FINAL REPORT

Demonstration Program for Low-Cost, High-Energy-Saving Dynamic Windows

ESTCP Project EW-201252

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14. ABSTRACT

The objective of this project is to demonstrate the energy savings and life-cycle cost benefits of an innovative new windows technology called "dynamic windows". The project showed that, compared to upgrading with state-of-the-art low-e windows, dynamic windows installed in a standard Department of Defense (DoD) building at Marine Corps Air Station Miramar, California, delivered: (1) twice the HVAC energy savings; (2) twice the reduction in whole-building peak-load; (3) 280% greater life-cycle cost savings; and (4) significantly improved occupant comfort by eliminating glare and providing better views to the outdoors by eliminating blinds or shades. Demonstrating the performance of dynamic windows in a full-scale DoD operating environment also provides the cost and performance data needed to validate the technology, educate energy managers about its potential, and give building designers the confidence needed to design new construction and major renovations using dynamic windows.

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Table of Contents

1.0 EXECUTIVE SUMMARY 1
2.0 INTRODUCTION 4
2.1. Objective of the Demonstration 4
2.2. Regulatory Drivers 5
3.0 TECHNOLOGY DESCRIPTION 6
3.1. Technology Overview 6
3.2. Technology Development 9
3.3. Advantages and Limitations of the Technology 9
4.0 PERFORMANCE OBJECTIVES 12
4.1. "Table 2" Summary of Performance Objectives 12
4.2. Performance Objective Descriptions 13
5.0 FACILITY/SITE DESCRIPTION 16
5.1. Facility/Site Location and Operations 16
5.2. Facility/Site Condition 16
5.3. Site-Related Permits and Regulations 20
6.0 TEST DESIGN 22
6.1. Fundamental Problem: 22
6.2. Demonstration Question: 22
6.3. Test Design 22
6.4. Baseline Characterization 24
6.5. Windows design and installation: 29
6.6. Operational Testing and Sampling Protocols 32
6.7. Sampling Results 33
7.0 PERFORMANCE ASSESSMENT 37
7.1. Total Building Energy Impact: 37
7.2. HVAC Energy and Peak Load impact: 38
7.3. Lighting 40
7.4. Lifecycle GHG Emissions: 40
7.5. Glare/Occupant Comfort: 40
8.0 COST ASSESSMENT 42
8.1. Assumptions for cost projections 42
8.2. Cost Analysis: 43
8.3. Cost Analysis and Comparison 43
9.0 IMPACT ACROSS ALL DOD BUILDING STOCK 47
10.0 IMPLEMENTATION ISSUES AND LESSONS LEARNED 50
10.1. Procurement and Installation 50
10.2. Structural Load 50
10.3. Window Operability 50
10.4. Occupant Training 51
10.5. Building Automation 51
11.0 REFERENCES 53
12.0 APPENDIX A: Points of Contact 54
13.0 APPENDIX B: Monitoring Plan 55
14.0 APPENDIX C: Occupant Info and Educational Information 66
15.0 APPENDIX D: Occupant Intelligent Control Overview Presentation: 70
16.0 APPENDIX E: Simulation and Field Evaluation 77
17.0 APPENDIX F: Occupant Feedback – Monitoring, Reporting 85
18.0 APPENDIX G: Lighting Monitoring 107
19.0 APPENDIX H: Energy Model Details: 110
20.0 APPENDIX I: Technical Performance Data 118
21.0 APPENDIX J: Anti-Terrorism Standards Certification 121

List of Tables

Table 1: View Dynamic IGU performance characteristics…….…….. 7
Table 2: Summary of Performance Objectives…...……..……...…. 12
Table 3: Specifications for existing HVAC units for Building 6311…….....18
Table 4: Baseline building window details……...…… 27
Table 5: Total building energy by component (baseline, low-e glass, and dynamic)…….. 36
Table 6: Cooling capacity and flow-rate for building (baseline, low-e and dynamic)…..... 38
Table 7: Greenhouse gas emission reduction from low-e and dynamic windows…… 39
Table 8: First costs and lifetime costs of Dynamic vs Low-e w……...…43
Table 9: Year 1 CapEx and OpEx (low-e vs dynamic windows)……..44
Table 10: NIST BLCCA cost analysis and 30-year Savings to Investment is……...45
Table 11: Annual savings with dynamic windows across US climate zones……48
Table 12: View Demonstration Points of Contact……..…...53

List of Figures

Figure 1: Cutaway view of an electrochromic window……... 6
Figure 2: Electrochromic window configuration and optical characteristics……...7
Figure 3: Location of MCAS Miramar base on a US map……. 16
Figure 4: Photo of west facing façade of Building 6311, before this project…….... 17
Figure 5: Floor plans for building 6311…….. 17
Figure 6: Original Windows and Blinds…….. 18
Figure 7: Monitoring hardware…….…….. 24
Figure 8: Data collection and storage system components……..... 24
Figure 9: Lighting Monitoring System…… 25
Figure 10: Energy Model (3D view and building elevations using Open Studio)…….. 26
Figure 11: Map of HVAC Zones in building…….. 26
Figure 12: Modeling results vs historic and baseline data……..... 27
Figure 13: Dynamic windows installation photos…….. 28
Figure 14: Building 6311 before and after dynamic windows installation…… 28
Figure 15: View in-line dynamic window controllers……..... 29
Figure 16: View network control box. …… 29
Figure 17: Dynamic window system and controls schematic …… 31
Figure 18: Daily energy consumption by HVAC Zone (before and after retrofit)…….. 32
Figure 19: Hourly lighting energy with and without dynamic windows……..... 33
Figure 20: Glare measurements with and without dynamic windows……..... 34
Figure 21: Average energy savings impact with low-e glass and with dynamic glass..... 37
Figure 22: Impact of windows on total building energy (baseline, low-e and dynamic).....37
Figure 23: HVAC load from per façade with and without dynamic windows…….38
Figure 24: Lighting energy (low-e vs dynamic)……39
Figure 25: Occupant satisfaction before and after the installation of dynamic windows….40

List of Acronyms

ASHRAE: American Society of Heating, Refrigerating and Air Conditioning Engineers
ASTM: American Society for Testing and Materials
AT/FP: Anti-Terrorism/Force Protection
BTU: British thermal unit
CRADA: Collaborative Research and Development Agreement
DC: direct current
DBOM: Design/build/operate/maintain
DoE: U.S. Department of Energy
ECIP: Energy Conservation Investment Program
EEM Suite: Enterprise Energy Management Suite
ERBSIC: Electricity, Resources, and Building Systems Integration Center of NREL
ESCOs: Energy service companies
ESPC: Energy Savings Performance Contracts
ESTCP: Environmental Security Technology Certification Program
FARs: Federal Acquisition Regulations
FEMP: Federal Energy Management Program
GHG: Greenhouse gases
GSA: General Services Administration
HVAC: Heating, ventilation, air-conditioning
IGU: Insulated glass unit
ISO: International Organization for Standardization
LBNL: Lawrence Berkeley National Laboratory
Low-e: low emissivity
M&V: Measurement and verifications
MCAS: Marine Corps Air Station
MCMWTC: Marine Corps Mountain Warfare Training Center
MELs: Miscellaneous equipment loads
MEP: Mechanical, Electrical, Plumbing
MILCON: Military construction
NASA: National Aeronautics and Space Administration
NREL: National Renewable Energy Laboratory
PO: Performance objectives
PV: Photovoltaic
PVB: Polyvinyl butyral
PVD: Physical vapor deposition
ROICC: Resident Officer In Charge of Construction
SHGC: Solar heat gain coefficient
S/RM: Sustainment, Restoration, and Modernization program
Sqft: square feet
TMY: Typical meteorological year
V: volts

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We would like to acknowledge the fantastic team at MCAS Miramar for their support and enthusiasm in this project. We would like to particularly thank Mick Wasco for helping make sure everything went so smoothly. Additional thanks go to the experienced and professional subcontractors that contributed to the successful completion of this project. They created a safe, clean environment for both the project team and the building occupants that continued to work on site throughout all phases of the project.

A final thanks goes to the ESTCP program and their vision of bringing forth technologies that will provide both energy security and a more sustainable future to our military infrastructure.

1.0 EXECUTIVE SUMMARY

Energy Problem:

Inefficient windows in buildings represent one of the biggest energy problems in the military today. Facilities consume 30% of all DOD energy demand. This massive energy footprint costs taxpayers billions of dollars each year and impacts DOD mission assurance by straining fragile public electricity grids. As such, it is no surprise that the DOD's #1 High Priority Performance Goal for 2011 was to "Reduce average building energy intensity." [i]

In the United States, over 50% of building energy is used for cooling, heating and lighting, all of which are directly impacted by windows. According to Lux Research, the thermal envelope impacts about 56% of total commercial energy consumption.[ii] Windows are considered to be the "Achilles Heel" of the building envelope. They allow unwanted solar heat to enter during the summer via radiation and conduction, increasing cooling energy requirements and peak loads. They also allow internal heat to escape during the winter increasing season heating. Beyond negative energy impacts, current windows allow glare to reduce occupant comfort, allow for the over-use of window blinds, and the over-use of artificial lighting energy.

Impact of this Problem on DOD:

A recent study concluded that two-thirds of the current 345,000 DOD buildings will be beyond their usable life within the next 15 years.[iii,iv] Under Executive Order 13514, the DOD must improve building efficiency by 30% for all new building construction and 20% for all existing building major renovations. Since the vast majority of DOD facilities' electricity comes from commercial utility companies and grid infrastructure, energy security is directly related to the peak-load for the facility.

Energy consumption by DOD impacts global operations by demanding enormous financial resources, constraining freedom of action and constraining self-sufficiency. In deployed environments, energy consumption puts many lives at risk in associated logistics support operations. As such, improving windows efficiency with significantly higher efficiency than today's state-of-the-art will not only reduce energy costs in order to refresh DOD's aging building-stock and allow DOD to meet the mandates of Executive Order 13514 in the coming decade, but it will also save lives.

Technology Opportunity:

This ESTCP project demonstrated the benefits for DOD building energy efficiency with dynamic windows, a new type of advanced "Smart Window" product. These windows can automatically tint and untint throughout the day to minimize solar heat-gain in the summer, maximize passive heating in the winter and maximize the use of natural daylighting throughout the year. If broadly adopted, View's dynamic windows technology could reduce global DOD energy consumption

from buildings by 15% and greenhouse gas (GHG) emissions by 24%, representing an annual savings of ~$680M. At the same time, replacing existing single pane windows with dynamic windows can reduce total facilities peak load by up to 25% , reducing strain on local electrical grid infrastructure, further improving energy security. Overall, the dynamic window technology addresses two of DOD's three key installation energy goals, to: 1) reduce energy usage/intensity and 2) improve energy security.

A Significant Capital Avoidance Opportunity:

In addition to energy savings, one of the major economic benefits of dynamic windows is the possible capital-savings and maintenance-savings from down-sizing HVAC systems that is enabled by the reduced heating and cooling peak-load with installed dynamic windows. The full-scale field data generated in this demonstration project and subsequent calibrated model allowed the team to quantify and validate this reduction in HVAC capacity, enabling the building designers to down-size future HVAC systems without risk. Our host site at MCAS Miramar is due to replace their HVAC system, and will specify an appropriately down-sized system. Since the average lifetime of these roof-top HVAC systems is 10-15 years, we expect this savings to be recurring (2-3x during the lifetime of the windows).

Similarly since dynamic windows allow for more natural daylighting than previously possible, future lighting systems will be able to take the advantage of dynamic windows via reduced lighting intensity and improved automated diming. The data generated in this demonstration project includes detailed studies of interior lighting conditions, and will enable accurate design and optimization of high efficiency lighting systems in the future.

Since HVAC, lighting and windows are key components of virtually all new construction and major renovations, the field data from this project will minimize the barrier to designing dynamic windows into future projects.

Data and guidance from this demonstration will be made broadly available to the DOD community through a federal microsite established on the View website. This site will include key excerpts from the report (as well as the full report), interviews, modeled data and access to key modeling tools. The site will also include a 1-hour video overview of the technology, hosted by View's engineering team, to further educate DOD energy managers and federal employees. In addition, View will publish peer reviewed papers on this case study, including the "Best 4" report, which will be published next year, to create broader awareness within the E&M and architectural community. Finally, as part of this ESTCP project, NREL developed new modeling modules for EnergyPlus, which are now scheduled to be included in the next version of EnergyPlus (release planned for later this year). This will provide accurate modeling capabilities for all future DOD building construction and renovation projects.

Scope of the Demonstration:

The purpose of this demonstration project was to demonstrate the energy, maintenance and capital savings enabled by View dynamic windows by performing a whole-building retrofit at Marine Corps Air Station (MCAS) Miramar. The total project extended over a period of 23 months. During this time, the team developed a detailed energy-model for our demonstration site, with and without dynamic windows. The team then installed monitoring equipment in our demonstration site and performed baseline energy measurements and occupant surveys for a period of 5 months. This data was then used to calibrate our baseline energy models and extrapolate energy consumption back over the past 3 years. That extrapolated energy model was verified against measured building energy consumption over that same 3 year time period from utility bills. The team then replaced the windows at the demonstration site with View dynamic windows while the building remained occupied and operational. The installation took 1 month and was followed by 5 months of energy and occupant monitoring. These results were used to further refine the energy models and then the modeled results were annualized to determine the total annual impact of dynamic windows. From this data we were able to quantify total lifecycle cost, energy savings and GHG reductions relative to upgrading to state-of-the-art low-e windows at the host site. These models were then used to extrapolate the impact of this new windows technology across the entire existing DOD building stock.

Demonstration Results:

The project demonstrated a reduction in HVAC energy consumption of 29% compared to the existing windows baseline, corresponding to 2.2x greater energy savings than if we had upgraded to state-of-the-art low-e windows. Lighting energy was reduced by 62%, corresponding to 2.4x enhanced savings over upgrading with low-e windows. Total building energy savings was 28%, a 2.4x enhancement over upgrading with low-e windows. Economic assessment of this project estimates a payback of upgrading to View dynamic windows over state-of-the-art low-e windows of less than 3 years and a lifetime savings-to-investment ratio of 4.3. For further details on the performance outcomes of this project please see Appendix I.

Overall, the project was completed on time and on budget. All performance objectives were met or exceeded, and the host site has been enthusiastic and pleased with the impact on comfort in their building. This project has also created awareness and, most importantly, confidence with installing dynamic glass across many DOD installations. Several other bases have visited the host site to tour and learn more about dynamic windows. Several follow-on installations are currently underway.

2.0 INTRODUCTION

2.1. OBJECTIVE OF THE DEMONSTRATION

The goal of this project was to validate the performance and lifecycle cost benefits of dynamic windows in an operational environment, generating the data and insights needed to create awareness and acceptance of the technology. The project was intended to facilitate future technology transfer across all DOD building-stock, while providing a direct benefit to our host base in terms of reduced energy consumption, reduced lifecycle cost, and improved occupant comfort. We accomplished these goals by pursuing the following objectives:

1. Installed dynamic windows in a demonstration site on a DOD installation
2. Monitored energy consumption, peak-load consumption and occupant comfort before and after installation
3. Developed detailed energy models for the site and calibrated them against baseline and experimental energy results
4. Used the calibrated models and historic weather data to predict the lifecycle energy savings (and resulting GHG and energy cost savings) at the site
5. Used calibrated models to estimate reductions in peak-load energy use and improvement in occupant comfort to propose the ability to down-size the HVAC capacity and eliminate blinds/shades in future new construction and major renovation projects
6. Quantified improvements in occupant comfort and satisfaction
7. Quantified the total predicted lifecycle cost-, energy- and GHG- savings relative to state-of-the-art low-e windows at the site and across the entire DOD building stock
8. Developed guidance documents and tools to assist with technology transfer across the DOD

To accelerate the transfer of dynamic windows technology to the DOD, the project team also engaged with major DOD Energy Service Companies, including Johnson Controls (JCI) and Noresco, to enable and accelerate future installation through Energy Savings Performance Contracts (ESPCs). Our collaboration with these companies in concert with this demonstration project will allow Federal agencies to implement dynamic windows without upfront capital costs and without the need for special Congressional appropriations.

2.2. REGULATORY DRIVERS

Two important federal mandates are addressed by this technology:

Executive Order 13514:

Federal Leadership in Environmental, Energy and Economic Performance:[v] This order requires aggressive improvements in energy efficiency across all Federal agencies by 2020. The Executive Order requires Federal agencies to increase energy efficiency, reduce fleet petroleum consumption, conserve water, reduce waste, support sustainable communities, and leverage Federal purchasing power to promote environmentally-responsible products and technologies. A top goal of the Executive Order is that of "reducing energy intensity in federal buildings."

Sustainability Rule for Procurement[vi] under the Federal Acquisition Regulations (FARs):

The DOD, the GSA, and NASA recently issued a joint interim rule that requires all new construction to reduce energy use by 30% compared to the existing standard. For major renovations, buildings must reduce their energy use by 20% below their 2003 pre-renovation baseline. The new rule also requires increased use of natural daylight in all new and renovated buildings. Dynamic windows are a perfect fit for enabling DOD to meet these aggressive goals.

3.0 TECHNOLOGY DESCRIPTION

3.1. TECHNOLOGY OVERVIEW

Technology Description:

View's dynamic windows technology is highly innovative and represents a significant advancement over the current state-of-the-art in energy-efficient windows. The product operates by the electrochromic effect, reversibly changing color when a charge is applied. While electrochromic glass is not new, View's innovative approach results in a product that consumes 2x less energy and costs 4x less than the electrochromic glass available during the initiation of the demonstration project. These benefits make it a viable energy-efficiency technology for military installations. Figure 1 shows the windows in the "Tint 1 - Clear" and "Tint 4 - Dark" states.

The electrochromic device is formed via a stack of five (5) thin coatings applied to the inner surface of the outer pane of glass in an insulated glass unit (IGU). To darken the window, low voltage direct current (<5V) is applied, driving ions from one coating to the next, causing the stack to change tint and also to absorb light and heat. Reversing the voltage reverses the flow of ions. This also reverses the effect and transitions the stack back to a clear state.

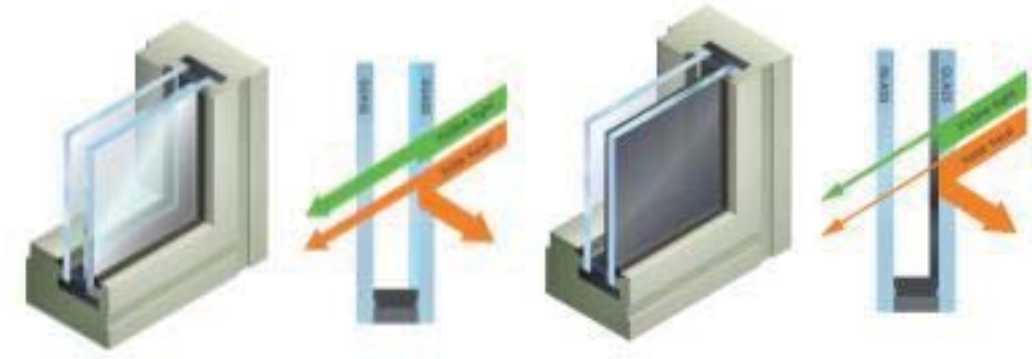


Figure 1*: Cutaway view of an electrochromic window in the "Tint 1 - Clear" (left) and "Tint 4 - Dark" (right) states.*

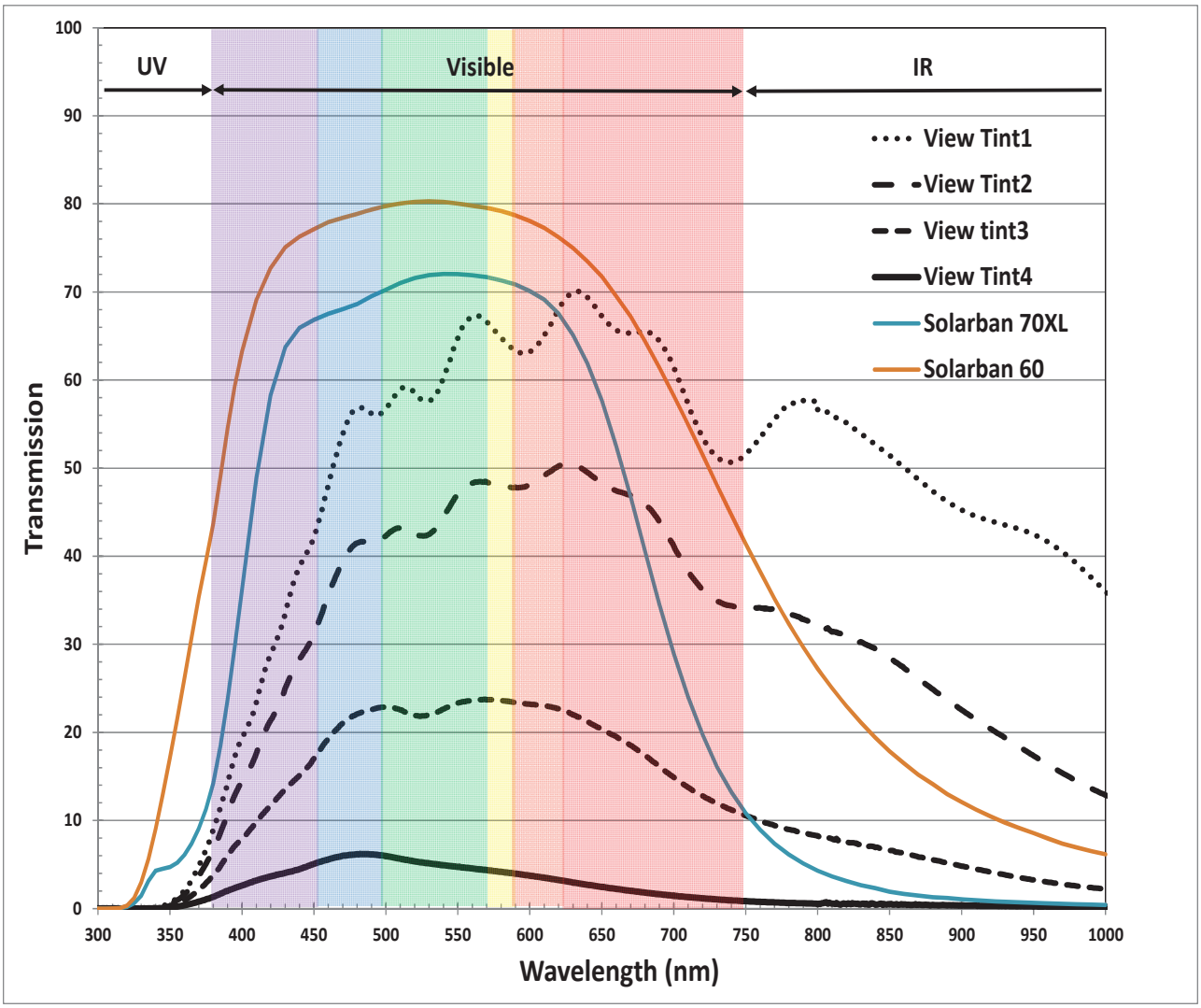


***Figure 2**: Electrochromic window configuration and optical characteristics plotted against low-e glass examples*

By controlling the voltage, a dynamic glass glazing assembly can vary its Solar Heat Gain Coefficient (SHGC) from 0.46 to 0.09, and its visible light transmission from 58% transmission to just 3% total light transmission (Figure 2). In addition, intermediate tint states can be selected to optimize performance of the windows throughout the day. All key performance parameters can be found in Table 1.

Tint Level	Transmittance (%)			Reflectance (%)			U-value	SHGC
	Visible	UV	Solar	Visible Out	Visible In	Solar Out		
Tint 1	58	3	37	18	20	18	0.29	0.46
Tint 2	40	2	21	12	19	12	0.29	0.26
Tint 3	20	1	8	8	17	11	0.29	0.16
Tint 4	3	0	1	7	17	11	0.29	0.09

***Table 1**: View dynamic window performance characteristics (including intermediate states).*

Total energy consumption by these windows is negligible (1800 sqft of glass uses less power than a 60W light bulb). All energy calculations in this proposal include this small energy consumption.

Technology Development To-Date:

At the start of this project, View's dynamic windows were a fully-developed pre-commercial technology. The maturity of this technology was well-aligned with ESTCP. All laboratory and proof-of-concept work was complete[vii]. Extensive durability testing and performance data from our windows had been collected under full operating conditions by NREL, validating their capabilities to a 50+ year rated lifespan. Full-size prototype windows were already being produced at View's full-volume manufacturing plant in Mississippi[viii]. This ESTCP project was the first demonstration of this technology at a DOD facility.

During the term of this ESTCP project, View has made tremendous progress on the commercial sale of this product, and now has more than 70 installations, with 50 more currently underway. This has not only provided additional validation of the results and reliability established under this ESTCP project, but is also providing significant economies-of-scale to drive-down costs. Both benefits can be leveraged by DOD for future installations.

Applications of the Technology:

This technology is applicable to virtually all of the DOD building stock, including both new construction and retrofits to the hundreds of thousands of buildings that currently feature aging, inefficient windows. This technology is particularly high-value in new construction, where the enabled capital avoidance can often completely offset the increased cost of the dynamic windows, generating all of the benefits demonstrated here at no net additional cost. Retrofit scenarios can also be compelling when the installation of dynamic glass is scheduled to coincide with an HVAC replacement. This technology has already generated strong enthusiasm among the DOD installation energy managers who were approached during this project, and who visited our host-site to see the technology in action. Multiple new DOD projects are currently in the planning stage.

Impact on LEED and ASHRAE Requirements:

Use of dynamic glass is explicitly recognized and accepted by the current ASHRAE Standards. ASHRAE 90.1 – 2013 describes the specific treatment of dynamic glass in determining project compliance either by the prescriptive or performance paths. With technology/product acceptance ensured, dynamic glass is a preferred project component based upon its energy performance and code required savings objectives. When used in a new construction or renovation project, it can have a beneficial energy impact of 5-20% total building energy savings. That incremental savings can be crucial to making a project compliant with the current standard.

Beyond minimum code requirements, the use of dynamic glass can often offset other capital-intensive building elements required for high performance or LEED certified design, as required for federal new construction and deep renovations. As an example, the promotion of ample daylighting (75% of floor area) drives larger window area and often requires the use of expensive external shades, louvers or light shelves. Or, in the case of hospital settings, operable shades are often encapsulated within the insulated glass unit to minimize the chance of infection prone materials. Dynamic glass eliminates these measures with a single solid state solution delivered at a lower net first cost.

Antiterrorism Standards:

Dynamic glass technology is compliant with UFC-4-010-01. Specifically, the completed ESTCP project demonstrated compliance with UFC directives including "DoD Minimum Antiterrorism Standards for Buildings" (4-010-02) and to the updated requirements applying to "New Construction" and "Existing Buildings". Also, we are aware that recently four CCRs have been submitted with regard to the use of chromogenic (dynamic glass). These include:

- UFGS 08 51 13 Aluminum Windows (CCR submitted 2014-07-09 17:06 UTC)
- UFGS 08 60 45 Skylights and Translucent Panels (CCR submitted 2014-07-09 17:22 UTC)
- UFGS 08 81 00 Glazing (CCR submitted 2014-07-09 17:38 UTC)
- UFC 3-101-01 Architecture (CCR submitted 2014-07-24 19:33 UTC)

Third-party certification of View Dynamic Glass windows was completed as part of this project, and can be found in Appendix J.

3.2. TECHNOLOGY DEVELOPMENT

NOT APPLICABLE. All technology development was completed in advance of initiating this ESTCP project.

3.3. ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Alternative Technologies:

Windows technology today represents a compromise of the DOD's competing of energy efficiency and workplace performance. Clear double pane insulated glass units (IGUs) provide thermal insulation and natural lighting, reducing interior heating and artificial lighting. However, these IGUs allow significant unwanted solar heat-gain to enter the building, increasing the size and consumption of HVAC systems due to a higher cooling load. Tinted and reflective IGUs provide thermal insulation and block solar heat-gain, reducing cooling and heating, but they also block natural light, increasing lighting requirements inside. Modern low-emissivity ("low-e") IGUs attempt to balance these extremes by blocking some solar heat-gain while allowing for

natural light to pass. However, they are still a compromise striking a single performance value for both summer and winter conditions for the life of the product. This leads to significant annual lighting and heating energy consumption. Further, these static low-e IGUs do not control glare, therefore requiring the use of blinds and limiting the use of daylighting. Typical practice leads to blinds that are often left in the closed position all day, significantly exacerbating lighting energy consumption beyond what building managers intend or budget for. Dynamic glass is a technical response to these issues. It has been designed to maximize daylight, energy efficiency, and comfort in response to the outdoor conditions.

Advantages and Limitations of Dynamic Windows Compared to Low-E Windows:

Advantages: There are significant benefits of dynamic glass compared to low-e windows:

1) *Cuts Solar Heat by 4x in the Summer:* With a SHGC that can be tuned as low as 0.09 in the summer compared to 0.38 for a typical static low-e window, dynamic windows can cut solar heat gain by 4x, thereby reducing the cooling load on peak days and throughout the cooling season.
2) *Increases Solar Heat by 33% in the Winter:* With a SHGC that can be tuned as high as 0.46, dynamic windows can allow 33% more passive solar heating than static low-e, reducing heating load in the winter.
3) *Reduces whole-building peak-load by up to 2x more:* By reducing cooling requirements, dynamic windows can reduce peak load by up to 2x compared to low-e. This peak load reduction can result in smaller, less expensive replacement HVAC systems during renovation cycles.
4) *Reduces Glare by 23x:* With a visible light transmittance (T_{vis}) that can be tuned as low as 3%, dynamic windows can cut glare by 23x below low-e (T_{vis} ~70%), improving occupant comfort without compromising outdoor views without the capital and maintenance costs associated with blinds and shades. (additional detail on pg 40).
5) *Improves Daylighting by 10x:* With T_{vis} that can be tuned as high as 58%, dynamic windows can allow 10x higher average daylight use throughout the day over low-e with blinds, thereby reducing artificial lighting energy.
6) *More than 3x Higher Lifecycle Cost Savings*: Through a combination of reduced energy consumption and reduced capital and maintenance costs, the total lifecycle cost savings can be 3x or more higher than those realized with low-e.

Limitations: The limitations of dynamic windows compared to low-e are minor and have been minimized through intelligent engineering:

1) *Higher Up-Front Cost*: The installed cost of dynamic windows is 50% higher than a comparable low-e system. However, this cost is easily offset by the reduction in HVAC capital expense (CAPEX), elimination of replacement blinds and their maintenance, and lifetime energy savings. For many installations, dynamic windows can be installed with a net cost at or below the cost of renovation with traditional low-e windows. Please see Section 8, “Cost Assessment” on page 46 for more details.

2) *Slightly More Complicated Installation*: Dynamic windows require low-voltage wiring and control systems, but do not require a licensed high-voltage electrician for installation. This wiring is akin to installing data network or alarm cables in the building and can be achieved at costs of $1-2 per square foot of window area.
3) *Single pane size limitation of 5 ft. by 10 ft.* – Today, maximum dynamic glass dimensions are 5’ by 10’. While traditional glass can be produced in larger formats, the 5’ x 10’ max size addresses 90% of the existing glass market. It also represents nearly 100% of the existing DOD building stock.

4.0 PERFORMANCE OBJECTIVES

The Performance Objectives (POs) for this project directly relate to energy security, cost-avoidance, GHG emissions and occupant comfort. They were generated based on the direct measure of the impact of dynamic windows on a previous small pilot installation. This demonstration project successfully achieved all POs. For further details on technical performance results, please see Appendix I.

4.1. "TABLE 2" SUMMARY OF PERFORMANCE OBJECTIVES

Table 2: *Summary of performance objectives*

Performance Objective	Metric	Data Requirements	Success Criteria	Results
1.HVAC Energy Usage	Average energy intensity (kWh/ft^2)	Sub meter readings for HVAC + lighting loads for the original building and for the building with View Dynamic Glass Square footage measurements Modeled savings for the building with low-e	>10% annual energy savings over original building baseline 2x increase in energy savings compared to modeled low-e glass performance	29% savings over existing building baseline 2.2x increase in energy savings compared to modeled low-e glass performance
2. Building Peak Load Requirement	Peak Power Intensity (kW_{peak}/ft^2)	Meter Readings during peak load for original building and the building with View Dynamic Glass Modeled results for the building with low-e	>25% reduction in peak load requirement vs. original building 2x reduction in peak load compared to modeled low-e glass performance	27% reduction in peak load requirement vs. original building 2.5x reduction in peak load compared to modeled low-e glass performance
3. Lifecycle GHG Emissions	Metric tons	Modeling data for original building, low-e and View Dynamic Glass, ISO14044-compliant lifecycle modeling	2x reduction in lifecycle GHG emissions compared to modeled low-e glass performance	2.3x reduction in lifecycle GHG emissions compared to modeled low-e glass performance
4. Lifecycle System Economics	Dollars spent	Calculations using building lifecycle cost of projected energy cost-savings, and capital and maintenance savings	2.9x increase in Lifecycle Cost Savings compared to modeled low-e glass performance	4.3x increase in Lifecycle Cost Savings compared to modeled low-e glass performance
5. Occupant Comfort	%	Feedback from Likert-type comfort survey	Statistically significant gains in occupant comfort	Overall "comfort" increased by 15%, to 96% (very high)
6. End-User Awareness & Acceptance	%	Feedback from Likert-type satisfaction survey	Statistically significant user satisfaction rates based on survey	Overall "satisfaction" increased by 31% with dynamic windows, to 98% (very high).

