0.00	0.45	0.00	0.00	207.41	149.65	0.00	0.45	0.00	0.00	27.41	30.35	0.00	1.16	0.00	0.00
21	20.88	133.25	-23.34	129.00	0.00	0.00	-51.00	54.70	0.00	0.91	0.00	0.00	129.00	125.30	0.00	0.45	0.00	0.00	219.00	135.52	0.00	0.45	0.00	0.00	39.00	44.48	0.00	1.02	0.00	0.00
22	21.88	148.25	-31.47	142.81	0.00	0.00	-37.19	47.20	0.00	0.99	0.00	0.00	142.81	132.80	0.00	0.45	0.00	0.00	232.81	121.03	0.00	0.45	0.00	0.00	52.81	58.97	0.00	0.86	0.00	0.00
23	22.88	163.25	-37.15	159.25	0.00	0.00	-20.75	41.81	0.00	1.05	0.00	0.00	159.25	138.19	0.00	0.45	0.00	0.00	249.25	106.40	0.00	0.45	0.00	0.00	69.25	73.60	0.00	0.70	0.00	0.00

May Total Surface Irradiance

LST	AST	H	β	φ	EDN	Er	North						South						East						West					
							γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et
Local Standard Time	Apparent Solar Time	Hour Angle	Solar Altitude	Solar Azimuth	Direct Normal Irradiance	Diffuse Ground-Reflected Ir	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance
0	-0.08	-181.21	-31.10	178.68	0.00	0.00	-1.32	31.12	0.00	1.15	0.00	0.00	178.68	148.88	0.00	0.45	0.00	0.00	268.68	91.13	0.00	0.54	0.00	0.00	88.68	88.87	0.00	0.56	0.00	0.00
1	0.92	-166.21	-29.71	165.05	0.00	0.00	-14.95	32.95	0.00	1.14	0.00	0.00	165.05	147.05	0.00	0.45	0.00	0.00	255.05	102.95	0.00	0.45	0.00	0.00	75.05	77.05	0.00	0.66	0.00	0.00
2	1.92	-151.21	-25.23	149.98	0.00	0.00	-30.02	38.44	0.00	1.08	0.00	0.00	149.98	141.56	0.00	0.45	0.00	0.00	239.98	116.91	0.00	0.45	0.00	0.00	59.98	63.09	0.00	0.81	0.00	0.00
3	2.92	-136.21	-18.25	136.78	0.00	0.00	-43.22	46.21	0.00	1.00	0.00	0.00	136.78	133.79	0.00	0.45	0.00	0.00	226.78	130.57	0.00	0.45	0.00	0.00	46.78	49.43	0.00	0.97	0.00	0.00
4	3.92	-121.21	-9.45	125.43	0.00	0.00	-54.57	55.12	0.00	0.90	0.00	0.00	125.43	124.88	0.00	0.45	0.00	0.00	215.43	143.49	0.00	0.45	0.00	0.00	35.43	36.51	0.00	1.10	0.00	0.00
5	4.92	-106.21	0.61	115.52	0.00	0.00	-64.48	64.48	0.00	0.80	0.00	0.00	115.52	115.52	0.00	0.45	0.00	0.00	205.52	154.47	0.00	0.45	0.00	0.00	25.52	25.53	0.00	1.20	0.00	0.00
6	5.92	-91.21	11.50	106.52	140.83	7.42	-73.48	73.82	39.24	0.70	12.74	59.40	106.52	106.18	0.00	0.45	8.24	15.66	196.52	159.97	0.00	0.45	8.24	15.66	16.52	20.03	132.31	1.24	22.64	162.38
7	6.92	-76.21	22.90	97.83	217.16	18.04	-82.17	82.79	27.26	0.61	17.21	62.51	97.83	97.21	0.00	0.50	14.12	32.15	187.83	155.87	0.00	0.45	12.70	30.74	7.83	24.13	198.17	1.21	34.14	250.35
8	7.92	-61.21	34.54	88.75	250.46	27.93	-91.25	91.03	0.00	0.54	17.66	45.59	88.75	88.97	4.50	0.56	18.17	50.60	178.75	145.44	0.00	0.45	14.65	42.59	-1.25	34.56	206.26	1.12	36.54	270.73
9	8.92	-46.21	46.13	78.17	267.72	36.45	-101.83	98.17	0.00	0.49	17.20	53.65	78.17	81.83	38.04	0.62	21.52	96.01	168.17	132.71	0.00	0.45	15.66	52.11	-11.83	47.29	181.59	0.99	34.47	252.51
10	9.92	-31.21	57.17	63.91	277.23	43.04	-116.09	103.79	0.00	0.45	16.22	59.26	63.91	76.21	66.09	0.67	24.22	133.35	153.91	119.13	0.00	0.45	16.22	59.26	-26.09	60.87	134.97	0.84	30.16	208.17
11	10.92	-16.21	66.50	41.13	282.16	47.27	-138.87	107.48	0.00	0.45	16.51	63.78	41.13	72.52	84.74	0.71	26.02	158.03	131.13	105.20	0.00	0.45	16.51	63.78	-48.87	74.80	73.99	0.69	25.17	146.43
12	11.92	-1.21	71.08	3.49	283.83	48.86	-176.51	108.88	0.00	0.45	16.60	65.47	3.49	71.12	91.85	0.72	26.72	167.44	93.49	91.13	0.00	0.54	19.98	68.84	-86.51	88.87	5.61	0.56	20.62	75.09
13	12.92	13.80	67.68	36.15	282.63	47.71	-143.85	107.86	0.00	0.45	16.53	64.24	36.15	72.14	86.69	0.71	26.21	160.62	126.15	102.95	0.00	0.45	16.53	64.24	-53.85	77.05	63.33	0.66	24.38	135.42
14	13.92	28.80	58.84	61.01	278.28	43.89	-118.99	104.52	0.00	0.45	16.28	60.17	61.01	75.48	69.79	0.68	24.57	138.25	151.01	116.91	0.00	0.45	16.28	60.17	-28.99	63.09	125.96	0.81	29.37	199.22
15	14.92	43.80	47.96	76.21	269.65	37.65	-103.79	99.19	0.00	0.49	17.11	54.77	76.21	80.81	43.05	0.63	22.01	102.70	166.21	130.57	0.00	0.45	15.77	53.43	-13.79	49.43	175.37	0.97	33.88	246.90
16	15.92	58.80	36.42	87.19	254.00	29.41	-92.81	92.26	0.00	0.53	17.61	47.02	87.19	87.74	10.02	0.57	18.75	58.18	177.19	143.49	0.00	0.45	14.86	44.27	-2.81	36.51	204.15	1.10	36.43	269.99
17	16.92	73.80	24.76	96.42	224.28	19.70	-83.58	84.17	22.78	0.60	17.42	59.90	96.42	95.83	0.00	0.51	14.84	34.53	186.42	154.47	0.00	0.45	13.12	32.82	6.42	25.53	202.38	1.20	34.96	257.04
18	17.92	88.80	13.30	105.12	158.58	9.14	-74.88	75.30	40.25	0.68	14.04	63.43	105.12	104.70	0.00	0.45	9.28	18.41	195.12	159.97	0.00	0.45	9.28	18.41	15.12	20.03	148.99	1.24	25.50	183.62
19	18.92	103.80	2.31	114.03	4.25	0.12	-65.97	65.99	1.73	0.78	0.43	2.27	114.03	114.01	0.00	0.45	0.25	0.36	204.03	155.87	0.00	0.45	0.25	0.36	24.03	24.13	3.88	1.21	0.67	4.66
20	19.92	118.80	-7.91	123.76	0.00	0.00	-56.24	56.61	0.00	0.89	0.00	0.00	123.76	123.39	0.00	0.45	0.00	0.00	213.76	145.44	0.00	0.45	0.00	0.00	33.76	34.56	0.00	1.12	0.00	0.00
21	20.92	133.80	-16.95	134.84	0.00	0.00	-45.16	47.58	0.00	0.99	0.00	0.00	134.84	132.42	0.00	0.45	0.00	0.00	224.84	132.71	0.00	0.45	0.00	0.00	44.84	47.29	0.00	0.99	0.00	0.00
22	21.92	148.80	-24.26	147.72	0.00	0.00	-32.28	39.57	0.00	1.07	0.00	0.00	147.72	140.43	0.00	0.45	0.00	0.00	237.72	119.13	0.00	0.45	0.00	0.00	57.72	60.87	0.00	0.84	0.00	0.00
23	22.92	163.80	-29.18	162.52	0.00	0.00	-17.48	33.62	0.00	1.13	0.00	0.00	162.52	146.38	0.00	0.45	0.00	0.00	252.52	105.20	0.00	0.45	0.00	0.00	72.52	74.80	0.00	0.69	0.00	0.00

June Total Surface Irradiance

LST	AST	H	β	φ	EDN	Er	North						South						East						West					
							γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et
Local Standard Time	Apparent Solar Time	Hour Angle	Solar Altitude	Solar Azimuth	Direct Normal Irradiance	Diffuse Ground-Reflected Ir	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance
0	-0.16	-182.38	-27.62	177.54	0.00	0.00	-2.46	27.72	0.00	1.18	0.00	0.00	177.54	152.28	0.00	0.45	0.00	0.00	267.54	92.18	0.00	0.53	0.00	0.00	87.54	87.82	0.00	0.57	0.00	0.00
1	0.84	-167.38	-26.55	167.05	0.00	0.00	-12.95	29.33	0.00	1.17	0.00	0.00	167.05	150.67	0.00	0.45	0.00	0.00	257.05	101.56	0.00	0.45	0.00	0.00	77.05	78.44	0.00	0.65	0.00	0.00
2	1.84	-152.38	-22.51	152.59	0.00	0.00	-27.41	34.91	0.00	1.12	0.00	0.00	152.59	145.09	0.00	0.45	0.00	0.00	242.59	115.17	0.00	0.45	0.00	0.00	62.59	64.83	0.00	0.79	0.00	0.00
3	2.84	-137.38	-16.00	139.74	0.00	0.00	-40.26	42.81	0.00	1.04	0.00	0.00	139.74	137.19	0.00	0.45	0.00	0.00	229.74	128.40	0.00	0.45	0.00	0.00	49.74	51.60	0.00	0.94	0.00	0.00
4	3.84	-122.38	-7.62	128.59	0.00	0.00	-51.41	51.82	0.00	0.94	0.00	0.00	128.59	128.18	0.00	0.45	0.00	0.00	218.59	140.78	0.00	0.45	0.00	0.00	38.59	39.22	0.00	1.08	0.00	0.00
5	4.84	-107.38	2.09	118.82	2.14	0.06	-61.18	61.20	1.03	0.83	0.24	1.33	118.82	118.80	0.00	0.45	0.13	0.19	208.82	151.11	0.00	0.45	0.13	0.19	28.82	28.89	1.87	1.17	0.34	2.27
6	5.84	-92.38	12.72	110.00	145.61	8.32	-70.00	70.51	48.58	0.73	14.58	71.48	110.00	109.49	0.00	0.45	8.98	17.30	200.00	156.44	0.00	0.45	8.98	17.30	20.00	23.56	133.47	1.21	24.21	166.00
7	6.84	-77.38	23.94	101.61	213.85	18.57	-78.39	79.40	39.33	0.64	18.78	76.68	101.61	100.60	0.00	0.48	14.07	32.64	191.61	153.54	0.00	0.45	13.18	31.76	11.61	26.46	191.45	1.19	34.93	244.95
8	7.84	-62.38	35.51	93.01	245.34	28.18	-86.99	87.55	10.48	0.57	19.13	57.79	93.01	92.45	0.00	0.53	17.88	46.06	183.01	144.38	0.00	0.45	15.13	43.31	3.01	35.62	199.43	1.11	37.38	264.98
9	8.84	-47.38	47.17	83.22	262.13	36.50	-96.78	94.60	0.00	0.52	18.56	55.07	83.22	85.40	21.04	0.59	21.08	78.63	173.22	132.46	0.00	0.45	16.16	52.66	-6.78	47.54	176.96	0.99	35.47	248.94
10	9.84	-32.38	58.53	70.22	271.57	43.01	-109.78	100.18	0.00	0.48	17.95	60.96	70.22	79.82	47.98	0.64	23.70	114.69	160.22	119.43	0.00	0.45	16.74	59.75	-19.78	60.57	133.42	0.84	31.26	207.69
11	10.84	-17.38	68.64	48.80	276.57	47.27	-131.20	103.88	0.00	0.45	17.05	64.33	48.80	76.12	66.36	0.67	25.50	139.13	138.80	105.90	0.00	0.45	17.05	64.33	-41.20	74.10	75.79	0.69	26.27	149.33
12	11.84	-2.38	74.43	8.16	278.40	49.01	-171.84	105.41	0.00	0.45	17.16	66.18	8.16	74.59	73.98	0.69	26.25	149.24	98.16	92.18	0.00	0.53	20.36	69.37	-81.84	87.82	10.61	0.57	21.63	81.25
13	12.84	12.62	71.20	38.46	277.47	48.11	-141.54	104.61	0.00	0.45	17.11	65.21	38.46	75.39	70.01	0.68	25.86	143.97	128.46	101.56	0.00	0.45	17.11	65.21	-51.54	78.44	55.61	0.65	24.71	128.44
14	13.84	27.62	61.95	64.75	273.55	44.62	-115.25	101.57	0.00	0.45	16.86	61.49	64.75	78.43	54.87	0.65	24.37	123.87	154.75	115.17	0.00	0.45	16.86	61.49	-25.25	64.83	116.35	0.79	29.70	190.67
15	14.84	42.62	50.83	79.59	265.74	38.79	-100.41	96.55	0.00	0.50	18.36	57.15	79.59	83.45	30.32	0.60	21.99	91.09	169.59	128.40	0.00	0.45	16.38	55.17	-10.41	51.60	165.08	0.94	34.30	238.17
16	15.84	57.62	39.22	90.10	251.77	30.99	-89.90	89.93	0.33	0.55	18.99	50.30	90.10	90.07	0.00	0.55	18.95	49.94	180.10	140.78	0.00	0.45	15.52	46.51	0.10	39.22	195.06	1.08	37.13	263.18
17	16.84	72.62	27.59	98.94	226.26	21.73	-81.06	82.09	31.15	0.62	19.10	71.98	98.94	97.91	0.00	0.50	15.37	37.09	188.94	151.11	0.00	0.45	13.95	35.67	8.94	28.89	198.09	1.17	36.35	256.16
18	17.84	87.62	16.23	107.32	174.03	11.60	-72.68	73.39	49.74	0.70	16.70	78.04	107.32	106.61	0.00	0.45	10.73	22.33	197.32	156.44	0.00	0.45	10.73	22.33	17.32	23.56	159.52	1.21	28.93	200.05
19	18.84	102.62	5.38	115.95	46.97	1.73	-64.05	64.18	20.46	0.80	5.15	27.34	115.95	115.82	0.00	0.45	2.90	4.63	205.95	153.54	0.00	0.45	2.90	4.63	25.95	26.46	42.05	1.19	7.67	51.45
20	19.84	117.62	-4.66	125.36	0.00	0.00	-54.64	54.78	0.00	0.91	0.00	0.00	125.36	125.22	0.00	0.45	0.00	0.00	215.36	144.38	0.00	0.45	0.00	0.00	35.36	35.62	0.00	1.11	0.00	0.00
21	20.84	132.62	-13.51	136.03	0.00	0.00	-43.97	45.59	0.00	1.01	0.00	0.00	136.03	134.41	0.00	0.45	0.00	0.00	226.03	132.46	0.00	0.45	0.00	0.00	46.03	47.54	0.00	0.99	0.00	0.00
22	21.84	147.62	-20.68	148.32	0.00	0.00	-31.68	37.23	0.00	1.10	0.00	0.00	148.32	142.77	0.00	0.45	0.00	0.00	238.32	119.43	0.00	0.45	0.00	0.00	58.32	60.57	0.00	0.84	0.00	0.00
23	22.84	162.62	-25.57	162.31	0.00	0.00	-17.69	30.75	0.00	1.16	0.00	0.00	162.31	149.25	0.00	0.45	0.00	0.00	252.31	105.90	0.00	0.45	0.00	0.00	72.31	74.10	0.00	0.69	0.00	0.00