4.2. PERFORMANCE OBJECTIVE DESCRIPTIONS

1. HVAC Energy Usage: Total energy consumption from HVAC equipment at the site.

   Purpose: To quantify the impact of dynamic windows on whole-building energy consumption and allow us to project future energy and cost-savings of dynamic glass compared to low-e glass windows.

   Metric: Average Energy Intensity (kbtu/ft^2/year)

   Data: Key data were sub-meter readings and accurate office area (square footage) measurements. We installed sub-meters on all cooling equipment to measure cooling loads in 15 minute intervals. We installed lighting monitors to measure lighting usage and extrapolate lighting energy consumption. We directly measured the area of the demonstration site based on facility floor-plans. For comparison purposes, the project team used the calibrated energy models of the demonstration site to model the predicted energy impact if the building had installed low-e glass instead of dynamic glass. We also included the impact of dimmable lighting as if it had been installed (as it must now be, per current building code requirements) in both the dynamic and low-e cases.

   Analytical Methodology: Data was evaluated to determine daily and hourly averages, seasonal trends, and correlation to environmental conditions. These data were screened via parametric statistical tests to identify and treat outliers.

   Success Criteria: The project goal was to deliver >10% annual energy savings over the existing building and 2x increase in energy savings compared to what would have been achieved by installing low-e windows.

   Project Results: The project delivered 29% savings in HVAC energy vs. the existing building, or 2.2x greater energy savings than an upgrade with low-e, exceeding this PO .

2. Peak Load: Peak HVAC cooling load for the site.

   Purpose: Quantify impact of dynamic windows on the peak HVAC power consumption and also validate the potential for HVAC down-sizing and corresponding capital cost savings. Beyond site savings, this impact can reduce strain on the commercial electrical grid.

   Metric: Peak Power Intensity (kW_{peak}/ft^2) required by the building.

   Data: The project team used the calibrated energy models of the demonstration site, along with HVAC load data from sub-meters, to estimate the peak energy intensity demands of the building for the baseline, dynamic glass case, and low-e glass case.

   Success Criteria: >25% reduction in absolute peak load over the existing building; and 2x greater peak load reduction compared to what would have been achieved by installing low-e glass.

Results: 27% reduction in peak load over original building and 2.5x greater load reduction than upgrading with low-e windows, exceeding this PO.

3. Lifecycle GHG Emissions: Total GHG emissions attributable to the demonstration site.

   Purpose: Measure the future environmental impact on the site, for both the dynamic glass and low-e glass cases.

   Metric: Total lifecycle greenhouse gas emissions (metric tons) for the project building over a 30 year time period.

   Data: Both measured physical data and energy modeling results for existing building, low-e and View dynamic glass conditions.

   Analytical Methodology: Standard ISO14044-compliant lifecycle modeling methodology

   Success Criteria: 2x reduction in lifecycle GHG emissions compared to what would have been achieved by installing low-e.

   Results: 2.3x greater reduction in GHG emissions than if we had upgraded with low-e windows

4. Lifecycle System Economics: Total cost savings over the operable lifetime of the windows

   Purpose: This is a direct measure of the system-wide cost-savings of installing dynamic windows

   Metric: Dollars spent.

   Data: Calculations of projected energy cost-savings, and estimates of capital and maintenance savings over the lifetime of the windows.

   Analytical Methodology: Simple payback and savings-to-investment ratio over a 5, 10, 20 and 30-year period using the NIST BLCCA process

   Success Criteria: 2.9x increase in Lifecycle Cost Savings compared to what would have been achieved by installing low-e.

   Results: 4.3x increase in lifecycle cost-savings compared to upgrading with low-e windows.

5. Occupant Comfort: Improvement in both visual and thermal occupant comfort

   Purpose: To improve user comfort and productivity. A key aspect of any facade strategy is the *user experience* with the system. Many designs fail because users are distracted by environmental changes or extremes (e.g. glare).

Metric: Statistical results of a Likert-Type occupant survey. We deployed a web-based occupant feedback system developed by NREL before and after dynamic window installation. Environmental factors (light level, temperature, and humidity) were tracked against feedback, tying occupant dis/satisfaction to environmental factors.

Data: User feedback from comfort survey.

Analytical Methodology: Correlation analysis between environmental variables and occupant responses to 7-point Likert Scales, using parametric statistical tests and analysis of variance.

Success Criteria: Statistically significant improvements in occupant comfort.

Result: Overall "comfort" increased by 15% with dynamic windows, to 96%

6. End-User Awareness/Acceptance: Awareness and acceptance by the site energy management team and building occupants.

Purpose: Provide feedback from users and installers that will help drive adoption at other installations

Metric: Survey results and reactions from building users and local stakeholders

Data: Direct feedback from current building stakeholders and installation staff

Analytical Methodology: Correlation analysis between environmental variables and occupant responses to 7-point Likert Scales, using parametric statistical tests such as the analysis of variance.

Success Criteria: Statistically significant user satisfaction rates based on surveys; plus anecdotal reactions from staff.

Results: Overall "satisfaction" increased by 31% with dynamic windows, to 98% (surprisingly close to 100% satisfaction). Occupants were very willing to share their positive experience with the technology. Testimonials have been captured on video and shared on the ESTCP website. The base energy manager has become an advocate for the technology as a host of several demonstration tours and discussions for regional base energy managers. Both the window subcontractors (Custom Engineered Openings and Bagatelos Architectural Glass) and the building automation contractor (Johnson Controls) have actively pursued additional projects employing dynamic glass.

Please see Section 7.5, "Glare/Occupant Comfort" on page 45 for additional detail regarding occupant satisfaction (due to dynamic glazing and window operability)

5.0 FACILITY/SITE DESCRIPTION

This demonstration was undertaken at Marine Corps Air Station Miramar in southern California. The specific facility was Building 6311, the Installation and Logistics building, also known as "City Hall". Marine Corps Air Station (MCAS) Miramar is one of the Marine Corps' targeted "Net Zero" bases, making it an ideal candidate for this project. The climate at Miramar is a representative mild climate zone. As such, the savings with dynamic glass in many other climate zones of the United States will be comparable or higher than what were documented in this study. For example, the modeled energy savings for this site is comparable to the same building located in climates ranging from Houston and Atlanta to San Francisco. Significantly higher savings (20-30% higher) in more extreme climates, such as Miami, Phoenix and Las Vegas.

***Figure 3**: Location of MCAS Miramar base on a US map.*

5.1. FACILITY/SITE LOCATION AND OPERATIONS

The selected site constitutes the heart of construction and energy management at Miramar. It houses the Installation Director, Public Works Department, and Station Planning teams. All issues and long term planning related to building construction, renovation or energy efficiency at Miramar is led by the occupants of this building. As a result, these occupants represent a very educated and discerning population of "DOD users", and were motivated to provide frank feedback on the performance and comfort issues associated with dynamic windows.

5.2. FACILITY/SITE CONDITION

Building 6311 is a 32,000 square foot U-shaped office building (Figures 4 and 5). The project scope included replacing the windows on the east, west and south facades, for a total of ~1807 sqft of glass. The existing conditions details for windows, HVAC, insulation and lighting system were gathered from a recent Public works report for Building 6311, provided by MCAS Miramar Energy Manager Mick Wasco. This report provided information about existing building conditioning system, the type and numbers of lighting fixtures, and full details about the building's structural layout and construction. Each of these elements was important for

generating a suitable baseline energy model. Due to the accuracy requirements of our energy models and the measurement and verification (M&V) planned for this project, McKinstry performed additional verification and documentation of the building details via multiple site visits and walkthroughs. McKinstry is an experienced M&V firm and federal contractor[ix], and was commissioned as the project's 3rd-party M&V provider for this project.

***Figure 4**: Photo of west facing façade of Building 6311, before this project.*

***Figure 5:** Floor plans for building (first floor is left, second floor is right). The red stars indicate the facade depicted in the photo; heavy dashed lines indicate facades that were retrofit with dynamic windows*

Original Windows Details:

In its original condition, the building was equipped with punched opening aluminum horizontal slider windows that were designed to hold traditional dual pane insulated glass units (Figure 6 left).

Figure 6: *Left) Photos of typical window frame for the original building, prior to the demonstration project. The inset shows a detail of the sliding sash meeting rail. Right) Photo of typical blinds position for the existing building, prior to the demonstration project.*

Prior to this project, the existing insulated glass units (IGUs) were primarily clear glass. The clear glass windows did very little to mitigate the glare and solar heat-gain typical of San Diego and as a result, glare and solar heat-gain were a severe problem in the building. Prior to the demonstration project, occupants reported keeping the blinds down all day long (Figure 6 right).

HVAC details

Building 6311 was divided into 10 separate HVAC zones. These zones are depicted for the first and second floor in Figure 11 of Section 5.4 (Baseline Energy Model). Model numbers, operational schedule, and zoning for each of the ten HVAC units was captured and used for installing monitoring equipment and for the energy model. A summary of the HVAC units and their specifications is detailed in Table 3. All HVAC units were near their end-of-life, with a planned replacement within 12 months following the completion of this project. Therefore, while this demonstration project did not include an HVAC upgrade, the host site will realize significant near term benefit from these capital savings of dynamic windows.

Zone Name	Type	Economizer	Heating Efficiency	Cooling Efficiency	Fan Efficiency	Pressure Drop
Flr1 Zn1	Packaged HP	Yes*	3.6 COP**	3.87 COP**	40%	500 Pa*
Flr1 Zn2	Packaged HP	Yes*	3.6 COP**	3.87 COP**		
Flr1 Zn3	Packaged HP	Yes*	80%	3.57 COP*		
Flr1 Zn4	Split system	No*	80%*	3.50 COP*		
Flr1 Zn5	Split system	No*	80%*	3.50 COP*		
Flr1 Zn6	Packaged HP	Yes*	3.2 COP**	3.67 COP**		
Flr1 Zn7	Packaged DX	Yes*	80%*	4.00 COP**		
Flr1 Zn8	Packaged HP	Yes*	3.1 COP*	3.50 COP*		
Flr2 Zn1	Packaged DX	Yes*	80 %*	3.50 COP*		
Flr2 Zn2	Packaged DX	Yes*	80%*	3.50 COP*		
*Source: engineering judgment **Source: Miramar 1st Floor Plan with zoning.dwfx and Miramar 2nd Floor Plan with zoning.dwfx						

***Table 3**: Specifications for the ten individual existing HVAC zones for Building 6311.*

Lighting details

In our original project scope, we intended to directly monitor lighting loads via monitoring hardware attached to the lighting system. During our site walkthroughs, the experienced M&V team determined that it was not practical to perform direct measurements of lighting energy at this site, due to the highly distributed layout of the lighting and electrical panel system. To address this, we installed light sensors and data-loggers to directly monitor lighting usage, rather than lighting energy. The output from these sensors was used to calibrate our energy models, allowing us to make accurate estimates of the impact of dynamic windows on lighting energy consumption. In addition, the lights in this building were non-dimmable and did not have occupancy sensors. Since dimmable lights are now required by national model building code, we used our calibrated lighting model from our lighting data to accurately determine the energy impact expected for both dynamic windows and low-e windows in any future installations, which will necessarily include dimmable lights.

Building anomalies

There were two additional characteristics of Building 6311 that bear mentioning here. First, this building had an atypically high level of plug-loads for an office building of this type (38% of the total building load, compared to a national average of only 18%). These plug-loads were also thermal loads that are not impacted by dynamic windows, which would tend to diminish the measured impact of dynamic windows on total building energy savings compared to the national

average building. Second, this building had a disproportionately high level of lighting energy compared to other buildings of this type (34% of total energy, compared to only 20% for the national average). This would tend to enhance the impact of dynamic windows, by providing additional benefit from daylighting. Coincidentally, these two effects have opposite and approximately equal impacts on the total building energy savings. As such, these characteristics did not materially impact the overall results of the project.

5.3. SITE-RELATED PERMITS AND REGULATIONS

Regulations - The demonstration project planning and implementation followed US Army Corps of Engineers *Safety and Health Requirements Manual* EM-385-1-1. Associated with the safety and health requirements, the project used an Accident Prevention Plan (APP), an Activity Hazard Analysis (AHA), a Quality Control Plan (QCP) and Quality Control Management to the Resident Officer In Charge of Construction (ROICC) office for review and approval prior to project initiation. The project team also identified all personnel trained to Federal OSHA protocol and submitted their names in to the facility manager.

The project design and implementation was in accordance with all relevant facility regulations. Specifically, the exterior window components and their controls will follow the guidance of the Unified Facilities Criteria: Administration Facilities, UFC 4-610-01.

Optimization of natural light (daylighting) – The demonstration project complied with UFC 3-530-01. The LEED green rating system is a consideration of UFC 3-530-01 and as considered as a complementary design requirement of the project.

Anti-terrorism – The applicable elements of the demonstration project complied with UFC 4-010-01, DOD Minimum Antiterrorism Standards for Buildings and UFC 4-020-01, DOD Security Engineering Facilities Planning Manual. See Appendix J for AT/FP certification.

Barrier-Free Design – The replacement façade was designed and implemented to be barrier-free and accessible in compliance with the Architectural Barriers Act (Public Law 90-480) and in accordance with the Uniform Federal Accessibility Standards (UFAS), published as FED-STD-795, and 28 CFR Part 36, the Americans With Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG).

Design Criteria – Referenced standards utilized for the framing system included:

- Department of Defense Minimum Antiterrorism Standards for Buildings, UFC-4-010-01, Department of Defense, 08 October 2003 (including change 1, 22 January 2003).
- Department of Defense Minimum Antiterrorism Standoff Distances for Buildings, UFC 4-010-02, Department of Defense, 08 October 2003 (including change 1, 19 January 2007).

- ASTM F2248-09 Standard Practice for Specifying an Equivalent 3 Second Duration Design Loading for Blast Resistant Glazing Fabricated with Laminated Glass.
- ASTM E1300-12a Standard Practice for Determining Load Resistance of Glass in Buildings.
- "Metal Curtainwall Fasteners", American Architectural Manufacturers Association, Report AAMA TIR A9-91, 1991.

Additional submittal documents were required. These included:

- A Site Logistics plan, including plans for material staging, parking, lunch areas, approved bathrooms, work hours, phased construction plan
- Product data sheet and full shop drawings for the window components. These shop drawings were provided were hard and soft copies on the NAVFAC template.
- Electrical cable interconnect drawings
- Activity Hazard Analysis Documents complying with US Army Corps of Engineering EM385-1-1 Safety and Health requirements.

6.0 TEST DESIGN

6.1. FUNDAMENTAL PROBLEM:

This project addressed the problem of inefficient windows in buildings, one of the biggest energy problems facing the military today. Traditional windows allow solar heat to enter, increasing the need for unnecessary cooling energy in the summer, while producing glare, which degrades occupant comfort and results in the overuse of blinds, increasing the need for unnecessary electrical lighting. View's innovative electrochromic windows addressed these problems by blocking solar heat gain while still allowing for natural light to enter, thereby reducing energy use, greenhouse gas emissions, and unwanted glare.

6.2. DEMONSTRATION QUESTION:

This demonstration sought to solve several related problems by answering the following questions:

1) Can dynamic windows be installed into an occupied office building without a significant disruption to the occupants?
2) What is the total energy savings from HVAC and lighting usage as a result of installing dynamic windows?
3) What is the impact of dynamic windows on the building's peak power consumption and total energy usage?
4) What was the reduction in lifecycle GHG emissions as a result of these energy savings?
5) What as the total cost savings attributable to dynamic windows over their operable lifetime?
6) What is the quantifiable improvement in occupant comfort and satisfaction due to reduced glare and improved visibility?

6.3. TEST DESIGN

Experimental Design:

The scope of this project was to demonstrate the impact of dynamic windows via energy savings and HVAC peak-load reduction; to validate the performance and cost benefits predictions; and to provide empirical data useful to make realistic projections of the benefit of this technology across all DOD building stock. To accomplish this, we collected both quantitative and qualitative data addressing each of the key Project Objectives.

- Hypothesis: Dynamic windows will provide significant lifecycle energy and cost savings, energy security, and occupant comfort relative to low-e replacement glazing in a range of DOD applicable building types and climates.
- Test Design: Relevant zones of the existing building were sub-metered and logged to quantify the actual energy consumption of each building system in the treated zones. This data was correlated to environmental conditions (weather and temperature) and occupancy

conditions. Sub-meter data was collected from the demonstration site throughout the test period – both before and after dynamic windows installation. A comprehensive and detailed energy model was developed using the Department of Energy's EnergyPlus software. The collected sub-meter data was used to calibrate the energy models so that predicted absolute and system relative consumption data matched the measurements. From the calibrated energy model, we projected the lifecycle energy savings, cost-savings and improvement in energy security directly attributable to dynamic windows, relative to state-of-the-art low-e glass windows.

- Independent variables: Glass type: a) original single pane tinted glass (measured and modeled); b) insulated dual pane dynamic glass (measured and modeled); and c) dual pane low-e glass (modeled only).
- Dependent variables: 1) Annual energy consumption; 2) HVAC peak load; and 3) Occupant comfort. In addition to these direct variables, the study calculated secondary impacts and cost-savings from: 1) reduced HVAC capacity requirements; 2) reduced operational costs associated with maintenance of the HVAC, blinds and curtains; and 3) reduced GHG emissions.
- Controlled variables: The major components of the building and its conditioning systems were not modified during the evaluation period. Example building systems include the exterior envelope, the major HVAC components (chiller, pumps, ductwork, controls), and the interior lighting. Occupant related control variables were also held fixed, including operating schedule, occupant density, and usage category (office/administrative)
- Test Phases: The demonstration program was broken into six phases as follows:
  1) Pre-measurement setup: detailed physical and operational site survey; installation of sub-meter monitoring hardware; development of an accurate and representative building energy models;
  2) Evaluation of baseline/existing building condition: baseline system level energy consumption measurements; baseline occupancy comfort and productivity surveys; and environmental conditions monitoring.
  3) Installation of dynamic windows and control systems: Installation of windows; commissioning for air/water integrity; installation of the controls system including sensors and network devices; commissioning of controls.
  4) Evaluation of dynamic windows building conditions: measurement of post-installation system level energy consumption; post-installation occupancy comfort and productivity surveys; and environmental conditions monitoring.
  5) Data analysis and lifecycle projections: Measurement data for the baseline and dynamic window conditions was compared against energy model predictions; compensating for actual weather data during the measurement periods. A third evaluation-tuned energy model was developed for the dual pane low-e building condition, based on the refined baseline model. The three models were extrapolated to project annual and 30-year-energy, peak-load, energy costs, capital savings, operational costs, maintenance costs,

and GHG emissions for each of the three building conditions (using NIST recognized values and methodologies). Occupant surveys were analyzed for impacts on comfort and productivity.

6) Documentation and user awareness: A comprehensive report summarizing the lifecycle GHG, energy and cost savings was compiled; analysis methodology was documented and reported; the findings were disseminated to both the project site and the larger DOD community via written reports, live and virtual presentations, and educational modules.

6.4. BASELINE CHARACTERIZATION

Baseline Monitoring:

The purpose of the baseline monitoring plan was to 1) provide a baseline upon which the energy savings of dynamic windows could be compared; and 2) provide experimental data to validate and calibrate our baseline energy model (and thereby improve our dynamic and low-e models). Monitoring was provided by McKinstry. Specific details of the Monitoring plan, including equipment and methodologies can be found in Appendix B.

The reference conditions of the baseline characterization phase were those of the facility in its original condition. Electricity consumption of each HVAC unit was monitored via independent sub-meters in each HVAC zone. Additional data including the occupancy schedule, set point temperatures, setback temperatures, and weather conditions were also monitored. Lighting sensors were used to estimate lighting energy in different zones. Measurements were taken every 15 minutes, and logged at a central repository.

The baseline evaluation period was 5 months of continuous measurement, from December 2012 to May 2013. Local weather data was collected during this time period, and used in conjunction with metrological weather file data for annualized environmental load estimates, to annualize the expected baseline energy consumption for the full year. Occupant comfort surveys were assumed to represent historic daylight and glare preferences.

Measured baseline energy consumption data was compared to historic energy consumption data from facility Utility bills over the past 3 years to validate our measurements and provide further calibration data for our baseline energy models.

Data collection equipment consisted of multiple current transformers (CTs) installed on appropriate electrical panels and circuits for each HVAC zone. The CTs communicated to a Dent Instruments PS-18 datalogger, connected to an Obvius AcquiSuite data acquisition panel with GSM communications (Figure 7). The AcquiSuite device polled the data, created a data package and uploaded to a web server automatically for storage and logging. Figure 7 and 8, below depicts all components of the data storage and analysis system. Weather and environmental

conditions were monitored and collected from local weather stations via the Internet. Weather and environmental data was stored on View computers during the baseline evaluation period.

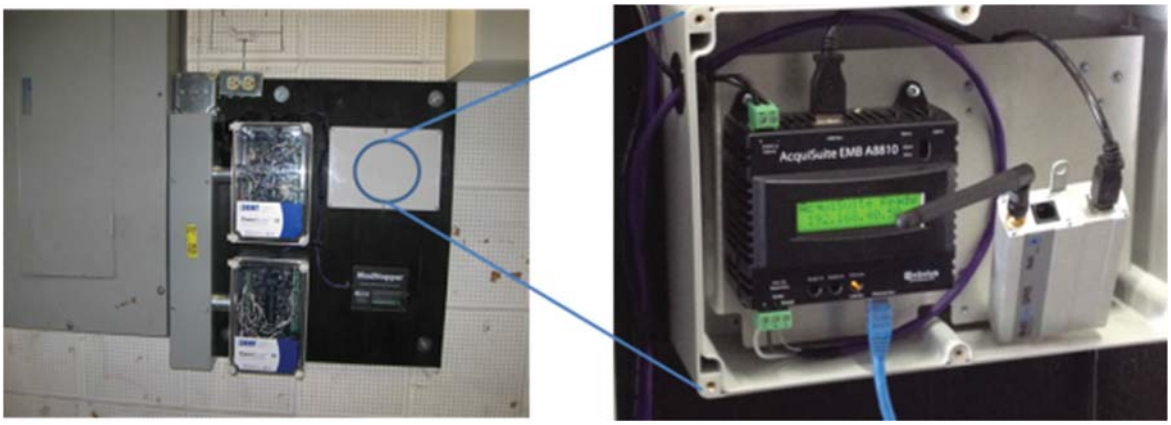


Figure 7: *Left) Dent sensors and a Modhopper control unit of M&V system in Building 6311. Right) Poling and GSM modem system to export monitoring data to central repository.*

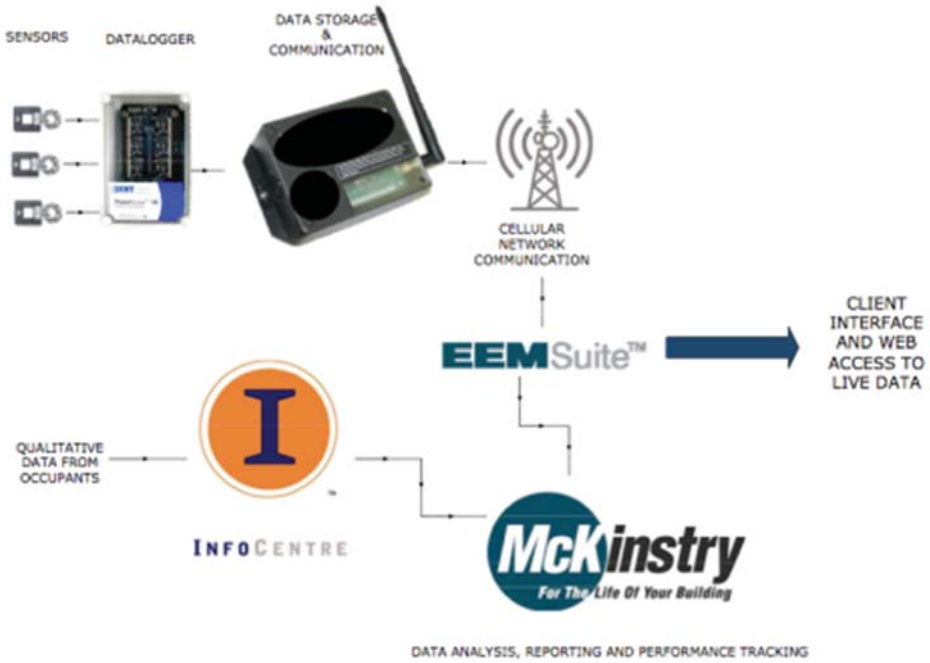


Figure 8*: Data collection and storage system components*

In addition, NREL installed prototype IPOS image sensing occupancy sensors, developed by NREL, to provide info on occupancy, lighting usage and blind usage based on light levels and contrast levels in the space. Figure 9 Shows li-cor sensors installed in perimeter space (each orientation) to measure vertical and horizontal illuminance. The output from the sensors was used to monitor the illuminance levels coming in the space from windows and the contribution by electric lights. This was used to analyze contrast ratios and glare and also for calibrating our

lighting models, and provide usage data from which to estimate total lighting energy consumption for the building (See section 4.2: Building Conditions for more details). Engineers placed local data loggers at key luminaires (one per switched zone) in order to observe the electric lighting usage in the building. These dataloggers are basic local units. Data was retrieved with a local computer over RS-232 serial connection. During site visits, NREL engineers pulled all the data from these units and cleared the memory.

***Figure 9**: Shows IPOS sensor installed to monitor the occupancy and artificial lights schedule*

Baseline Sampling Protocol:

Data was collected for the conditioning system energy usage, and dynamic glass setting. All data was automatically ported to discrete data logger hardware and ultimately to an Internet database. The hardware and database were managed by McKinstry. All data collection for the project was automatic and on a 15min basis. Throughout the project, data resided in three robust locations. First, the data was recorded to a data logger. This data logger has onboard memory that can store a period of data internally, in the case of a network disruption or error. Second, via a cellular network the data was transmitted to an online database. This database consisted of two secure data storage units – the prime server and a second, back-up server. Finally, throughout the project, the online data was downloaded and processed by members of the team including View and McKinstry. This download activity represents another redundant repository for the evaluation data.

Baseline Occupant Surveys:

Detailed surveys using standard 7-point Likert scales were developed by NREL to assess occupant comfort, satisfaction and productivity. These surveys were manually distributed to building occupants during the baseline period. As part of this process, educational material and informational seminars were provided to the occupants to inform them about the technology (Details in Appendices C and D).

Baseline Energy Models:

Initial parameters for our baseline energy model were extracted from the Miramar Public Works report for Building 6311. Multiple additional on-site walkthroughs were performed to verify and collect additional information. Any missing information was acquired from the DOE commercial reference building database for pre-1980 medium office buildings. All information was provided to NREL to develop the initial baseline energy model using Energy Plus software. Figure 10 shows the basic model design. Interior zones were divided, as shown in Figure 11.

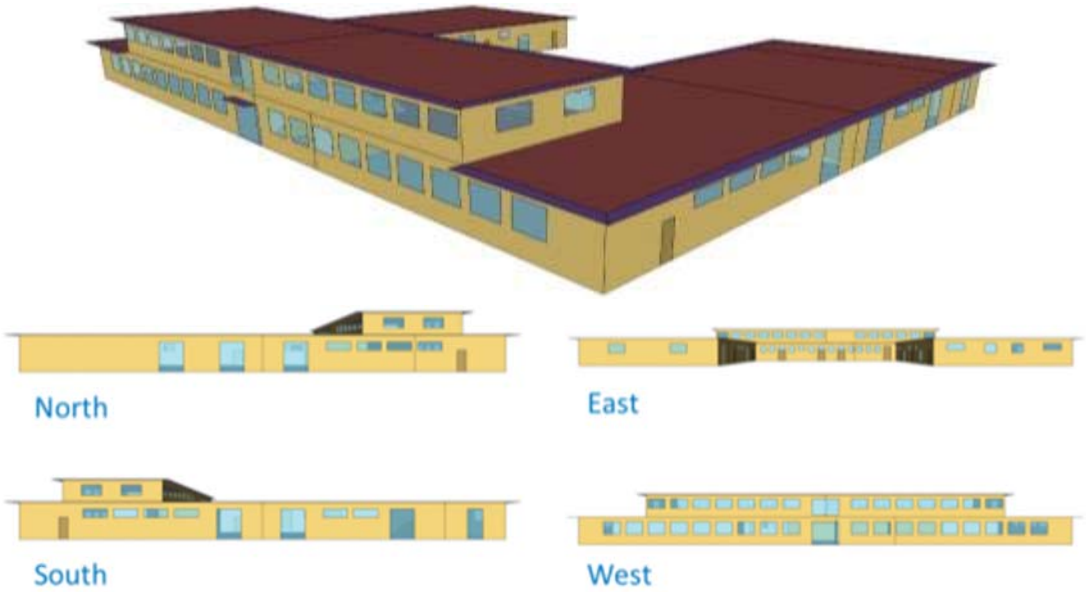


***Figure 10**: 3D view and building elevations used for the energy models (Graphics generated using Open studio)*

***Figure 11:** Left) First floor zoning plan for Building 6311. Right) Second floor zoning plan for Building 6311. Ten total conditioning zones*

Baseline fenestration parameters can be found in Table 4. All other details of HVAC, lighting, plug-loads, occupancy, and various operating schedules used to develop the detailed baseline energy model can be found in Appendix I.

Orientation of window	U-value (W/m2K)	SHGC	Visible Transmittance	Window to wall ratio
East	1.09	0.81	0.88	17.8%
West	0.48	0.47	0.38	32%
North	1.09	0.81	0.88	15.9%
South	1.09	0.81	0.88	18.4%

Table 4: *Baseline building window details*

The baseline energy model was then compared to actual baseline energy monitoring data and to historic utility bills for the previous 3 years, and minor adjustments were made to refine the overall calibration.

Overall, our detailed energy model correlated well with actual building energy consumption. Figure 12 shows our modeled energy consumption for a 12 month period, compared to the actual energy consumption for that same period. Also shown is the average measured monthly energy consumption for the whole building over our 5-month baseline monitoring period (separately from our monitoring system and from utility bills for that same period), compared to our modeled results. Both measurements matched our modeled results within 10%, indicating an acceptable correlation. This baseline model was then used to develop a low-e windows model and the dynamic windows model, against which we compared our experimental data after retrofitting the building with dynamic windows. Additional details on all models can be found in Appendix I.

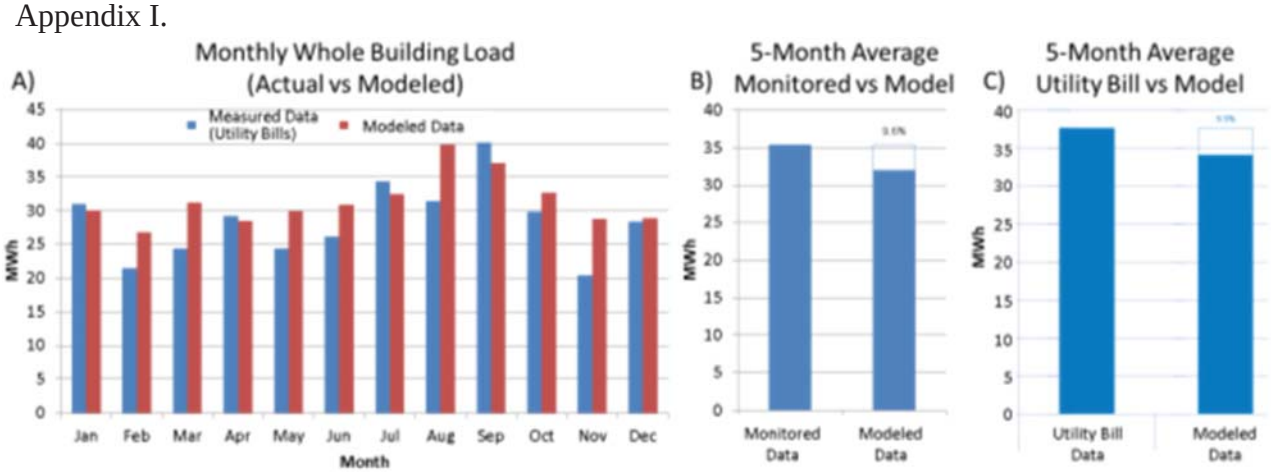


Figure 12*: A) Monthly average load for Building 6311 from our detailed energy model, compared to actual average monthly loads from utility bills over the same 12 month period in 2012. B) Average building load over our baseline monitoring period (Dec-May, 2013), based on the project monitoring equipment vs modeled data. C) Modeled average load over the same period compared to actual utility bills.*

6.5. WINDOWS DESIGN AND INSTALLATION:

Windows:

All windows on the east, west and south facades were measured, and any special requirements for blast protection, beyond window and IGU parameters, were identified. Scaffolding plans were established to not disrupt occupant ingress/egress and to avoid damage to ground cover.

Dynamic IGUs were fabricated by View, including 3/8" interior glass, and integrated into Wausau 3250 Casement / Fixed Aluminum windows designed for DOD Minimum Anti-Terrorism Standards – UFC 4-010-01. Completed IGUs were delivered to the site for installation (Figure 13a). Existing windows and frames were removed (Figure 13b) and replaced with dynamic windows (Figure 13c), for a total of 1807 ft^2 of dynamic glass.

***Figure 13**: A) View dynamic glass IGUs received at Miramar. B) Construction crew removing old window frames. C) Final installed dynamic windows.*

Installation was performed on a "rolling" basis, where occupants were moved from individual offices for a day, while the windows in that office were replaced, and then they were relocated into their offices. Over time, the entire building was retrofit, without major facility disruption.

Figure 14 shows the site before and after installation of dynamic windows. Note that, other than eliminating blinds, providing a more uniform look for the façade, there is no discernable change to the exterior façade. This will enable future energy efficiency upgrades to virtually all DOD buildings, including heritage buildings.

***Figure 14**: Western façade of Building 6311 before dynamic retrofit (left) and after (right).*

Control Systems:

Low-voltage power- and control-wiring was installed and routed to a central control panel, including independent in-line control units (Figure 15) and central controls unit (Figure 16), located in the building's electrical room. Additional interior and exterior lighting sensors, integrated into the window frames provide individual control signals to each window, in addition to central networked control signals. Together this system is able to manage the performance of the dynamic windows to minimize energy usage and maximize occupant comfort based on interior and exterior lighting conditions.

Figure 15: *View in-line dynamic window controllers within UL plenum-rated metal boxes (shown open).*

Figure 16*: View network control box. The center-positioned grey squares are two 240-Watt power supplies (similar to a desktop computer). The network controllers are black and green (2 total, lower left side) and a 3G modem (orange and black, lower right side).*

The installed dynamic window system (hardware and controls) were fully automated and configured for the specific site location. They operate across a range of tint states (from clear to heavily-tinted) based on environmental conditions such as temperature and glare. While the

dynamic window system does not directly control the HVAC or lighting of the facility, those systems are designed to respond to building needs for heat and light to maintain their preset conditions (as is typical in all buildings). In the case of this project, automatic lighting dimmers were not available in the building. Since dimmable lights are now part of federal building code for all new construction and deep retrofits; NREL's interior li-cor light sensors were used to estimate the energy savings that would have resulted from dynamic windows, based on interior illuminance levels, if industry-standard automatic dimming had been installed.

The three systems, dynamic windows, HVAC, and lighting, operate independently (they do not control each other) but function in a complementary manner. For example, when the dynamic windows reduced the solar load in a room, the HVAC unit in that zone sees lower demand via its own room thermostat and trims its output according to its own internal control algorithm. Similarly, automatic lighting dimmers respond to occupancy and total illumination of each room, and automatically adjust to changes in tint by the dynamic windows throughout the day, based on the instantaneous daylighting available. This intrinsic automatic cooperation between systems dramatically reduced the installation cost of a fully integrated system in the building. Additionally, the dynamic windows in each room can be controlled or overridden via a user wall switch or digital device (phone or tablet), or by the building automation system, whenever needed.

Note on wall-switch operation:

The windows override switches are an important feature of the system, since there are situations where user control is required (e.g. dimming a conference room for a presentation). However, what we found is that once the system was tuned to occupant preferences and operating under full intelligence, the wall switches were almost never used. As a result, this override switch was estimated to have no impact on the overall building energy performance.

In addition, the manual override is reset each day by the central logic module to return the system to its commissioned state (the "midnight switch", triggered at 12pm each night). This is a feature that overcomes the manual reset issues that have plagued programmable thermostats (and their long term benefits) in the past. In addition, we found that virtually all override commands were for greater tint levels, actually increasing energy savings over the programmed /expected levels.

A graphical representation of the integrated dynamic windows and control system hardware is in Figure 17. The illustration shows the basic components of the façade and control components, and their physical relationship to each other.

Figure 17*: Dynamic window system. Controls are highlighted in red circles. The Window Controller determines automatic operation, while the Wall Switch allows direct user control.*

All windows, control systems and monitoring equipment from this demonstration have been left in-place for future use. The system deployed for the evaluation is fully automated and will function without further interaction or adjustment from the facility managers. Ongoing data logging and error detection will be performed by View. However, the building staff has been trained on the basic components of the system and its operation. A comprehensive operations and maintenance manual was developed and provided to the facility staff. An overview video was produced that describes the system, its key operational components, and its benefits. This has been made available to the facilities team for their public use and technology outreach. Finally, an information kiosk was installed in the building lobby with information about the system and demonstration. Written permission for all of this was obtained from Lieutenant Colonel Eric Wolf and is included here in Appendix J.

6.6. OPERATIONAL TESTING AND SAMPLING PROTOCOLS

Identical monitoring of the building, post installation and commissioning of the dynamic windows system, was performed for a period of 6 months, from February to July, 2014. Meteorological weather data was used to annualize these results. Additional monitoring data will be added to this study over time to refine and improve the precision of our results. This will be done by View, outside of this demonstration contract. Measured data was normalized for environmental effects and then compared (dynamic glass case versus the baseline-case) to yield the monthly and annual energy savings and cost impacts attributable to the use of dynamic glass. All Operational data was used to validate and further refine the dynamic windows energy model.

6.7. SAMPLING RESULTS

Energy Consumption and Load Sampling Results:

Figure 18 shows the average HVAC daily energy consumption of 4 different zones in the building, before and after retrofit with dynamic windows. These 4 representative zones provide insight into the impact of different building characteristics and uses on energy savings. The HVAC monitoring data by zone shows that the savings of energy consumption varies dramatically by zone, depending on its location within the building, façade orientation, the window-to-wall ratio within the zone and workplace usage within the zone. The primary controlling factors are the sun exposure and window to wall ratio, with the greatest savings found in zones with western exposure and in zones with higher window-to-wall ratios. Also worth noting, the HVAC energy in some zones of the building are dominated by the internal thermal loads of office equipment (example AC 7) so the HVAC energy savings are lower in those zones.

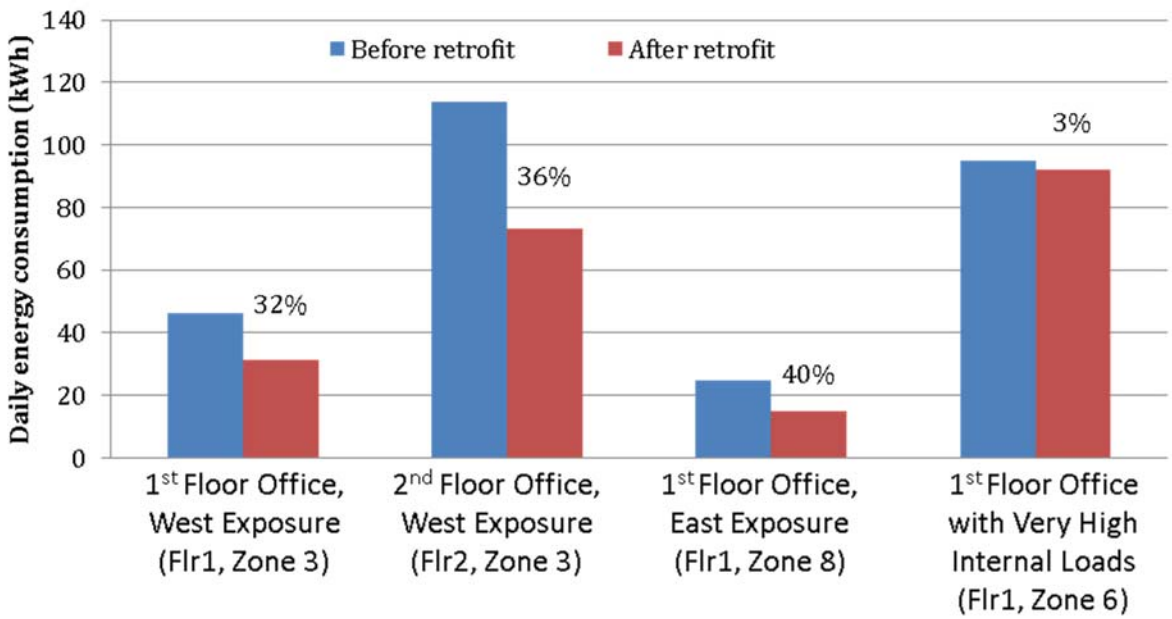


***Figure 18**: Plot of daily HVAC energy consumption in 4 representative zones, before and after dynamic windows retrofit. Overall, energy savings in all eastern and western oriented offices were in the range of 30-40%. However, several zones with higher-than-normal internal loads (see 1st Floor, Zone 6) tended to shift the total building average results to lower values.*

Lighting Sampling Results:

From our lighting/occupancy sensors, we were able to track the lighting use in each switched zones throughout the building to estimate lighting energy usage. Figure 19 shows the average reduction in lighting energy use throughout the course of the day. Note that because existing lights in Building 6311 did not have dimmers, the savings seen in Figure 19 is a direct result of occupants actually turning off the lights when sufficient daylighting was available. Automated

dimmers will do a significantly more effective job than this. Behavior change seems to have occurred in general as shown by nighttime lighting use reduction.

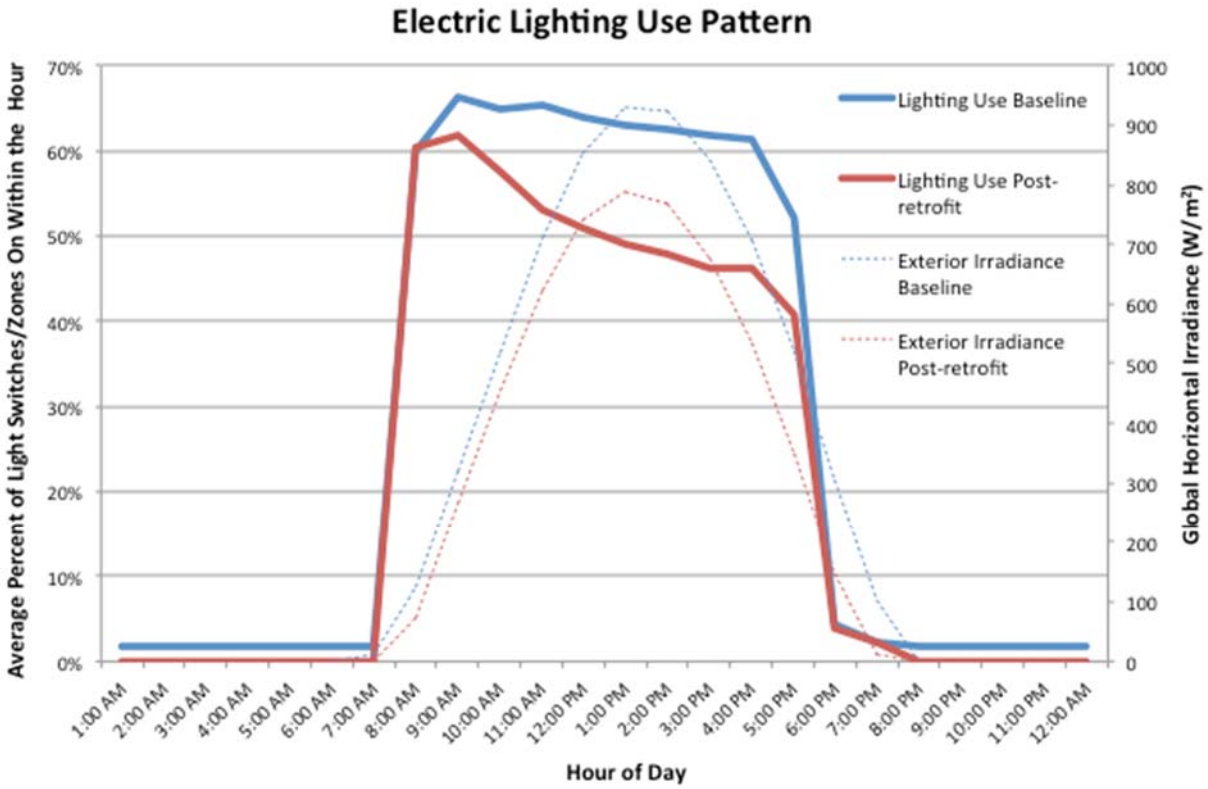


Figure 19: *Average interior electrical lighting energy consumption throughout the day, with and without dynamic windows. Also shown as dotted lines are the average exterior irradiance during each monitoring period.*

This data is an average of two switched zones that run the north-south length of the open office. Due to the limited number of sample points, there is a strong onset and offset of lights at the beginning and end of the day. In the case of a full office building it is expected that these edge times would be more gradual across time, but reflect a similar positive benefit.

Glare Reduction Sampling Results:

Figure 20 shows the reduced glare resulting from View dynamic glass. This data was collected from a west-facing open office workstation. The vertical illuminance is taken for two representative points, W1 and W2. The points face the west window and are at approximately eye height.

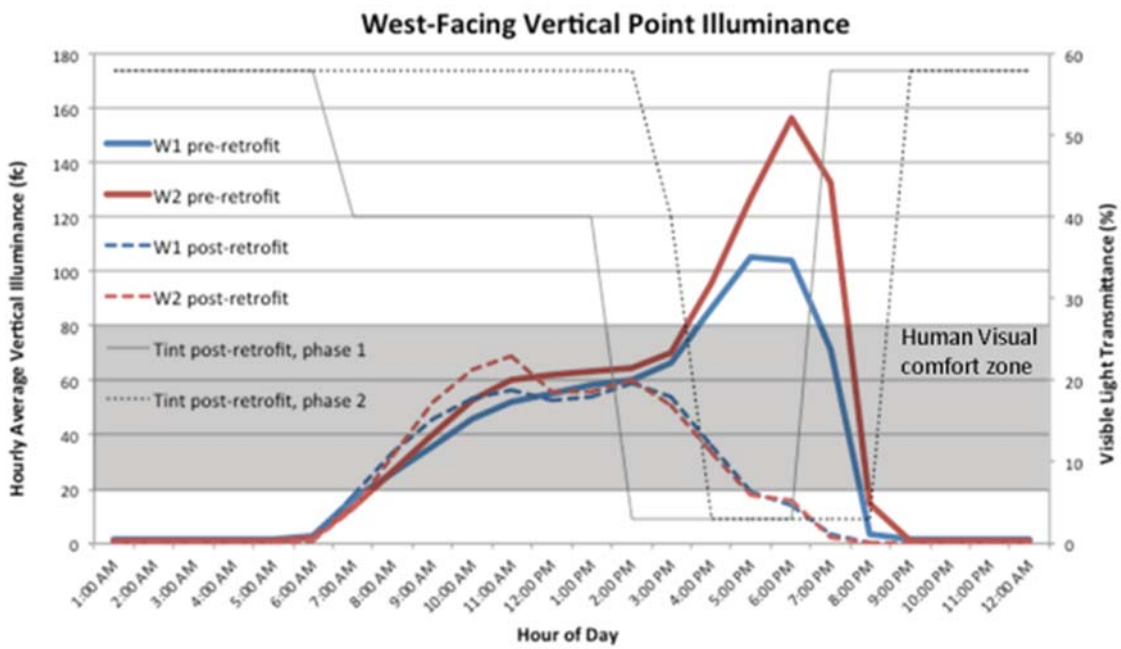


Figure 20: *Illuminance measurements to determine glare. Shown is the total illuminance at two locations, before and after installation of dynamic glass. The wide horizontal grey band is the range of illuminances generally accepted as "comfortable" by people. Note that the "before" conditions did not meet this comfort criteria. Light grey lines indicate dynamic windows (Phase 1) tint algorithms for this site (Phases 1 and 2).*

Vertical illuminance can be used as a proxy for glare, which the View dynamic glass is reducing. Note that the difference in the hourly average illuminance for the two vertical points is due to the difference in sensor position relative to interior finishes and mullions. It is likely, for example that the sensor at point W1 is in partial shadow between the hours of 6 pm and 7 pm.

Figure 20 shows the tint profile of the dynamic windows for two different control algorithms. Phase 1 was the original algorithm sent from the factory. Phase 2 was an optimized algorithm installed based on initial glare measurements, to allow for increased morning illuminance and better alignment of tint state with heat and glare potential in the afternoon.

In addition to these direct measurements, the glare control efficacy of View Glass was evaluated through simulation, by producing annual glare profiles. Radiance and local Miramar weather data was used, along with the existing calibrated Miramar building model, to calculate the vertical illuminance and hemispherical luminance maps at the (seated) eye height, for several views (vectors) in Building 6311 at MCAS Miramar. These views correspond to actual occupant locations, locations where we have also obtained occupant satisfaction feedback throughout the monitoring period. Additional information about lighting and glare measurements can be found in Appendix G.

It is worth noting that a very small population of the building occupants found the remaining glare unacceptable at the 4% tint state during direct, full sunlight. This is consistent with other View dynamic glass installations and has prompted a revision and improvement to the existing product. View has completed the development of a 1% tint product that will begin deploying Q1 2015. Initial customer feedback indicates that at 1% tint, glare deduction satisfaction exceeds 95% (up from the approximately 75% satisfaction rating with 4% tint).

7.0 PERFORMANCE ASSESSMENT

7.1. TOTAL BUILDING ENERGY IMPACT:

Building energy consumption data was analyzed using multi-variate regression analysis to identify the actual performance and its variability due to weather and other variables such as occupancy and user preferences. This data was correlated to our calibrated energy models of the site, with configurations for the baseline-case, for the simulation of low-e windows installed, and simulation of the building with the dynamic windows installed. This model was then used to project annual energy savings and peak-load reduction, as well as lifetime energy savings and potential impact across all DOD building-stock.

Overall energy consumption breakdown at host-site with and without dynamic windows:

Table 5 and Figure 21 show the total building energy load, broken out by component, for the original building with single-pane windows, the building if low-e windows had been installed, and the building after installation of dynamic windows, including the relative energy savings in each case.

End Use	Baseline Glass (kWh/sqft/yr)	Upgrade to low-e (kWh/sqft/yr)	%-savings	Upgrade to Dynamic Glass (kWh/sqft/yr)	%-savings
Interior Equipment (electric)	4.21	4.21	0%	4.21	0%
Interior Lighting (electric)	3.77	2.82	25%	1.45	62%
Heating (electric)	0.035	0.041	-17%	0.044	-25%
Heating (gas)	0.10	0.14	-34%	0.18	-71%
Cooling (electric)	0.57	0.46	18%	0.36	37%
Fans (electric)	2.30	2.01	13%	1.66	28%
SWH (gas)	0.22	0.22	0%	0.22	0%
Total Building Energy	**11.20**	**9.89**	**12%**	**8.11**	**28%**

Table 5: *Combined Rules Energy Modeling Results. Total building energy consumption by component load for three building conditions: the baseline (single-pane glass) building, the building with low-e glass, and the building with dynamic glass.*

Overall, we see 2.5x greater savings on lighting energy by using View dynamic windows compared to low-e windows, from increased use of daylighting. We see a little over 2x greater energy savings on air-conditioning and fan energy with View dynamic windows than low-e, from reduced solar heat gain, plus reduced thermal load from electrical lighting. Overall, by upgrading to dynamic windows, we can reduce the total building energy by 28%, or 2.4x greater increase in energy savings than upgrading with Low-e (only 12%). Figure 21 shows the breakdown of key building loads in the original building, low-e and dynamic cases. Based on these results, the total lifetime energy savings for this building is 2,968,000 kWh.

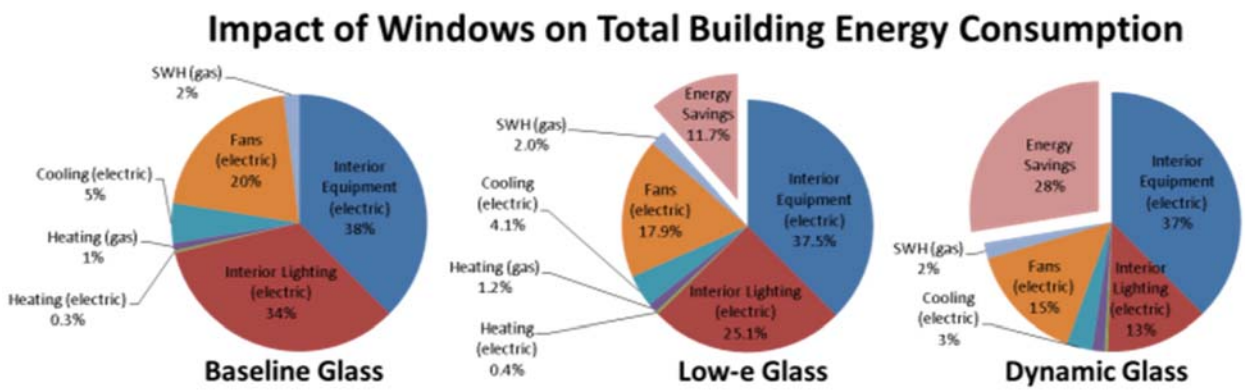


Figure 21: *Impact of windows on total building energy consumption for three conditions: the baseline (single-pane glass) building, the building with low-e glass, and the building with dynamic glass*

7.2. HVAC ENERGY AND PEAK LOAD IMPACT:

Figure 22 shows the average HVAC related energy consumption for building 6311 before and after dynamic windows. Across the whole building, the net average energy savings was 29%, compared to only 13% for low-e windows, corresponding to 2.2x higher HVAC energy savings.

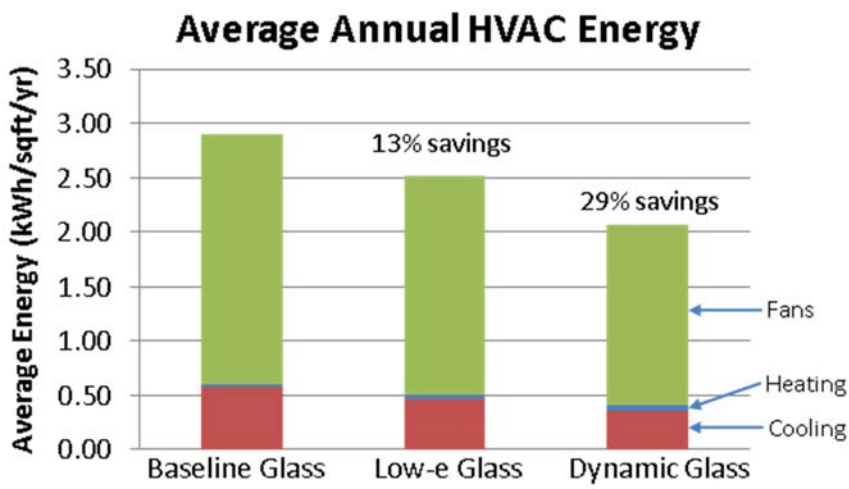


Figure 22*: Average energy savings impact with low-e glass and with dynamic glass.*

Use of dynamic glass has profound impacts on whole building HVAC system size and flow rate requirements. Building 6311 can reduce its system capacity by 27% and required flow rate by 28%. This is 2.4x and 2.7x greater reductions, respectively, than when upgrading with Low-e). As a result, the required equipment size of the pending and future HVAC replacements (average refresh every 15 years) can be reduced. This results in a significant CapEx savings over the lifetime of the dynamic windows. Table 6 shows the total cooling peak-load and fan peak-load for Building 6311 for the baseline, low-e and dynamic cases.

	Baseline	Upgrade with Low-e	%-Reduction	Upgrade with Dynamic	%-Reduction
Cooling Capacity	45 tons	40 tons	11%	33 tons	27%
Cooling Flow Rate	26420 cfm	23747 cfm	10%	19078 cfm	28%

Table 6: *Cooling capacity and flow-rate for Building 6311 under Baseline, low-e and dynamic cases.*

While the whole-building impact on HVAC load is a compelling business case alone, it overlooks the even greater impact of dynamic glass on the individual zones. Figure 23 shows the cooling loads coming from the façade (dominated by both the conductive and radiative solar loads) for the baseline and dynamic windows case. The conductive loads are mainly reduced due to the improved U-factor of dual pane glass units inherent to View dynamic glass. Radiative loads are reduced by the variable solar heat gain coefficient (SHGC) of the glass. Once again, these zone-measurements tell the full story, while the building-average savings is somewhat reduced due to a couple of individual zones with higher-than-usual internal thermal loads.

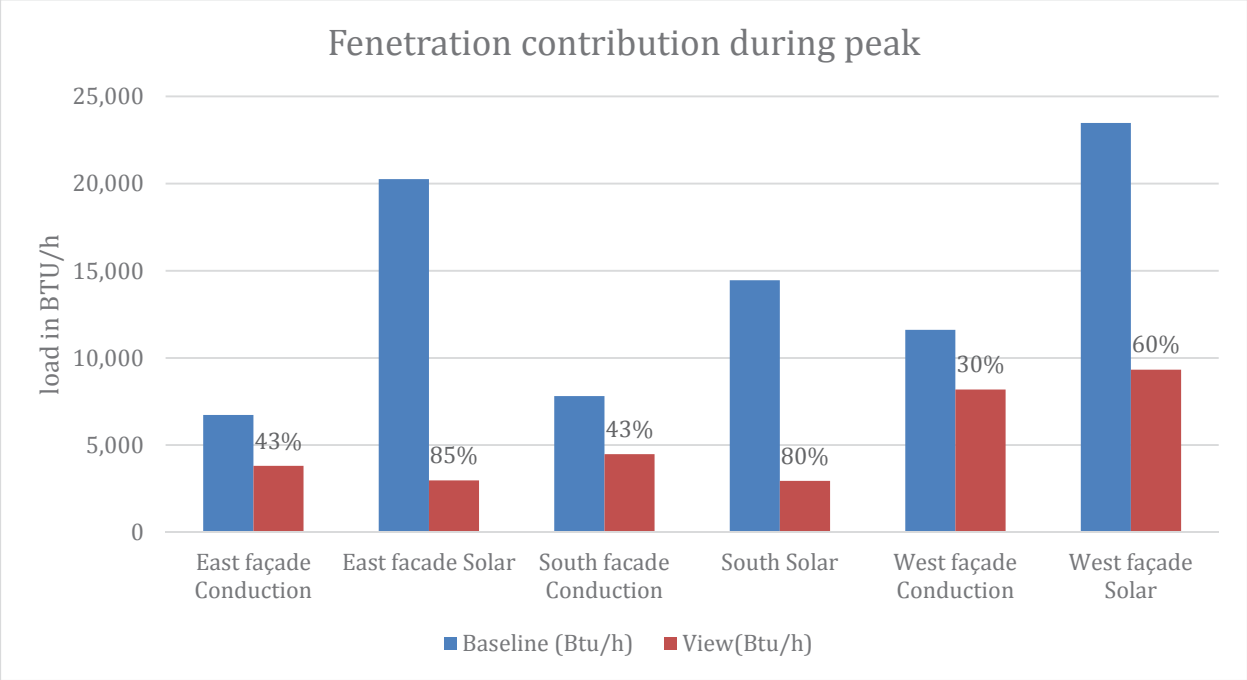


Figure 23: *Reduction in HVAC load from per façade and load type (excluding internal loads) before and after dynamic windows.*

NOTE: While an HVAC upgrade was not part of this project, Building 6311 is scheduled for an HVAC upgrade within the next 12 months. This renovation is already in the planning stage. Over the remaining 30 years of the dynamic window lifetime, Building 6311 is expected to undergo 1-2 additional HVAC replacements, further multiplying this savings.

7.3. LIGHTING

Figure 24 shows that daylighting control from dynamic windows with dimmable lights compared to low-e glass with dimmable lights has a significant impact on total building lighting energy.

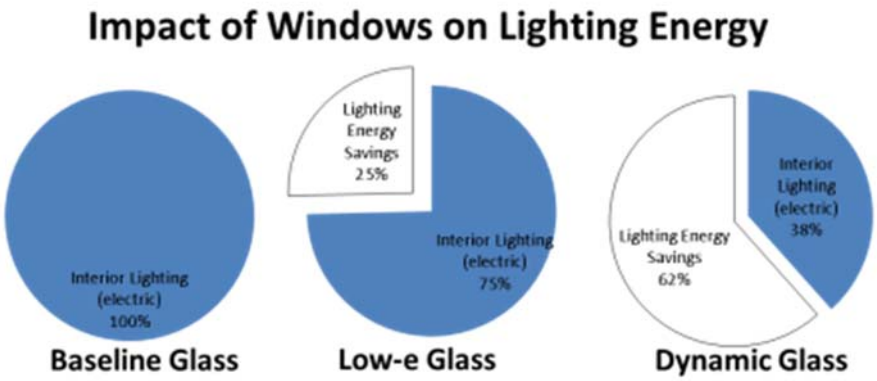


***Figure 24**: Impact on lighting energy from daylighting control of dynamic windows, compared to low-e windows.*

7.4. LIFECYCLE GHG EMISSIONS:

Lifecycle GHG emissions were calculated using standard ISO14044-compliant lifecycle modeling methodology based on the results of the energy analysis and projections described above. Total GHG emissions were reduced by ~35% by retrofitting the building to dynamic glass. For this site, the total lifecycle GHG emissions will be reduced by almost 5 million kg of CO2e

Greenhouse Gas	Baseline (kg)	Low-e (kg)	Dynamic (kg)
CO2	111455.3	94609	71642
CO	86.8	74	56
CH4	579	491	372
NOx	95.4	81	61
N2O	2.3	2	1
SO2	1033.6	877	664

***Table 7:** Greenhouse gas emission reduction for Building 6311 from upgrading with low-e and dynamic windows.*

7.5. GLARE/OCCUPANT COMFORT:

A comprehensive 7-point Likert Scale occupant comfort and satisfaction survey was completed before and after installation of dynamic windows. The project received survey responses back from 75 building occupants before the retrofit and 53 building occupants after the retrofit. These totals represented a valid survey pool for both cases. Quantitative measurements of real time

environmental variables were made during the surveying period. These were correlated to the 7-point Likert Scales using an analysis of variance.

Occupant satisfaction increased significantly with dynamic windows in each of the three target areas of "comfort", "access to views" and "environmental control". Figure 25 shows the improvement in terms of percentage of positive responses. It is exceptional that the level of satisfaction for comfort and views is almost 100% with the dynamic windows condition.

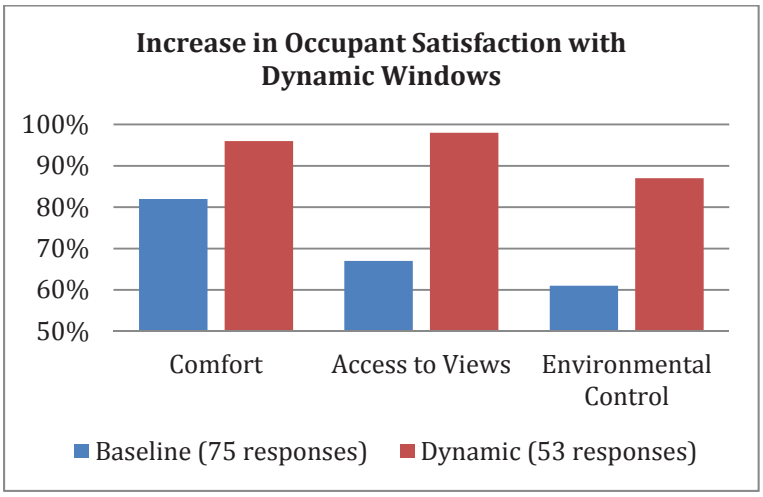


***Figure 25**: Increase of occupant satisfaction before and after the installation of dynamic windows.*

These results not only quantify the satisfaction of occupants of Building 6311, but also validate that blinds and external shades can be eliminated with the installation of dynamic windows. For this demonstration installation, this resulted in $81,000 in capital savings, and an expected $8,000 in maintenance savings over the window's 30-year lifetime. Data on Glare Reduction can also be found in Section 6.7 on page 40 including learning from this project and in the private sector.