July Total Surface Irradiance

LST	AST	H	β	φ	EDN	Er	North						South						East						West					
							γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et
Local Standard Time	Apparent Solar Time	Hour Angle	Solar Altitude	Solar Azimuth	Direct Normal Irradiance	Diffuse Ground-Reflected Ir	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance
0	-0.24	-183.58	-30.42	176.11	0.00	0.00	-3.89	30.64	0.00	1.16	0.00	0.00	176.11	149.36	0.00	0.45	0.00	0.00	266.11	93.35	0.00	0.53	0.00	0.00	86.11	86.65	0.00	0.58	0.00	0.00
1	0.76	-168.58	-29.56	167.70	0.00	0.00	-12.30	31.80	0.00	1.15	0.00	0.00	167.70	148.20	0.00	0.45	0.00	0.00	257.70	100.68	0.00	0.48	0.00	0.00	77.70	79.32	0.00	0.64	0.00	0.00
2	1.76	-153.58	-25.57	152.50	0.00	0.00	-27.50	36.85	0.00	1.10	0.00	0.00	152.50	143.15	0.00	0.45	0.00	0.00	242.50	114.61	0.00	0.45	0.00	0.00	62.50	65.39	0.00	0.79	0.00	0.00
3	2.76	-138.58	-18.99	139.09	0.00	0.00	-40.91	44.39	0.00	1.02	0.00	0.00	139.09	135.61	0.00	0.45	0.00	0.00	229.09	128.26	0.00	0.45	0.00	0.00	49.09	51.74	0.00	0.94	0.00	0.00
4	3.76	-123.58	-10.49	127.52	0.00	0.00	-52.48	53.21	0.00	0.92	0.00	0.00	127.52	126.79	0.00	0.45	0.00	0.00	217.52	141.25	0.00	0.45	0.00	0.00	37.52	38.75	0.00	1.08	0.00	0.00
5	4.76	-108.58	-0.64	117.46	0.00	0.00	-62.54	62.54	0.00	0.82	0.00	0.00	117.46	117.46	0.00	0.45	0.00	0.00	207.46	152.53	0.00	0.45	0.00	0.00	27.46	27.47	0.00	1.18	0.00	0.00
6	5.76	-93.58	10.10	108.39	116.83	5.86	-71.61	71.91	36.28	0.72	11.54	53.68	108.39	108.09	0.00	0.45	7.25	13.11	198.39	159.10	0.00	0.45	7.25	13.11	18.39	20.90	109.14	1.23	19.85	134.86
7	6.76	-78.58	21.42	99.74	202.70	16.32	-80.26	80.94	31.93	0.63	17.53	65.77	99.74	99.06	0.00	0.49	13.68	30.00	189.74	156.57	0.00	0.45	12.59	28.91	9.74	23.43	185.99	1.21	33.97	236.28
8	7.76	-63.58	33.03	90.85	239.82	26.21	-89.15	89.29	2.97	0.56	18.38	47.56	90.85	90.71	0.00	0.54	18.02	44.24	180.85	146.96	0.00	0.45	14.89	41.10	0.85	33.04	201.04	1.14	37.61	264.86
9	8.76	-48.58	44.66	80.70	258.92	34.84	-99.30	96.60	0.00	0.50	18.00	52.84	80.70	83.40	29.76	0.60	21.59	86.19	170.70	134.58	0.00	0.45	16.08	50.91	-9.30	45.42	181.74	1.01	36.12	252.70
10	9.76	-33.58	55.88	67.38	269.47	41.64	-112.62	102.46	0.00	0.45	16.73	58.38	67.38	77.54	58.14	0.66	24.50	124.28	157.38	121.18	0.00	0.45	16.73	58.38	-22.62	58.82	139.51	0.86	31.99	213.14
11	10.76	-18.58	65.71	46.48	275.08	46.19	-133.52	106.45	0.00	0.45	17.08	63.27	46.48	73.55	77.90	0.70	26.53	150.62	136.48	107.35	0.00	0.45	17.08	63.27	-43.52	72.65	82.04	0.71	26.88	155.12
12	11.76	-3.58	71.45	10.59	277.25	48.18	-169.41	108.22	0.00	0.45	17.22	65.40	10.59	71.78	86.69	0.72	27.44	162.31	100.59	93.35	0.00	0.53	20.11	68.29	-79.41	86.65	16.21	0.58	22.06	86.45
13	12.76	11.42	69.24	31.52	276.50	47.47	-148.48	107.59	0.00	0.45	17.17	64.64	31.52	72.41	83.56	0.71	27.12	158.14	121.52	100.68	0.00	0.48	18.31	65.78	-58.48	79.32	51.25	0.64	24.49	123.20
14	13.76	26.42	60.85	58.78	272.64	44.12	-121.22	104.62	0.00	0.45	16.93	61.05	58.78	75.38	68.83	0.68	25.59	138.54	148.78	114.61	0.00	0.45	16.93	61.05	-31.22	65.39	113.55	0.79	29.58	187.26
15	14.76	41.42	50.11	74.92	264.73	38.34	-105.08	99.60	0.00	0.49	17.75	56.09	74.92	80.40	44.17	0.63	23.07	105.58	164.92	128.26	0.00	0.45	16.44	54.78	-15.08	51.74	163.94	0.94	34.36	236.64
16	15.76	56.42	38.60	86.24	250.38	30.52	-93.76	92.93	0.00	0.53	18.26	48.78	86.24	87.07	12.82	0.57	19.81	63.14	176.24	141.25	0.00	0.45	15.55	46.07	-3.76	38.75	195.26	1.08	37.36	263.14
17	16.76	71.42	26.94	95.57	223.76	21.16	-84.43	85.03	19.38	0.59	18.22	58.76	95.57	94.97	0.00	0.51	15.89	37.05	185.57	152.53	0.00	0.45	13.90	35.06	5.57	27.47	198.53	1.18	36.56	256.26
18	17.76	86.42	15.45	104.24	167.82	10.86	-75.76	76.28	39.80	0.67	15.55	66.20	104.24	103.72	0.00	0.45	10.42	21.28	194.24	159.10	0.00	0.45	10.42	21.28	14.24	20.90	156.78	1.23	28.52	196.16
19	18.76	101.42	4.40	113.04	29.79	1.02	-66.96	67.03	11.62	0.77	3.16	15.80	113.04	112.97	0.00	0.45	1.85	2.87	203.04	156.57	0.00	0.45	1.85	2.87	23.04	23.43	27.33	1.21	4.99	33.35
20	19.76	116.42	-5.93	122.56	0.00	0.00	-57.44	57.63	0.00	0.87	0.00	0.00	122.56	122.37	0.00	0.45	0.00	0.00	212.56	146.96	0.00	0.45	0.00	0.00	32.56	33.04	0.00	1.14	0.00	0.00
21	20.76	131.42	-15.14	133.35	0.00	0.00	-46.65	48.50	0.00	0.98	0.00	0.00	133.35	131.50	0.00	0.45	0.00	0.00	223.35	134.58	0.00	0.45	0.00	0.00	43.35	45.42	0.00	1.01	0.00	0.00
22	21.76	146.42	-22.71	145.86	0.00	0.00	-34.14	40.23	0.00	1.07	0.00	0.00	145.86	139.77	0.00	0.45	0.00	0.00	235.86	121.18	0.00	0.45	0.00	0.00	55.86	58.82	0.00	0.86	0.00	0.00
23	22.76	161.42	-28.02	160.25	0.00	0.00	-19.75	33.81	0.00	1.13	0.00	0.00	160.25	146.19	0.00	0.45	0.00	0.00	250.25	107.35	0.00	0.45	0.00	0.00	70.25	72.65	0.00	0.71	0.00	0.00

August Total Surface Irradiance

LST	AST	H	β	φ	EDN	Er	North						South						East						West					
							γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et	γ	θ	ED	Y	Ed	Et
Local Standard Time	Apparent Solar Time	Hour Angle	Solar Altitude	Solar Azimuth	Direct Normal Irradiance	Diffuse Ground-Reflected Ir	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance	Surface-Solar Azimuth	Incident Angle	Surface Direct Irradiance	Sky Diffuse Ratio	Diffuse Irradiance	Total Surface Irradiance
0	-0.18	-182.63	-38.75	176.70	0.00	0.00	-3.30	38.87	0.00	1.08	0.00	0.00	176.70	141.13	0.00	0.45	0.00	0.00	266.70	92.57	0.00	0.53	0.00	0.00	86.70	87.43	0.00	0.57	0.00	0.00
1	0.82	-167.63	-37.52	164.70	0.00	0.00	-15.30	40.09	0.00	1.07	0.00	0.00	164.70	139.91	0.00	0.45	0.00	0.00	254.70	102.08	0.00	0.45	0.00	0.00	74.70	77.92	0.00	0.66	0.00	0.00
2	1.82	-152.63	-32.79	147.70	0.00	0.00	-32.30	44.72	0.00	1.02	0.00	0.00	147.70	135.28	0.00	0.45	0.00	0.00	237.70	116.69	0.00	0.45	0.00	0.00	57.70	63.31	0.00	0.81	0.00	0.00
3	2.82	-137.63	-25.35	133.23	0.00	0.00	-46.77	51.76	0.00	0.94	0.00	0.00	133.23	128.24	0.00	0.45	0.00	0.00	223.23	131.18	0.00	0.45	0.00	0.00	43.23	48.82	0.00	0.97	0.00	0.00
4	3.82	-122.63	-16.04	121.11	0.00	0.00	-58.89	60.23	0.00	0.84	0.00	0.00	121.11	119.77	0.00	0.45	0.00	0.00	211.11	145.37	0.00	0.45	0.00	0.00	31.11	34.63	0.00	1.12	0.00	0.00
5	4.82	-107.63	-5.54	110.69	0.00	0.00	-69.31	69.41	0.00	0.74	0.00	0.00	110.69	110.59	0.00	0.45	0.00	0.00	200.69	158.62	0.00	0.45	0.00	0.00	20.69	21.38	0.00	1.23	0.00	0.00
6	5.82	-92.63	5.67	101.24	54.29	2.02	-78.76	78.82	10.53	0.65	4.70	17.26	101.24	101.18	0.00	0.48	3.47	5.49	191.24	167.43	0.00	0.45	3.27	5.30	11.24	12.57	52.99	1.27	9.27	64.28
7	6.82	-77.63	17.26	92.06	185.30	12.77	-87.94	88.03	6.38	0.57	14.04	33.18	92.06	91.97	0.00	0.54	13.29	26.06	182.06	162.62	0.00	0.45	11.17	23.94	2.06	17.38	176.84	1.25	31.09	220.70
8	7.82	-62.63	28.91	82.37	234.85	23.20	-97.63	96.67	0.00	0.50	15.84	39.04	82.37	83.33	27.29	0.61	19.04	69.53	172.37	150.19	0.00	0.45	14.16	37.36	-7.63	29.81	203.77	1.16	36.66	263.63
9	8.82	-47.63	40.26	71.07	258.23	32.24	-108.93	104.33	0.00	0.45	15.57	47.81	71.07	75.67	63.93	0.68	23.44	119.61	161.07	136.21	0.00	0.45	15.57	47.81	-18.93	43.79	186.40	1.03	35.59	254.23
10	9.82	-32.63	50.73	56.34	270.53	39.31	-123.66	110.54	0.00	0.45	16.31	55.62	56.34	69.46	94.90	0.74	26.89	161.10	146.34	121.79	0.00	0.45	16.31	55.62	-33.66	58.21	142.53	0.87	31.43	213.27
11	10.82	-17.63	59.15	35.24	276.85	43.96	-144.76	114.76	0.00	0.45	16.69	60.66	35.24	65.24	115.94	0.79	29.23	189.14	125.24	107.21	0.00	0.45	16.69	60.66	-54.76	72.79	81.92	0.71	26.22	152.11
12	11.82	-2.63	63.31	5.73	279.15	45.89	-174.27	116.55	0.00	0.45	16.83	62.72	5.73	63.45	124.77	0.81	30.22	200.88	95.73	92.57	0.00	0.53	19.86	65.75	-84.27	87.43	12.52	0.57	21.33	79.73
13	12.82	12.37	61.23	25.78	278.06	44.96	-154.22	115.68	0.00	0.45	16.77	61.73	25.78	64.32	120.50	0.80	29.74	195.20	115.78	102.08	0.00	0.45	16.77	61.73	-64.22	77.92	58.20	0.66	24.41	127.57
14	13.82	27.37	54.01	49.85	273.29	41.24	-130.15	112.27	0.00	0.45	16.48	57.72	49.85	67.73	103.56	0.76	27.85	172.65	139.85	116.69	0.00	0.45	16.48	57.72	-40.15	63.31	122.76	0.81	29.64	193.64
15	14.82	42.37	44.08	66.42	263.44	34.97	-113.58	106.70	0.00	0.45	15.89	50.85	66.42	73.30	75.71	0.70	24.76	135.44	156.42	131.18	0.00	0.45	15.89	50.85	-23.58	48.82	173.46	0.97	34.36	242.79
16	15.82	57.37	32.94	78.66	244.89	26.56	-101.34	99.49	0.00	0.49	15.96	42.52	78.66	80.51	40.39	0.63	20.69	87.64	168.66	145.37	0.00	0.45	14.77	41.32	-11.34	34.63	201.50	1.12	36.80	264.86
17	16.82	72.37	21.35	88.77	207.59	16.54	-91.23	91.14	0.00	0.54	15.06	31.60	88.77	88.86	4.15	0.56	15.55	36.23	178.77	158.62	0.00	0.45	12.52	29.06	-1.23	21.38	193.30	1.23	34.17	244.01
18	17.82	87.37	9.71	98.03	116.31	5.63	-81.97	82.09	16.01	0.62	9.60	31.25	98.03	97.91	0.00	0.50	7.73	13.36	188.03	167.43	0.00	0.45	7.01	12.65	8.03	12.57	113.52	1.27	19.87	139.02
19	18.82	102.37	-1.67	107.30	0.00	0.00	-72.70	72.71	0.00	0.71	0.00	0.00	107.30	107.29	0.00	0.45	0.00	0.00	197.30	162.62	0.00	0.45	0.00	0.00	17.30	17.38	0.00	1.25	0.00	0.00
20	19.82	117.37	-12.47	117.30	0.00	0.00	-62.70	63.40	0.00	0.81	0.00	0.00	117.30	116.60	0.00	0.45	0.00	0.00	207.30	150.19	0.00	0.45	0.00	0.00	27.30	29.81	0.00	1.16	0.00	0.00
21	20.82	132.37	-22.26	128.74	0.00	0.00	-51.26	54.61	0.00	0.91	0.00	0.00	128.74	125.39	0.00	0.45	0.00	0.00	218.74	136.21	0.00	0.45	0.00	0.00	38.74	43.79	0.00	1.03	0.00	0.00
22	21.82	147.37	-30.45	142.33	0.00	0.00	-37.67	46.97	0.00	0.99	0.00	0.00	142.33	133.03	0.00	0.45	0.00	0.00	232.33	121.79	0.00	0.45	0.00	0.00	52.33	58.21	0.00	0.87	0.00	0.00
23	22.82	162.37	-36.23	158.48	0.00	0.00	-21.52	41.37	0.00	1.05	0.00	0.00	158.48	138.63	0.00	0.45	0.00	0.00	248.48	107.21	0.00	0.45	0.00	0.00	68.48	72.79	0.00	0.71	0.00	0.00

September Total Surface Irradiance

LST Local Standard Time	AST Apparent Solar Time	H Hour Angle	β Solar Altitude	φ Solar Azimuth	EDN Direct Normal Irradiance	Er Diffuse Ground-Reflected Irr.	North γ Surface-Solar Azimuth	North θ Incident Angle	North ED Surface Direct Irradiance	North Y Sky Diffuse Ratio	North Ed Diffuse Irradiance	North Et Total Surface Irradiance	South γ Surface-Solar Azimuth	South θ Incident Angle	South ED Surface Direct Irradiance	South Y Sky Diffuse Ratio	South Ed Diffuse Irradiance	South Et Total Surface Irradiance
0	-0.01	-180.16	-51.11	179.75	0.00	0.00	-0.25	51.11	0.00	0.95	0.00	0.00	179.75	128.89	0.00	0.45	0.00	0.00
1	0.99	-165.16	-48.80	157.11	0.00	0.00	-22.89	52.64	0.00	0.93	0.00	0.00	157.11	127.36	0.00	0.45	0.00	0.00
2	1.99	-150.16	-42.46	137.58	0.00	0.00	-42.42	57.01	0.00	0.88	0.00	0.00	137.58	122.99	0.00	0.45	0.00	0.00
3	2.99	-135.16	-33.50	122.26	0.00	0.00	-57.74	63.57	0.00	0.81	0.00	0.00	122.26	116.43	0.00	0.45	0.00	0.00
4	3.99	-120.16	-23.02	110.04	0.00	0.00	-69.96	71.62	0.00	0.72	0.00	0.00	110.04	108.38	0.00	0.45	0.00	0.00
5	4.99	-105.16	-11.74	99.65	0.00	0.00	-80.35	80.55	0.00	0.63	0.00	0.00	99.65	99.45	0.00	0.49	0.00	0.00
6	5.99	-90.16	-0.12	90.10	0.00	0.00	-89.90	89.90	0.00	0.55	0.00	0.00	90.10	90.10	0.00	0.55	0.00	0.00
7	6.99	-75.16	11.50	80.55	153.45	7.87	-99.45	99.26	0.00	0.49	9.06	16.92	80.55	80.74	24.68	0.63	11.67	44.22
8	7.99	-60.16	22.79	70.19	229.25	18.65	-109.81	108.21	0.00	0.45	12.48	31.13	70.19	71.79	71.63	0.72	19.89	110.17
9	8.99	-45.16	33.29	58.02	259.87	27.85	-121.98	116.28	0.00	0.45	14.15	42.00	58.02	63.72	115.05	0.80	25.31	168.21
10	9.99	-30.16	42.30	42.78	274.68	34.90	-137.22	122.88	0.00	0.45	14.96	49.85	42.78	57.12	149.12	0.88	29.23	213.24
11	10.99	-15.16	48.70	23.34	281.79	39.33	-156.66	127.30	0.00	0.45	15.34	54.67	23.34	52.70	170.76	0.93	31.70	241.79
12	11.99	-0.16	51.11	0.25	283.95	40.86	-179.75	128.89	0.00	0.45	15.46	56.32	0.25	51.11	178.27	0.95	32.56	251.69
13	12.99	14.85	48.80	22.89	281.88	39.39	-157.11	127.36	0.00	0.45	15.35	54.74	22.89	52.64	171.06	0.93	31.74	242.19
14	13.99	29.85	42.46	42.42	274.89	35.02	-137.58	122.99	0.00	0.45	14.97	49.98	42.42	57.01	149.70	0.88	29.30	214.01
15	14.99	44.85	33.50	57.74	260.29	28.02	-122.26	116.43	0.00	0.45	14.17	42.20	57.74	63.57	115.87	0.81	25.40	169.29
16	15.99	59.85	23.02	69.96	230.16	18.85	-110.04	108.38	0.00	0.45	12.53	31.39	69.96	71.62	72.59	0.72	20.02	111.47
17	16.99	74.85	11.74	80.35	156.01	8.10	-99.65	99.45	0.00	0.49	9.19	17.29	80.35	80.55	25.61	0.63	11.90	45.60
18	17.99	89.85	0.12	89.90	0.00	0.00	-90.10	90.10	0.00	0.55	0.00	0.00	89.90	89.90	0.00	0.55	0.00	0.00
19	18.99	104.85	-11.50	99.45	0.00	0.00	-80.55	80.74	0.00	0.63	0.00	0.00	99.45	99.26	0.00	0.49	0.00	0.00
20	19.99	119.85	-22.79	109.81	0.00	0.00	-70.19	71.79	0.00	0.72	0.00	0.00	109.81	108.21	0.00	0.45	0.00	0.00
21	20.99	134.85	-33.29	121.98	0.00	0.00	-58.02	63.72	0.00	0.80	0.00	0.00	121.98	116.28	0.00	0.45	0.00	0.00
22	21.99	149.85	-42.30	137.22	0.00	0.00	-42.78	57.12	0.00	0.88	0.00	0.00	137.22	122.88	0.00	0.45	0.00	0.00
23	22.99	164.85	-48.70	156.66	0.00	0.00	-23.34	52.70	0.00	0.93	0.00	0.00	156.66	127.30	0.00	0.45	0.00	0.00

LST Local Standard Time	East γ Surface-Solar Azimuth	East θ Incident Angle	East ED Surface Direct Irradiance	East Y Sky Diffuse Ratio	East Ed Diffuse Irradiance	East Et Total Surface Irradiance	West γ Surface-Solar Azimuth	West θ Incident Angle	West ED Surface Direct Irradiance	West Y Sky Diffuse Ratio	West Ed Diffuse Irradiance	West Et Total Surface Irradiance
0	269.75	90.16	0.00	0.55	0.00	0.00	89.75	89.84	0.00	0.55	0.00	0.00
1	247.11	104.85	0.00	0.45	0.00	0.00	67.11	75.16	0.00	0.68	0.00	0.00
2	227.58	119.85	0.00	0.45	0.00	0.00	47.58	60.16	0.00	0.84	0.00	0.00
3	212.26	134.85	0.00	0.45	0.00	0.00	32.26	45.16	0.00	1.01	0.00	0.00
4	200.04	149.85	0.00	0.45	0.00	0.00	20.04	30.16	0.00	1.16	0.00	0.00
5	189.65	164.85	0.00	0.45	0.00	0.00	9.65	15.16	0.00	1.26	0.00	0.00
6	180.10	179.84	0.00	0.45	0.00	0.00	0.10	0.16	0.00	1.30	0.00	0.00
7	170.55	165.16	0.00	0.45	8.36	16.22	-9.45	14.85	148.33	1.26	23.49	179.68
8	160.19	150.16	0.00	0.45	12.48	31.13	-19.81	29.85	198.85	1.16	32.30	249.80
9	148.02	135.16	0.00	0.45	14.15	42.00	-31.98	44.85	184.25	1.02	31.98	244.09
10	132.78	120.16	0.00	0.45	14.96	49.85	-47.22	59.85	137.99	0.85	28.20	201.08
11	113.34	105.16	0.00	0.45	15.34	54.67	-66.66	74.85	73.67	0.69	23.38	136.37
12	90.25	90.15	0.00	0.55	18.86	59.72	-89.75	89.85	0.77	0.55	18.94	60.57
13	112.89	104.85	0.00	0.45	15.35	54.74	-67.11	75.16	72.22	0.68	23.28	134.89
14	132.42	119.85	0.00	0.45	14.97	49.98	-47.58	60.16	136.80	0.84	28.11	199.92
15	147.74	134.85	0.00	0.45	14.17	42.20	-32.26	45.16	183.55	1.01	31.93	243.51
16	159.96	149.85	0.00	0.45	12.53	31.39	-20.04	30.16	199.02	1.16	32.36	250.23
17	170.35	164.85	0.00	0.45	8.49	16.59	-9.65	15.16	150.58	1.26	23.85	182.53
18	179.90	179.84	0.00	0.45	0.00	0.00	-0.10	0.16	0.00	1.30	0.00	0.00
19	189.45	165.16	0.00	0.45	0.00	0.00	9.45	14.85	0.00	1.26	0.00	0.00
20	199.81	150.16	0.00	0.45	0.00	0.00	19.81	29.85	0.00	1.16	0.00	0.00
21	211.98	135.16	0.00	0.45	0.00	0.00	31.98	44.85	0.00	1.02	0.00	0.00
22	227.22	120.16	0.00	0.45	0.00	0.00	47.22	59.85	0.00	0.85	0.00	0.00
23	246.66	105.16	0.00	0.45	0.00	0.00	66.66	74.85	0.00	0.69	0.00	0.00

October Total Surface Irradiance

LST Local Standard Time	AST Apparent Solar Time	H Hour Angle	β Solar Altitude	φ Solar Azimuth	EDN Direct Normal Irradiance	Er Diffuse Ground-Reflected In	North γ Surface-Solar Azimuth	North θ Incident Angle	North ED Surface Direct Irradiance	North Y Sky Diffuse Ratio	North Ed Diffuse Irradiance	North Et Total Surface Irradiance	South γ Surface-Solar Azimuth	South θ Incident Angle	South ED Surface Direct Irradiance	South Y Sky Diffuse Ratio	South Ed Diffuse Irradiance	South Et Total Surface Irradiance
0	0.12	-178.18	-61.56	176.24	0.00	0.00	-3.76	61.63	0.00	0.83	0.00	0.00	176.24	118.37	0.00	0.45	0.00	0.00
1	1.12	-163.18	-57.89	147.64	0.00	0.00	-32.36	63.32	0.00	0.81	0.00	0.00	147.64	116.68	0.00	0.45	0.00	0.00
2	2.12	-148.18	-49.88	126.43	0.00	0.00	-53.57	67.50	0.00	0.76	0.00	0.00	126.43	112.50	0.00	0.45	0.00	0.00
3	3.12	-133.18	-39.65	111.37	0.00	0.00	-68.63	73.71	0.00	0.70	0.00	0.00	111.37	106.29	0.00	0.45	0.00	0.00
4	4.12	-118.18	-28.41	99.80	0.00	0.00	-80.20	81.39	0.00	0.62	0.00	0.00	99.80	98.61	0.00	0.49	0.00	0.00
5	5.12	-103.18	-16.79	89.93	0.00	0.00	-90.07	90.06	0.00	0.55	0.00	0.00	89.93	89.94	0.00	0.55	0.00	0.00
6	6.12	-88.18	-5.17	80.67	0.00	0.00	-99.33	99.29	0.00	0.49	0.00	0.00	80.67	80.71	0.00	0.63	0.00	0.00
7	7.12	-73.18	6.14	71.20	85.59	2.99	-108.80	108.69	0.00	0.45	4.28	7.26	71.20	71.31	27.43	0.72	6.86	37.28
8	8.12	-58.18	16.80	60.78	211.77	13.56	-119.22	117.86	0.00	0.45	10.58	24.13	60.78	62.14	98.97	0.82	19.34	131.86
9	9.12	-43.18	26.34	48.66	254.95	22.63	-131.34	126.30	0.00	0.45	12.73	35.36	48.66	53.70	150.93	0.92	25.99	199.55
10	10.12	-28.18	34.07	34.09	274.04	29.43	-145.91	133.31	0.00	0.45	13.69	43.12	34.09	46.69	187.99	1.00	30.33	247.75
11	11.12	-13.18	39.11	16.79	282.60	33.54	-163.21	137.98	0.00	0.45	14.12	47.65	16.79	42.02	209.94	1.05	32.86	276.34
12	12.12	1.82	40.58	2.36	284.70	34.69	-177.64	139.36	0.00	0.45	14.22	48.91	2.36	40.64	216.05	1.06	33.56	284.29
13	13.12	16.82	38.18	21.22	281.20	32.81	-158.78	137.12	0.00	0.45	14.05	46.85	21.22	42.88	206.05	1.04	32.41	271.26
14	14.12	31.82	32.40	37.88	270.65	28.01	-142.12	131.79	0.00	0.45	13.52	41.53	37.88	48.21	180.35	0.98	29.45	237.81
15	15.12	46.82	24.16	51.80	247.63	20.61	-128.20	124.35	0.00	0.45	12.37	32.98	51.80	55.65	139.73	0.90	24.63	184.98
16	16.12	61.82	14.30	63.43	193.39	11.08	-116.57	115.68	0.00	0.45	9.66	20.74	63.43	64.32	83.81	0.80	17.13	112.02
17	17.12	76.82	3.44	73.55	27.81	0.76	-106.45	106.42	0.00	0.45	1.39	2.15	73.55	73.58	7.86	0.70	2.16	10.78
18	18.12	91.82	-7.97	82.91	0.00	0.00	-97.09	97.02	0.00	0.50	0.00	0.00	82.91	82.98	0.00	0.61	0.00	0.00
19	19.12	106.82	-19.63	92.24	0.00	0.00	-87.76	87.89	0.00	0.57	0.00	0.00	92.24	92.11	0.00	0.53	0.00	0.00
20	20.12	121.82	-31.19	102.40	0.00	0.00	-77.60	79.42	0.00	0.64	0.00	0.00	102.40	100.58	0.00	0.48	0.00	0.00
21	21.12	136.82	-42.26	114.62	0.00	0.00	-65.38	72.04	0.00	0.71	0.00	0.00	114.62	107.96	0.00	0.45	0.00	0.00
22	22.12	151.82	-52.09	130.91	0.00	0.00	-49.09	66.28	0.00	0.78	0.00	0.00	130.91	113.72	0.00	0.45	0.00	0.00
23	23.12	166.82	-59.27	153.98	0.00	0.00	-26.02	62.66	0.00	0.82	0.00	0.00	153.98	117.34	0.00	0.45	0.00	0.00