Finally, while not included specifically as part of this demonstration project, significant scientific research has demonstrated that increased levels of daylighting and greater access to views results in dramatic increases in occupant productivity.[x] Based on these studies, and our current installation in Building 6311, we would estimate an increase in occupant productivity of 6-15%.

The complete detailed surveys and results of the project's occupant study can be found in Appendix F.

8.0 COST ASSESSMENT

8.1. ASSUMPTIONS FOR COST PROJECTIONS

In addition to developing models to predict the energy and greenhouse gas benefits of dynamic glass technology, the project team also developed an empirically derived economic model to assess the deployment costs and benefits for the installation site and for DOD building stock adoption. For this, several assumptions about expected project costs were made. These included:

Glass (IGU) Costs: The total cost from the glass vendor. For the low-e baseline, this includes glass material cost only. For the dynamic scenario, the glass cost includes the dynamic IGU, associated electrical components, and commissioning.

Shading Costs: Glare control blinds are assumed to be an installation requirement on low-e replacement windows, but not dynamic windows. Cost for the installed blinds was assumed to be $15/sqft. The assumed average usable lifetime of blinds is 10 years, with maintenance cost of $0.15/sqft/yr.

HVAC Costs: The assumed average usable lifetime of a typical HVAC system is 15 years. (This estimate is deemed conservative. This service life can be significantly lower if they are poorly maintained, or are located in a corrosive environment.) HVAC maintenance costs were assumed to be 1% of system cost.

It was also assumed that any future HVAC upgrades will be downsized to the revised and proper peak-load requirement for the building for a given window condition (for either dynamic or low-e windows). HVAC size and cost calculations were validated by a third party engineering firm (S3H Engineering).

In calculating the total costs for the demonstration project, it was assumed that an HVAC replacement was eminent due to the end the existing unit's serviceable life. This assumption was verified as accurate by the base facilities team.

Building lifetime: It was assumed that each site has a remaining service life of 30+ years and the full benefits of glazing and HVAC upgrades will be realized.

Energy: Energy results were derived directly from the validated Energy Plus whole building model. Total savings due to efficiency gains were calculated by multiplying energy savings (kWh) by actual San Diego utility rates ($/kWh). It was assumed that energy costs will increase 2% annually. This is consistent with national recognized energy prediction models.

Electrical Labor costs: Electrical labor cost for wiring dynamic glass BOS components throughout the façade and bringing power to the control box was calculated using the RS Means construction labor reference guide and actual quotes/bids from mechanical contractors and engineering firms for other dynamic glass installations.

8.2. COST ANALYSIS:

All cost assessments were done using simple payback and savings-to-investment ratio over a 30-year period using the NIST BLCCA process (NIST Handbook 135). Using our measured data and energy models, we projected the future potential energy and cost savings (including future capital and maintenance costs from HVAC and blinds replacements) from the use of dynamic windows as compared to traditional low-e glazing at each site.

The model includes an analysis based on a simple ROI/payback and the total realized benefits over a 30-year lifecycle. Each analysis was broken into two categories of expenditures: Capital expenditures (CAPEX), which captures all first time costs/savings including the HVAC system and peripheral components retrofit cost, and window shades/blinds costs.

Also broken out is the second category of Operating expenditures (OPEX), which is a total of all reoccurring expenses/savings impacted by the efficiency measure on an annual basis. Opex captures the costs associated with energy consumption, HVAC maintenance, and window shades/blinds maintenance. A description of each line item and section are listed in the tables below, along with any stated assumptions. All assumptions on glazing, materials, equipment, labor, utility rates, etc. were gathered by industry standard reference sources such as the RS Means Construction Cost guide and actual quotes/bids from mechanical contractors and engineering firms. These are summarized in Section 7.1, above.

8.3. COST ANALYSIS AND COMPARISON

As seen in Section 6, View dynamic glass has significant impact on annual energy and peak load reduction. This results in: 1) energy costs and demand charge savings, 2) capital equipment cost savings (e.g. HVAC downsizing and elimination of blinds/shades), and 3) maintenance cost savings (e.g. from HVAC and blinds). The economic impact of retrofitting with View dynamic glass was compared against retrofitting with low-e glass, both with dimmable lights. Table 8 shows the “first costs” of integrating dynamic windows as part a deep retrofit, showing a total net first cost increase of only 6% relative to low-e, while generating a net annual cost savings from dynamic windows of 34%. Table 9 shows the overall economic analysis for this site for the first year.

First Costs for Dynamic Windows vs Low-e Retrofits		
Component	**Low- E Glass System ($/sqft of window)**	**Dynamic Glass System ($/sqft of window)**
IGU	$20	$97
Window Frame	$30	$30
Installation Labor	$25	$28
Low Voltage Labor	$0	$2
HVAC Capex Cost*	$236	$190
Shading Capex	$15	$0
Total Net First-Cost	**$326**	**$347**
First Cost %-Increase	NA	6.4% increase

* HVAC cost normalized to the sqft of glass, by dividing the total capital equipment cost by 1807 sqft of glass

Annual Operational Expenses for Dynamic Windows vs Low-e		
Element	**Low-E Glass System ($/sqft of glass/year)**	**Dynamic Glass System ($/sqft of glass/year)**
Energy Consumption	$28.78	$21.58
HVAC Maintenance	$2.21	$1.66
Shading Maintenance	$0.17	$0.00
Total Annual Cost	**$31.16**	**$23.24**
Percentage Annual Savings	NA	34% decrease

Table 8: First Costs and Annual Operational Costs for dynamic windows and low-e . For ease of comparison, all costs have been normalized to square footage of installed glass. Costs per square footage of floor-space can be calculated by multiplying each value by 17.7 (32,000 sqft of floor space/1807 sqft of windows).

As can be seen in Table 9, there are multiple potential savings from the use of dynamic glass. In terms of capital and operational savings, the use of dynamic glass saves $82,000 in HVAC equipment up-front, plus an additional $82,000 for future HVAC replacements during the lifetime of the windows (assumed to occur every 15 years) and $30,000 savings on HVAC maintenance during this same period. Dynamic glass also results in $27,000 in up-front savings for shading attachments, plus an additional $54,000 savings on future shading replacement during the lifetime of the windows (assumed to occur every 10 years) and $9,000 savings on shades maintenance during this same period. Finally, the use of dynamic glass saves approximately $13,000 in electricity per year, or $390,000 in electricity savings over the lifetime of the windows. Overall, dynamic windows results in a $$655,000 lifetime return on investment.

Low-E vs View Dynamic Glass			
Façade Package	Low-e	Dynamic	
Glass	1,807 sf	1,807	
Internal Shading	Manual blinds	None	
Exterior Shading	None	None	
Dimmable lights	Yes	Yes	
First Time Costs (CAPEX)	Low-e ($)	Dynamic($)	Difference (Savings)
Glass installed cost	145K	293K	148K
Electrical labor	-	4K	4K
HVAC	426K	343K	(82K)
Internal shades	27K	-	(27K)
External shading			
Total CAPEX	$597K	$640K	**$42K**
Annual Operating Costs (OPEX)	($)	($)	Difference (Savings)
Energy consumption	52K	39K	(13K)
HVAC maintenance	4K	3K	(1K)
Shading maintenance	0.3K	-	(0.3K)
Total OPEX	$57K	$42K	**($14.536K)**

*Assumptions	
Low-e Glass cost	$20/sf glass cost; $68/sf installed cost
View Dynamic Glass cost	$97/sf glass cost; $155/sf installed cost
Electrical labor (dynamic only)	$2.00/sf
HVAC savings	7.0 ton reduction @ $1,60
HVAC CFM reduction	4,669 CFM; $4.08/CFM
HVAC related components	19.7% reduction from bas
Energy consumption savings	25.6% from baseline energ
HVAC Maintenance	1.0%/year of HVAC cost
Internal shades	$15.00/sf
External shades	None
Shading maintenance	$0.15/sqft/yr

Table 9: Year 1 CapEx and OpEx comparison between upgrading with View Dynamic windows vs state of the art Low-e windows.

Table 10 depicts the output of a standard NIST BLCCA analysis for this site. Year 1 Savings-to-Investment (SIR) ratio is 0.82, with a payback of less than 3 years. The 30-year SIR is 4.3, with

a total lifetime cost savings of $655,000. This case study recognizes that View windows and state-of-the-art Low-e windows both have an expected lifetime of 30 years, as does building 6311.

Dynamic vs Low-E	Years				
	1	5	10	20	30
Initial Investment (Windows) ($k)	**151.9**	**151.9**	**151.9**	**151.9**	**151.9**
Other Capex Savings ($k)	109.6	109.6	136.7	219.2	219.2
Energy Savings ($k)	13.4	67.2	134.4	268.8	403.2
Maintenance Savings ($k)	1.1	5.5	11.0	21.9	32.9
Total Savings ($k)	**124.1**	**182.3**	**282.0**	**509.9**	**655.2**
Savings/Investment	0.82	1.20	1.86	3.36	4.31
Payback	**2.91 Years**				

Table 10: NIST BLCCA cost analysis and 30-year Savings to Investment analysis

9.0 IMPACT ACROSS ALL DOD BUILDING STOCK

The analysis presented in this report is specific to the 6311 Building installation. However, in order to understand the benefit of View dynamic glass in various other building types like small and medium offices, hospital building, apartments, outpatient building etc., View and NREL worked on a detailed analysis comparing these various building types across all the climate zones in North America.

The U.S. Department of Energy (DOE), in conjunction with three of its national laboratories, developed commercial reference buildings, formerly known as commercial building benchmark models. These reference buildings play a critical role in the program's energy modeling software research by providing complete descriptions for whole building energy analysis using EnergyPlus simulation software.

There are 16 building types that represent approximately 70% of the commercial buildings in the U.S., according to the report published by the National Renewable Energy Laboratory, titled U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. These buildings are also representative of typical DOD building stock. These modules provide a consistent baseline of comparison and improve the value of computer energy simulations using software such as EnergyPlus. (http://energy.gov/eere/buildings/commercial-reference-buildings)

The baseline buildings that were used for the study were constructed pre-1980. These buildings are a close representation of old buildings which need retrofit because they were not built to any codes and standards.

The following building types were used for this analysis

Building Type Name	Floor Area (ft^2)	Number of Floors
Medium Office	53,628	3
Small Office	5,500	1
Stand-alone Retail	24,962	1
Hospital	241,351	5
Outpatient Health Care	40,946	3
Midrise Apartment	33,740	4

The 16 climate zones used to create the reference buildings are:

Climate Zone	Representative City
1A	Miami, Florida
2A	Houston, Texas
2B	Phoenix, Arizona
3A	Atlanta, Georgia
3B-Coast	Los Angeles, California
3B	Las Vegas, Nevada
3C	San Francisco, California
4A	Baltimore, Maryland
4B	Albuquerque, New Mexico
4C	Seattle, Washington
5A	Chicago, Illinois
5B	Boulder, Colorado
6A	Minneapolis, Minnesota
6B	Helena, Montana
7	Duluth, Minnesota
8	Fairbanks, Alaska

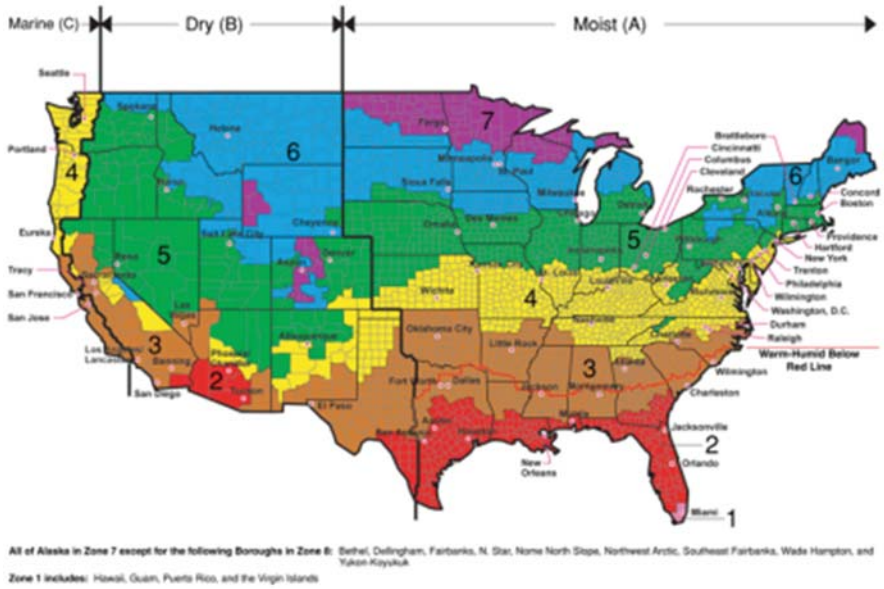


***Figure 28**: Top) standard building types. Middle) ASHRAE climate zone designations. 3) ASHRAE map of climate zones.*

Using this information and the data collected from Building 6311, we estimated the energy savings potential for each building type and across all US climate zones. Figure 29 shows the average energy savings for each building type by zone. Details of the analysis can be found in Appendix H.

	1A	2A	2B	3A	3B	3B*	3C	4A	4B	4C	5A	5B	6A	6B	7	8
Medium Office	17%	16%	20%	15%	17%	16%	16%	13%	13%	13%	8%	9%	7%	7%	7%	7%
Small Office	18%	16%	19%	14%	15%	18%	15%	10%	11%	10%	6%	7%	5%	5%	4%	4%
Outpatient Facility	10%	11%	13%	13%	13%	14%	17%	14%	14%	17%	9%	10%	9%	10%	9%	11%
Hospital	6%	7%	10%	8%	11%	6%	7%	8%	9%	9%	5%	6%	4%	6%	4%	3%
Mid-rise Apartment	6%	4%	6%	3%	3%	4%	0%	2%	1%	2%	2%	1%	1%	1%	1%	2%
Stand-alone Retail	7%	6%	7%	5%	6%	7%	5%	4%	4%	4%	2%	3%	2%	2%	2%	1%

Table 11: Annual savings with View dynamic glass in different building types and different US climate zones. All areas marked in green are savings above 10%. Detailed breakdown of annual energy and savings across different climate zones can be seen in below charts

10.0 IMPLEMENTATION ISSUES AND LESSONS LEARNED

At the center of this technology's successful demonstration is its full compatibility with modern construction practices and delivery channels. The innovation of an active coating is delivered in a form factor that is familiar to building codes and requirements and the associated installation trades. Further, the energy saving and comfort benefits apply to a broad spectrum of DOD building types and locations. However, these intrinsic technology advantages can create unforeseen project hurdles.

10.1. PROCUREMENT AND INSTALLATION

With regards to the demonstration project, there were no procurement or installation issues. View dynamic glass is positioned as a smart glass product designed for purchase and installation by DOD-qualified glazing subcontractors and low voltage subcontractors, as was the case with this project.

For future installations, it should be noted that the subcontractors control the product markup and installation pricing. As a result, it can vary based on the region of the country and the familiarity of the contractor with our product. This potential issue can be mitigated through active training and education of installers.

Further, because View dynamic glass is procured by the glazier and not the government directly, it is not currently listed on the GSA Purchasing Schedule. This has not been a barrier to date, but that situation may change. If so, View dynamic glass will become listed on the Purchasing Schedule in the future.

10.2. STRUCTURAL LOAD

There were no structural load issues with the demonstration project. View dynamic glass weighs approximately the same as traditional low-e insulated glass units (approximately 4 pounds per square foot) and replaced a mixture of single pane and dual pane existing glass. However, for future renovation and retrofit projects where single pane glass is being removed or added to, the additional skin load can potentially be an issue (as would dual-pane low-e windows). As such, in renovation projects where single pane glass is in place the project team should include a structural engineer in early discussions.

10.3. WINDOW OPERABILITY

For this demonstration project, operable windows were replaced with inoperable (fixed) windows to optimize energy efficiency and HVAC load management (note: View dynamic glass is also available in operable windows). The operable windows had been in place for decades, with employees accustomed to their presence and flexibility. The conversion to inoperable

windows caused an unforeseen reluctance to accept the design and environment change in their familiar office space. This was mitigated via training, user surveys and a closely monitored employee transition period. This change was unrelated to the dynamic glass technology, but impacted its immediate acceptance.

A change of window operator type should be considered as a potential objection in future installations. Although there are positive energy benefits, occupants tend to reject the loss of operability and can weigh that against the energy and comfort benefits of dynamic glass. When possible, replacement dynamic glass windows should match the prior operation type. Note that View dynamic windows are available in operable, as well as inoperable formats.

10.4. Occupant Training

With the experience from this project, we learned that occupant training is a key element of project commissioning and should be included as a project milestone in any installation. Following the successful completion of this project, the project team feels that it may be the most important milestone for successful adoption.

The basis of the training should be to set expectations on glass tint transition time. The glass is designed to predictively tint and clear to maximize comfort. This is a gradual process that may occur infrequently throughout the day. However, occupants expected the glass to transition quickly and often in response to non-comfort or energy conditions. If occupants' expectations are not aligned with the glass' purpose and performance, it may be rejected as a technology due to a misunderstanding.

It is recommended that future project teams share key features and benefits of dynamic glass with the building occupants both before and after the product installation. Occupants should also be encouraged to participate in satisfaction surveys designed to improve the behavior algorithm for that project site.

10.5. Building Automation

For the scope of this demonstration project, View dynamic glass was designed to operate as a fully autonomous network with integrated intelligence to maximize comfort and energy efficiency. This made it ideal for both this application and the aging DOD building stock that has little or no building automation in place. During project execution, the team learned that a Johnson Controls Metasys building automation system was in place. In order to demonstrate the ability for building automation integration, the View dynamic glass was integrated into that existing system.

Full integration of the two systems is possible, in fact it was successfully completed during this demonstration project, but it requires planning and coordination between the View and automation software teams. This should be an early discussion topic during the scoping phase of a renovation project. Also, software compatibility should be a consideration. View uses a standard BACnet protocol, which is nearly universal in building automation systems. As a result, it may be incompatible with some non- BACnet systems.

11.0 REFERENCES

[i] FY 2012 Budget of the United States Government, Fiscal Year 2012. It is often referred to as the "President's budget request"

[ii] "Opening the Thermal Envelope: Emerging Innovation in Dynamic Windows and Advanced Insulation Webinar", Lux Research, August 16, 2011.

[iii] Office of the Deputy Under Secretary of Defense Installations and Environment, "Real Property Inventory Requirements Document"

[iv] "Demonstrating the Relative Cost-Benefit of Reusing Historic & Non-Historic DOD Properties Using Scientifically-Derived Data", Cherilyn Widell, Demonstration Plan, ESTCP Project Number SI 0931. Unpublished

[v] Executive Order 13514, "Federal Leadership in Environmental, Energy and Economic Performance" (October 5, 2009)

[vi] Federal Acquisition Regulation, Sustainable Acquisition interim rule "FAR Case 2010-001"

[vii] View grant progress report, Department of Energy Technology Laboratory, Funding Opportunity Number: DE-FOA-2010-0000115

[viii] Ibid Reference MI plant PR

[ix] http://www.mckinstry.com/capabilities/energy/Federal

[x] http://www.terrapinbrightgreen.com/report/economics-of-biophilia/

12.0 APPENDIX A: Points of Contact

Point of Contact	Organization	Mailing Address (and FedEx address, if different)	Phone & E-mail	Role in Project
Brandon Tinianov	View, Inc.		408-828-4758 Brandon.tinianov@View.com	PI
Namrata Vora	View Inc.		(408) 263-9225 namrata.vora@View.com	
Deepika Khowal	View Inc.		318-243-2094 Deepika.khowal@viewglass.com	Energy modeling and data analysis lead
Vaibhav Potnis	McKinstry		(503) 278-3943 vaibhavp@McKinstry.com	M&V Lead
Rob Gugliemetti	National Renewable Energy Lab (NREL)		(303) 275-4319 robert.guglielmetti@nrel.gov	Energy Modeling and Analysis Lead
Mick Wasco	Marine Corps Air Station Miramar		(858) 864-3466 mick.wasco@usmc.mil	Host Site Utilities and Energy Manager

Table 12: View Demonstration Points of Contact

13.0 APPENDIX B: Monitoring Plan

13.1. BACKGROUND AND PROJECT DESCRIPTION:

View Inc., through a partnership with the Department of Energy (DOE) ESPTC program, enlisted McKinstry to provide M&V technical expertise, technical analysis and support in the development and implementation of dynamic glass. McKinstry provided the National Laboratory technical expertise in the area of Monitoring and Measurement and Verification (M&V) at MCAS Miramar Public Works Building 6311.

The following areas were identified as monitoring targets for this facility.

- Major HVAC Equipment
- Lighting Systems

The Public Works facility, Building 6311, was targeted for deployment of the Dynamic Glass design. To support the design effort working with View Inc. and the DOE, McKinstry developed a detailed monitoring plan for the facility.

13.2. MONITORING PLAN OBJECTIVE AND SCOPE:

The objectives of this monitoring plan were:

1. To provide an understanding of measured energy flows as it applies to building 6311
2. To Help establish a baseline for the energy performance
3. To Support the Technical Team's modeling effort with discrete monitored data

The information gathered during the implementation of this plan provided the details needed to complete a comprehensive calibrated computer simulation of existing energy use, loads and baselines that were later used to verify the energy savings after construction was complete.

The monitoring plan as described herein identifies the scope of work at the facility along with the equipment that wasneeded and the parameters around which these measurements were taken. Information detailing equipment used and means for collecting data was included.

13.3. SECTION 2: MONITORING SOLUTION

MONITORING BOUNDARY:

The suggested monitoring approach for this project consisted of live monitoring data through Dent Energy & Power Measurement Solutions utilizing Modbus communications protocol.

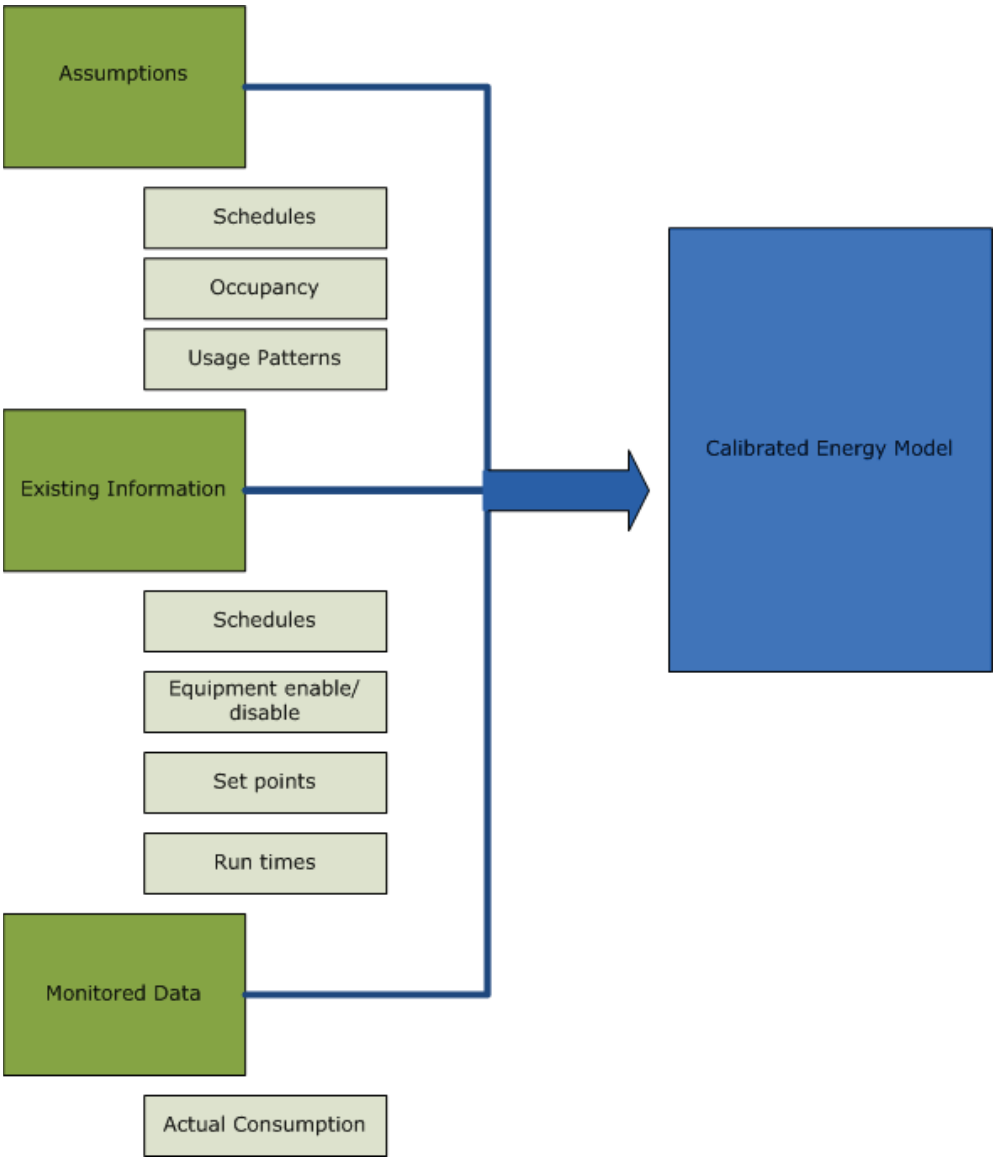


Figure B-1: Monitoring Approach

McKinstry supported the data acquisition, formatting and analysis of the monitored data.

MONITORING APPROACH:

The monitoring solution was deployed at the Public Works Facility, Building 6311, at MCAS Miramar in San Diego, CA with a focus on HVAC and Lighting systems using Current Transducers (CTs) installed at the electrical panels identified during the site audit.

The design was based on a combination of Dent Instruments PowerScout 18 type data loggers, compatible split-core CTs and an Obvius Acquisuite EMB A8810 data acquisition sever which communicates via GSM/GPRS. A diagram of the proposed solution is provided below.

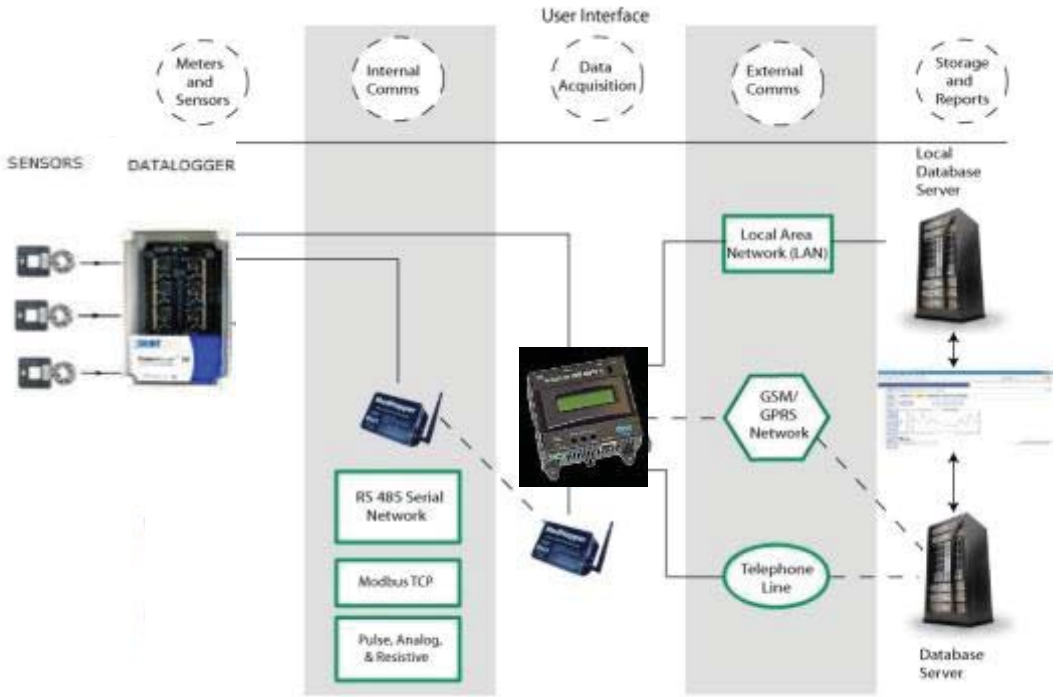


Figure B-2: Integrated monitoring system

Once the CTs were connected to the data logger, the data streams were collected back to our database servers. McKinstry utilized its Remote Operations Center (ROC) to poll the data loggers connected to the Acquisuite to periodically download data and transfer the data to an InfoCenter™ site. InfoCenter™ is a McKinstry developed platform that allows data storage, retrieval and communication among various team members (see Appendix for details). We then formated the data as required.

Monitoring architecture

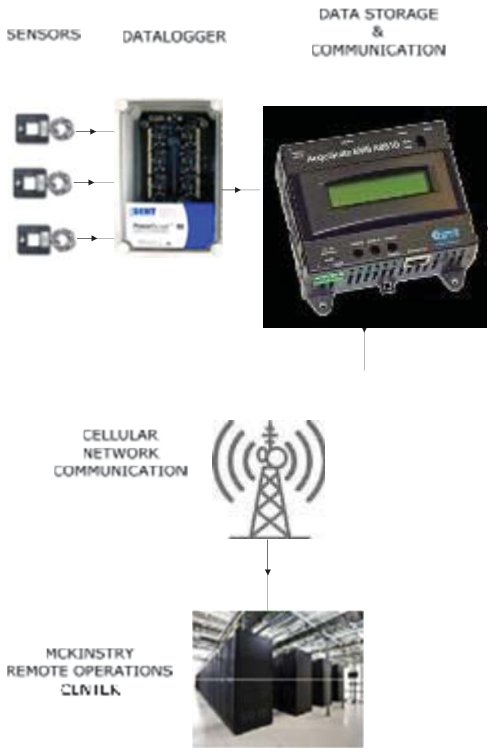


Figure B-3: Data logger and data communication systems

MONITORING POINTS:

The following monitoring points were covered for this project:

Sr. No.	Tag	Description	Location	Panel Name	Panel/Breaker Details		# of CT's per Location	Equipment Type	P/N	Installation Location	Notes
					Amper-age	Phas					
1	6311- AC1	Carrier WeatherMaster 9.5 Ton RTU. S/N: 4109G20631	Electrical Room (Vault No C4-F27-4)	PANEL K	100	3	3	100A Model: 2 - 130A AC Small Split Core	CT-SCS-0100-U/B	In panel	Wire to PowerScout 1
2	6311- AC2	Northside gas-pack RTU, no nameplate	Electrical Room (Vault No C4-F27-4)	PANEL K	100	3	3	100A Model: 2 - 130A AC Small Split Core	CT-SCS-0100-U/B	In panel	Wire to PowerScout 1
3	6311- AC3	Southside gas-pack RTU, no nameplate	Electrical Room (Vault No C4-F27-4)	PANEL K	100	3	3	100A Model: 2 - 130A AC Small Split Core	CT-SCS-0100-U/B	In panel	Wire to PowerScout 1
4	6311- AC4	Carrier WeatherMaker, 3 Ton RTU. S/N: 2409G10273	Electrical Room (Vault No C4-F27-4)	PANEL K	30	2	2	50A Model: 5 - 65A AC Small Split Core	CT-SCS-0050-U/B	In panel	Wire to PowerScout 1
5	6311- AC5	Trane 10 ton Packaged HP. S/N: 939100295L	Electrical Room (Vault No C4-F27-4)	PANEL K	30	2	2	50A Model: 5 - 65A AC Small Split Core	CT-SCS-0050-U/B	In panel	Wire to PowerScout 1

6	6311- AC6	Trane 10 ton Packaged HP. S/N: 938100289L	Electrical Room (Vault No C4-F27-4)	PANEL K	30	2	2	50A Model: 5 - 65A AC Small Split Core	CT-SCS-0050-U/B	In panel	Wire to PowerScout 1
7	6311- AC7	Trane Voyager Pack- aged HP. S/N: Z46100912D	Electrical Room (Vault No C4-F27-4)	PANEL K	40	2	2	50A Model: 5 - 65A AC Small Split Core	CT-SCS-0050-U/B	In panel	Wire to PowerScout 2
8	6311- AC8	Ruud 5 ton Packaged HP. S/N: 5581F479812928	Electrical Room (Vault No C4-F27-4)	PANEL K	40	2	2	50A Model: 5 - 65A AC Small Split Core	CT-SCS-0050-U/B	In panel	Wire to PowerScout 2
9	Verify Unit on site	Verify connected unit on site	Electrical Room (Vault No C4-F27-4)	PANEL K	?	?	?	50A Model: 5 - 65A AC Small Split Core	CT-SCS-0050-U/B	In panel	Wire to PowerScout 2
10	PowerScout1	BACnet Power Meter	Electrical Room (Vault No	-	-	-	-	PowerScout 18	PS18-D	Adjacent panel K	

11	PowerScout2	BACnet Power Meter	Electrical Room (Vault No C4-F27-4)	-	-	-	-	PowerScout 18	PS18-D	Adjacent panel K	
12	6311-LTG1	Area served to be veri- fied by electrician	Electrical Room	PANEL P	50	3	3	50A High Perf. Mini Current Transformer	CT-HSC-050- U	In panel	Wire to PowerScout 3
13	6311-LTG2	Area served to be verified by electrician	Electrical Room	PANEL P	50	3	3	50A High Perf. Mini Current Transformer	CT-HSC-050- U	In panel	Wire to PowerScout 3
14	6311-LTG3	Area served to be verified by electrician	Electrical Room	PANEL P	50	3	3	50A High Perf. Mini Current Transformer	CT-HSC-050- U	In panel	Wire to PowerScout 3
15	6311-LTG4	Area served to be verified by electrician	Electrical Room	PANEL P	50	3	3	50A High Perf. Mini Current Transformer	CT-HSC-050- U	In panel	Wire to PowerScout 3
16	6311-LTG5	Area served to be verified by electrician	Electrical Room	PANEL P	50	3	3	50A High Perf. Mini Current Transformer	CT-HSC-050- U	In panel	Wire to PowerScout 3

17	6311-LTG6	Area served to be verified by electrician	Electrical Room	PANEL P	5	3	3	50A High Perf. Mini Current Transformer	CT-HSC-050- U	In panel	Wire to PowerScout 3
18	PowerScout3	BACnet Power Meter	Electrical Room (Vault No C4-F27-4)	-	-	-	-	PowerScout 18	PS18-D	Adjacent panel K	

Section 3: Implementation

PROCUREMENT:

McKinstry procured the monitoring equipment.

IMPLEMENTATION STEPS:

The following milestones were met to ensure successful implementation of this monitoring plan:

1. Reviewed and approve monitoring plan and equipment specifications by electrician/installer *(2 days, by 9/19/2012)*

2. Equipment arrived at McKinstry for pre-install configuration of AcquiSuite, ModHoppers and data loggers *(3 days*; by *9/24/2012)*

3. View Inc. worked with a local sub-contractor to have a licensed electrician on site to install the sensors in the electrical panels specified in the submittal packet

4. McKinstry was available on site to provide installation guidance (Total one day required on site for installation and configuration; installation completed by 9/28/2012)

5. Once installed, McKinstry configured the data collection and downloaded setup

6. Every week McKinstry's Remote Operations Center (ROC) downloaded data and sent to the M&V team for formatting and analysis.

7. Formatted datasets will be available on InfoCenter™ on a weekly basis.

EQUIPMENT INSTALLATION

The following tasks were to be completed by a designated Vew Inc.engineer and electrician prior to equipment procurement.

1. Verified connectivity, circuit size and labeling of HVAC equipment to electrical panel K located in Vault Room C4-F27-4 on East facing wall

2. Verified connectivity, circuit size and labeling of lighting systems on electrical panel P located in the room CONC 117 as designated on drawing number 6311-1, dated 3/16/2009

3. Ensured adequate space at specified mounting location for PowerScout 1, 2 & 3 and AcquiSuite A8810 enclosure

Installation of McKinstry specified data collection equipment was installed by the project construction contractor while data collection equipment wascoordinated by McKinstry team. The following tasks were to be completed by an electrician once equipment was procured

1. Mounted and terminated three (3) Dent PowerScout 18 meters (units 1, 2, & 3) at specified location(s)

2. Mounted one (1) AcquiSuite A8810-GSM EMB in provided Nema enclosure in electric vault C4-F27-4 and terminated to daisy-chained PowerScout 18 Meters 1 & 2.

3. Mounted and terminated two (2) ModHopper R9120-3 wireless transceivers (units MH01 and MH02) at specified location

4. Attached and terminated all equipment specified in section 2.3 of the of this document

Appendices

APPENDIX A: DESIGN DRAWINGS AND SITE PLANS

APPENDIX B: DENT POWERSCOUT 18 INFORMATION AND INSTALLATIONGUIDE

APPENDIX C: DENT CURRENT TRANSFORMER DATASHEETS

APPENDIX D: OBVIUS ACQUISUITE DATASHEETS APPENDIX E: OBVIUS MODHOPPER DATASHEETS

ModHopper- Wireless Modbus *I* Pulse Tranceiver

Collecting information from multiple meter points at existing sites can be challenging. The Obvius ModHopper makes it easy. The ModHopper is specifically designed to wirelessly transmit meter data from multiple meter points over long distances. Obvius' unique "mesh" technology provides optimized routing of communications, allowing the ModHopper to function with a high level of reliability where other wireless solutions have failed. The ModHopper is self-configuring and does not require a PC or software for setup, minimizing installation time and disruption of site operations. The ModHopper can be used with any Modbus master making it the ideal solution for metering projects.

14.0 APPENDIX C: Occupant Info and Educational Information

view

Occupant Information Sheet

View Dynamic Glass

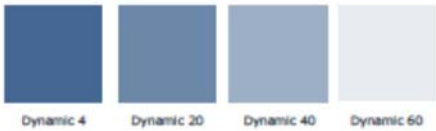
Benefits

Enjoy the many benefits of View Dynamic Glass in your space:

- Unobstructed views all day keeps you connected to the outdoors
- More natural daylight that improves productivity and well-being
- Greater occupant comfort
- Significant energy savings
- Intelligent control keeps the glass in an optimal state
- More architectural design freedom to use more glass in building designs

Operation

View Dynamic Glass is capable of transitioning to four different tint states. Dynamic 4 is the fully tinted state and Dynamic 60 is the fully clear state, with Dynamic 20 and Dynamic 40 being the two intermediate states.



The glass will exhibit a "theater curtain" effect during transition; the transition begins along the long edges of the glass and gradually moves toward the center. Once the transition is complete the glass will look uniform again.

During transition the change in color will begin along the two long edges of the glass inward to the center

The time it takes for a dynamic glass window to change between tint states depends on the size of the glass, ranging from 10 min. for smaller windows and on the order of 20 min. for larger windows in this building.

To accurately control states, the system is "disabled" and cannot be commanded to go to another tint state during transition.

Control

Intelligence Control

If your dynamic glass system is outfitted with Intelligence control, the system will automatically tint based on the position and intensity of the sun and on the interior space's design requirements.

Intelligence's first directive is to prevent direct glare on an occupant. Direct glare is calculated using sun penetration parameters for the specific layout of the room. When direct glare is anticipated, the glass will transition to its darkest state, Dynamic 4. If direct glare is not predicted, the glass will maintain a state that maximizes daylight (Dynamic 20, 40 or 60) while balancing heat gain.

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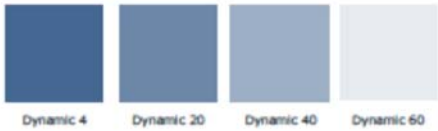

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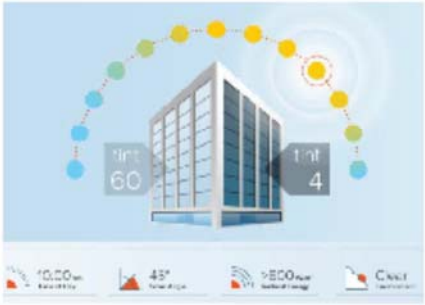

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Operation

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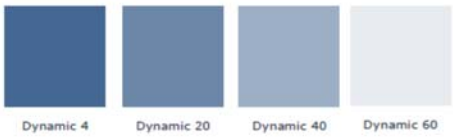


The glass will exhibit a "theater curtain" effect during transition; the transition begins along the long edges of the glass and gradually moves toward the center. Once the transition is complete the glass will look uniform again.

The time it takes for a dynamic glass window to change between tint states depends on the size of the glass, ranging from 10 min. for smaller windows and on the order of 20 min. for larger windows in this building.

To accurately control states, the system is "disabled" and cannot be commanded to go to another tint state during transition.

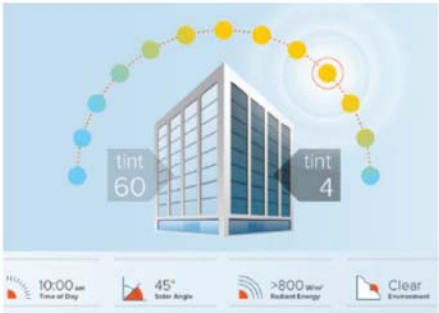
During transition the change in color will begin along the two long edges of the glass inward to the center

Control

Intelligence Control

If your dynamic glass system is outfitted with Intelligence control, the system will automatically tint based on the position and intensity of the sun and on the interior space's design requirements.

Intelligence's first directive is to prevent direct glare on an occupant. Direct glare is calculated using sun penetration parameters for the specific layout of the room. When direct glare is anticipated, the glass will transition to its darkest state, Dynamic 4. If direct glare is not predicted, the glass will maintain a state that maximizes daylight (Dynamic 20, 40 or 60) while balancing heat gain.



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Occupant Information Sheet

Schedule Control

The glass can also be controlled using time schedules. These user created schedules tint the glass at set times throughout the day.

Manual control using Wall switch or Mobile app (iOS)

View's wall switch and mobile app give users the freedom to change tint states by a push of a button. The wall switch will change the tint state of the glass. The four vertical buttons correspond to the four tint states, ranging from clearest (top) to darkest (bottom). To change the tint state of the glass, press the desired button once. A flashing light indicates the glass is currently transitioning to a tint state. During this time user override is disabled.

The user can override the glass using the wall switch or mobile app. Control reverts back to Intelligence after the override time-out duration:

- Override timeout when using a wall switch: 3 hour default
- Override timeout when using the View mobile app:
  User selectable time-out ranging from 30 min to 8 hrs

Support

If you have further questions about the operation of your system, contact your facilities/building manager:

Mick Wasco, Energy Manager
mick.wasco@usmc.mil

To allow us to continually improve our product and the user experience, please provide feedback on your experience with View Dynamic Glass installed in your building. This survey asks about visual and thermal comfort, views and your overall satisfaction as an occupant of the space.

http://www.nrel.gov/ap/workspace_survey/followup.cfm.

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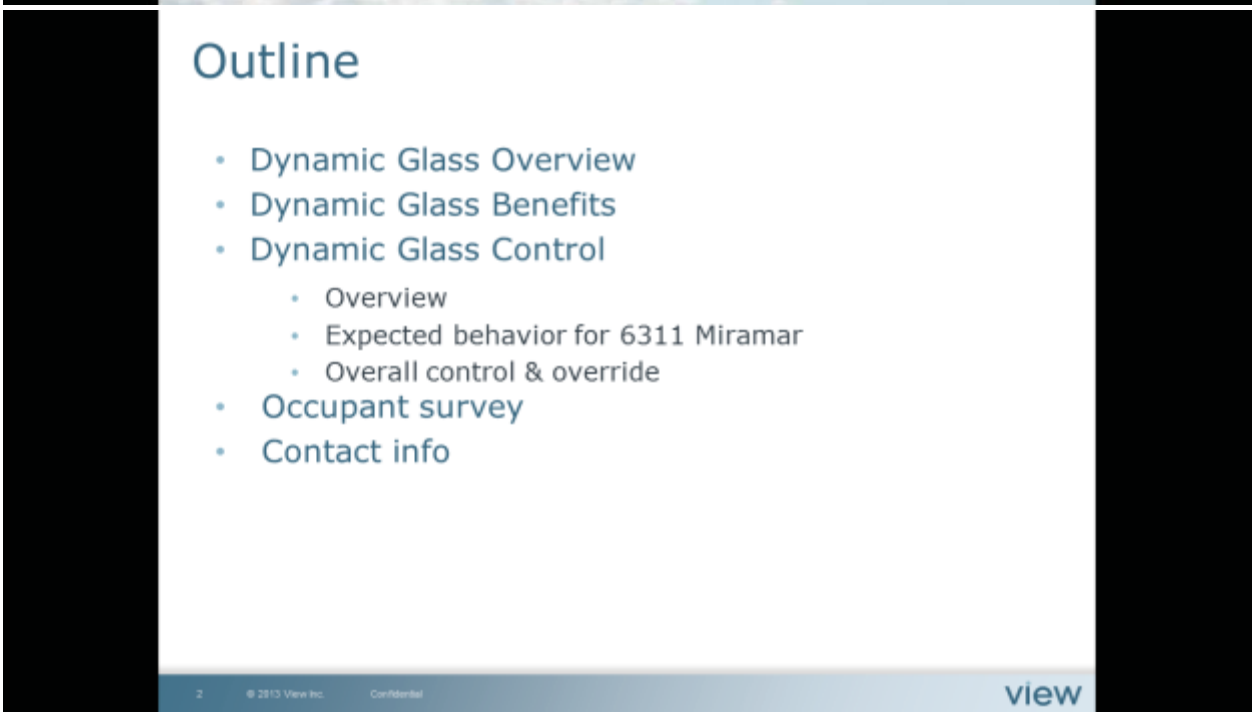
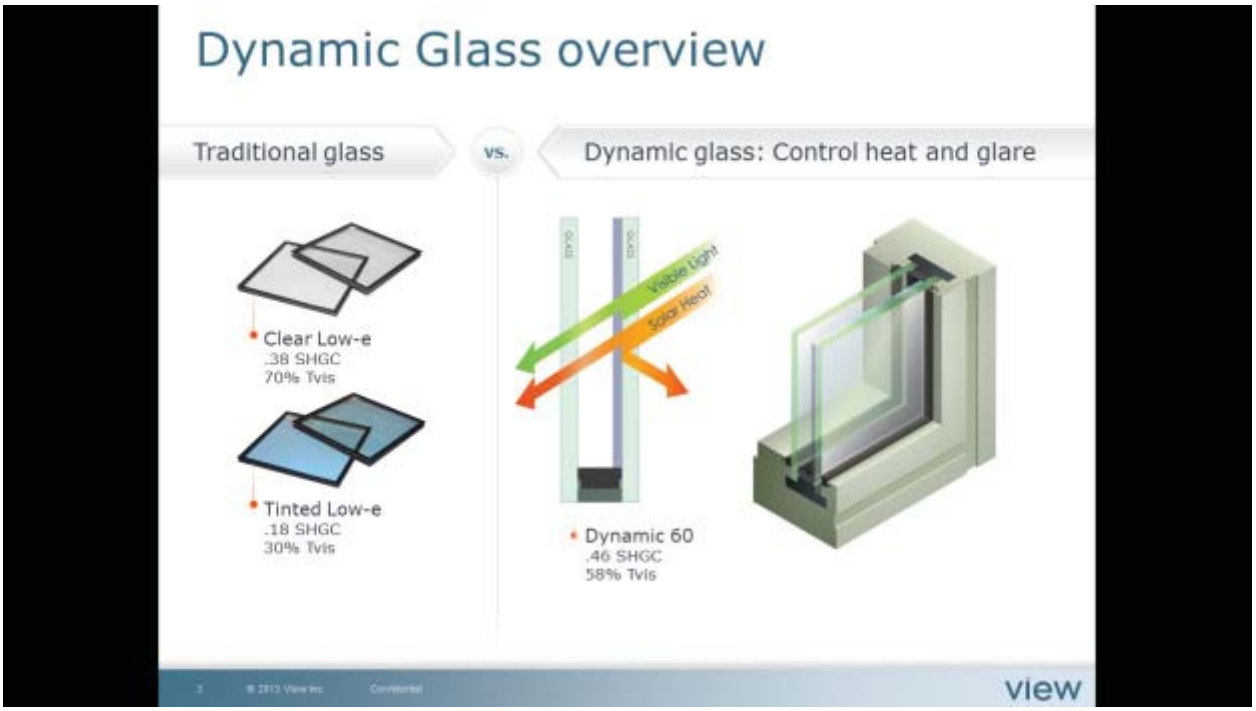
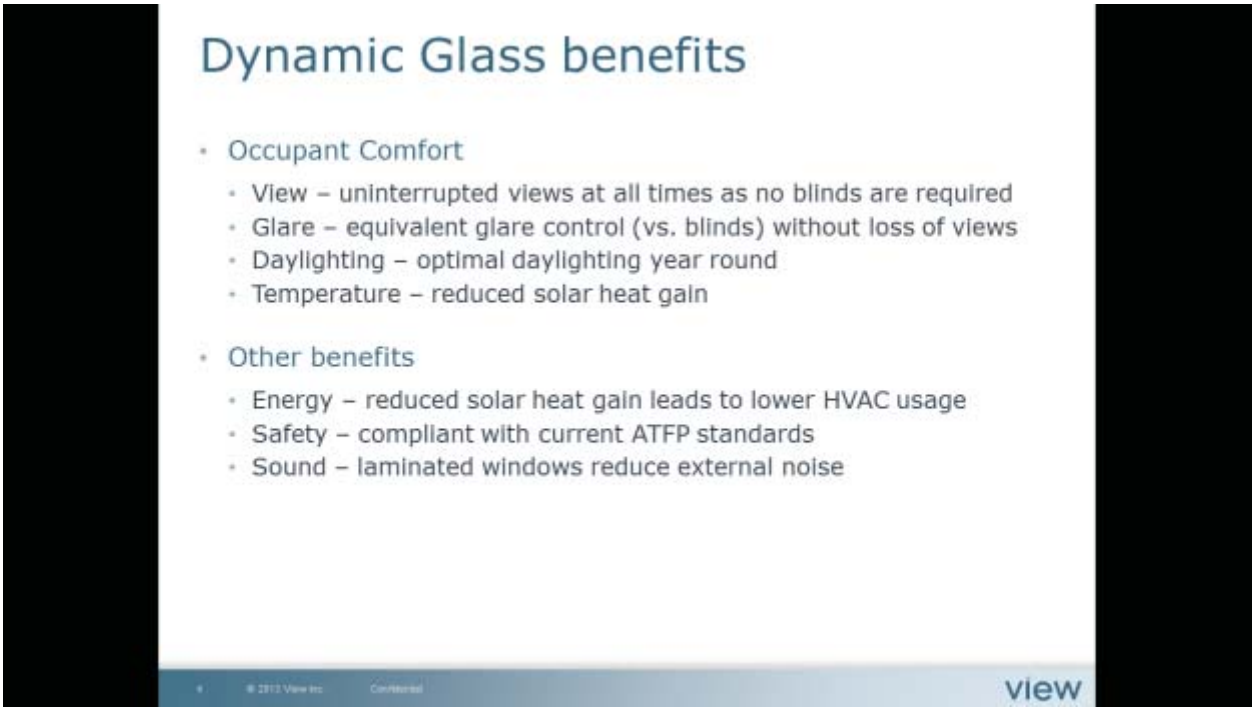
15.0 APPENDIX D: Occupant Intelligent Control Overview Presentation:




Dynamic Glass overview
Traditional glass
vs.
Dynamic glass: Control heat and glare
Clear Low-e
.38 SHGC
70% Tvis
Tinted Low-e
.18 SHGC
30% Tvis
Visible Light
Solar Heat
Dynamic 60
.46 SHGC
58% Tvis
view


Dynamic Glass benefits
Occupant Comfort
View – uninterrupted views at all times as no blinds are required
Glare – equivalent glare control (vs. blinds) without loss of views
Daylighting – optimal daylighting year round
Temperature – reduced solar heat gain
Other benefits
Energy – reduced solar heat gain leads to lower HVAC usage
Safety – compliant with current ATFP standards
Sound – laminated windows reduce external noise
view

Predictive Intelligence Control
Glass is always in the optimum state for comfort and performance
tint
60
tint
4
10:00
45°
Adjusts according to location, space type, weather & user preference
view

Predictive Intelligence Control
Glass is always in the optimum state for comfort and performance
tint
4
tint
40
02:00
45°
Adjusts according to location, space type, weather & user preference
view

Predictive Intelligence Control

Glass is always in the optimum state for comfort and performance

Adjusts according to location, space type, weather & user preference

view

Dynamic Glass Control in 6311 Miramar

Example behavior on east façade

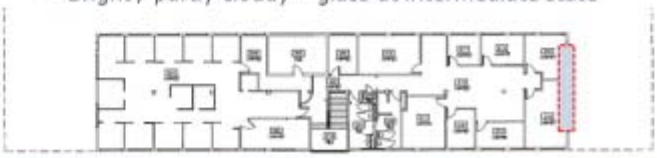
- Clear days (Summer or winter)
  - Mornings Direct sun → direct glare → glass mostly at darkest state
  - Afternoon/evenings No direct sun → no glare → Intermediate or clear state
- Cloudy days
  - Dull cloudy (low light level) – glass at clearest state
  - Bright / partly cloudy – glass at intermediate state

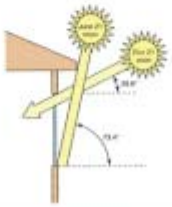
view

Dynamic Glass Control in 6311 Miramar

Example behavior on south façade

- Clear days – Summer
  - No direct sun → no direct glare → glass rarely at darkest tint
  - Clearest state in early mornings and late evenings
  - Intermediate states during most of the day
- Clear days – Winter
  - Direct sun for most day → direct glare → glass mostly at darkest tint
  - When no direct sun then glass likely at clearest state
- Cloudy days
  - Dull cloudy (low light level) – glass at clearest state
  - Bright / partly cloudy – glass at intermediate state





view

Dynamic Glass Control in 6311 Miramar

BEFORE
Glare, blinds blocking views

AFTER
No Glare, uninterrupted views

view

Dynamic Glass Control in 6311 Miramar

- Automated control all year around
  - All windows belonging to same zone will be in same state
  - Transition time varies by glass sizes
- Wall switch
  - Overrides the glass to any of the 4 states
  - Override lockout during glass transition (blinking light)
  - Override timeout = 3 hrs. (i.e. will revert back to Automated control)
  - E.g. users might override the glass state for following reasons
    - Special events: like conference etc.
    - Override for user comfort

WALL SWITCHES WILL BE BLOCKED FOR INITIAL MONITORING PERIOD TO REVIEW PERFORMANCE OF THE AUTOMATED SYSTEM

Wall switch picture

view

Occupant Survey

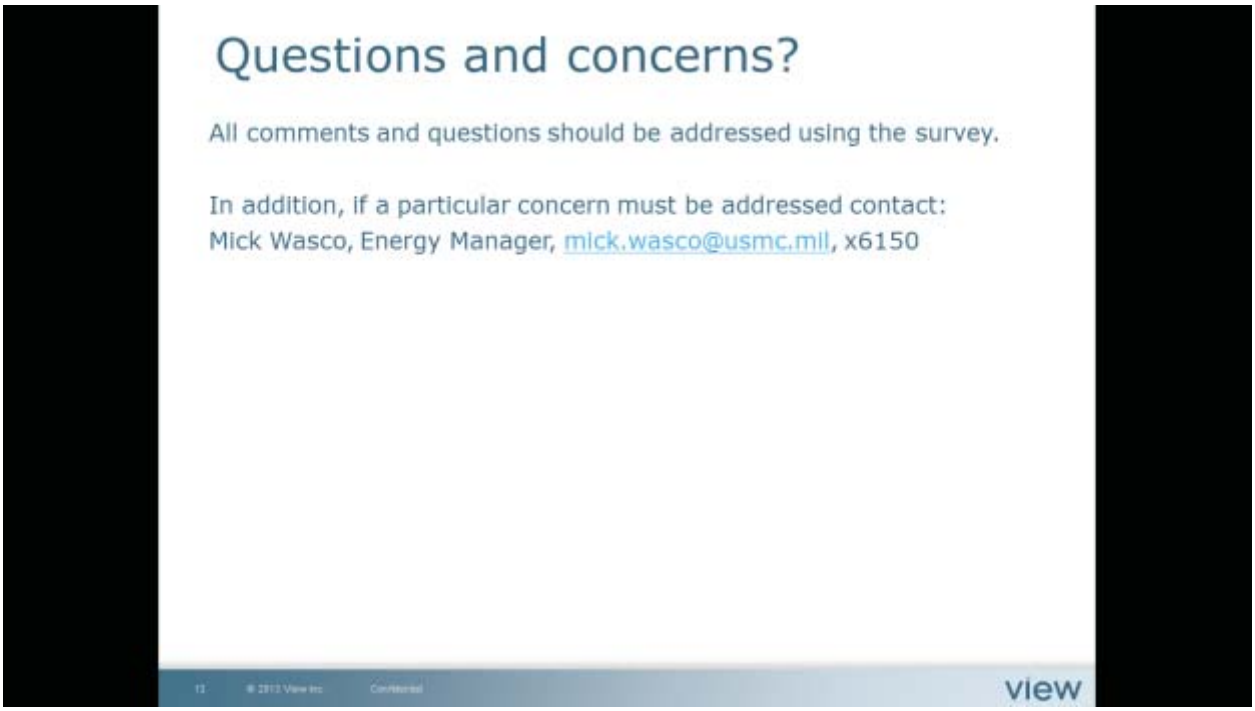
- The technology will be evaluated based, in part, on your feedback before and after the installation
- An ongoing survey about existing and new building features will be available starting September 2013. Your participation is very important. Please give feedback at the time that you experience comfort or discomfort

  http://www.nrel.gov/ap/workspace_survey/followup.cfm
- We encourage users to keep their blinds open

Examples of survey submissions:

- "There is glare in my office at 8am because the window is too clear..."
- "My space feels cool with the windows tinted, even with the sun out."
- "I like the uninterrupted Views through my windows".
- "I like the atmosphere of my office with the windows tinted and the blinds open."

view


Questions and concerns?
All comments and questions should be addressed using the survey.
In addition, if a particular concern must be addressed contact:
Mick Wasco, Energy Manager, mick.wasco@usmc.mil, x6150
view

16.0 APPENDIX E: Simulation and Field Evaluation

Executive Summary

In support of ESTCP project "Simulation and Field Evaluation Support for ESTCP Dynamic Windows Technology Evaluation," NREL has performed several functions:

- Building survey and monitoring of retrofit View Glass electrochromic glazing performance factors at Building 6311, MCAS Miramar, San Diego, CA
- Detailed modeling of building energy use at Building 6311, based on survey data and McKinstry audit data
- Modeling exercise designed to extrapolate View Glass performance from in situ data at MCAS Miramar to broader DoD building stock/climate zones
- Solicitation of occupant feedback at MCAS Miramar building, during 12-month post-retrofit monitoring period

This report details the preliminary findings from the in situ evaluation, the detailed Miramar building energy modeling, and the building stock performance extrapolation. Due to delays in completing the glazing retrofit, the 12-month occupant feedback data collection is still underway. The final results of the occupant feedback – and companion glare prediction simulation – will be completed in September 2014; this report will be revised at that time to include all data and has therefore been termed a "draft" report for this June 30 2014 issue.

In general, the solar control capability of the View Glass product lends itself to envelope-dominant building types and climates with high solar load potential. As such, potential energy savings were highest in office buildings, located in predominantly warm climates. Buildings with a significant internal load, or those driven by unique ventilation or other internal loads (e.g., hospitals) did not benefit significantly from the addition of View Glass, in the modeling exercise. Unsurprisingly, the introduction of View Glass to older/existing buildings -- which tend to have poorly-performing glazing installed -- showed a greater benefit than on new construction, particularly in the cases cited above.

Acknowledgments

This work was performed under contract with the US Department of Defense - Environmental Security Technology Certification Program (ESTCP); DOD work order W7RDV21985497; NREL OTT Agreement Number IAG 12-1848.

The Project participants are also grateful for the continued support from the US Department of Energy via the NREL OpenStudio project.

1.0 Building 6311 Detailed Modeling

In support of ESTCP project "Simulation and Field Evaluation Support for ESTCP Dynamic Windows Technology Evaluation," NREL has implemented n-state electrochromic (EC) glazing actuators in EnergyPlus, and have created a baseline model of Building 6311 at MCAS Miramar in San Diego, California. View Glass, Inc. and a subcontractor have shared control logic details and a Radiance utility script to facilitate implementation of a Radiance/EnergyPlus cosimulation process, in order to create a working predictive model for extrapolating the performance of View Glass' product in other climate zones.

1.1 SUMMARY

View Glass control rules A, B, and C were implemented in EnergyPlus and work together programmatically as the algorithm intends. We first present results for each rule independently, and then show "combined results" which reflect the energy performance of the View Glass operating under the engineered algorithm.

Once the operation of the model controls was confirmed, the Miramar model was additionally run using weather from other nationally-representative climate zones on opposite extremes (DOE Climate Zone 2A [representative city Houston, Texas] and 5A [representative city Chicago, Illinois]), in order to roughly bound the performance potential ahead of the full building type/climate zone sweep.

Savings at the Miramar test site are not significant, but this is likely due to the moderate climate in San Diego. This was a primary reason for running the model in the additional climate zones. Basic findings are that the View Glass product works well in warm sunny climates, but the intelligent control of window tint has a negative impact in cold climates, through the loss of passive solar heating.

1.2 RULE A

For this rule, the tint state of the glass is dictated by the sun penetration depth into the space. The penetration depth is determined with the solar horizontal projection angle. The tint state is determined using Table E-1:

Table E-1 Glass Tint States Determined by Penetration Depth

Penetration Depth	Phase	Tint Level	Glass VLT	Glass SHGC
< 2 ft	0	Dynamic 60	58%	0.46
2 – 4 ft	10	Dynamic 20	20%	0.16
> 4 ft	15	Dynamic 4	3%	0.09

1.3 RULE B

For this rule, the tint state is determined by the maximum solar radiation for each façade and a fixed datum SHGC compared to the current solar radiation value and the SHGC of each tint state of the glass. At each simulation iteration for each façade, the product of each of the tint state SHGCs (0.04, 0.20, and 0.60) and the clear sky radiation is compared to the product of the maximum clear sky radiation and a datum SHGC (0.25). The tint state is chosen such that the product of each of the tint states' SHGCs (0.04, 0.20, or 0.60) and the clear sky radiation is less than the product of the maximum clear sky radiation and the datum SHGC (0.25).

1.4 RULE C

This rule is very similar to Rule B except that instead of the maximum clear sky radiation, the value from a solar radiation sensor placed at each window is used. If the sensor value is greater than the clear sky radiation value, the tint state is determined by the sensor value for each window and a fixed datum SHGC compared to the current solar radiation value and the SHGC of each tint state of the glass. At each simulation iteration for each façade, if the sensor value is greater than the clear sky radiation value, the product of each of the tint state SHGCs (0.04, 0.20, and 0.60) and the clear sky radiation is compared to the product of the sensor value and a datum SHGC (0.25). The tint state is chosen such that the product of each of the tint state SHGCs (0.04, 0.20, or 0.60) and the clear sky radiation is less than the product of the sensor value and the datum SHGC (0.25).

1.5 COMBINED RULES

Rules A, B, and C were combined according to the following logic: if the value of a solar radiation sensor placed at each window is less than 100 W/m², then Rule C will determine the final tint state of the glass. If the sensor reading is greater than 100 W/m², first check the output of a modified version of Rule A, where tint state is determined using Table E-2:

Table E-2 Modified Glass Tint States Determined by Penetration Depth

Penetration Depth	Phase	Tint Level	Glass VLT	Glass SHGC
< 2 ft	0	Dynamic 60	58%	0.46
> 2 ft	15	Dynamic 4	3%	0.09

If the output of the modified version of Rule A is Phase 15, then that is the final tint state of the glass. However, if the output of the modified version of Rule A is Phase 0, then the final tint state of the glass is determined by running Rule B.

The results of an annual energy simulation using the combined rules can be found Table E-3 in and Figure E-1. The simulations were performed using EnergyPlus, EMS controllers for the windows, and TMY2 weather input data. Similar to Rule A, B, and C, the results show that the EC glass resulted in a small increase in heating energy due to times when the building is in heating mode and the increased solar gain is beneficial. However, the EC glass also resulted in a decrease in cooling and fan energy that overcame the small heating energy increase, resulting in an annual whole-building energy savings of about 4.5% and an annual HVAC savings of 16.8%. Greenhouse gas differences between the two simulations are in Table E-4.