LST Local Standard Time	East γ Surface-Solar Azimuth	East θ Incident Angle	East ED Surface Direct Irradiance	East Y Sky Diffuse Ratio	East Ed Diffuse Irradiance	East Et Total Surface Irradiance	West γ Surface-Solar Azimuth	West θ Incident Angle	West ED Surface Direct Irradiance	West Y Sky Diffuse Ratio	West Ed Diffuse Irradiance	West Et Total Surface Irradiance
0	266.24	91.79	0.00	0.54	0.00	0.00	86.24	88.21	0.00	0.56	0.00	0.00
1	237.64	106.53	0.00	0.45	0.00	0.00	57.64	73.47	0.00	0.70	0.00	0.00
2	216.43	121.23	0.00	0.45	0.00	0.00	36.43	58.77	0.00	0.86	0.00	0.00
3	201.37	135.81	0.00	0.45	0.00	0.00	21.37	44.19	0.00	1.02	0.00	0.00
4	189.80	150.08	0.00	0.45	0.00	0.00	9.80	29.92	0.00	1.16	0.00	0.00
5	179.93	163.21	0.00	0.45	0.00	0.00	-0.07	16.79	0.00	1.26	0.00	0.00
6	170.67	169.35	0.00	0.45	0.00	0.00	-9.33	10.65	0.00	1.28	0.00	0.00
7	161.20	160.25	0.00	0.45	4.28	7.26	-18.80	19.75	80.55	1.24	11.77	95.31
8	150.78	146.67	0.00	0.45	10.58	24.13	-29.22	33.33	176.93	1.13	26.65	217.13
9	138.66	132.29	0.00	0.45	12.73	35.36	-41.34	47.71	171.54	0.99	27.90	222.06
10	124.09	117.67	0.00	0.45	13.69	43.12	-55.91	62.33	127.25	0.82	24.96	181.63
11	106.79	102.96	0.00	0.45	14.12	47.65	-73.21	77.04	63.36	0.66	20.82	117.71
12	92.36	91.79	0.00	0.54	16.96	51.65	-87.64	88.21	8.89	0.56	17.82	61.40
13	111.22	106.53	0.00	0.45	14.05	46.85	-68.78	73.47	80.01	0.70	21.84	134.65
14	127.88	121.23	0.00	0.45	13.52	41.53	-52.12	58.77	140.31	0.86	25.86	194.18
15	141.80	135.81	0.00	0.45	12.37	32.98	-38.20	44.19	177.55	1.02	28.15	226.31
16	153.43	150.08	0.00	0.45	9.66	20.74	-26.57	29.92	167.61	1.16	24.98	203.68
17	163.55	163.21	0.00	0.45	1.39	2.15	-16.45	16.79	26.62	1.26	3.87	31.26
18	172.91	169.35	0.00	0.45	0.00	0.00	-7.09	10.65	0.00	1.28	0.00	0.00
19	182.24	160.25	0.00	0.45	0.00	0.00	2.24	19.75	0.00	1.24	0.00	0.00
20	192.40	146.67	0.00	0.45	0.00	0.00	12.40	33.33	0.00	1.13	0.00	0.00
21	204.62	132.29	0.00	0.45	0.00	0.00	24.62	47.71	0.00	0.99	0.00	0.00
22	220.91	117.67	0.00	0.45	0.00	0.00	40.91	62.33	0.00	0.82	0.00	0.00
23	243.98	102.96	0.00	0.45	0.00	0.00	63.98	77.04	0.00	0.66	0.00	0.00

November Total Surface Irradiance

LST Local Standard Time	AST Apparent Solar Time	H Hour Angle	β Solar Altitude	φ Solar Azimuth	EDN Direct Normal Irradiance	Er Diffuse Ground-Reflected In	North γ Surface-Solar Azimuth	North θ Incident Angle	North ED Surface Direct Irradiance	North Y Sky Diffuse Ratio	North Ed Diffuse Irradiance	North Et Total Surface Irradiance	South γ Surface-Solar Azimuth	South θ Incident Angle	South ED Surface Direct Irradiance	South Y Sky Diffuse Ratio	South Ed Diffuse Irradiance	South Et Total Surface Irradiance
0	0.09	-178.58	-70.87	175.92	0.00	0.00	-4.08	70.92	0.00	0.73	0.00	0.00	175.92	109.08	0.00	0.45	0.00	0.00
1	1.09	-163.58	-66.23	138.72	0.00	0.00	-41.28	72.36	0.00	0.71	0.00	0.00	138.72	107.64	0.00	0.45	0.00	0.00
2	2.09	-148.58	-56.89	116.11	0.00	0.00	-63.89	76.09	0.00	0.67	0.00	0.00	116.11	103.91	0.00	0.45	0.00	0.00
3	3.09	-133.58	-45.85	101.89	0.00	0.00	-78.11	81.75	0.00	0.62	0.00	0.00	101.89	98.25	0.00	0.49	0.00	0.00
4	4.09	-118.58	-34.26	91.31	0.00	0.00	-88.69	88.92	0.00	0.56	0.00	0.00	91.31	91.08	0.00	0.54	0.00	0.00
5	5.09	-103.58	-22.62	82.22	0.00	0.00	-97.78	97.18	0.00	0.50	0.00	0.00	82.22	82.82	0.00	0.61	0.00	0.00
6	6.09	-88.58	-11.22	73.52	0.00	0.00	-106.48	106.16	0.00	0.45	0.00	0.00	73.52	73.84	0.00	0.70	0.00	0.00
7	7.09	-73.58	-0.32	64.49	0.00	0.00	-115.51	115.51	0.00	0.45	0.00	0.00	64.49	64.49	0.00	0.80	0.00	0.00
8	8.09	-58.58	9.74	54.55	156.86	6.90	-125.45	124.86	0.00	0.45	7.48	14.39	54.55	55.14	89.66	0.90	15.00	111.57
9	9.09	-43.58	18.53	43.16	233.66	15.85	-136.84	133.75	0.00	0.45	11.15	26.99	43.16	46.25	161.60	1.00	24.82	202.26
10	10.09	-28.58	25.50	29.91	263.06	22.58	-150.09	141.48	0.00	0.45	12.55	35.13	29.91	38.52	205.82	1.08	30.21	258.61
11	11.09	-13.58	29.95	14.77	275.47	26.67	-165.23	146.91	0.00	0.45	13.14	39.81	14.77	33.09	230.80	1.14	33.17	290.64
12	12.09	1.42	31.29	1.56	278.58	27.88	-178.44	148.67	0.00	0.45	13.29	41.17	1.56	31.33	237.96	1.15	34.01	299.85
13	13.09	16.42	29.33	17.76	273.95	26.11	-162.24	146.13	0.00	0.45	13.07	39.18	17.76	33.87	227.45	1.13	32.77	286.34
14	14.09	31.42	24.35	32.57	259.21	21.50	-147.43	140.15	0.00	0.45	12.36	33.86	32.57	39.85	199.01	1.07	29.40	249.91
15	15.09	46.42	16.99	45.45	224.55	14.31	-134.55	132.13	0.00	0.45	10.71	25.02	45.45	47.87	150.64	0.98	23.42	188.37
16	16.09	61.42	7.91	56.53	129.15	5.04	-123.47	123.11	0.00	0.45	6.16	11.20	56.53	56.89	70.55	0.88	12.08	87.66
17	17.09	76.42	-2.33	66.25	0.00	0.00	-113.75	113.73	0.00	0.45	0.00	0.00	66.25	66.27	0.00	0.78	0.00	0.00
18	18.09	91.42	-13.35	75.17	0.00	0.00	-104.83	104.42	0.00	0.45	0.00	0.00	75.17	75.58	0.00	0.68	0.00	0.00
19	19.09	106.42	-24.81	83.89	0.00	0.00	-96.11	95.55	0.00	0.51	0.00	0.00	83.89	84.45	0.00	0.60	0.00	0.00
20	20.09	121.42	-36.47	93.16	0.00	0.00	-86.84	87.46	0.00	0.57	0.00	0.00	93.16	92.54	0.00	0.53	0.00	0.00
21	21.09	136.42	-48.00	104.21	0.00	0.00	-75.79	80.55	0.00	0.63	0.00	0.00	104.21	99.45	0.00	0.49	0.00	0.00
22	22.09	151.42	-58.84	119.54	0.00	0.00	-60.46	75.22	0.00	0.68	0.00	0.00	119.54	104.78	0.00	0.45	0.00	0.00
23	23.09	166.42	-67.60	144.57	0.00	0.00	-35.43	71.91	0.00	0.72	0.00	0.00	144.57	108.09	0.00	0.45	0.00	0.00

LST Local Standard Time	East γ Surface-Solar Azimuth	East θ Incident Angle	East ED Surface Direct Irradiance	East Y Sky Diffuse Ratio	East Ed Diffuse Irradiance	East Et Total Surface Irradiance	West γ Surface-Solar Azimuth	West θ Incident Angle	West ED Surface Direct Irradiance	West Y Sky Diffuse Ratio	West Ed Diffuse Irradiance	West Et Total Surface Irradiance
0	265.92	91.34	0.00	0.54	0.00	0.00	85.92	88.66	0.00	0.56	0.00	0.00
1	228.72	105.42	0.00	0.45	0.00	0.00	48.72	74.58	0.00	0.69	0.00	0.00
2	206.11	119.37	0.00	0.45	0.00	0.00	26.11	60.63	0.00	0.84	0.00	0.00
3	191.89	132.97	0.00	0.45	0.00	0.00	11.89	47.03	0.00	0.99	0.00	0.00
4	181.31	145.71	0.00	0.45	0.00	0.00	1.31	34.29	0.00	1.12	0.00	0.00
5	172.22	156.15	0.00	0.45	0.00	0.00	-7.78	23.85	0.00	1.21	0.00	0.00
6	163.52	160.15	0.00	0.45	0.00	0.00	-16.48	19.85	0.00	1.24	0.00	0.00
7	154.49	154.49	0.00	0.45	0.00	0.00	-25.51	25.51	0.00	1.20	0.00	0.00
8	144.55	143.41	0.00	0.45	7.48	14.39	-35.45	36.59	125.95	1.10	18.33	151.19
9	133.16	130.44	0.00	0.45	11.15	26.99	-46.84	49.56	151.56	0.97	23.90	191.31
10	119.91	116.75	0.00	0.45	12.55	35.13	-60.09	63.25	118.40	0.81	22.59	163.57
11	104.77	102.76	0.00	0.45	13.14	39.81	-75.23	77.24	60.86	0.66	19.32	106.85
12	91.56	91.34	0.00	0.54	15.95	43.82	-88.44	88.66	6.50	0.56	16.55	50.92
13	107.76	105.42	0.00	0.45	13.07	39.18	-72.24	74.58	72.86	0.69	19.99	118.96
14	122.57	119.37	0.00	0.45	12.36	33.86	-57.43	60.63	127.14	0.84	23.07	171.71
15	135.45	132.97	0.00	0.45	10.71	25.02	-44.55	47.03	153.05	0.99	23.64	190.99
16	146.53	145.71	0.00	0.45	6.16	11.20	-33.47	34.29	106.71	1.12	15.40	127.14
17	156.25	156.15	0.00	0.45	0.00	0.00	-23.75	23.85	0.00	1.21	0.00	0.00
18	165.17	160.15	0.00	0.45	0.00	0.00	-14.83	19.85	0.00	1.24	0.00	0.00
19	173.89	154.49	0.00	0.45	0.00	0.00	-6.11	25.51	0.00	1.20	0.00	0.00
20	183.16	143.41	0.00	0.45	0.00	0.00	3.16	36.59	0.00	1.10	0.00	0.00
21	194.21	130.44	0.00	0.45	0.00	0.00	14.21	49.56	0.00	0.97	0.00	0.00
22	209.54	116.75	0.00	0.45	0.00	0.00	29.54	63.25	0.00	0.81	0.00	0.00
23	234.57	102.76	0.00	0.45	0.00	0.00	54.57	77.24	0.00	0.66	0.00	0.00