Table E-3 Combined Rules Energy Modeling Results

End Use	Baseline (kBtu/ft²yr)	Combined (kBtu/ft²yr)
Interior Equipment (electric)	14.35	14.35
nterior Lighting (electric)	12.87	12.87
Heating (electric)	0.12	0.13
Heating (gas)	0.35	0.44
Cooling (electric)	1.93	1.54
Fans (electric)	7.84	6.41
SWH (gas)	0.76	0.76
Total	38.23	36.51

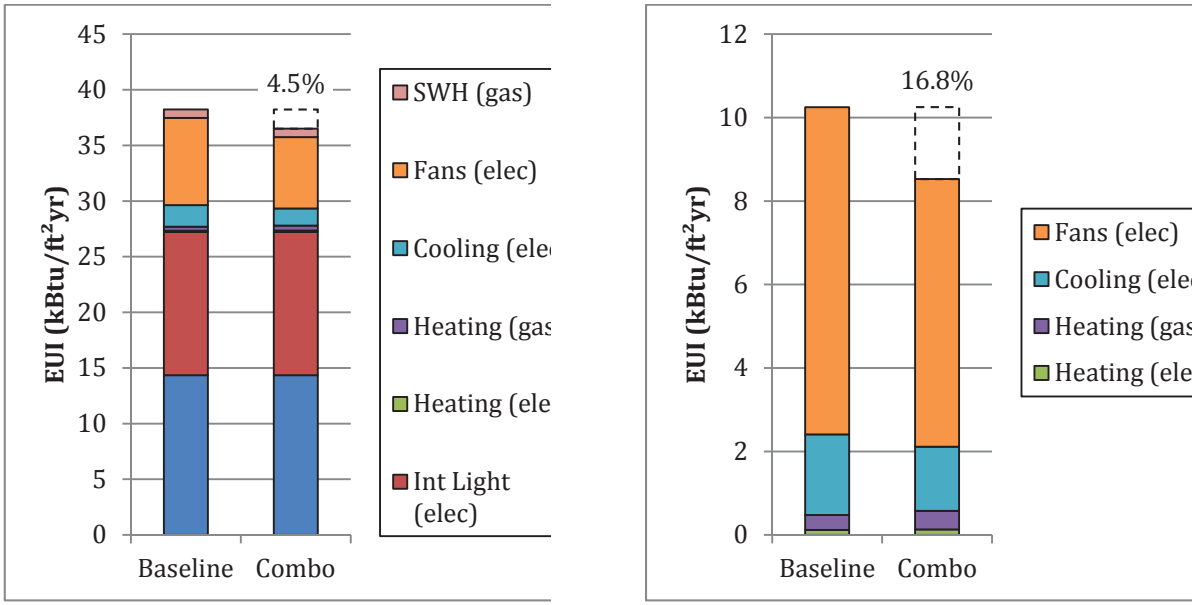


Figure E-1 Combined Rules Energy Modeling Results

Table E-4 Combined Rules Greenhouse Gas Results

Greenhouse Gas	Baseline (kg)	Combined (kg)	Difference (kg)
CO2	111455.3	106307.9	5147.5
CO	86.8	82.8	4.0
CH4	579.0	551.3	27.7
NOx	95.4	91.0	4.4
N2O	2.3	2.2	0.1
SO2	1033.6	984.2	49.5

Table E-5 shows the estimated fenestration component of the cooling peak load for the east, south, and west zone with the highest window-to-wall ratio.

Table E-5 Components of Peak Cooling Load

Orientation	Component	Baseline (Btu/h)	Combined (Btu/h)
East	People	6,951.7	7,677.5
	Lights	35,046.9	41,519.3
	Equipment	30,883.2	36,919.4
	Infiltration	4,971.2	4,956.1
	Roof	17,011.5	18,027.4
	Interzone Ceiling	0.0	0.0
	Exterior Wall	-4,074.8	-4,080.2
	Interzone Wall	-3,307.0	-3,292.4
	Interzone Floor	-13,347.3	-12,264.6
	Ground Contact Floor	0.0	0.0
	Fenestration Conduction	6,728.5	3,807.3
	Fenestration Solar	20,258.9	2,972.9
	Opaque Door	0.0	0.0
South	People	12,999.6	13,447.5
	Lights	66,627.7	71,126.8

	Equipment	59,640.7	63,853.4
	Infiltration	5,242.2	5,231.9
	Roof	11,166.9	12,005.0
	Interzone Ceiling	-1,695.8	-1,560.0
	Exterior Wall	-8,200.1	-8,762.0
	Interzone Wall	-34,772.5	-34,756.1
	Interzone Floor	0.0	0.0
	Ground Contact Floor	-16,726.3	-15,681.5
	Fenestration Conduction	7,813.6	4,476.8
	Fenestration Solar	14,456.8	2,944.3
	Opaque Door	-8,335.5	-8,413.7
West	People	10,120.1	10,466.5
	Lights	51,656.2	54,689.2
	Equipment	46,207.7	49,062.1
	Infiltration	3,405.0	3,333.3
	Roof	2,056.1	1,814.3
	Interzone Ceiling	-4,251.9	-3,169.2
	Exterior Wall	-4,544.6	-4,759.6
	Interzone Wall	-24,017.0	-23,392.3
	Interzone Floor	0.0	0.0
	Ground Contact Floor	-11,740.2	-11,971.8
	Fenestration Conduction	11,616.6	8,189.1
	Fenestration Solar	23,476.6	9,327.2
	Opaque Door	-6,415.5	-6,502.9

Table E-6 shows electricity and natural gas use and cost data and Table E-7 shows HVAC capacity information. For these tables, continuous dimming to off daylighting controls with a 400 lux setpoint were added to both the baseline and combined rules simulations.

Table E-6 Electricity and Natural Gas Use and Cost

	Baseline	Combined	Baseline + Daylight Controls	Combined + Daylight Controls
Electricity Use (kWh)	355,217	338,214	265,814	253,933
Electricity Cost ($)	$47,856.52	$45,302.88	$35,751.02	$33,917.42
Natural Gas Use (therm)	113.5	142.1	145.9	193.2
Natural Gas Cost ($)	$107.60	$134.71	$138.22	$182.93

Table E-7 HVAC Capacities

	Baseline	Combined	Baseline + Daylight Controls	Combined + Daylight Controls
Cooling Capacity (tons)	45	37	40	33
Heating Capacity (Btu/h)	481,848	467,911	481,848	467,911

Cooling Flow Rate (cfm)	26,420.3	21,680.4	23,559.8	19,078.4
Heating Flow Rate (cfm)	12,192.0	11,842.4	12,192.0	11,842.4

1.6 OTHER CLIMATE ZONES

The combined rule was also simulated in DOE Climate Zone 2A (representative city: Houston, Texas) and 5A (representative city: Chicago, Illinois). The results of an annual energy simulation using the combined rule in 2A can be found Table E-8 and

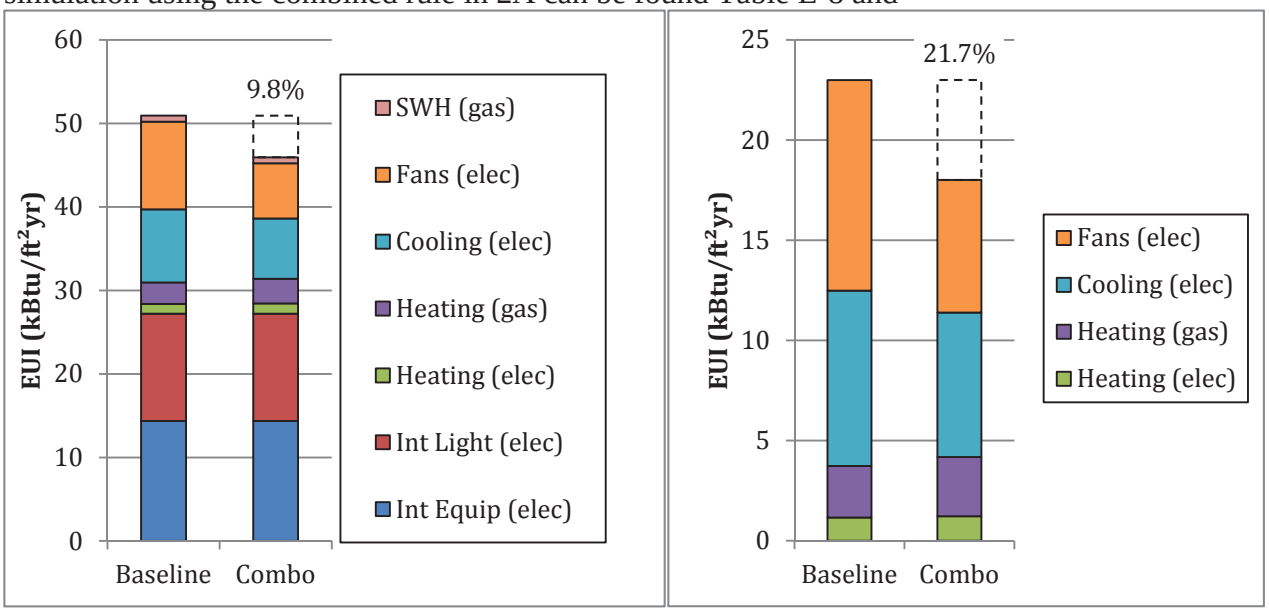


Figure E-2. The simulations were performed using EnergyPlus, EMS controllers for the windows, and TMY2 weather input data. The results show that the EC glass resulted in a small increase in heating energy due to times when the building is in heating mode and the increased solar gain is beneficial. However, the EC glass also resulted in a decrease in cooling and fan energy that overcame the small heating energy increase, resulting in an annual whole-building energy savings of about 9.8% and an annual HVAC savings of 21.7%. Greenhouse gas differences between the two simulations are in Table E-9.

Table E-8 Combined Rules Energy Modeling Results – Climate Zone 2A

End Use	Baseline (kBtu/ft²yr)	Combined (kBtu/ft²yr)
Interior Equipment (electric)	14.35	14.35
Interior Lighting (electric)	12.87	12.87
Heating (electric)	1.16	1.22
Heating (gas)	2.57	2.95
Cooling (electric)	8.76	7.22
Fans (electric)	10.51	6.62
SWH (gas)	0.71	0.71
Total	50.93	45.94

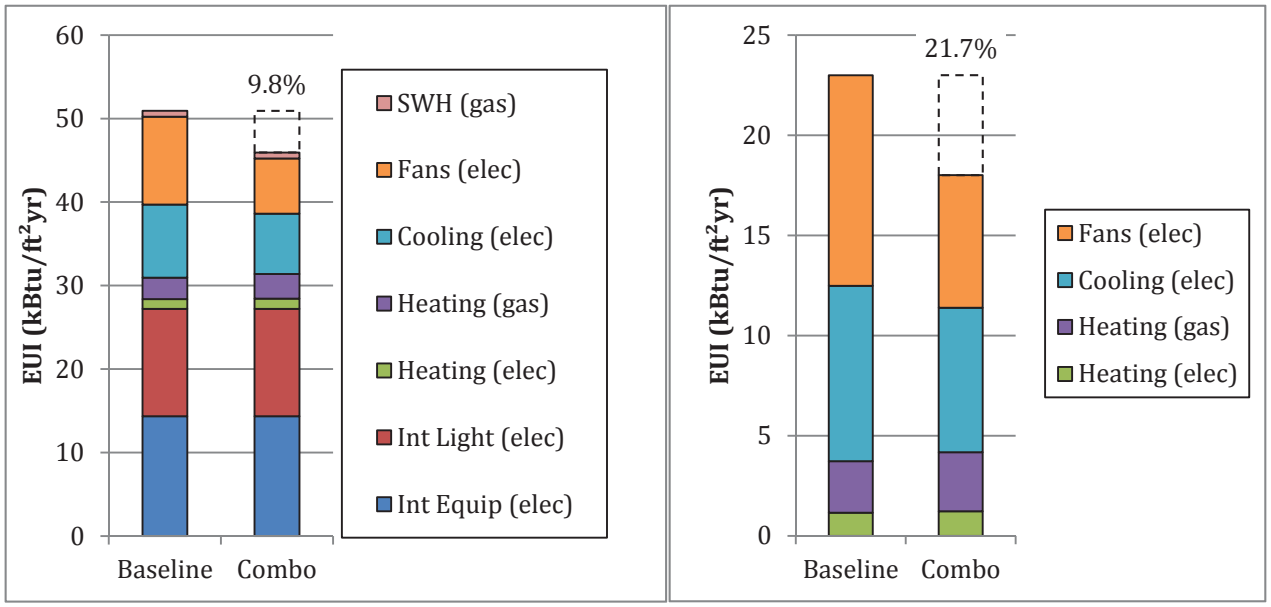


Figure E-2 Combined Rules Energy Modeling Results – Climate Zone 2A

Table E-9 Combined Rules Greenhouse Gas Results – Climate Zone 2A

Greenhouse Gas	Baseline (kg)	Combined (kg)	Difference (kg)
CO2	384148.7	342673.4	41475.4
CO	204.5	182.7	21.8
CH4	1193.0	1060.6	132.4
NOx	503.1	448.3	54.8
N2O	9.1	8.1	1.0
SO2	2163.5	1923.3	240.2

The results of an annual energy simulation using the combined rule in 5A can be found Table E-10 and Figure E-3. The simulations were performed using EnergyPlus, EMS controllers for the windows, and TMY2 weather input data. The results show that the EC glass resulted in a small increase in heating energy due to times when the building is in heating mode and the increased solar gain is beneficial. However, the EC glass also resulted in a decrease in cooling and fan energy that overcame the small heating energy increase, resulting in an annual whole-building energy savings of about 1.8% and an annual HVAC savings of approximately 2.8%. Greenhouse gas differences between the two simulations are in Table E-11.

Table E-10 Combined Rules Energy Modeling Results – Climate Zone 5A

End Use	Baseline (kBtu/ft²yr)	Combined (kBtu/ft²yr)
Interior Equipment (electric)	14.35	14.35
Interior Lighting (electric)	12.87	12.87
Heating (electric)	10.77	10.81
Heating (gas)	20.79	20.41
Cooling (electric)	2.79	2.37
Fans (electric)	15.44	14.83
SWH (gas)	0.90	0.90
Total	77.92	76.53

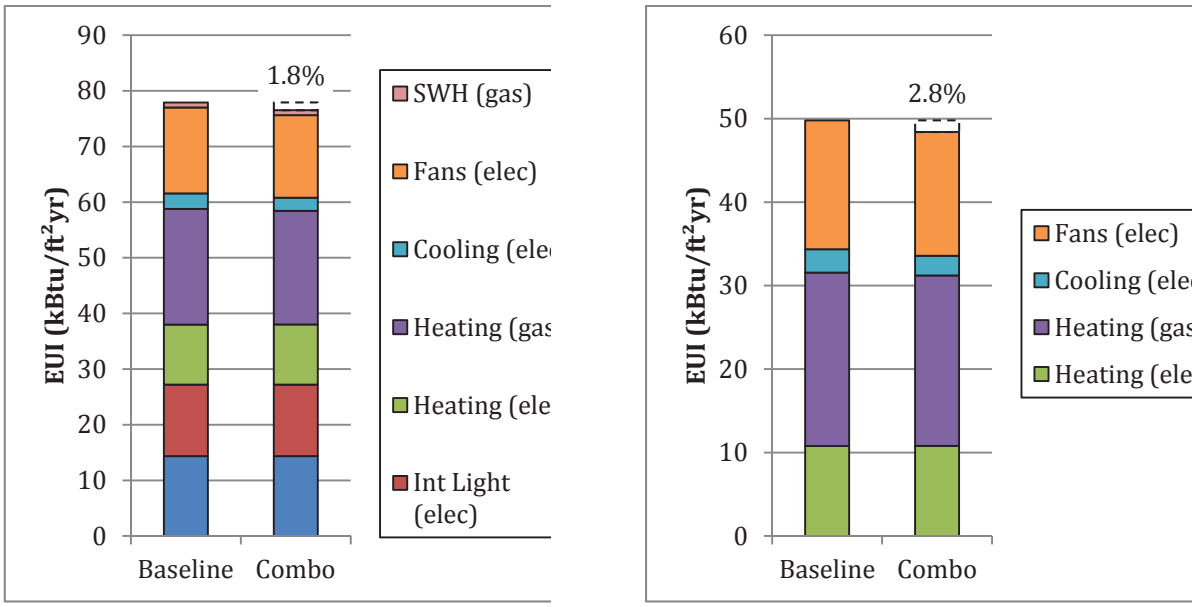


Figure E-3 Combined Rules Energy Modeling Results – Climate Zone 5A

Table E-11 Combined Rules Greenhouse Gas Results – Climate Zone 5A

Greenhouse Gas	Baseline (kg)	Combined (kg)	Difference (kg)
CO2	695615.3	683359.9	12255.4
CO	256.8	252.2	4.5
CH4	1441.9	1416.6	25.3
NOx	1233.3	1211.6	21.7
N2O	16.2	15.9	0.3
SO2	3610.7	3547.3	63.4

17.0 APPENDIX F: Occupant Feedback – Monitoring, Reporting

In this section we present a summary of the product performance/occupant feedback experiment installed at MCAS Miramar Building 6311.

We present a simple overview of the building and relevant controls, and detailed descriptions of the survey questions, occupant solicitations, and feedback. In addition, we present a plotting methodology for the Likert scale data that clearly illustrates the acceptance trends. The data contained herein was captured between January 2013 and May 2014, which includes a 9-month period prior to the completion of the retrofit from standard single pane glazing to the View dynamic glazing product. A one-year post-retrofit period will not conclude until September 2014. As such, this report will serve as interim feedback about the baseline (pre-retrofit) results and the fall, winter, and spring (partial post-retrofit) results. The baseline survey will be administered again as a "follow-up" survey in September 2014, at which point this report will be finalized.

The results and analysis from the baseline survey period (pre-retrofit) are contained below. The results and analysis from the ongoing survey period (partial post-retrofit) are presented in Section 1.11. Phase 1 of the post-retrofit refers to September 2013 through April 2014. Phase 2 of the post-retrofit refers to June 2014 through September 2014. The phases are separated by seasons and by a change from the dynamic glass control system from time-of-day in phase 1 to variable control based on incident solar angle and flux in phase 2

1.7 BUILDING SYSTEM CONTROL DESCRIPTION

HVAC

- Manual and programmable thermostats
- Operable windows in some locations

Lighting

- No daylighting controls, manual switching via wallbox switches (coarse circuiting), and limited occupancy sensors
- Blinds/drapes on many windows

1.8 SURVEY DEPLOYMENT PLAN

1. Release baseline survey: 12/14/2012 (Monday morning)
2. Close baseline survey: 1/2/2013
3. Send reminder emails about ongoing survey: 12/26/2012, if 50% participation not already achieved.
4. Release ongoing survey: 12/14/2012
5. Close ongoing survey: 9/30/2014
6. Send reminder emails about ongoing survey: 1/28/2013, 3/4/2013, 5/6/2013
7. Release follow-up survey: 9/2014
8. Close follow-up survey: 9/2014
9. Send reminder emails about ongoing survey: release + 1 week, if 50% participation not already achieved *NOTE: Participation incentive measures could not be used at this site.*

1.9 SURVEY ROLLOUT

Transcript of email to occupants:
"Dear Occupants: The National Renewable Energy Laboratory (NREL) has developed an online survey to evaluate your satisfaction with our building and identify what features contribute to or interfere with your general comfort. Your participation is very important. Please visit this web address before January 2, 2013: (url removed)

This survey gives you an opportunity to comment on your satisfaction with office temperature, daylighting, electric lighting, and the building overall.

The baseline survey takes less than 15 minutes to complete and is confidential. The results will greatly assist us in understanding the effectiveness of our building features. If you have questions about the survey or experience any technical difficulties, please contact NREL via e-mail at Jennifer.scheib@nrel.gov. Thank you in advance for your participation.

Once you have completed the baseline survey, visit and bookmark this web address: (url removed). This link will display a short survey about lighting and temperature comfort in your work environment. Please try to answer the questions a few times each week from now until December 27, 2013. We would greatly appreciate your feedback periodically as you notice unpleasant or pleasant conditions over the monitoring period.

On survey before baseline:
"Welcome! Thank you for your participation in this building evaluation study. This study is a joint effort between MCAS Miramar and the National Renewable Energy Laboratory.

Your feedback will provide valuable data that will be used to identify how successful your building features are in meeting design goals. Results will be presented to MCAS Miramar, technology installation partners, and the National Renewable Energy Laboratory research staff."

Additional text for intro:
Time: The survey usually takes less than 15 minutes to complete.

Confidentiality: Your answers are confidential.

You may return at any time before January 2, 2013 to complete the survey.

On the intake survey (administered prior to ongoing monitoring period):
"Thank you for completing the baseline survey. To provide continuous feedback, please use the ongoing survey (link text removed) to answer questions about your workspace comfort. The questions take less than a couple of minutes to answer. We would appreciate your participation a few times a week until December 27, 2013. Please submit feedback at the exact times you are feeling either comfort or discomfort. We will then correlate your feedback to measurements of actual conditions in your space to help us determine the success of the building features.

On the ongoing survey:
"Welcome! Thank you for your participation in this building evaluation study. This study is a joint effort between MCAS Miramar and the National Renewable Energy Laboratory.

Your feedback will provide valuable data that will be used to identify how successful your building features are in meeting design goals. Results will be presented to MCAS Miramar, technology installation partners, and the National Renewable Energy Laboratory research staff."

Please submit feedback at the exact times you are feeling either comfort or discomfort.

Reminder Text

"Dear Occupants: As a reminder, the National Renewable Energy Laboratory (NREL) has developed an online survey to evaluate your satisfaction with our building and identify what features contribute to or interfere with your general comfort. Your participation is very important. The survey will remain open until January 18, 2013. Please visit the website to complete the survey at your earliest convenience: http://www.nrel.gov/ap/workspace_survey/.

This survey gives you an opportunity to comment on your satisfaction with office temperature, daylighting, electric lighting, and the building overall.

The baseline survey takes less than 15 minutes to complete and is confidential. The results will greatly assist us in understanding the effectiveness of our building features. If you have questions about the survey or experience any technical difficulties, please contact NREL via e-mail at Jennifer.scheib@nrel.gov. Thank you in advance for your participation.

Once you have completed the baseline survey, visit and bookmark this web address: http://www.nrel.gov/ap/workspace_survey/followup.cfm. This link will display a short survey about lighting and temperature comfort in your work environment. **Please try to answer the questions a few times each week** (emphasis in original) from now until December 27, 2013. We would greatly appreciate your feedback periodically as you notice unpleasant or pleasant conditions over the monitoring period.

1.10 BASELINE SURVEY

1.10.1 Occupant Comfort Survey Questions (baseline survey)

General comments for creating survey:

All questions beginning with, "How satisfied are you with…" will be given these responses. The 7-point scale will be listed from left to right and will have color clues to aid the occupant in box selection.

Very Satisfied < - > Very Dissatisfied (7-point scale)

Consider adding this question type to one large table.

All questions with a satisfaction response will break out for comments if the 3 toggles associated with dissatisfaction are selected. If a specific breakout question is not provided then use:

"Please provide detail regarding nature/cause of dissatisfaction."

All questions beginning with, "… enhance or interfere with your ability to perform work?" will be given the following responses. *The 7-point scale will be listed from left to right and will have color clues to aid the occupant in box selection.*

Enhances < - > Interferes (7-point scale)

Show a progress bar and use any other relevant survey methods to increase likelihood of survey completion.

General

1. Please select your workspace zone (link to floor plan) from the following list.

2. How would you describe your typical activity level at work?
- ☐ Seated inactive, reading or writing
- ☐ Seated active, typing, on the phone, filing
- ☐ Standing relaxed, slight activity
- ☐ Standing, active

3. What is your age?
- ☐ 30 or under
- ☐ 31-40
- ☐ 41-50
- ☐ Over 50

4. What is your gender?
- ☐ Female
- ☐ Male

5. How many months have you worked in this building?
- ☐ Less than six months
- ☐ More than six months

6. Which direction does your workspace's primary work surface face?
- ☐ North
- ☐ East
- ☐ South
- ☐ West

7. Which direction do you face during typical work tasks?
- ☐ North
- ☐ East
- ☐ South
- ☐ West

8. Which of the following best describes your personal workspace?
- ☐ Enclosed office, private
- ☐ Cubicles with low partitions (<55 inches)
- ☐ Cubicles with high partitions (>55 inches)
- ☐ Workspace in open office with no partitions (just desks)
- ☐ Other: _____

9. In a typical week, how many hours do you spend in your workspace?
- ☐ 10 or less
- ☐ 31-50
- ☐ Over 50

Thermal Comfort

10. Do you typically feel that you are dressed appropriately for the weather?
- ☐ Yes
- ☐ No

If you answered no please state why:_____

11. Which of the following can and do you personally adjust or control in your workspace? (Check all that apply)
- ☐ Operable window
- ☐ Thermostat
- ☐ Portable heater
- ☐ Portable fan
- ☐ Door to interior space
- ☐ Door to exterior space
- ☐ None of the above
- ☐ Other:_____

12. How often do you use thermal comfort controls available?
- ☐ Never
- ☐ About once a week
- ☐ About once a day
- ☐ Many times a day
- ☐ Other:_____

13. How satisfied are you with the indoor temperature during the winter season?

14. How satisfied are you with the indoor temperature during the summer season?

15. How satisfied are you with the indoor temperature during the spring and fall seasons?

16. (Breakout for previous three questions) What is the nature/cause of temperature dissatisfaction?
- ☐ Hot
- ☐ Too warm
- ☐ Too cool
- ☐ Cold

17. (Breakout for temperature discomfort question) If your workspace is too warm, what might be the cause? (Check all that apply)
- ☐ Proximity to air diffuser
- ☐ Proximity to window(s)
- ☐ The heating system is set too high
- ☐ Other:_____

18. (Breakout for temperature discomfort question) If your workspace is too cool, what might be the cause?
- ☐ Proximity to air diffuser
- ☐ Proximity to window(s)
- ☐ The air conditioning is set too cool
- ☐ Other:_____

19. (Breakout for temperature discomfort question) When is workspace temperature most often a problem?

Hot

- ☐ Morning before 10am
- ☐ Mid day
- ☐ Afternoon
- ☐ Evening

Cold

- ☐ Morning before 10am
- ☐ Mid day
- ☐ Afternoon
- ☐ Evening

20. (Breakout for temperature discomfort question) Could your discomfort typically be changed by adding or removing a sweater or jacket?

- ☐ Yes
- ☐ No

21. Does the heating and cooling in your workspace enhance or interfere with your ability to perform work?
    - Enhance
    - Interfere
    - Neither or unsure

Lighting

22. Describe the lighting controls available to you:

- ☐ Individual switch
- ☐ Community switch
- ☐ None
- ☐ Other:_____

23. How often to you use the lighting controls available?

- ☐ Never
- ☐ About once a week
- ☐ About once a day
- ☐ Many times a day
- ☐ Other:_____

24. How satisfied are you with the task light (desk lamp) at your workspace?

25. (Breakout) What is the nature/cause of task lighting dissatisfaction?

- ☐ I don't have a task light
- ☐ Too bright
- ☐ Too dim
- ☐ Not the right distribution for my work tasks
- ☐ Glary
- ☐ Other:_____

26. When do you use a task light (desk lamp)?

- ☐ Never
- ☐ When I am at work after dark
- ☐ Occasionally during the day
- ☐ Often
- ☐ Other:_____

27. How satisfied are you with the amount of light at your work station during the **day**?

28. (Breakout) What is the nature/cause of daytime lighting *quantity* dissatisfaction?
- ☐ Very bright
- ☐ Bright
- ☐ Dark
- ☐ Very dark
- ☐ Other:_____

29. How satisfied are you with the amount of light at your work station during the **night**?

30. (Breakout) What is the nature/cause of nighttime lighting *quantity* dissatisfaction?
- ☐ Very bright
- ☐ Bright
- ☐ Dark
- ☐ Very dark
- ☐ Other:_____

31. How satisfied are you with the lighting *quality* (color, general appearance) at your work station during the **day**?

32. (Breakout) What is the nature/cause of daytime lighting *quality* dissatisfaction?
- ☐ Lack of light uniformity at the desk
- ☐ Poor color rendering or appearance (daylight)
- ☐ Poor color rendering or appearance (electric lighting)
- ☐ Other:_____

33. How satisfied are you with the lighting *quality* (color, general appearance) at your work station during the **night**?

34. (Breakout) What is the nature/cause of nighttime lighting quality dissatisfaction?
- ☐ Lack of uniformity at the desk
- ☐ Poor color rendering or appearance (electric lighting)
- ☐ Other:_____

35. How satisfied are you with the amount of light in auxiliary spaces (e.g., kitchen, hallways)?

36. (Breakout) What is the nature/cause of lighting *quantity* dissatisfaction?
- ☐ Very bright
- ☐ Bright
- ☐ Dark
- ☐ Very dark

☐ Other:_____

37. How satisfied are you with the lighting *quality* (color, general appearance) in auxiliary spaces?

38. (Breakout) What is the nature/cause of lighting *quality* dissatisfaction?
☐ Lack of uniformity at the task area
☐ Poor color rendering or appearance (daylight)
☐ Poor color rendering or appearance (electric lighting)
☐ Other:_____

39. Do you have glare problems at your workspace?
☐ Yes
☐ No

40. (Breakout if yes) What is the nature/cause of the glare problem?
☐ Direct sun in the morning
☐ Direct sun in the evening
☐ Overhead electric lighting fixture are too bright
☐ Daylight reflection off of interior surfaces
☐ Daylight reflection off of computer screen
☐ General brightness out of windows
☐ Daylight reflection off of nearby building components
☐ Daylight reflection off of snow in the winter
☐ Other:_____

41. (Breakout if yes) How long does the glare typically last?
☐ 1 hour or less
☐ 1 to 4 hours
☐ More than 4 hours

42. (Breakout if yes) What do you typically do to mitigate glare?
☐ Reorient working position or computer monitor temporarily
☐ Lower blinds or shades
☐ Other:_____

43. Does the lighting at your workspace enhance or interfere with your ability to perform work?
- Enhance
- Interfere
- Neither or unsure

Building Controls

44. How satisfied are you with the electric light switches?

45. (Breakout) What is the nature/cause of light switch dissatisfaction?
☐ Unclear how to operate
☐ Not in convenient locations
☐ One switch control too large of an electric lighting zone
☐ Other:_____

46. How satisfied are you with the electric lighting occupancy controls in auxiliary spaces?

47. (Breakout) What is the nature/cause of occupancy control dissatisfaction?
- ☐ Too sensitive in auxiliary spaces (i.e., stay on all the time)
- ☐ Not sensitive enough in auxiliary spaces (i.e., turn off when I am in a space)
- ☐ Other:_____

48. How satisfied are you with the blinds and/or drapes?

49. (Breakout) What is the nature/cause of blind/drape dissatisfaction?
- ☐ Unclear how to operate
- ☐ Do not block out enough daylight
- ☐ Are closed too often due to different user preferences
- ☐ Are open too often due to different user preferences
- ☐ Other:_____

50. How satisfied are you with the air diffusers?

51. (Breakout) What is the nature/cause of air diffuser dissatisfaction?
- ☐ Creates discomfort due to close proximity to my workspace
- ☐ Too far away from my workspace
- ☐ Other:_____

52. How satisfied are you with the thermostats?

53. (Breakout) What is the nature/cause of thermostat dissatisfaction?
- ☐ Unclear how to operate
- ☐ Inconvenient locations
- ☐ One thermostat controls too large of a zone
- ☐ Other:_____

54. How satisfied are you with the operable windows?

55. (Breakout) What is the nature/cause of operable window dissatisfaction?
- ☐ There are no operable windows in my work area
- ☐ Difficult to open
- ☐ Difficult to close
- ☐ Lack of window operation consensus in my work area
- ☐ Other:_____

Energy Efficiency

56. How do you perceive your building's energy performance?
- ☐ Exceeding design intent
- ☐ Meeting design intent
- ☐ Unsure
- ☐ Underperforming

57. Do you feel that you receive information about energy performance of the building?
- ☐ Yes
- ☐ No
- ☐ If you answered no please provide examples of information that would be useful to you:_____

58. What barriers do you see to saving energy in your work environment?
- ☐ I have no control over the systems
- ☐ I get busy and forget to control systems
- ☐ *Other:*_____

59. Do you have specific ideas for energy efficiency or occupant interaction improvement?

Other

60. How satisfied are you with the overall comfort of the building and/or your personal workspace?

61. Based on your previous response, which building feature contributes most to your overall satisfaction or dissatisfaction?
- ☐ Electric lighting
- ☐ Daylighting
- ☐ Views of the outdoors
- ☐ Heating
- ☐ Cooling
- ☐ Other/Comments:_____

62. What barriers do you see to feeling comfortable in your work environment? Do you have specific ideas for improvement?

1.10.2 Occupant Comfort Survey Results (baseline survey)

The purpose of the baseline survey was to measure occupant comfort in Building 6311 prior to the installation of View Dynamic Glass. The survey focused on thermal and lighting system comfort using a base set of seven-point, Likert-type scale questions with follow-up questions that were presented if the occupant indicated that they were not satisfied with a specific condition. This section of the report graphically presents the base set of seven-point scale responses. The responses to the follow-up questions are discussed in the text.

The baseline survey was opened to occupants on December 19, 2012 and closed on February 4, 2013. Forty-three occupants, 48% of the notified staff, participated by responding via the NREL survey webpage. On average, one question of the 62 (listed in the previous section) was left blank by the respondents.

The following stacked bar chart shows the percent of occupant responses in each Likert Scale category, shown in the bottom of the chart area. The survey question key is shown on the left axis; the full-length questions are given after the plot. The number of responses for each question is shown on the right axis. This plot type reveals distribution of responses around the neutral (0) point, the spread of responses for each question, the dominant response selection for each question. The

questions are sorted in descending order from top to bottom, show the generally preferred systems/conditions toward the top.

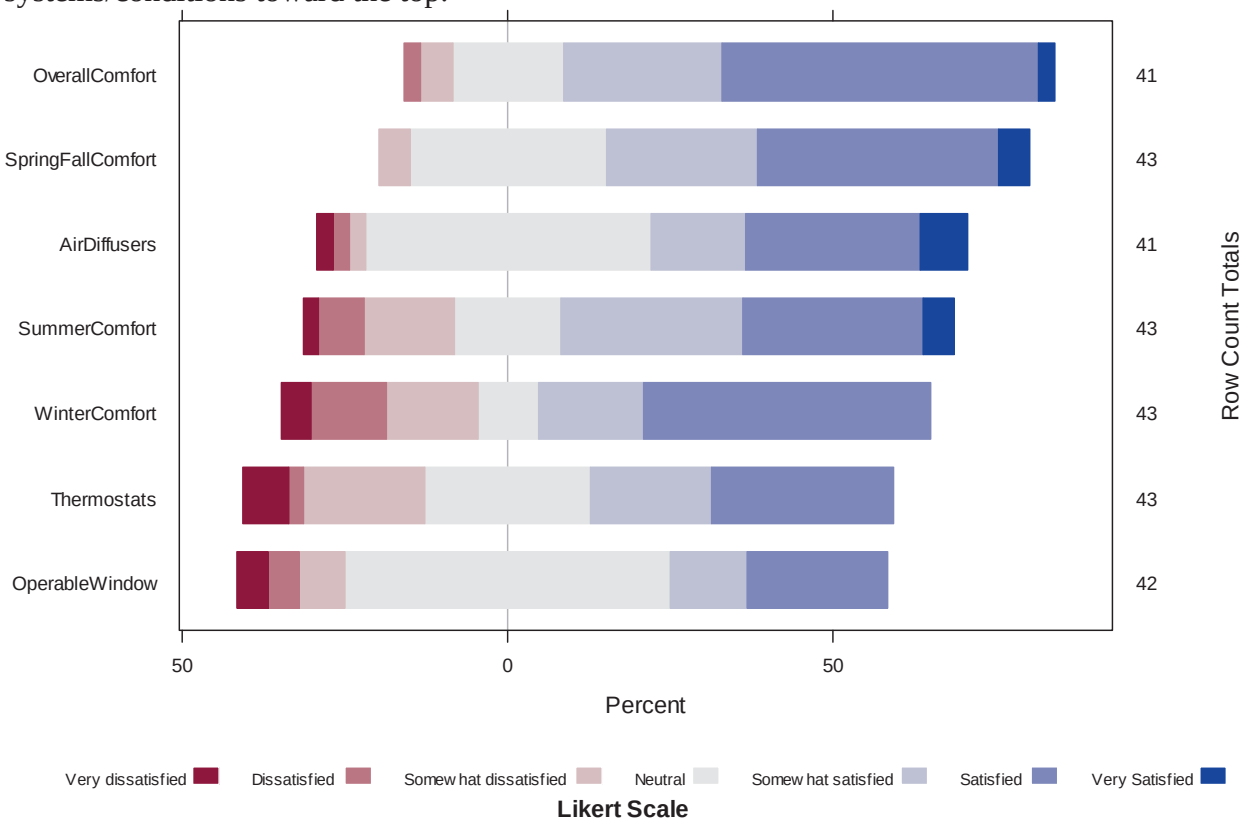


Figure F-1 Baseline Occupant Comfort Results—Thermal System Base Questions

Table F-1 Baseline Occupant Comfort Results—Thermal System Base Questions

Question Key	Question Text
Conditions	
WinterComfort	How satisfied are you with the indoor temperature during the winter season?
SummerComfort	How satisfied are you with the indoor temperature during the summer season?
SpringFallComfort	How satisfied are you with the indoor temperature during the fall season?
System Components	
AirDiffusers	How satisfied are you with the air diffusers?
Thermostats	How satisfied are you with the thermostats?
OperableWindow	How satisfied are you with the operable windows?
General Comfort Question (shown on both plots)	
OverallComfort	How satisfied are you with the overall comfort of the building and/or your personal workspace?

The thermal system responses are skewed toward satisfaction for the thermal conditions but are skewed toward dissatisfaction for the thermal system components such as operable windows and thermostats. Both are skewed toward less comfort then the overall comfort feedback for the building. The follow-up questions associated with the "very dissatisfied" responses elicited the following example feedback:

> "One thermostat controls too large of a zone"
>
> "too large of zones AND inconsistent temp/extremes"
>
> "There are no operable windows in my work area"
>
> "Difficult to open AND close"

The data do not show an obvious correlation between satisfaction and working orientation (north, east, south, west) or workstation type (cubicle or private office).

The setup of the following lighting comfort results plot is similar to the thermal comfort results plot. The difference between the two plots is the skew of the lighting systems toward "satisfaction" responses. The frequency ratio of "very satisfied" to "very dissatisfied" is higher for lighting system components/conditions as shown by the greater dark blue versus dark red area on the bars. The overall comfort feedback for the space ranks fifth in terms of positive responses, topped by daylighting quantity and quality, light switches, and auxiliary space light quantity.

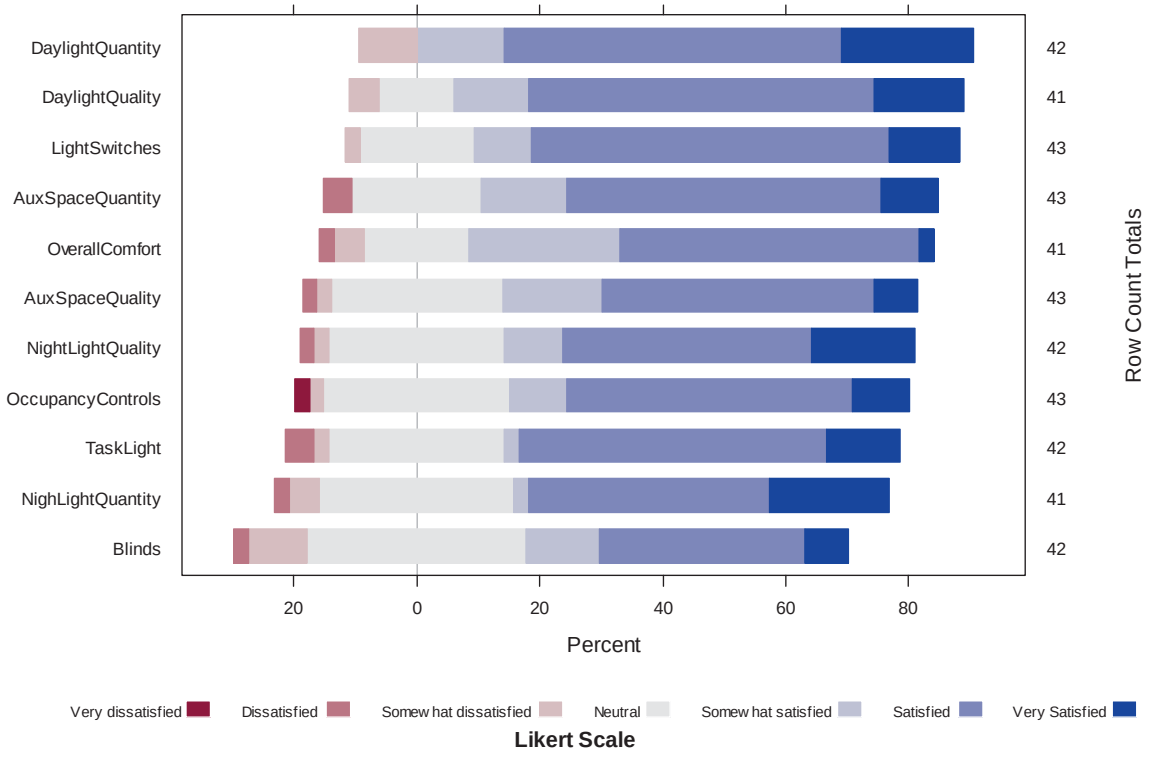


Figure F-2 Baseline Occupant Comfort Results—Lighting System Base Questions

Table F-2 Question Key, Lighting System Base Questions

Question Key	Question Text
Conditions	
DaylightQuantity	How satisfied are you with the amount of light at your work station during the day?
NighLightQuantity	How satisfied are you with the amount of light at your work station during the night?
DaylightQuality	How satisfied are you with the lighting quality (color, general appearance) at your work station during the day?
NightLightQuality	How satisfied are you with the lighting quality (color, general appearance) at your work station during the night?
AuxSpaceQuantity	How satisfied are you with the amount of light in auxiliary spaces (e.g., kitchen, hallways)?
AuxSpaceQuality	How satisfied are you with the lighting quality (color, general appearance) in auxiliary spaces?
System Components	
TaskLight	How satisfied are you with the task light (desk lamp) at your workspace?
LightSwitches	How satisfied are you with the electric light switches?
OccupancyControls	How satisfied are you with the electric lighting occupancy controls in auxiliary spaces?
Blinds	How satisfied are you with the blinds and/or drapes?
General Comfort Question (shown on both plots)	
OverallComfort	How satisfied are you with the overall comfort of the building and/or your personal workspace?

The building's blinds ranked lowest on the seven-point satisfaction scale in terms of average response. This is largely due to occupant indifference but specific complaints were given:

- *"Are closed too often due to different user preferences"*
- *"Flop around if windows are open"*
- *"cumbersome to operate"*
- *"old and dirty"*

The responses to the following question reinforces the conclusion that the heating and cooling system are, on average, less accepted as a comfort-assisting feature of the building than the lighting system:

Does the heating and cooling in your workspace enhance or interfere with your ability to perform work?

For heating and cooling, 30% of the occupants reported that the system interfered with their ability to perform work and 16% selected "enhance". For lighting, 9% selected "interfere" and 23%

selected “enhance” in response to the question. The building features that were selected as most helpful to maintaining the occupant’s comfort rank from highest to lowest as:

- Electric lighting (37%)
- Daylighting (26%)
- Views of the outdoors (13%)

The general trends in the data show that View Dynamic Glass has the potential to improve occupant comfort as it relates to occupant frustration interacting with façade systems such as blinds and operable windows and improve thermal comfort in broadly controlled zones.

This section will be edited to include the results of the follow-up survey at the project’s conclusion. The follow-up survey will be opened to the occupants in the exact same format as the baseline survey. It will capture differences in occupant comfort with the View Glass installation and concurrent building system upgrades. The updated results presentation will be more meaningful; the difference of means between the baseline and follow-up survey will be presented allowing measurement of the potential shift in occupant comfort due to building system changes.

1.11 ONGOING SURVEY

1.11.1 Occupant Comfort Survey Questions (ongoing survey)

The following survey questions will be continuously available for occupants to answer, throughout the product performance evaluation.

Thermal Comfort

1. How satisfied are you with the indoor temperature?
   Too cold < - > Too hot (7-point scale)

2. (Breakout) Do you feel you are dressed appropriately for the weather today?
   - ☐ Yes
   - ☐ No

   If you answered no please state why:_____

3. (Breakout) How would you describe your current activity level at work?
   - ☐ Seated inactive, reading or writing
   - ☐ Seated active, typing, on the phone, filing
   - ☐ Standing relaxed, slight activity
   - ☐ Standing, active

Lighting Comfort

4. How satisfied are you with the indoor lighting conditions?
   Too bright < - > Too dark (7-point scale)

5. (Breakout) If you are experiencing glare, please indicate the cause? Check all that apply.
   - ☐ Direct sun
   - ☐ Overhead electric lighting fixture are too bright
   - ☐ Daylight reflection off of ceiling systems

- ☐ Daylight reflection off of computer screen
- ☐ General brightness out of windows
- ☐ Daylight reflection off of nearby building components
- ☐ Other/Comments:_____

6. (Breakout) What is the status of the shades/blinds?
- ☐ All nearby blinds are closed
- ☐ Some of the blinds in my area are closed
- ☐ All nearby blinds are open
- ☐ Other/Comments:_____

(Switch to window state question once dynamic glass installed)

7. (Breakout) Are you using a desk lamp?
- ☐ Yes
- ☐ No

Comments:_____

8. (Breakout) Are the electric lights on overhead?
- ☐ Yes
- ☐ No
- ☐ Comments:_____

9. (Breakout) Are the electric lights on in adjacent zones?
- ☐ Yes
- ☐ No
- ☐ Comments:_____

10. (Breakout) What type of work are you currently doing?
- ☐ Computer work
- ☐ Paper work
- ☐ Other/Comments:_____

General

11. How satisfied are you with the overall comfort of the building and/or your personal workspace?

Very satisfied < - > Very dissatisfied (7-point scale)

12. How satisfied are you with your access to views from your workspace?

Very satisfied < - > Very dissatisfied (7-point scale)

13. How satisfied are you with your ability to control the environmental conditions (e.g., light level, temperature) in your workspace?

Very satisfied < - > Very dissatisfied (7-point scale)

14. Please provide any additional comments you may have, including any personal stories about your experience with the product or how it affects your use of the space.

1.11.2 Occupant Comfort Survey Results (ongoing survey)

The purpose of the ongoing survey is to measure occupant comfort in Building 6311 in real time relative the monitored conditions of the exterior and interior lighting environment. Similarly to the baseline survey, the ongoing survey questions focus on thermal and lighting system comfort using a base set of seven-point, Likert-type scale questions with follow-up questions that are presented if the occupant indicates that they are not satisfied with a specific condition. Three general questions are also presented to assess satisfaction with overall comfort, access to views, and ability to control the environment. This section of the report graphically presents the seven-point scale responses to the lighting and general comfort questions. The responses to the follow-up questions are discussed in the text.

The ongoing survey was opened to occupants on December 19, 2012 and this reporting period concluded on May 31, 2014. Forty-three occupants, 48% of the notified staff, participated by responding via the NREL survey webpage.

The following stacked bar charts shows the percent of occupant responses in each Likert Scale category, shown in the bottom of the chart area. The survey question key is shown on the left axis; the full-length questions are given in a table after each plot. The number of responses for each question is shown on the right axis. This plot type reveals distribution of responses around the neutral (0) point, the spread of responses for each question, the dominant response selection for each question. The baseline (pre-retrofit) and post-retrofit responses are paired into one plot for each question.

1.11.3 General Comfort

The overall comfort result distribution was similar before and after the View Dynamic Glass retrofit, with a slight shift toward the "satisfied" responses as shown in the following plot.

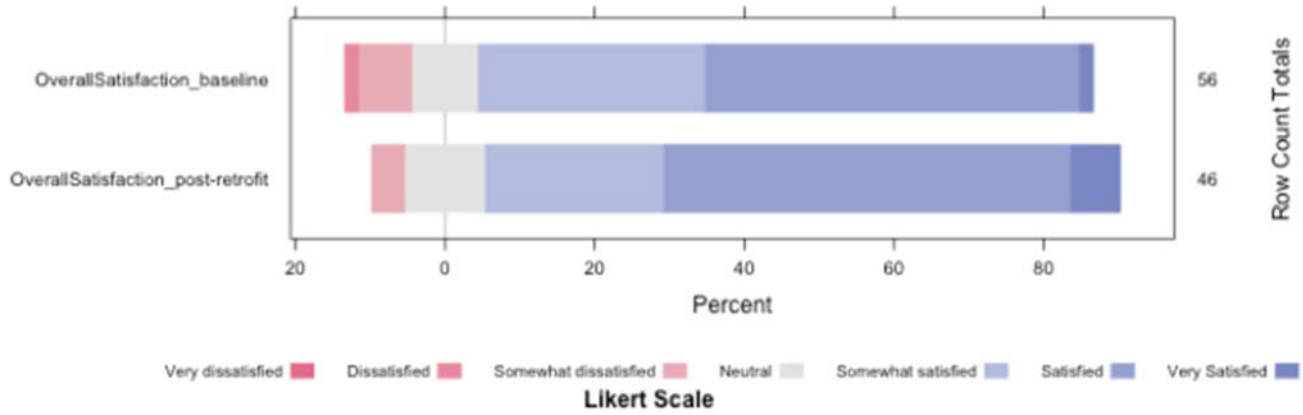


Figure F-3 Overall Comfort Distribution

Table F-3 General Comfort Question

Question Key	Question Text
General Comfort Question	
Overall Satisfaction	How satisfied are you with the overall comfort of the building and/or your personal workspace?

The following occupant comments reveal a mixed perspective on the darker tint of the View Dynamic Glass. Aesthetically, the tint may provide an enhancement:

"I noticed last week that the building looks very nice from the outside when driving by. The windows give a more modern look to the architecture, which is appealing to military bases, which has mostly bland aesthetics and old buildings."

Functionally, the glass received a mixed response in terms of a general impression of brightness. The following plot shows that the glass retrofit coincided with a reduced percent of "bright" responses and an increased percent of "dark" responses. Factors other than glass tint may have contributed to the result, such as the different seasonal analysis periods (spring dominated for pre-retrofit period and fall dominated for the post-retrofit period). However, the View Dynamic Glass was the only retrofit measure to occur during the analysis period and so it is not likely that electric lighting was a major factor in the response shift.

Table F-4 Lighting Condition Options

Lighting Condition	Baseline percent of respondents	Post-retrofit percent of respondents
Too bright, bright, or somewhat bright	46%	22%
Too dark, dark, or somewhat dark	11%	16%

The numerical results are corroborated by occupant comments such as, "Windows are a non-factor to me in terms of comfort as I am away from the window, however, I prefer to look out a clear window vs. a tinted window during the afternoon."

1.11.4 Views

The following plot confirms that occupant use of blinds changed after the View Dynamic Glass retrofit. Blinds were open more often after the retrofit, during the time of occupant reporting, and it appears rare that all blinds were closed as was frequently the case before the retrofit.

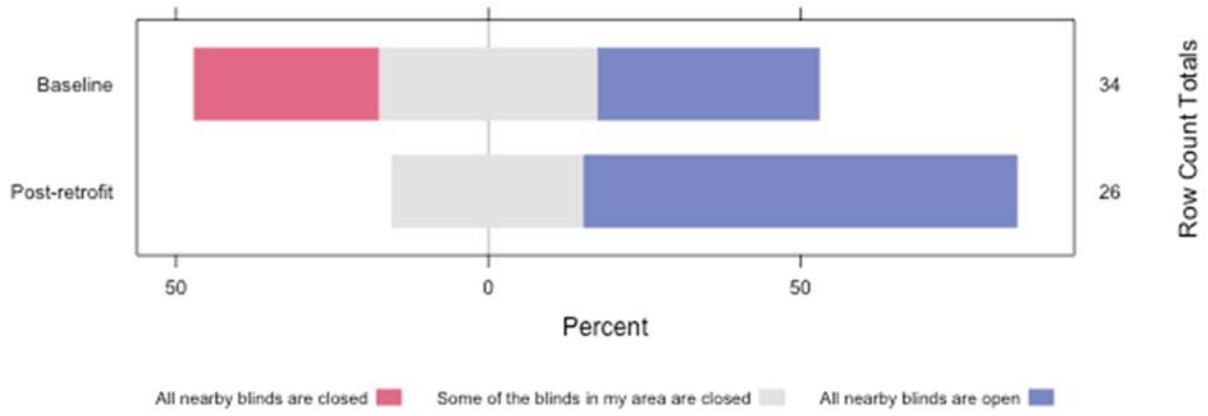


Figure F-4 View Treatment Distribution

Table F-5 Blinds Options

Question Key	Question Text
General Comfort Question	
Blinds	What is the status of the shades/blinds? (Not a 7-point scale response) • All nearby blinds are closed • Some blinds in my area are closed • All nearby blinds are closed • Other

The occupant satisfaction with access to views increased from the baseline to the post-retrofit analysis periods as shown in the following plot.

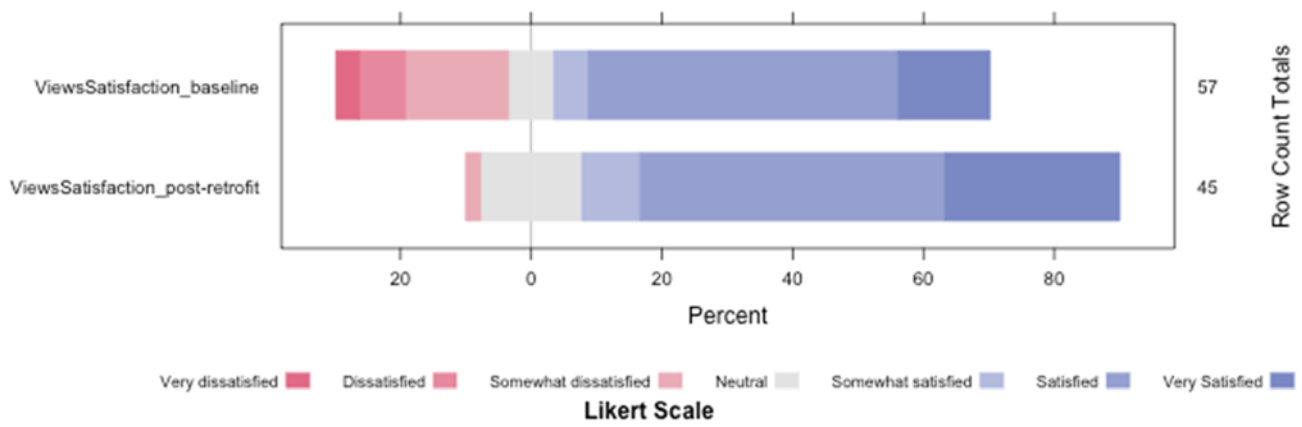


Figure F-5 View Satisfaction Distribution

Table F-6 View Satisfaction Question

Question Key	Question Text
General Comfort Question	
ViewSatisfaction	How satisfied are you with your access to views from your workspace?

Occupant did not provide comments about views in the ongoing survey. This could indicate a tendency to report on issues rather than a general positive outcome.

1.11.5 Controls

The result distribution for occupant satisfaction with their ability to control environmental conditions was similar before and after the View Dynamic Glass retrofit, with a slight shift toward the "satisfied" responses as shown in Figure F-.

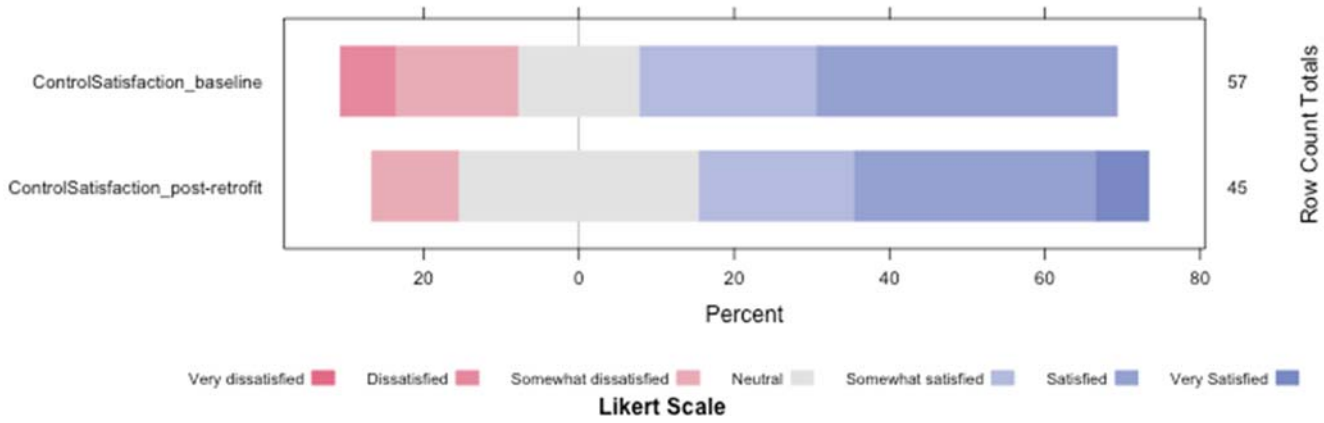


Figure F-6 Environmental Control Satisfaction Distribution

Table F-7 Environmental Control Satisfaction Question

Question Key	Question Text
General Comfort Question	
ControlSatisfaction	How satisfied are you with your ability to control the environmental conditions (e.g., light level, temperature) in your workspace?

The following occupant comments connect general comfort, the perception of brightness, and controllability of the View Dynamic Glass to substantiate the need for a more agile control sequence of operations (versus the time-of-day control used in phase 1) for both occupant comfort and additional lighting energy savings. In phase 2 of the retrofit, View Dynamic Glass implemented a higher-resolution control sequence that is based on time of day, exterior irradiance, and interior sun penetration calculations.

"Due to a very foggy day, I'm manually switching my office to clear because the control system is on a schedule. When the control system is going of sensors it would be very beneficial to have this change implemented automatically for the building to let in light."

"I came in this morning and my windows setting is at the darkest the light is at the lowest scale this morning and outside is overcast, definitely not working with the outside sun light."

The final report will address the impact of the sequence of operations chance made in May of 2014.

1.11.6 Glare

One of the primary questions to consider in a dynamic glass retrofit is the ability to mitigate glare. It is logical to expect the occupant feedback about general comfort will be neutral (assuming windows already exist, which was the case for this project) and satisfaction with views will increase (assuming that blinds are removed or occupant behavior changes with respect to their use, which was the case for this project). It is not well understood, though, to what extend dynamic glass can mitigate glare.

The preliminary occupant survey results indicate that glare potential existed with View Dynamic Glass but that the timing and orientation was more predictable than with the baseline solution of manually controlled blinds only. The following plot shows that glare reporting was somewhat random for the baseline scenario but for the retrofit scenario glare coincided with potential view of the direct sun. (Note that the first plot is the count of glare reports while the second plot is relative frequency of reporting so it reveals pre-retrofit versus post-retrofit patterns, not magnitude.) The predominant issue in the retrofit scenario occurred with afternoon sun where occupants face the west glass. The glare reports coincide with a potential glass tint of 3-4%, which appears insufficient for glare control of the solar disk when occupant is perpendicular to the window

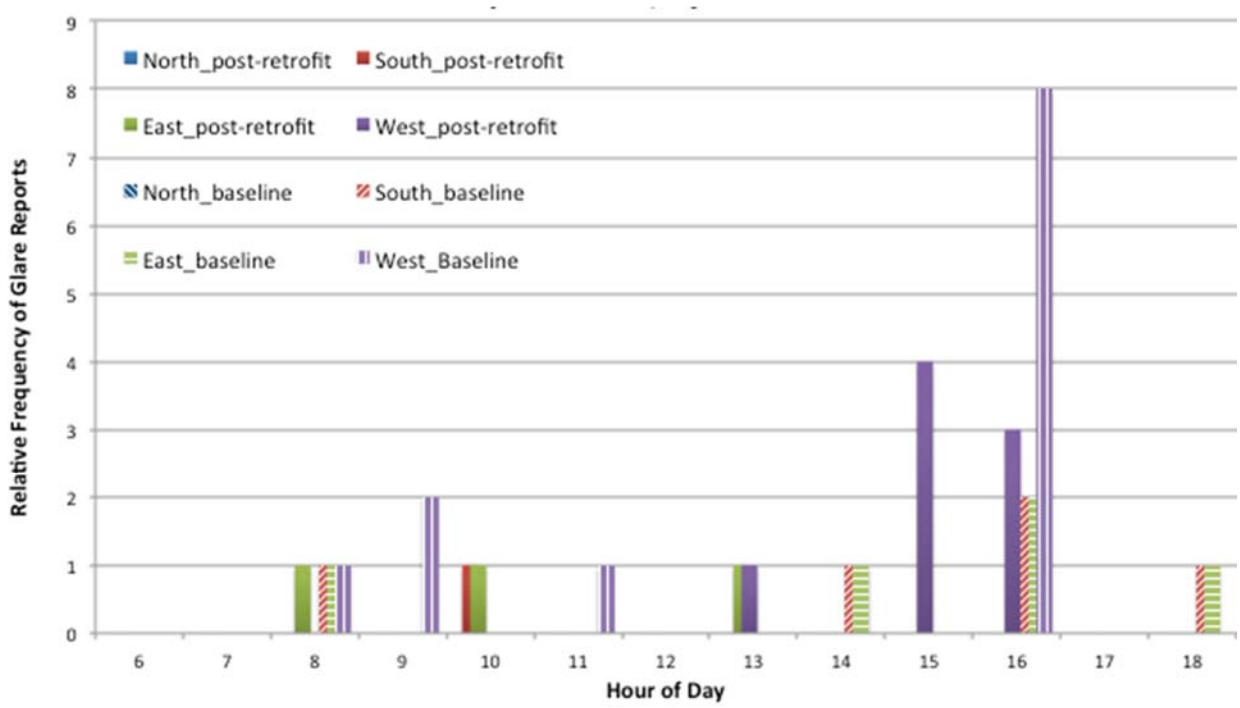


Figure F-7 Glare Report Count by Orientation

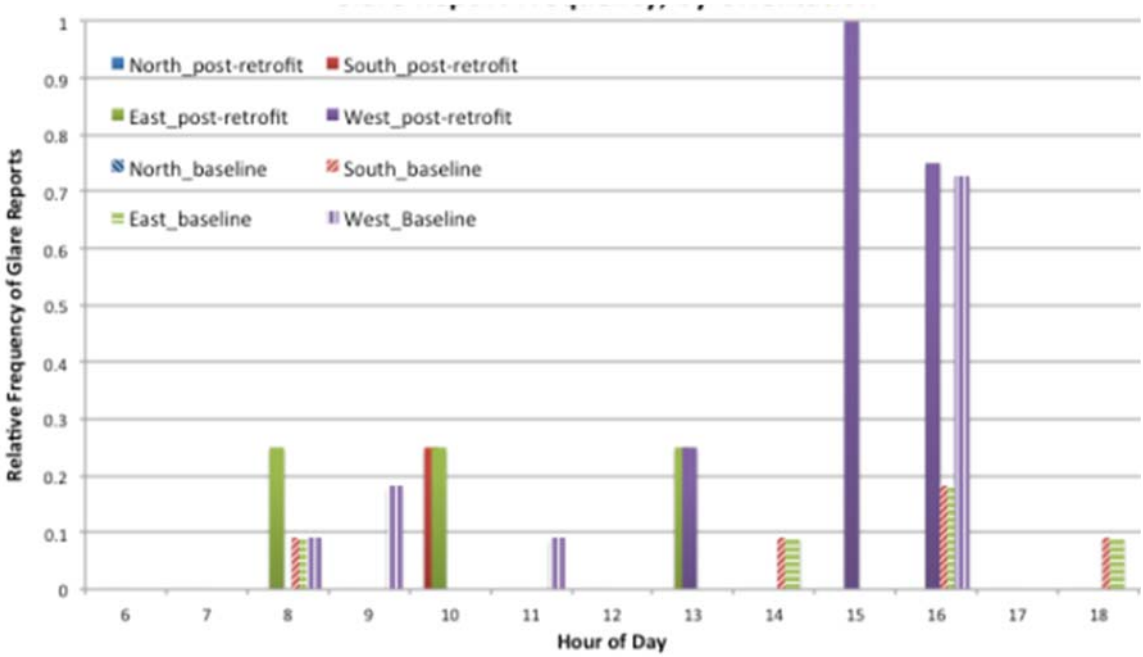


Figure F-8 Glare Report Frequency by Orientation

Overall, the glare mitigation potential of View Dynamic Glass is improved over the baseline, when interpreted as percent of occupant reports about glare issues. The percent of reports that included a sun and/or window glare issue were:

- Baseline: 40%
- Post-retrofit: 23%.

The higher percentage of glare reports during the baseline scenario are likely caused by a number of broken blinds that prevent occupants from using manual control to provide complete glare mitigation.

To address the persistent glare issues, View Dynamic Glass is testing a 1% tint level in phase 2 of the retrofit period, which will be assessed in the final report. (Two private offices-east and southwest facing.)

1.12 Occupant Feedback Summary

From the occupant perspective, the View Dynamic Glass retrofit is neutral to positive change. The primary *advantage* proved to be **increased satisfaction with access to views**. The primary *disadvantage* is **general comfort** with the darker tint. The latter issue is being addressed through improved control algorithms in the second phase of the retrofit (May 2014-September 2014). The following table demonstrates this summary by showing the percent of occupant responses that fall in the neutral to very satisfied categories.

Table F-8 Occupant Satisfaction

Neutral and Satisfied Reponses Survey Question	Baseline (75 responses)	Post-retrofit (53 responses)
How satisfied are you with the **overall comfort** of the building and/or your personal workspace?	82%	96%

How satisfied are you with your access to **views** from your workspace?	67%	98%
How satisfied are you with your ability to **control** the environmental conditions (e.g., light level, temperature) in your workspace?	61%	87%

For comparison, the following table shows the percent of occupant responses that fall in the somewhat dissatisfied to satisfied categories.