December Total Surface Irradiance

LST Local Standard Time	AST Apparent Solar Time	H Hour Angle	β Solar Altitude	φ Solar Azimuth	EDN Direct Normal Irradiance	Er Diffuse Ground-Reflected In	North γ Surface-Solar Azimuth	North θ Incident Angle	North ED Surface Direct Irradiance	North Y Sky Diffuse Ratio	North Ed Diffuse Irradiance	North Et Total Surface Irradiance	South γ Surface-Solar Azimuth	South θ Incident Angle	South ED Surface Direct Irradiance	South Y Sky Diffuse Ratio	South Ed Diffuse Irradiance	South Et Total Surface Irradiance
0	-0.11	-181.63	-74.50	174.40	0.00	0.00	-5.60	74.57	0.00	0.69	0.00	0.00	174.40	105.43	0.00	0.45	0.00	0.00
1	0.89	-166.63	-70.83	139.75	0.00	0.00	-40.25	75.49	0.00	0.68	0.00	0.00	139.75	104.51	0.00	0.45	0.00	0.00
2	1.89	-151.63	-61.42	114.32	0.00	0.00	-65.68	78.64	0.00	0.65	0.00	0.00	114.32	101.36	0.00	0.48	0.00	0.00
3	2.89	-136.63	-50.26	99.81	0.00	0.00	-80.19	83.75	0.00	0.60	0.00	0.00	99.81	96.25	0.00	0.51	0.00	0.00
4	3.89	-121.63	-38.63	89.44	0.00	0.00	-90.56	90.44	0.00	0.55	0.00	0.00	89.44	89.56	0.00	0.55	0.00	0.00
5	4.89	-106.63	-27.01	80.64	0.00	0.00	-99.36	98.33	0.00	0.49	0.00	0.00	80.64	81.67	0.00	0.62	0.00	0.00
6	5.89	-91.63	-15.67	72.26	0.00	0.00	-107.74	107.06	0.00	0.45	0.00	0.00	72.26	72.94	0.00	0.71	0.00	0.00
7	6.89	-76.63	-4.86	63.61	0.00	0.00	-116.39	116.29	0.00	0.45	0.00	0.00	63.61	63.71	0.00	0.80	0.00	0.00
8	7.89	-61.63	5.13	54.14	77.01	2.37	-125.86	125.69	0.00	0.45	3.57	5.94	54.14	54.31	44.93	0.91	7.23	54.53
9	8.89	-46.63	13.92	43.40	207.23	11.39	-136.60	134.85	0.00	0.45	9.61	21.00	43.40	45.15	146.16	1.01	21.64	179.19
10	9.89	-31.63	20.99	31.02	251.24	18.54	-148.98	143.15	0.00	0.45	11.65	30.18	31.02	36.85	201.03	1.10	28.47	248.04
11	10.89	-16.63	25.74	16.95	269.21	23.15	-163.05	149.50	0.00	0.45	12.48	35.62	16.95	30.50	231.96	1.16	32.13	287.24
12	11.89	-1.63	27.64	1.69	274.84	24.93	-178.31	152.31	0.00	0.45	12.74	37.67	1.69	27.69	243.36	1.18	33.47	301.77
13	12.89	13.37	26.42	13.70	271.28	23.78	-166.30	150.47	0.00	0.45	12.57	36.35	13.70	29.53	236.04	1.17	32.61	292.44
14	13.89	28.37	22.24	28.10	256.61	19.77	-151.90	144.74	0.00	0.45	11.89	31.66	28.10	35.26	209.53	1.12	29.48	258.78
15	14.89	43.37	15.62	40.85	220.61	13.14	-139.15	136.76	0.00	0.45	10.23	23.36	40.85	43.24	160.70	1.03	23.50	197.35
16	15.89	58.37	7.16	51.93	120.16	4.38	-128.07	127.72	0.00	0.45	5.57	9.95	51.93	52.28	73.51	0.93	11.57	89.46
17	16.89	73.37	-2.61	61.64	0.00	0.00	-118.36	118.33	0.00	0.45	0.00	0.00	61.64	61.67	0.00	0.83	0.00	0.00
18	17.89	88.37	-13.27	70.42	0.00	0.00	-109.58	109.03	0.00	0.45	0.00	0.00	70.42	70.97	0.00	0.73	0.00	0.00
19	18.89	103.37	-24.52	78.81	0.00	0.00	-101.19	100.17	0.00	0.48	0.00	0.00	78.81	79.83	0.00	0.64	0.00	0.00
20	19.89	118.37	-36.10	87.44	0.00	0.00	-92.56	92.07	0.00	0.53	0.00	0.00	87.44	87.93	0.00	0.57	0.00	0.00
21	20.89	133.37	-47.75	97.33	0.00	0.00	-82.67	85.08	0.00	0.59	0.00	0.00	97.33	94.92	0.00	0.51	0.00	0.00
22	21.89	148.37	-59.07	110.58	0.00	0.00	-69.42	79.59	0.00	0.64	0.00	0.00	110.58	100.41	0.00	0.48	0.00	0.00
23	22.89	163.37	-69.07	132.68	0.00	0.00	-47.32	75.99	0.00	0.67	0.00	0.00	132.68	104.01	0.00	0.45	0.00	0.00

LST Local Standard Time	East γ Surface-Solar Azimuth	East θ Incident Angle	East ED Surface Direct Irradiance	East Y Sky Diffuse Ratio	East Ed Diffuse Irradiance	East Et Total Surface Irradiance	West γ Surface-Solar Azimuth	West θ Incident Angle	West ED Surface Direct Irradiance	West Y Sky Diffuse Ratio	West Ed Diffuse Irradiance	West Et Total Surface Irradiance
0	264.40	91.50	0.00	0.54	0.00	0.00	84.40	88.50	0.00	0.56	0.00	0.00
1	229.75	102.25	0.00	0.45	0.00	0.00	49.75	77.75	0.00	0.66	0.00	0.00
2	204.32	115.84	0.00	0.45	0.00	0.00	24.32	64.16	0.00	0.80	0.00	0.00
3	189.81	129.05	0.00	0.45	0.00	0.00	9.81	50.95	0.00	0.95	0.00	0.00
4	179.44	141.36	0.00	0.45	0.00	0.00	-0.56	38.64	0.00	1.08	0.00	0.00
5	170.64	151.53	0.00	0.45	0.00	0.00	-9.36	28.47	0.00	1.18	0.00	0.00
6	162.26	156.50	0.00	0.45	0.00	0.00	-17.74	23.50	0.00	1.21	0.00	0.00
7	153.61	153.19	0.00	0.45	0.00	0.00	-26.39	26.81	0.00	1.19	0.00	0.00
8	144.14	143.83	0.00	0.45	3.57	5.94	-35.86	36.17	62.16	1.11	8.78	73.31
9	133.40	131.83	0.00	0.45	9.61	21.00	-46.60	48.17	138.20	0.98	20.93	170.53
10	121.02	118.76	0.00	0.45	11.65	30.18	-58.98	61.24	120.88	0.83	21.55	160.96
11	106.95	105.22	0.00	0.45	12.48	35.62	-73.05	74.78	70.68	0.69	19.03	112.86
12	91.69	91.50	0.00	0.54	15.25	40.18	-88.31	88.50	7.17	0.56	15.90	48.00
13	103.70	102.25	0.00	0.45	12.57	36.35	-76.30	77.75	57.55	0.66	18.35	99.68
14	118.10	115.84	0.00	0.45	11.89	31.66	-61.90	64.16	111.86	0.80	21.14	152.77
15	130.85	129.05	0.00	0.45	10.23	23.36	-49.15	50.95	138.98	0.95	21.58	173.70
16	141.93	141.36	0.00	0.45	5.57	9.95	-38.07	38.64	93.86	1.08	13.40	111.63
17	151.64	151.53	0.00	0.45	0.00	0.00	-28.36	28.47	0.00	1.18	0.00	0.00
18	160.42	156.50	0.00	0.45	0.00	0.00	-19.58	23.50	0.00	1.21	0.00	0.00
19	168.81	153.19	0.00	0.45	0.00	0.00	-11.19	26.81	0.00	1.19	0.00	0.00
20	177.44	143.83	0.00	0.45	0.00	0.00	-2.56	36.17	0.00	1.11	0.00	0.00
21	187.33	131.83	0.00	0.45	0.00	0.00	7.33	48.17	0.00	0.98	0.00	0.00
22	200.58	118.76	0.00	0.45	0.00	0.00	20.58	61.24	0.00	0.83	0.00	0.00
23	222.68	105.22	0.00	0.45	0.00	0.00	42.68	74.78	0.00	0.69	0.00	0.00

January Fenestration Analysis

			CONDUCTION = $Q_{cond} = UA(\Delta t)$				SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	41.0	60	-19.0	-143009.2	-138396	-133783	0.00	0.00	0.00	0.00	0	0	0	-143009	-138396	-133783	0	0
1:00	40.0	60	-20.0	-150536	-145680	-140824	0.00	0.00	0.00	0.00	0	0	0	-150536	-145680	-140824	0	0
2:00	38.7	60	-21.3	-160320.84	-155149.2	-149978	0.00	0.00	0.00	0.00	0	0	0	-160321	-155149	-149978	0	0
3:00	37.5	60	-22.5	-169353	-163890	-158427	0.00	0.00	0.00	0.00	0	0	0	-169353	-163890	-158427	0	0
4:00	36.3	60	-23.7	-178385.16	-172630.8	-166876	0.00	0.00	0.00	0.00	0	0	0	-178385	-172631	-166876	0	0
5:00	35.5	60	-24.5	-184406.6	-178458	-172509	0.00	0.00	0.00	0.00	0	0	0	-184407	-178458	-172509	0	0
6:00	35.0	70	-35.0	-263438	-254940	-246442	0.00	0.00	0.00	0.00	0	0	0	-263438	-254940	-246442	0	0
7:00	35.3	70	-34.7	-261179.96	-252754.8	-244330	0.00	0.00	0.00	0.00	0	0	0	-261180	-252755	-244330	0	0
8:00	36.8	70	-33.2	-249889.76	-241828.8	-233768	6.73	54.81	6.73	86.02	510730	368861	264823	260840	127032	31055	133808	229785
9:00	39.3	70	-30.7	-231072.76	-223618.8	-216165	22.32	172.50	22.32	189.16	1342815	969811	696275	1111743	746192	480110	365550	631633
10:00	42.3	70	-27.7	-208492.36	-201766.8	-195041	32.09	241.55	32.09	181.69	1608417	1161634	833994	1399925	959868	638953	440057	760972
11:00	45.5	70	-24.5	-184406.6	-178458	-172509	38.21	283.70	38.21	133.82	1627135	1175153	843700	1442728	996695	671190	446033	771538
12:00	50.0	70	-20.0	-150536	-145680	-140824	40.97	302.54	42.93	67.28	1491941	1077513	773599	1341405	931833	632775	409572	708630
13:00	51.2	70	-18.8	-141503.84	-136939.2	-132375	40.37	298.46	41.41	92.24	1554675	1122821	806128	1413171	985882	673753	427290	739418
14:00	51.0	70	-19.0	-143009.2	-138396	-133783	36.42	271.43	36.42	153.80	1641798	1185743	851303	1498789	1047347	717520	451442	781269
15:00	50.3	70	-19.7	-148277.96	-143494.8	-138712	29.07	220.48	29.07	190.75	1549764	1119274	803581	1401486	975779	664870	425707	736616
16:00	49.3	70	-20.7	-155804.76	-150778.8	-145753	17.68	138.67	17.68	172.65	1146461	827999	594461	990656	677221	448708	313435	541948
17:00	48.5	70	-21.5	-161826.2	-156606	-151386	0.37	3.12	0.37	5.59	31310	22613	16235	-130516	-133993	-135151	0	0
18:00	47.3	70	-22.7	-170858.36	-165346.8	-159835	0.00	0.00	0.00	0.00	0	0	0	-170858	-165347	-159835	0	0
19:00	46.2	70	-23.8	-179137.84	-173359.2	-167581	0.00	0.00	0.00	0.00	0	0	0	-179138	-173359	-167581	0	0
20:00	45.0	70	-25.0	-188170	-182100	-176030	0.00	0.00	0.00	0.00	0	0	0	-188170	-182100	-176030	0	0
21:00	44.0	60	-16.0	-120428.8	-116544	-112659	0.00	0.00	0.00	0.00	0	0	0	-120429	-116544	-112659	0	0
22:00	42.9	60	-17.1	-128708.28	-124556.4	-120405	0.00	0.00	0.00	0.00	0	0	0	-128708	-124556	-120405	0	0
23:00	42.0	60	-18.0	-135482.4	-131112	-126742	0.00	0.00	0.00	0.00	0	0	0	-135482	-131112	-126742	0	0
														8296813	4958938	2547364	3412895	5901809

February Fenestration Analysis

			CONDUCTION = $Q_{cond} = UA(\Delta t)$				SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	36.5	60	-23.5	-176879.8	-171174	-165468	0.00	0.00	0.00	0.00	0	0	0	-176880	-171174	-165468	0	0
1:00	35.3	60	-24.7	-185911.96	-179914.8	-173918	0.00	0.00	0.00	0.00	0	0	0	-185912	-179915	-173918	0	0
2:00	34.0	60	-26.0	-195696.8	-189384	-183071	0.00	0.00	0.00	0.00	0	0	0	-195697	-189384	-183071	0	0
3:00	32.7	60	-27.3	-205481.64	-198853.2	-192225	0.00	0.00	0.00	0.00	0	0	0	-205482	-198853	-192225	0	0
4:00	31.6	60	-28.4	-213761.12	-206865.6	-199970	0.00	0.00	0.00	0.00	0	0	0	-213761	-206866	-199970	0	0
5:00	30.7	60	-29.3	-220535.24	-213421.2	-206307	0.00	0.00	0.00	0.00	0	0	0	-220535	-213421	-206307	0	0
6:00	30.7	70	-39.3	-295803.24	-286261.2	-276719	0.00	0.00	0.00	0.00	0	0	0	-295803	-286261	-276719	0	0
7:00	31.5	70	-38.5	-289781.8	-280434	-271086	0.00	0.00	0.00	0.00	0	0	0	-289782	-280434	-271086	0	0
8:00	33.7	70	-36.3	-273222.84	-264409.2	-255596	17.14	95.45	17.14	191.74	1064467	768782	551946	791244	504373	296350	286872	494894
9:00	36.5	70	-33.5	-252147.8	-244014	-235880	30.53	175.77	30.53	235.43	1561183	1127521	809502	1309036	883507	573622	425528	735413
10:00	39.0	70	-31.0	-233330.8	-225804	-218277	39.90	233.98	39.90	210.74	1731073	1250219	897593	1497742	1024415	679316	473327	818426
11:00	41.7	70	-28.3	-213008.44	-206137.2	-199266	46.03	272.68	46.03	154.18	1709525	1234657	886420	1496517	1028520	687154	467997	809362
12:00	44.5	70	-25.5	-191933.4	-185742	-179551	48.92	291.00	50.80	81.02	1551141	1120269	804295	1359208	934527	624745	424681	734463
13:00	46.3	70	-23.7	-178385.16	-172630.8	-166876	48.47	288.17	49.61	101.46	1604503	1158808	831965	1426118	986177	665088	439941	761030
14:00	46.6	70	-23.4	-176127.12	-170445.6	-164764	44.72	264.33	44.72	171.34	1730757	1249991	897430	1554630	1079546	732665	475084	821964
15:00	46.2	70	-23.8	-179137.84	-173359.2	-167581	37.73	220.39	37.73	221.27	1707425	1233140	885331	1528287	1059781	717751	468506	810536
16:00	45.5	70	-24.5	-184406.6	-178458	-172509	27.44	156.90	27.44	233.21	1471674	1062876	763090	1287267	884418	590581	402850	696687
17:00	44.3	70	-25.7	-193438.76	-187198.8	-180959	12.46	68.42	12.46	154.84	822148	593773	426299	628709	406575	245340	222134	383369
18:00	43.3	70	-26.7	-200965.56	-194482.8	-188000	0.00	0.00	0.00	0.00	0	0	0	-200966	-194483	-188000	0	0
19:00	42.0	70	-28.0	-210750.4	-203952	-197154	0.00	0.00	0.00	0.00	0	0	0	-210750	-203952	-197154	0	0
20:00	40.8	70	-29.2	-219782.56	-212692.8	-205603	0.00	0.00	0.00	0.00	0	0	0	-219783	-212693	-205603	0	0
21:00	39.6	60	-20.4	-153546.72	-148593.6	-143640	0.00	0.00	0.00	0.00	0	0	0	-153547	-148594	-143640	0	0
22:00	38.5	60	-21.5	-161826.2	-156606	-151386	0.00	0.00	0.00	0.00	0	0	0	-161826	-156606	-151386	0	0
23:00	37.5	60	-22.5	-169353	-163890	-158427	0.00	0.00	0.00	0.00	0	0	0	-169353	-163890	-158427	0	0
														9978682	5985312	3099639	4086920	7066144

March Fenestration Analysis

			CONDUCTION = $Q_{cond} = UA(\Delta t)$				SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	46.2	60	-13.8	-103869.84	-100519.2	-97169	0.00	0.00	0.00	0.00	0	0	0	-103870	-100519	-97169	0	0
1:00	44.8	60	-15.2	-114407.36	-110716.8	-107026	0.00	0.00	0.00	0.00	0	0	0	-114407	-110717	-107026	0	0
2:00	43.0	60	-17.0	-127955.6	-123828	-119700	0.00	0.00	0.00	0.00	0	0	0	-127956	-123828	-119700	0	0
3:00	41.5	60	-18.5	-139245.8	-134754	-130262	0.00	0.00	0.00	0.00	0	0	0	-139246	-134754	-130262	0	0
4:00	40.0	60	-20.0	-150536	-145680	-140824	0.00	0.00	0.00	0.00	0	0	0	-150536	-145680	-140824	0	0
5:00	38.8	60	-21.2	-159568.16	-154420.8	-149273	0.00	0.00	0.00	0.00	0	0	0	-159568	-154421	-149273	0	0
6:00	38.3	70	-31.7	-238599.56	-230902.8	-223206	0.00	0.00	0.00	0.00	0	0	0	-238600	-230903	-223206	0	0
7:00	39.0	70	-31.0	-233330.8	-225804	-218277	12.79	30.39	12.03	154.64	695898	502593	360836	462567	276789	142559	185778	320008
8:00	40.6	70	-29.4	-221287.92	-214149.6	-207011	28.23	98.74	28.23	256.23	1362275	983865	706365	1140987	769716	499353	371271	641633
9:00	43.2	70	-26.8	-201718.24	-195211.2	-188704	39.89	160.62	39.89	260.31	1655023	1195294	858160	1453305	1000083	669456	453222	783849
10:00	46.0	70	-24.0	-180643.2	-174816	-168989	48.52	210.23	48.52	221.61	1745109	1260356	904871	1564465	1085540	735882	478925	828583
11:00	48.5	70	-21.5	-161826.2	-156606	-151386	54.16	243.76	54.16	158.17	1680461	1213666	871350	1518634	1057060	719964	461574	798670
12:00	51.1	70	-18.9	-142256.52	-137667.6	-133079	56.64	258.72	58.96	81.11	1496950	1081131	776196	1354694	943463	643118	411231	711576
13:00	54.2	70	-15.8	-118923.44	-115087.2	-111251	55.86	253.98	56.74	119.13	1598002	1154113	828594	1479079	1039026	717343	440053	761736
14:00	56.4	70	-13.6	-102364.48	-99062.4	-95760	51.84	229.88	51.84	190.89	1728881	1248636	896457	1626516	1149574	800696	476943	825820
15:00	57.4	70	-12.6	-94837.68	-91778.4	-88719	44.75	188.25	44.75	244.08	1723276	1244588	893550	1628438	1152810	804831	475628	823607
16:00	57.2	70	-12.8	-96343.04	-93235.2	-90127	34.71	132.21	34.71	265.44	1545070	1115884	801147	1448727	1022648	711020	426078	737707
17:00	56.4	70	-13.6	-102364.48	-99062.4	-95760	21.29	66.21	21.29	227.04	1112939	803789	577079	1010574	704727	481319	305848	529255
18:00	55.0	70	-15.0	-112902	-109260	-105618	1.82	2.83	1.62	25.21	104473	75453	54171	-8429	-33807	-51447	25378	43018
19:00	53.7	70	-16.3	-122686.84	-118729.2	-114772	0.00	0.00	0.00	0.00	0	0	0	-122687	-118729	-114772	0	0
20:00	52.2	70	-17.8	-133977.04	-129655.2	-125333	0.00	0.00	0.00	0.00	0	0	0	-133977	-129655	-125333	0	0
21:00	50.5	60	-9.5	-71504.6	-69198	-66891	0.00	0.00	0.00	0.00	0	0	0	-71505	-69198	-66891	0	0
22:00	49.0	60	-11.0	-82794.8	-80124	-77453	0.00	0.00	0.00	0.00	0	0	0	-82795	-80124	-77453	0	0
23:00	47.7	60	-12.3	-92579.64	-89593.2	-74661	0.00	0.00	0.00	0.00	0	0	0	-92580	-89593	-74661	0	0
														13141832	8679506	5447523	4511929	7805462

April Fenestration Analysis

			CONDUCTION = $Q_{cond} = UA(\Delta t)$				SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	57.4	60	-2.6	-19569.68	-17044.56	-15782	0.00	0.00	0.00	0.00	0	0	0	-19570	-17045	-15782	0	0
1:00	55.6	60	-4.4	-33117.92	-28844.64	-26708	0.00	0.00	0.00	0.00	0	0	0	-33118	-28845	-26708	0	0
2:00	53.5	60	-6.5	-48924.2	-42611.4	-39455	0.00	0.00	0.00	0.00	0	0	0	-48924	-42611	-39455	0	0
3:00	51.8	60	-8.2	-61719.76	-53755.92	-49774	0.00	0.00	0.00	0.00	0	0	0	-61720	-53756	-49774	0	0
4:00	50.0	60	-10.0	-75268	-65556	-60700	0.00	0.00	0.00	0.00	0	0	0	-75268	-65556	-60700	0	0
5:00	49.3	60	-10.7	-80536.76	-70144.92	-64949	0.00	0.00	0.00	0.00	0	0	0	-80537	-70145	-64949	0	0
6:00	49.7	70	-20.3	-142936.36	-133078.68	-123221	20.37	6.64	6.36	82.82	380956	275135	197533	238020	142056	74312	95964	163708
7:00	51.0	70	-19.0	-133782.8	-124556.4	-115330	30.32	26.83	24.56	237.01	1055016	761956	547046	921234	637400	431716	283834	489518
8:00	53.2	70	-16.8	-118292.16	-110134.08	-101976	39.07	76.13	37.67	274.01	1412627	1020231	732473	1294335	910097	630497	384238	663838
9:00	56.0	70	-14.0	-98576.8	-91778.4	-84980	47.97	127.49	47.97	259.97	1597417	1153690	828290	1498840	1061912	743310	436929	755530
10:00	58.2	70	-11.8	-83086.16	-77356.08	-71626	55.68	169.42	55.68	215.13	1635754	1181378	848169	1552668	1104022	776543	448646	776125
11:00	60.3	70	-9.7	-68299.64	-63589.32	-58879	60.59	197.22	60.59	150.56	1543732	1114918	800454	1475432	1051328	741575	424104	733858
12:00	63.0	70	-7.0	-49288.4	-45889.2	-42490	62.49	208.21	65.53	75.15	1351421	976026	700737	1302132	930137	658247	371995	643886
13:00	65.7	70	-4.3	-30277.16	-28189.08	-26101	61.31	201.37	61.31	133.58	1505397	1087231	780576	1475120	1059042	754475	416078	720645
14:00	68.0	70	-2.0	-14082.4	-13111.2	-12140	57.09	177.32	57.09	201.45	1625231	1173778	842712	1611149	1160667	830572	450482	780576
15:00	69.3	70	-0.7	-4928.84	-4588.92	-4249	50.01	138.36	50.01	251.77	1619039	1169306	839502	1614110	1164717	835253	449393	778857
16:00	69.8	70	-0.2	-1408.24	-1311.12	-1214	41.41	88.65	40.31	274.27	1470883	1062305	762680	1469475	1060994	761466	408482	708009
17:00	69.0	70	-1.0	-7041.2	-6555.6	-6070	30.31	35.30	27.94	252.24	1145520	827320	593973	1138479	820764	587903	317714	550575
18:00	67.8	70	-2.2	-15490.64	-14422.32	-13354	29.71	11.97	11.33	137.10	624691	451166	323914	609200	436743	310560	172457	298640
19:00	66.3	70	-3.7	-26052.44	-24255.72	-22459	0.00	0.00	0.00	0.00	0	0	0	-26052	-24256	-22459	0	0
20:00	64.4	70	-5.6	-39430.72	-36711.36	-33992	0.00	0.00	0.00	0.00	0	0	0	-39431	-36711	-33992	0	0
21:00	62.6	60	2.6	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
22:00	60.5	60	0.5	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
23:00	59.0	60	-1.0	-7526.8	-6555.6	-6070	0.00	0.00	0.00	0.00	0	0	0	-7527	-6556	-6070	0	0
														15808048	11194399	7816540	4660316	8063765

May Fenestration Analysis

			CONDUCTION = $Q_{cond} = UA(\Delta t)$				SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	62.8	60	2.8	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
1:00	61.0	60	1.0	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
2:00	58.8	60	-1.2	-9032.16	-7866.72	-7284	0.00	0.00	0.00	0.00	0	0	0	-9032	-7867	-7284	0	0
3:00	56.8	60	-3.2	-24085.76	-20977.92	-19424	0.00	0.00	0.00	0.00	0	0	0	-24086	-20978	-19424	0	0
4:00	55.5	60	-4.5	-33870.6	-29500.2	-27315	0.00	0.00	0.00	0.00	0	0	0	-33871	-29500	-27315	0	0
5:00	55.4	60	-4.6	-34623.28	-30155.76	-27922	0.00	0.00	0.00	0.00	0	0	0	-34623	-30156	-27922	0	0
6:00	56.2	70	-13.8	-97168.56	-90467.28	-83766	59.40	15.66	15.66	162.38	824700	595617	427622	727532	505149	343856	222382	383675
7:00	57.9	70	-12.1	-85198.52	-79322.76	-73447	62.51	32.15	30.74	250.35	1234531	891606	640127	1149332	812283	566680	337049	582652
8:00	59.9	70	-10.1	-71116.12	-66211.56	-61307	45.59	50.60	42.59	270.73	1354375	978160	702269	1283259	911948	640962	371311	642297
9:00	62.0	70	-8.0	-56329.6	-52444.8	-48560	53.65	96.01	52.11	252.51	1500443	1083653	778008	1444114	1031209	729448	412905	714666
10:00	64.0	70	-6.0	-42247.2	-39333.6	-36420	59.26	133.35	59.26	208.17	1517143	1095714	786667	1474895	1056381	750247	418515	724649
11:00	65.9	70	-4.1	-28868.92	-26877.96	-24887	63.78	158.03	63.78	146.43	1421766	1026831	737212	1392897	999953	712325	392944	680572
12:00	68.0	70	-2.0	-14082.4	-13111.2	-12140	65.47	167.44	68.84	75.09	1237621	893837	641729	1223539	880726	629589	342812	593949
13:00	70.4	70	0.4	2816.48	2622.24	2428	64.24	160.62	64.24	135.42	1396573	1008636	724149	1399389	1011258	726577	388131	672812
14:00	72.5	70	2.5	17603	16389	15175	60.17	138.25	60.17	199.22	1509323	1090066	782612	1526926	1106455	797787	420470	729139
15:00	74.0	70	4.0	28164.8	26222.4	24280	54.77	102.70	53.43	246.90	1511669	1091761	783829	1539834	1117984	808109	421851	731726
16:00	74.9	70	4.9	34501.88	32122.44	29743	47.02	58.18	44.27	269.99	1387007	1001727	719189	1421508	1033849	748932	387659	672577
17:00	74.6	70	4.6	32389.52	30155.76	27922	59.90	34.53	32.82	257.04	1264139	912989	655479	1296528	943145	683401	353383	613127
18:00	73.6	70	3.6	25348.32	23600.16	21852	63.43	18.41	18.41	183.62	926245	668955	480275	951593	692555	502127	259038	449466
19:00	72.0	70	2.0	14082.4	13111.2	12140	2.27	0.36	0.36	4.66	24779	17896	12848	38861	31007	24988	7854	13873
20:00	70.2	70	0.2	1408.24	1311.12	1214	0.00	0.00	0.00	0.00	0	0	0	1408	1311	1214	97	194
21:00	68.1	60	8.1	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
22:00	66.0	60	6.0	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
23:00	64.5	60	4.5	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
														16770005	12046713	8584296	4736403	8205375

June Fenestration Analysis

			CONDUCTION = $Q_{cond} = UA(\Delta t)$				SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	72.6	78	-5.4	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
1:00	70.8	78	-7.2	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
2:00	68.7	78	-9.3	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
3:00	67.0	78	-11.0	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
4:00	65.8	78	-12.2	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
5:00	65.8	78	-12.2	0	0	0	1.33	0.19	0.19	2.27	12841	9274	6658	12841	9274	6658	3567	6183
6:00	66.7	70	-3.3	-23235.96	-21633.48	-20031	71.48	17.30	17.30	166.00	883867	638348	458301	860631	616715	438270	243916	422361
7:00	68.0	70	-2.0	-14082.4	-13111.2	-12140	76.68	32.64	31.76	244.95	1263862	912790	655336	1249780	899678	643196	350102	606584
8:00	69.9	70	-0.1	-704.12	-655.56	-607	57.79	46.06	43.31	264.98	1359137	981599	704738	1358433	980944	704131	377490	654302
9:00	71.8	70	1.8	12674.16	11800.08	10926	55.07	78.63	52.66	248.94	1437505	1038198	745373	1450179	1049998	756299	400181	693880
10:00	73.5	70	3.5	24644.2	22944.6	21245	60.96	114.69	59.75	207.69	1461009	1055173	757560	1485653	1078118	778805	407535	706848
11:00	75.0	70	5.0	35206	32778	30350	64.33	139.13	64.33	149.33	1372841	991496	711844	1408047	1024274	742194	383773	665854
12:00	76.9	70	6.9	48584.28	45233.64	41883	66.18	149.24	69.37	81.25	1202306	868332	623418	1250890	913565	665301	337324	585589
13:00	78.9	70	8.9	62666.68	58344.84	54023	65.21	143.97	65.21	128.44	1324861	956844	686965	1387528	1015189	740988	372339	646540
14:00	80.7	70	10.7	75340.84	70144.92	64949	61.49	123.87	61.49	190.67	1442076	1041499	747743	1517417	1111644	812692	405773	704725
15:00	82.2	70	12.2	85902.64	79978.32	74054	57.15	91.09	55.17	238.17	1457576	1052694	755780	1543479	1132672	829834	410807	713645
16:00	83.2	70	13.2	92943.84	86533.92	80124	50.30	49.94	46.51	263.18	1354848	978501	702514	1447792	1065035	782638	382757	665154
17:00	83.2	70	13.2	92943.84	86533.92	80124	71.98	37.09	35.67	256.16	1315644	950188	682186	1408588	1036721	762310	371867	646278
18:00	82.4	70	12.4	87310.88	81289.44	75268	78.04	22.33	22.33	200.05	1051100	759128	545015	1138411	840417	620283	297994	518128
19:00	81.0	70	11.0	77453.2	72111.6	66770	27.34	4.63	4.63	51.45	284413	205410	147474	361867	277521	214244	84345	147623
20:00	79.5	70	9.5	66891.4	62278.2	57665	0.00	0.00	0.00	0.00	0	0	0	66891	62278	57665	4613	9226
21:00	77.5	78	-0.5	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
22:00	75.5	78	-2.5	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
23:00	74.0	78	-4.0	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
														17948427	13114045	9555507	4834381	8392919

July Fenestration Analysis

				CONDUCTION = $Q_{cond} = UA(\Delta t)$			SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	78.7	78	0.7	5268.76	4588.92	4249	0.00	0.00	0.00	0.00	0	0	0	5269	4589	4249	680	1020
1:00	77.1	78	-0.9	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
2:00	75.2	78	-2.8	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
3:00	73.7	78	-4.3	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
4:00	72.4	78	-5.6	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
5:00	72.0	78	-6.0	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
6:00	72.7	70	2.7	19011.24	17700.12	16389	53.68	13.11	13.11	134.86	698585	504534	362229	717597	522234	378618	195363	338978
7:00	74.0	70	4.0	28164.8	26222.4	24280	65.77	30.00	28.91	236.28	1183749	854930	613796	1211914	881153	638076	330762	573838
8:00	75.8	70	5.8	40838.96	38022.48	35206	47.56	44.24	41.10	264.86	1314523	949378	681605	1355362	987400	716811	367962	638552
9:00	77.8	70	7.8	54921.36	51133.68	47346	52.84	86.19	50.91	252.70	1462143	1055993	758148	1517065	1107126	805494	409939	711570
10:00	79.5	70	9.5	66891.4	62278.2	57665	58.38	124.28	58.38	213.14	1498212	1082042	776850	1565103	1144320	834515	420783	730588
11:00	81.0	70	11.0	77453.2	72111.6	66770	63.27	150.62	63.27	155.12	1423113	1027804	737911	1500567	1099916	804681	400651	695886
12:00	82.9	70	12.9	90831.48	84567.24	78303	65.40	162.31	68.29	86.45	1256473	907453	651505	1347305	992020	729808	355285	617497
13:00	84.8	70	14.8	104209.76	97022.88	89836	64.64	158.14	65.78	123.20	1354286	978095	702222	1458495	1075118	792058	383377	666437
14:00	86.5	70	16.5	116179.8	108167.4	100155	61.05	138.54	61.05	187.26	1476118	1066085	765395	1592298	1174253	865550	418045	726748
15:00	88.0	70	18.0	126741.6	118000.8	109260	56.09	105.58	54.78	236.64	1495636	1080182	775515	1622378	1198183	884775	424195	737603
16:00	88.8	70	18.8	132374.56	123245.28	114116	48.78	63.14	46.07	263.14	1392058	1005375	721808	1524432	1128620	835924	395812	688509
17:00	88.7	70	18.7	131670.44	122589.72	113509	58.76	37.05	35.06	256.26	1274311	920336	660754	1405981	1042925	774263	363056	631719
18:00	87.8	70	17.8	125333.36	116689.68	108046	66.20	21.28	21.28	196.16	995817	719201	516350	1121151	835891	624396	285260	496755
19:00	86.7	70	16.7	117588.04	109478.52	101369	15.80	2.87	2.87	33.35	177753	128377	92168	295341	237856	193537	57485	101804
20:00	85.0	70	15.0	105618	98334	91050	0.00	0.00	0.00	0.00	0	0	0	105618	98334	91050	7284	14568
21:00	83.3	78	5.3	39892.04	34744.68	32171	0.00	0.00	0.00	0.00	0	0	0	39892	34745	32171	5147	7721
22:00	81.6	78	3.6	27096.48	23600.16	21852	0.00	0.00	0.00	0.00	0	0	0	27096	23600	21852	3496	5244
23:00	80.1	78	2.1	15806.28	13766.76	12747	0.00	0.00	0.00	0.00	0	0	0	15806	13767	12747	2040	3059
														18428671	13602049	10040575	4826621	8388096

August Fenestration Analysis

				CONDUCTION = $Q_{cond} = UA(\Delta t)$			SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	78.9	78	0.9	6774.12	5900.04	5463	0.00	0.00	0.00	0.00	0	0	0	6774	5900	5463	874	1311
1:00	77.4	78	-0.6	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
2:00	75.7	78	-2.3	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
3:00	74.0	78	-4.0	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
4:00	72.8	78	-5.2	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
5:00	72.0	78	-6.0	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
6:00	72.2	70	2.2	15490.64	14422.32	13354	17.26	5.49	5.30	64.28	302356	218368	156777	317847	232790	170131	85056	147715
7:00	73.3	70	3.3	23235.96	21633.48	20031	33.18	26.06	23.94	220.70	1004464	725446	520833	1027700	747080	540864	280620	486836
8:00	75.0	70	5.0	35206	32778	30350	39.04	69.53	37.36	263.63	1355104	978686	702646	1390310	1011464	732996	378846	657313
9:00	77.2	70	7.2	50696.64	47200.32	43704	47.81	119.61	47.81	254.23	1551255	1120351	804354	1601951	1167551	848058	434400	753893
10:00	79.3	70	9.3	65483.16	60967.08	56451	55.62	161.10	55.62	213.27	1601850	1156892	830589	1667334	1217859	887040	449475	780293
11:00	81.0	70	11.0	77453.2	72111.6	66770	60.66	189.14	60.66	152.11	1522751	1099765	789575	1600205	1171877	856345	428328	743860
12:00	83.1	70	13.1	92239.72	85878.36	79517	62.72	200.88	65.75	79.73	1344081	970725	696931	1436320	1056603	776448	379717	659873
13:00	85.5	70	15.5	109138.6	101611.8	94085	61.73	195.20	61.73	127.57	1467826	1060096	761095	1576964	1161708	855180	415256	721784
14:00	87.5	70	17.5	123221	114723	106225	57.72	172.65	57.72	193.64	1587928	1146837	823370	1711149	1261560	929595	449589	781554
15:00	88.8	70	18.8	132374.56	123245.28	114116	50.85	135.44	50.85	242.79	1584931	1144672	821816	1717306	1267918	935932	449388	781374
16:00	89.2	70	19.2	135191.04	125867.52	116544	42.52	87.64	41.32	264.86	1443080	1042224	748264	1578271	1168092	864808	410179	713463
17:00	88.7	70	18.7	131670.44	122589.72	113509	31.60	36.23	29.06	244.01	1128932	815340	585372	1260603	937930	698881	322673	561721
18:00	87.6	70	17.6	123925.12	115378.56	106832	31.25	13.36	12.65	139.02	644881	465747	334383	768806	581126	441215	187680	327591
19:00	86.4	70	16.4	115475.68	107511.84	99548	0.00	0.00	0.00	0.00	0	0	0	115476	107512	99548	7964	15928
20:00	84.9	70	14.9	104913.88	97678.44	90443	0.00	0.00	0.00	0.00	0	0	0	104914	97678	90443	7235	14471
21:00	83.2	78	5.2	39139.36	34089.12	31564	0.00	0.00	0.00	0.00	0	0	0	39139	34089	31564	5050	7575
22:00	81.5	78	3.5	26343.8	22944.6	21245	0.00	0.00	0.00	0.00	0	0	0	26344	22945	21245	3399	5099
23:00	80.2	78	2.2	16558.96	14422.32	13354	0.00	0.00	0.00	0.00	0	0	0	16559	14422	13354	2137	3205
														17963971	13266104	9799110	4697867	8164860

September Fenestration Analysis

				CONDUCTION = $Q_{cond} = UA(\Delta t)$			SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	66.4	60	6.4	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
1:00	65.3	60	5.3	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
2:00	64.0	60	4.0	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
3:00	62.8	60	2.8	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
4:00	61.7	60	1.7	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
5:00	60.9	60	0.9	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
6:00	60.7	70	-9.3	-65483.16	-60967.08	-56451	0.00	0.00	0.00	0.00	0	0	0	-65483	-60967	-56451	0	0
7:00	61.4	70	-8.6	-60554.32	-56378.16	-52202	16.92	44.22	16.22	179.68	851901	615262	441726	791346	558883	389524	232463	401822
8:00	62.9	70	-7.1	-49992.52	-46544.76	-43097	31.13	110.17	31.13	249.80	1397203	1009091	724476	1347211	962547	681379	384664	665832
9:00	65.0	70	-5.0	-35206	-32778	-30350	42.00	168.21	42.00	244.09	1639628	1184176	850177	1604422	1151398	819827	453024	784594
10:00	67.0	70	-3.0	-21123.6	-19666.8	-18210	49.85	213.24	49.85	201.08	1695238	1224338	879012	1674114	1204671	860802	469443	813312
11:00	68.7	70	-1.3	-9153.56	-8522.28	-7891	54.67	241.79	54.67	136.37	1604615	1158888	832022	1595461	1150366	824131	445095	771330
12:00	70.9	70	0.9	6337.08	5900.04	5463	56.32	251.69	59.72	60.57	1407009	1016173	729560	1413346	1022073	735023	391273	678323
13:00	73.0	70	3.0	21123.6	19666.8	18210	54.74	242.19	54.74	134.89	1601397	1156565	830354	1622521	1176231	848564	446289	773957
14:00	74.4	70	4.4	30981.28	28844.64	26708	49.98	214.01	49.98	199.92	1694744	1223981	878756	1725725	1252826	905464	472899	820261
15:00	74.9	70	4.9	34501.88	32122.44	29743	42.20	169.29	42.20	243.51	1642475	1186232	851654	1676977	1218355	881397	458623	795580
16:00	74.7	70	4.7	33093.64	30811.32	28529	31.39	111.47	31.39	250.23	1404602	1014435	728312	1437696	1045246	756841	392450	680855
17:00	73.9	70	3.9	27460.68	25566.84	23673	17.29	45.60	16.59	182.53	868351	627142	450256	895812	652709	473929	243102	421883
18:00	73.0	70	3.0	21123.6	19666.8	18210	0.00	0.00	0.00	0.00	0	0	0	21124	19667	18210	1457	2914
19:00	71.8	70	1.8	12674.16	11800.08	10926	0.00	0.00	0.00	0.00	0	0	0	12674	11800	10926	874	1748
20:00	70.7	70	0.7	4928.84	4588.92	4249	0.00	0.00	0.00	0.00	0	0	0	4929	4589	4249	340	680
21:00	69.5	60	9.5	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
22:00	68.3	60	8.3	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
23:00	67.4	60	7.4	0	0	0	0.00	0.00	0.00	0.00	0	0	0	0	0	0	0	0
														15757874	11370395	8153816	4391995	7613090

October Fenestration Analysis

				CONDUCTION = $Q_{cond} = UA(\Delta t)$			SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	55.5	60	-4.5	-33870.6	-32778	-31685	0.00	0.00	0.00	0.00	0	0	0	-33871	-32778	-31685	0	0
1:00	54.2	60	-5.8	-43655.44	-42247.2	-40839	0.00	0.00	0.00	0.00	0	0	0	-43655	-42247	-40839	0	0
2:00	52.9	60	-7.1	-53440.28	-51716.4	-49993	0.00	0.00	0.00	0.00	0	0	0	-53440	-51716	-49993	0	0
3:00	51.4	60	-8.6	-64730.48	-62642.4	-60554	0.00	0.00	0.00	0.00	0	0	0	-64730	-62642	-60554	0	0
4:00	50.1	60	-9.9	-74515.32	-72111.6	-69708	0.00	0.00	0.00	0.00	0	0	0	-74515	-72112	-69708	0	0
5:00	49.0	60	-11.0	-82794.8	-80124	-77453	0.00	0.00	0.00	0.00	0	0	0	-82795	-80124	-77453	0	0
6:00	48.5	70	-21.5	-161826.2	-156606	-151386	0.00	0.00	0.00	0.00	0	0	0	-161826	-156606	-151386	0	0
7:00	48.7	70	-21.3	-160320.84	-155149.2	-149978	7.26	37.28	7.26	95.31	487493	352078	252774	327172	196929	102796	130243	224375
8:00	50.4	70	-19.6	-147525.28	-142766.4	-138008	24.13	131.86	24.13	217.13	1314252	949182	681464	1166727	806416	543456	360311	623270
9:00	53.1	70	-16.9	-127202.92	-123099.6	-118996	35.36	199.55	35.36	222.06	1626120	1174420	843173	1498917	1051320	724177	447597	774740
10:00	56.3	70	-13.7	-103117.16	-99790.8	-96464	43.12	247.75	43.12	181.63	1700148	1227885	881558	1597031	1128094	785094	468937	811937
11:00	59.0	70	-11.0	-82794.8	-80124	-77453	47.65	276.34	47.65	117.71	1610467	1163115	835057	1527672	1082991	757604	444681	770068
12:00	62.5	70	-7.5	-56451	-54630	-52809	48.91	284.29	51.65	61.40	1466627	1059231	760473	1410176	1004601	707664	405575	702512
13:00	65.0	70	-5.0	-37634	-36420	-35206	46.85	271.26	46.85	134.65	1645051	1188092	852989	1607417	1151672	817783	455745	789633
14:00	66.2	70	-3.8	-28601.84	-27679.2	-26757	41.53	237.81	41.53	194.18	1699012	1227064	880969	1670410	1199385	854213	471025	816197
15:00	66.0	70	-4.0	-30107.2	-29136	-28165	32.98	184.98	32.98	226.31	1576957	1138913	817681	1546850	1109777	789517	437072	757333
16:00	65.3	70	-4.7	-35375.96	-34234.8	-33094	20.74	112.02	20.74	203.68	1182092	853733	612937	1146716	819498	579843	327218	566873
17:00	64.2	70	-5.8	-43655.44	-42247.2	-40839	2.15	10.78	2.15	31.26	153615	110944	79652	109960	68697	38813	41263	71146
18:00	63.0	70	-7.0	-52687.6	-50988	-49288	0.00	0.00	0.00	0.00	0	0	0	-52688	-50988	-49288	0	0
19:00	61.8	70	-8.2	-61719.76	-59728.8	-57738	0.00	0.00	0.00	0.00	0	0	0	-61720	-59729	-57738	0	0
20:00	60.5	70	-9.5	-71504.6	-69198	-66891	0.00	0.00	0.00	0.00	0	0	0	-71505	-69198	-66891	0	0
21:00	59.0	60	-1.0	-7526.8	-7284	-7041	0.00	0.00	0.00	0.00	0	0	0	-7527	-7284	-7041	0	0
22:00	57.7	60	-2.3	-17311.64	-16753.2	-16195	0.00	0.00	0.00	0.00	0	0	0	-17312	-16753	-16195	0	0
23:00	56.6	60	-3.4	-25591.12	-24765.6	-23940	0.00	0.00	0.00	0.00	0	0	0	-25591	-24766	-23940	0	0
														12857872	8892437	5998249	3989667	6908087

November Fenestration Analysis

				CONDUCTION = $Q_{cond} = UA(\Delta t)$			SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	48.4	60	-11.6	-87310.88	-84494.4	-81678	0.00	0.00	0.00	0.00	0	0	0	-87311	-84494	-81678	0	0
1:00	47.4	60	-12.6	-94837.68	-91778.4	-88719	0.00	0.00	0.00	0.00	0	0	0	-94838	-91778	-88719	0	0
2:00	46.1	60	-13.9	-104622.52	-101247.6	-97873	0.00	0.00	0.00	0.00	0	0	0	-104623	-101248	-97873	0	0
3:00	45.0	60	-15.0	-112902	-109260	-105618	0.00	0.00	0.00	0.00	0	0	0	-112902	-109260	-105618	0	0
4:00	44.0	60	-16.0	-120428.8	-116544	-112659	0.00	0.00	0.00	0.00	0	0	0	-120429	-116544	-112659	0	0
5:00	43.3	60	-16.7	-125697.56	-121642.8	-117588	0.00	0.00	0.00	0.00	0	0	0	-125698	-121643	-117588	0	0
6:00	43.0	70	-27.0	-203223.6	-196668	-190112	0.00	0.00	0.00	0.00	0	0	0	-203224	-196668	-190112	0	0
7:00	44.0	70	-26.0	-195696.8	-189384	-183071	0.00	0.00	0.00	0.00	0	0	0	-195697	-189384	-183071	0	0
8:00	46.5	70	-23.5	-176879.8	-171174	-165468	14.39	111.57	14.39	151.19	964382	696498	500050	787502	525324	334582	262178	452920
9:00	49.6	70	-20.4	-153546.72	-148593.6	-143640	26.99	202.26	26.99	191.31	1478176	1067572	766462	1324630	918978	622821	405651	701808
10:00	52.5	70	-17.5	-131719	-127470	-123221	35.13	258.61	35.13	163.57	1623783	1172732	841962	1492064	1045262	718741	446802	773324
11:00	56.0	70	-14.0	-105375.2	-101976	-98577	39.81	290.64	39.81	106.85	1570418	1134191	814291	1465043	1032215	715714	432828	749329
12:00	58.0	70	-12.0	-90321.6	-87408	-84494	41.17	299.85	43.82	50.92	1432290	1034431	742669	1341968	947023	658174	394945	683794
13:00	58.4	70	-11.6	-87310.88	-84494.4	-81678	39.18	286.34	39.18	118.96	1592551	1150176	825767	1505240	1065681	744089	439559	761151
14:00	58.0	70	-12.0	-90321.6	-87408	-84494	33.86	249.91	33.86	171.71	1614092	1165733	836937	1523771	1078325	752442	445445	771328
15:00	57.3	70	-12.7	-95590.36	-92506.8	-89423	25.02	188.37	25.02	190.99	1418652	1024582	735597	1323062	932075	646174	390986	676888
16:00	56.4	70	-13.6	-102364.48	-99062.4	-95760	11.20	87.66	11.20	127.14	784846	566833	406957	682482	467771	311197	214711	371285
17:00	55.4	70	-14.6	-109891.28	-106346.4	-102802	0.00	0.00	0.00	0.00	0	0	0	-109891	-106346	-102802	0	0
18:00	54.3	70	-15.7	-118170.76	-114358.8	-110547	0.00	0.00	0.00	0.00	0	0	0	-118171	-114359	-110547	0	0
19:00	53.3	70	-16.7	-125697.56	-121642.8	-117588	0.00	0.00	0.00	0.00	0	0	0	-125698	-121643	-117588	0	0
20:00	52.2	70	-17.8	-133977.04	-129655.2	-125333	0.00	0.00	0.00	0.00	0	0	0	-133977	-129655	-125333	0	0
21:00	51.1	60	-8.9	-66988.52	-64827.6	-62667	0.00	0.00	0.00	0.00	0	0	0	-66989	-64828	-62667	0	0
22:00	50.2	60	-9.8	-73762.64	-71383.2	-69004	0.00	0.00	0.00	0.00	0	0	0	-73763	-71383	-69004	0	0
23:00	49.3	60	-10.7	-80536.76	-77938.8	-75341	0.00	0.00	0.00	0.00	0	0	0	-80537	-77939	-75341	0	0
														9692017	6315484	3863335	3433105	5941826

December Fenestration Analysis

				CONDUCTION = $Q_{cond} = UA(\Delta t)$			SOLAR RADIATION = $Q_{sol} = SHGC(A)(E_t)$							TOTAL ENERGY TRANSFER			SAVINGS (Cooling Only)	
time	T_o	T_i	ΔT	VE 1-85	VRE 1-67	VNE 1-63	$E_{t,N}$	$E_{t,S}$	$E_{t,E}$	$E_{t,W}$	VE 1-85	VRE 1-67	VNE 1-63	VE 1-85	VRE 1-67	VNE 1-63	VRE 1-67	VNE 1-63
0:00	41.9	60	-18.1	-136235.08	-131840.4	-127446	0.00	0.00	0.00	0.00	0	0	0	-136235	-131840	-127446	0	0
1:00	40.8	60	-19.2	-144514.56	-139852.8	-135191	0.00	0.00	0.00	0.00	0	0	0	-144515	-139853	-135191	0	0
2:00	39.5	60	-20.5	-154299.4	-149322	-144345	0.00	0.00	0.00	0.00	0	0	0	-154299	-149322	-144345	0	0
3:00	38.3	60	-21.7	-163331.56	-158062.8	-152794	0.00	0.00	0.00	0.00	0	0	0	-163332	-158063	-152794	0	0
4:00	37.0	60	-23.0	-173116.4	-167532	-161948	0.00	0.00	0.00	0.00	0	0	0	-173116	-167532	-161948	0	0
5:00	36.1	60	-23.9	-179890.52	-174087.6	-168285	0.00	0.00	0.00	0.00	0	0	0	-179891	-174088	-168285	0	0
6:00	35.7	70	-34.3	-258169.24	-249841.2	-241513	0.00	0.00	0.00	0.00	0	0	0	-258169	-249841	-241513	0	0
7:00	36.0	70	-34.0	-255911.2	-247656	-239401	0.00	0.00	0.00	0.00	0	0	0	-255911	-247656	-239401	0	0
8:00	38.1	70	-31.9	-240104.92	-232359.6	-224614	5.94	54.53	5.94	73.31	462325	333902	239724	222220	101542	15110	120678	207110
9:00	42.0	70	-28.0	-210750.4	-203952	-197154	21.00	179.19	21.00	170.53	1294116	934640	671023	1083366	730688	473870	352678	609496
10:00	45.5	70	-24.5	-184406.6	-178458	-172509	30.18	248.04	30.18	160.96	1548256	1118185	802800	1363850	939727	630290	424123	733560
11:00	50.0	70	-20.0	-150536	-145680	-140824	35.62	287.24	35.62	112.86	1552060	1120932	804772	1401524	975252	663948	426272	737576
12:00	52.4	70	-17.6	-132471.68	-128198.4	-123925	37.67	301.77	40.18	48.00	1405679	1015213	728871	1273207	887014	604946	386193	668262
13:00	52.8	70	-17.2	-129460.96	-125284.8	-121109	36.35	292.44	36.35	99.68	1529972	1104980	793319	1400511	979695	672210	420816	728301
14:00	52.4	70	-17.6	-132471.68	-128198.4	-123925	31.66	258.78	31.66	152.77	1565861	1130899	811928	1433389	1002701	688003	430688	745386
15:00	51.5	70	-18.5	-139245.8	-134754	-130262	23.36	197.35	23.36	173.70	1379777	996506	715440	1240531	861752	585178	378780	655353
16:00	50.6	70	-19.4	-146019.92	-141309.6	-136599	9.95	89.46	9.95	111.63	730946	527906	379009	584926	386596	242410	198330	342516
17:00	49.5	70	-20.5	-154299.4	-149322	-144345	0.00	0.00	0.00	0.00	0	0	0	-154299	-149322	-144345	0	0
18:00	48.3	70	-21.7	-163331.56	-158062.8	-152794	0.00	0.00	0.00	0.00	0	0	0	-163332	-158063	-152794	0	0
19:00	47.2	70	-22.8	-171611.04	-166075.2	-160539	0.00	0.00	0.00	0.00	0	0	0	-171611	-166075	-160539	0	0
20:00	46.0	70	-24.0	-180643.2	-174816	-168989	0.00	0.00	0.00	0.00	0	0	0	-180643	-174816	-168989	0	0
21:00	44.9	60	-15.1	-113654.68	-109988.4	-106322	0.00	0.00	0.00	0.00	0	0	0	-113655	-109988	-106322	0	0
22:00	43.8	60	-16.2	-121934.16	-118000.8	-114067	0.00	0.00	0.00	0.00	0	0	0	-121934	-118001	-114067	0	0
23:00	42.8	60	-17.2	-129460.96	-125284.8	-121109	0.00	0.00	0.00	0.00	0	0	0	-129461	-125285	-121109	0	0
														7503122	4445222	2236877	3138558	5427561

References

2005 AHRAE Handbook of Fundamentals. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. Atlanta, GA. 2005.

Concrete Reinforcing Steel Institute Design Handbook. Concrete Reinfocing Steel Institute, 2002.

Green Roof Feasibility Review. Paladino Green Building Strategies, Seattle, WA. Mar. 2004.

http://www.greenroofs.org/

http://www.greenspec.co.uk/html/durability/rooflights.html/

Hoff, J. Equivalent Uniform Annual Cost: A New Approach to Roof Life Cycle Analysis. *Interface*. Jan. 2007.

Howell, R. and Sauer Jr., H. Environmental Control Principles. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA. 1985.

LEED Green Building Rating System For Core & Shell Development, Version 2.0. United States Green Building Council. Jul. 2006.

Ling, M. Thermal Analysis of Building Sites. AE 202, Class Notes. Climatology Practicum.

http://www.mcquay.com/

http://www.mngreenroofs.org/benefits/

Multnomah County Green Roof , Case Study. Dec. 2004.

Peck, S & Kuhn, M. Design Guidelines for Green Roofs. Ontario Association of Architects.

Sauer Jr., H; Howell, R.; Coad, W. Principles of Heating, Ventilating, and Air Conditioning. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA. 2001.

Sika Sarnafil Green Roof Design Guide. Sika Sarnafil, 2008.

http://www.sikasarnafilus.com/

Trost, J. Heating, Ventilating, and Air Conditioning. *Efficient Building Design Series*, Vol. 2. Prentice Hall, Upper Saddle River, NJ. 1999.

http://www.usgbc.org/

Vedavarz, A.; Kumar, S.; Hussain, M. HVAC: Handbook of Heating, Ventilation and Air Conditioning for Design and Implementation. Industrial Press, NY, NY. 2007.

Viracon Product Manual. *Architectural Glass: Specs & Tech*. Viracon. Owatonna, MN. 2007.

http://www.viracon.com/

Washington, District of Columbia Rise and Set for the Sun for 2008. US Naval Observatory, Astronomical Application Department. Washington, DC. <http://aa.usno.navy.mil/>.

Wasington Reagan Airport: Annual Climatalogical Summary (2006). US Department of Commerce, National Oceanic & Atmospheric Administration. National Climatic Data Center. Asheville, NC. 2006. <http://cdo.ncdc.noaa.gov/>.

Whittemore, G. Waterproofing Design Options for Green Roofs. *Construction, The Specifier*. Apr. 2007.