Table F-9 Occupant Dissatisfaction

Dissatisfied Responses Survey Question	Baseline (75 responses)	Post-retrofit (53 responses)
How satisfied are you with the **overall comfort** of the building and/or your personal workspace?	7%	4%
How satisfied are you with your access to **views** from your workspace?	20%	2%
How satisfied are you with your ability to **control** the environmental conditions (e.g., light level, temperature) in your workspace?	18%	12%

18.0 APPENDIX G: Lighting Monitoring

Separate from direct occupant feedback, two open offices were monitored for:

- Light fixture on/off status
- General occupancy patterns (occupied hours)
- Workplane illuminance

The luminaire status (on/off) monitoring allowed for finer resolution results on occupant behavior than can be offered by building electrical submetering. The results for the second-floor, north open office show a 20% lighting energy use reduction for a limited test period comparison:

- Baseline: March 17 – April 1, 2013
- Post-Retrofit: September 15 – October 30, 2013

The limited test period was selected for similar exterior irradiance. The following plot shows that the reduction in lighting energy use is due partially to less ambient lighting use overall (8 am) and decreasing use over the course of the day (11 am – 4 pm).

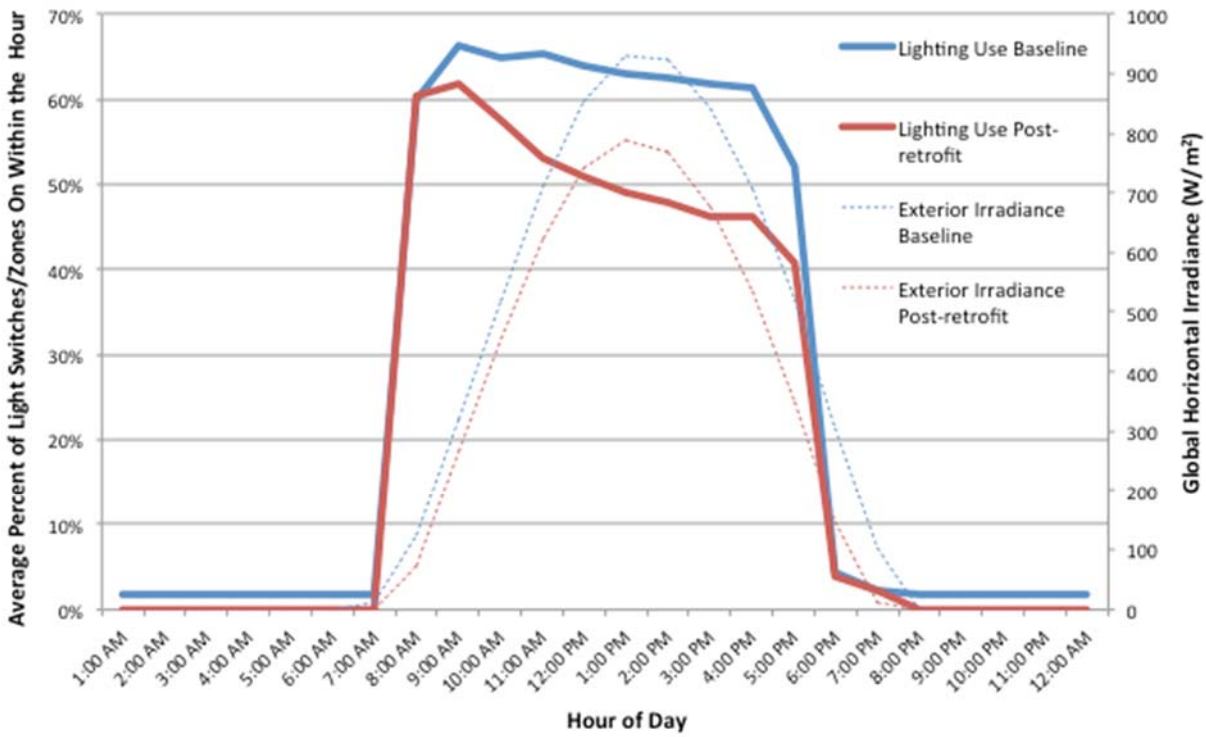


Figure G-1 Electric Lighting Use Pattern

Note that the measured illuminance is an average of five dynamic glass switching zones that run the north-south length of the open office. Behavior change seems to have occurred in general as shown by nighttime lighting use reduction.

The following plot confirms the reduced glare potential offered by View Dynamic Glass through a west open office workstation example. The vertical illuminance is taken for two representative occupant viewpoints, W1 and W2. The points face the west window and are slightly higher than typical sitting, eye height.

While not an exact correlation—due to the integration of luminous flux across the hemisphere and thus losing spatial bias—vertical illuminance can be used as a proxy for glare potential, which the View Dynamic Glass is reducing. Note that the difference in the hourly average illuminance for the two vertical points is due to the difference in sensor position relative to interior finishes, and obstructions, e.g., window mullions. It is likely, for example that the sensor at point W1 is in partial shadow between the hours of 6 pm and 7 pm.

The light grey lines show the typical hourly visible light transmittance for phase 1 and phase 2 of the post-retrofit scenario. For the west façade, the second phase will allow for increased morning illuminance and better alignment of tint state with heat and glare potential in the afternoon. The baseline glass on the west faced had a visible light transmittance of 40%, which is why the morning data for phase 1 of the post-retrofit shown in the plot is similar to the baseline analysis period.

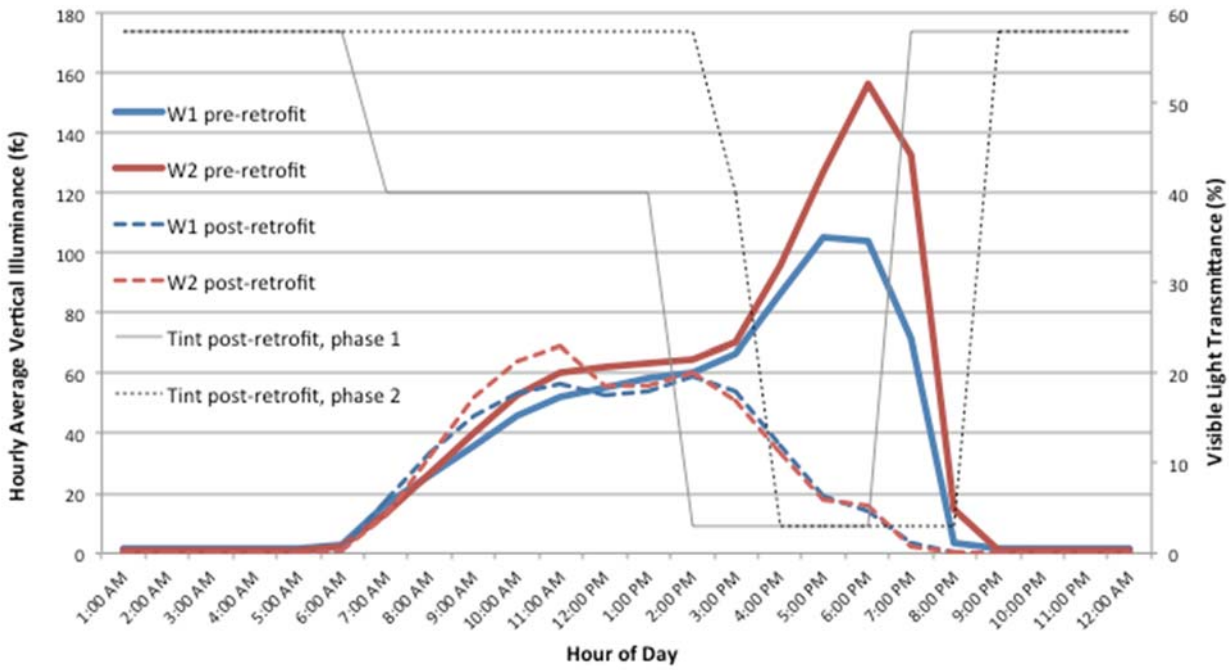


Figure G-2 West-Facing Vertical Point Illuminance

1.13 OCCUPANT MONITORING CONCLUSIONS

1.13.1 Lessons Learned

- Satisfaction with respect to overall comfort and views improved during the first year of dynamic glass demonstration
- Timer-based control scheme presents issues with:

  -Adequate glare control
  -Dark glass under cloudy sky conditions
- Focus on afternoon glare issues on the west façade when adjusting control system for the remainder of the project (unique to this project, not general lesson learned).

1.13.2 Next Steps

- Control algorithm changed to an automatic sequence based on direct insolation calculations and exterior irradiation measurement
- Continue to monitor occupant feedback in the summer months, with the new control algorithm

- Provide monthly updates on occupant acceptance of the new control algorithm as adjust as needed during the remaining six months of the demonstration; provide a formal update in September.

19.0 APPENDIX H: Energy Model Details:

Baseline energy model:

Initial parameters for our baseline energy model were extracted from the Miramar Public Works report for Building 6311 provided by Mick Wasco (Base Resources Energy Manager) to collect relevant site information and information about HVAC. Multiple additional on-site walkthroughs were performed to verify and collect any missing information. Any missing information was acquired from the DOE commercial reference building database for pre-1980 medium office buildings. All the information was provided to NREL to develop the initial baseline energy model using Energy Plus software. Figure H-1 shows the basic model design. Interior zones were divided, as shown in Figure H-1.

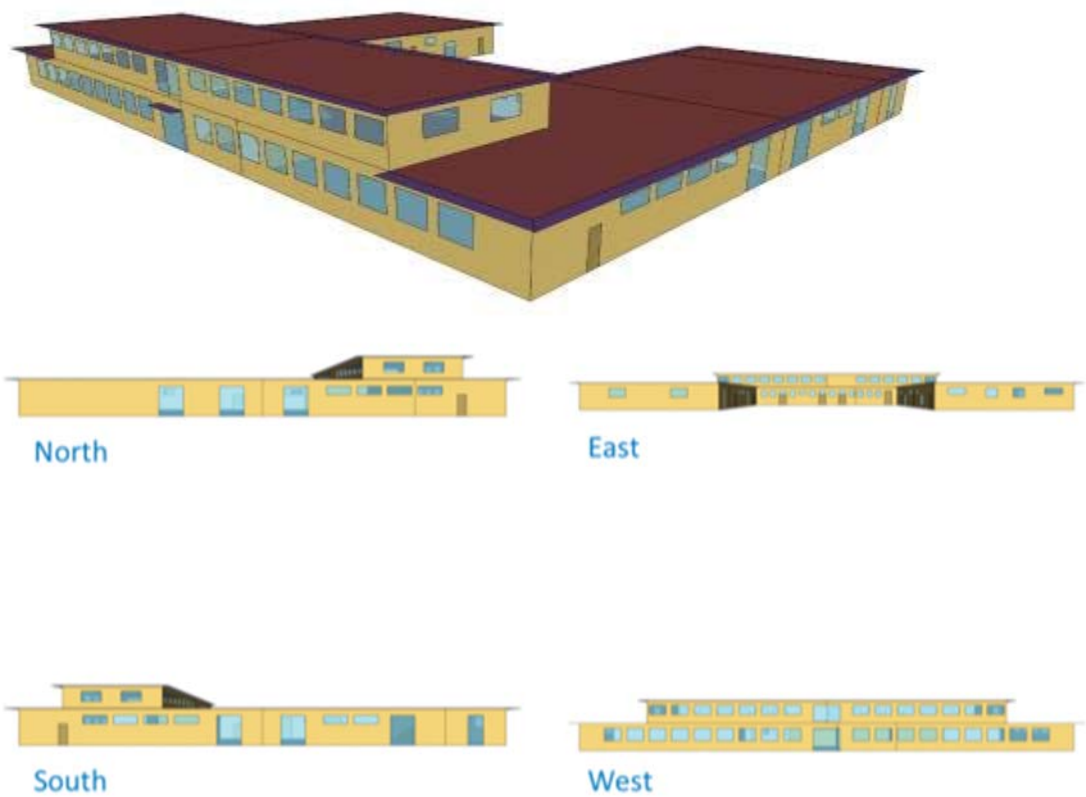


Figure H-1: 3D view and building elevations (Graphics generated using Open studio)

Key Baseline Fenestration Parameters:

Orientation of window	U-value (W/m2K)	SHGC	Visible Transmittance	Window to wall ratio
East	1.09	0.81	0.88	17.8%
West	0.48	0.47	0.38	32%
North	1.09	0.81	0.88	15.9%
South	1.09	0.81	0.88	18.4%

Table H-1:

Key Baseline Opaque Constructions Parameters:

- U-0.10 insulation entirely above deck roof
- U-0.23 mass exterior walls
- 4-inch concrete slab
- Hollow steel swinging doors

Key Baseline Occupancy Parameters:

- 313.77 ft^2 per person
- 102 total people

Key Baseline Lighting Parameters:

- Power density: 1.5 W/ft^2

Key Baseline Miscellaneous Equipment Loads Parameters:

- Power density: 0.9 W/ft^2

- Lighting
  - 0.4 radiant fraction
    -
  - 0.4 return air fraction
    - Source: pre-1980 medium office DOE commercial reference building
- Equipment
  - 0.5 radiant fraction
- Infiltration
  - 0.223 CFM/ft^2 of exterior surface area
  - 6AM-10PM quarter on
- Service water heating
  - 9.9 gal/h in Flr1 Zn6 and Flr2 Zn2 (zones with restrooms)
  - Electric water heater with storage tank
- Ventilation
  - 21.19 CFM per person

Lighting schedule

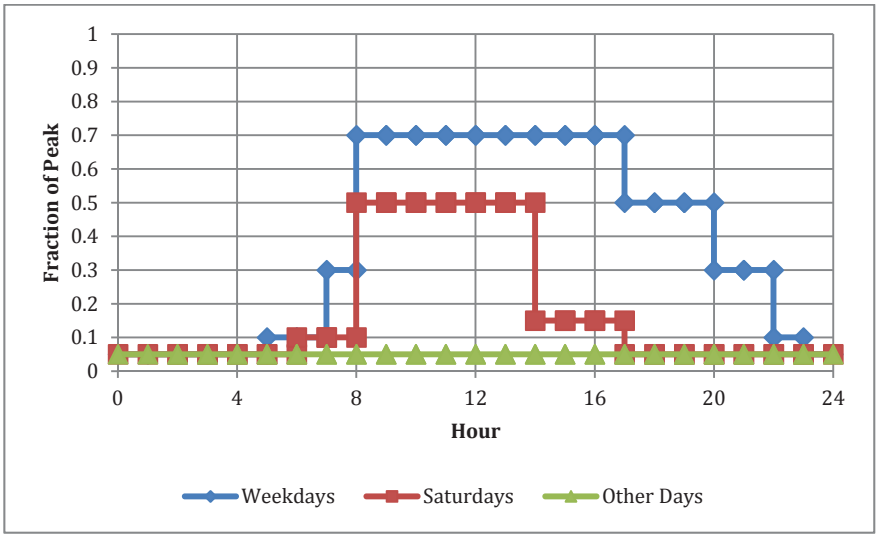


Figure H-2: *lighting schedule*

Plug load schedule

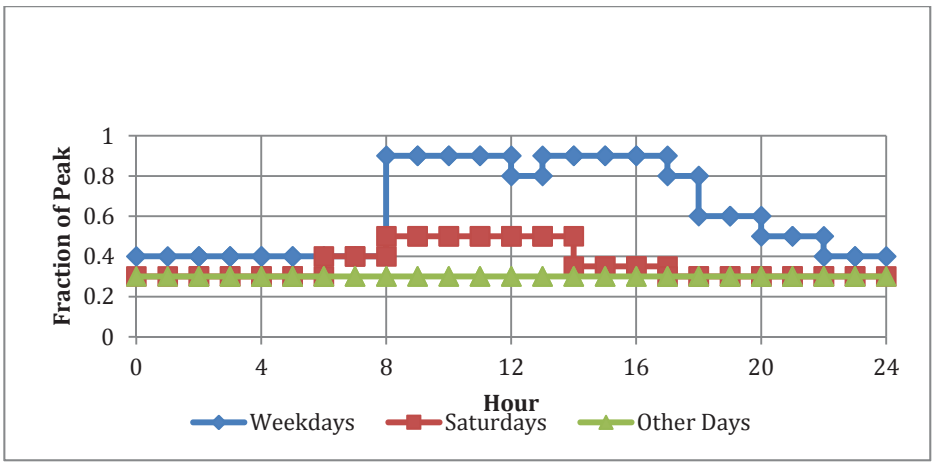


Figure H-3: *Plug load schedule*

Occupancy schedule

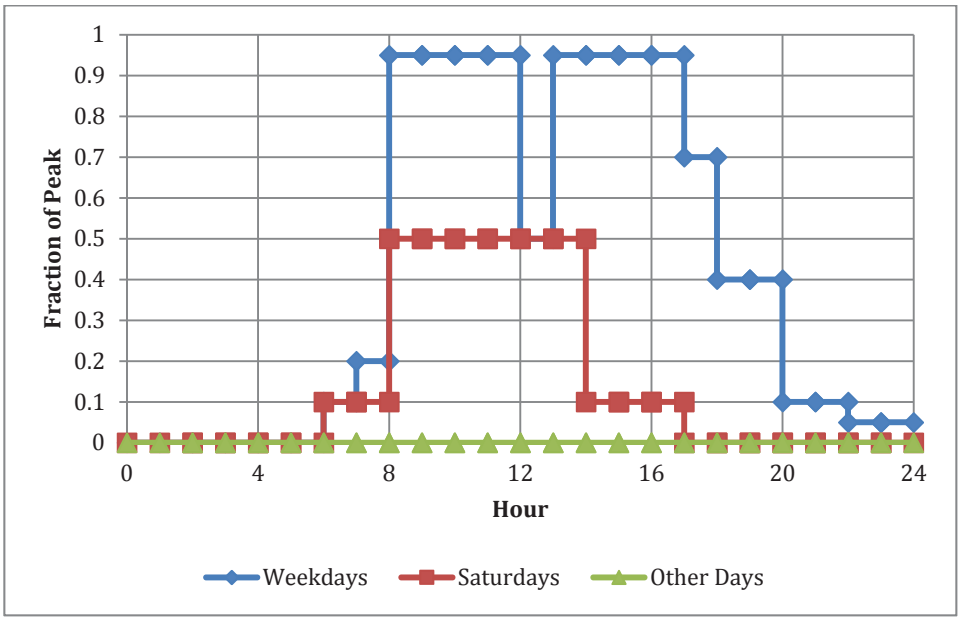


Figure H-4: *Occupancy Schedule*

Thermostat schedule

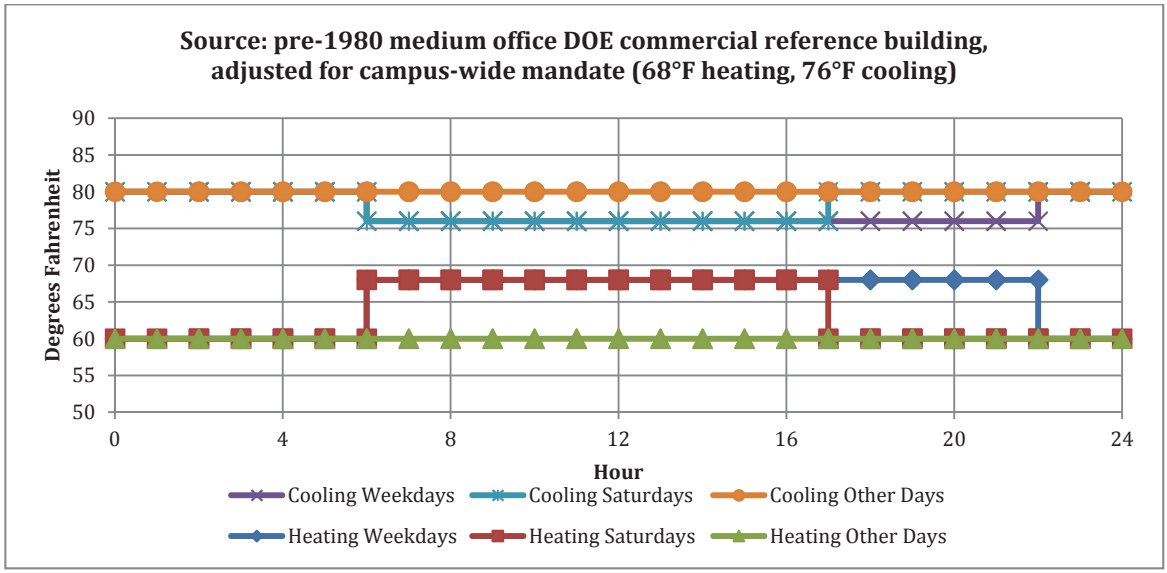


Figure H-5: *Thermostat Schedule*

Baseline energy model results

- Design periods
  - TMY3 San Diego Annual Heating 99.6%
  - TMY3 San Diego Annual Cooling 0.4%
- Weather file
  - KNKX San Diego CA QYBL 2012 Actual Meteorological Year EPW file
  - Purchased from Weather Analytics
- Simulation info
  - 10 minute time step
  - EnergyPlus version 7.2
- Annual Energy Use
  - 44.5 kBtu/ft^{2}yr

Breakdown of energy consumption

Int Equip (elec, kBtu/ft^{2}yr)	14.4
Int Light (elec, kBtu/ft^{2}yr)	16.1
Heating (gas, kBtu/ft^{2}yr)	0.5
Heating (elec, kBtu/ft^{2}yr)	0.2
Cooling (elec, kBtu/ft^{2}yr)	3.5
Fans (elec, kBtu/ft^{2}yr)	9.0
Pumps (elec, kBtu/ft^{2}yr)	0.0
SWH (elec, kBtu/ft^{2}yr)	0.8

Table H-2: *Breakdown of energy consumption*

Peak electric demand for the baseline

building based on energy model

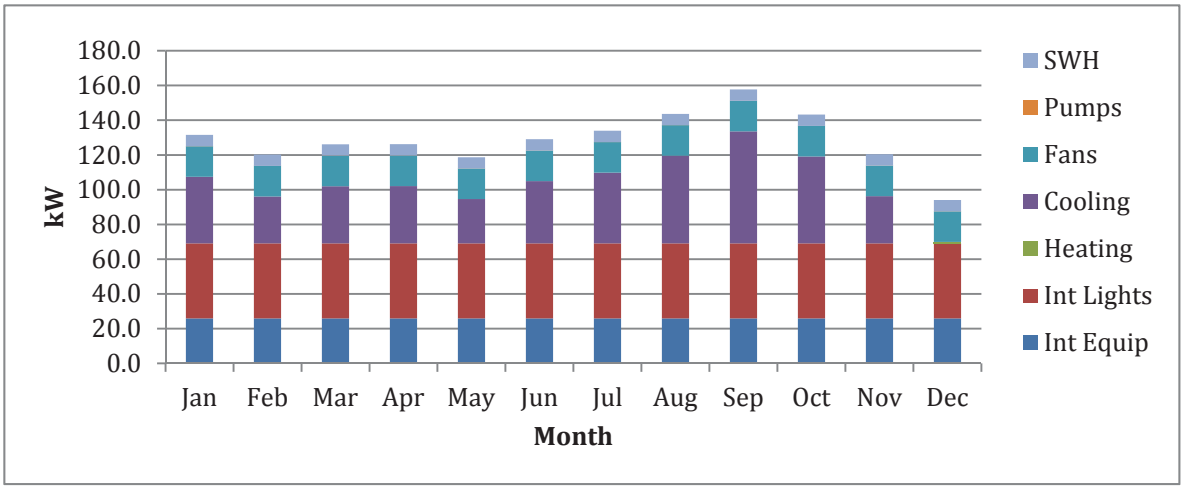


Figure H-6: *building based on energy model*

Model calibration from baseline and dynamic monitoring results:

1. Post retrofit (with dynamic glass) analysis and monitoring

19.1. CALIBRATING THE BASELINE MODEL

The baseline monitoring started in end of November 2012 and was completed in May 2013 when the dynamic glass retrofit started. The baseline monitored energy data was used to calibrate the baseline energy model by NREL.

NREL used the monitored HVAC information to calibrate the Energy model and check for differences.

- HVAC trend data
  - Provided 5 months of baseline data for 15-minute trend data for each HVAC unit
    - One unit (AC7) did not have a full years' worth of trend data
  - Filled in trend data holes assuming linear regression between data points
  - Generated EnergyPlus data for each HVAC unit by simulating the baseline model using actual weather data for 2013 purchased from Weather Analytics
  - Plotted 15-minute trend data overlaid with EnergyPlus data for each HVAC unit
  - Plotted 15-minute trend data overlaid with EnergyPlus data for all units
  - Compared annual totals for all units
  - Date (horizontal axis) range for all plots: 1/1/2013 – 5/31/2013
- Utility bill data
  - Used electricity and natural gas utility bill energy consumption data for FY11, FY12, FY13, and the first two months of FY14
    - This maps into data for Oct-Dec 2010, 2011, 2012, and Jan-Nov 2013
  - Generated electricity and natural gas EnergyPlus energy consumption data for 2012 and 2013 using previously purchased actual weather data from Weather Analytics
    - No data for December 2013
  - Plotted utility bill and EnergyPlus monthly energy consumption data side-by-side

Plotted annual totals of utility bill and EnergyPlus energy consumption data side-by-side

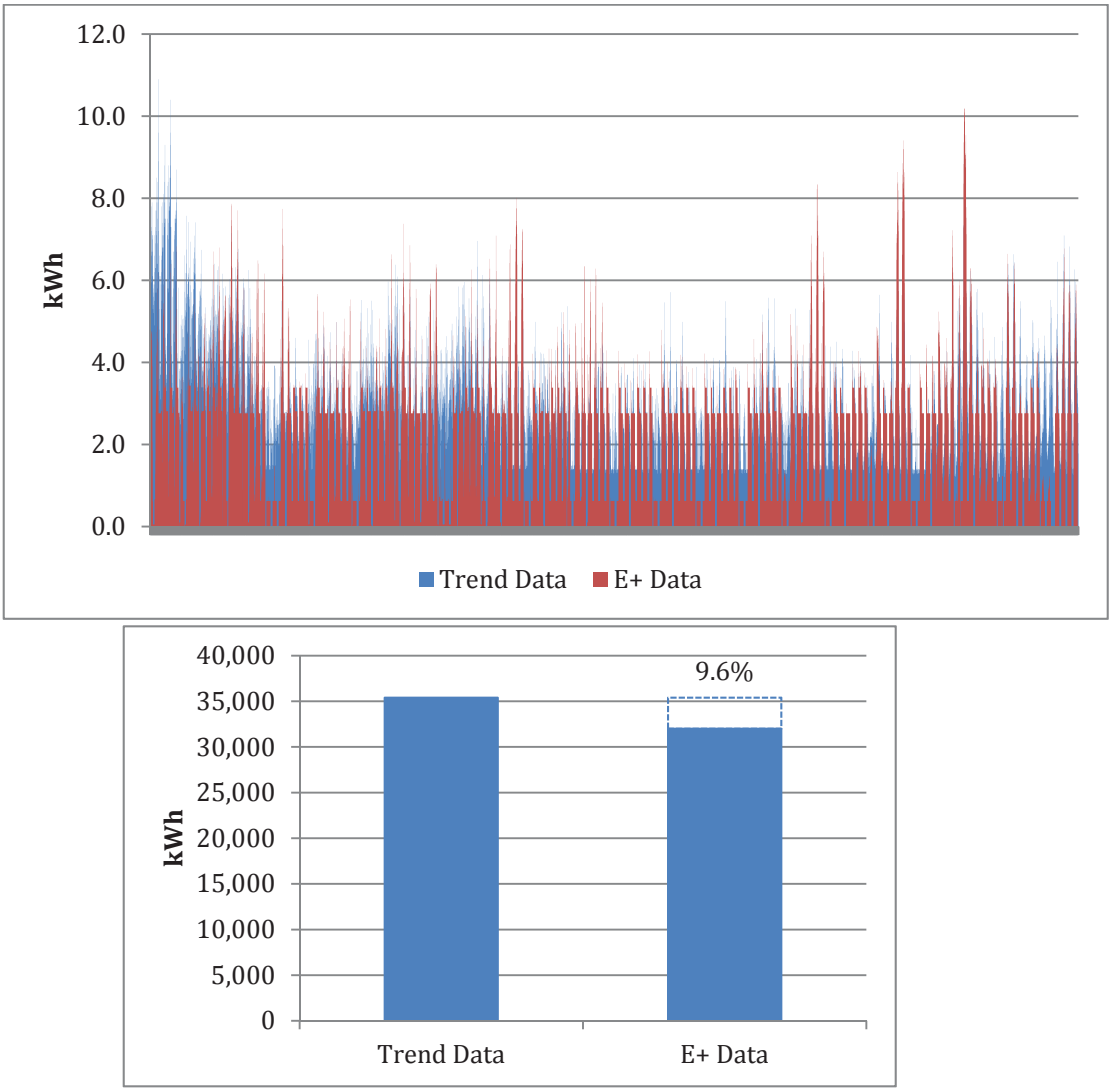


Figure H-7: *HVAC data comparison before energy model and monitored data*

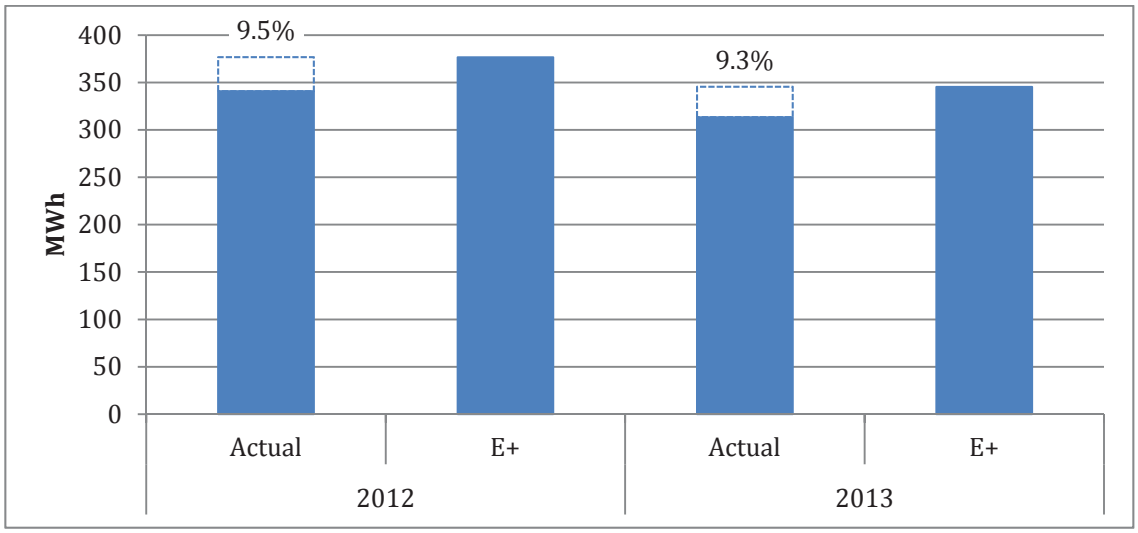


Figure H-8: *Utility data comparison between model and actual data from utility meters*

Calibrating against weather data:
Since there was an existing weather station at site, View purchased the detailed weather files from weather analytics for all years during the monitoring period to get the weather information. This information was used to compare the before and after HVAC monitored data as well as calibrate the energy model.

Conclusions

- HVAC trend data
  - Accuracy for each individual unit varied
    - Some matched well
    - Some did not match well at all
  - Five month totals seemed to match well (within 10%)
- Utility bill data
  - Electricity data matched fairly well, both on a month-by-month and annual total basis
  - Natural gas data did not match well at all, a units problem is suspected
- The HVAC percentage between the metered/utility data and modeled data matches well

After the calibration from baseline model against monitored data was complete, the Dynamic model was created to calculate potential energy savings

1.1. Before after HVAC real-time monitored data analysis

The HVAC monitored data shows that the savings in energy consumption varies by zone. This is mainly due to the sun exposure and window to wall ratio.

20.0 APPENDIX I: Technical Performance Data

Table I-1: *Baseline Usage Condition*

Category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Operational HVAC electric use (KWH)	6739	5652	6646	6349	6254	8420	10342	11870	9754	7804	6124	6849
Operational HVAC natural gas use (Therms)	46	10	5	2	1	0	0	0	0	0	5	45
Lighting electric use (KWH)	10,052	9,138	10,828	9,737	10,440	10,394	9,783	10,828	9,737	10,052	9,887	9,783
Total building electric use (KWH)	28,751	25,620	29,904	27,616	28,852	30,736	31,832	35,066	30,990	29,775	27,681	28,394
Total building natural gas use (Therms)	46	10	5	2	1	0	0	0	0	0	5	45
Total building energy use (MBTU)	103	88	103	94	99	105	109	120	106	102	95	101
Peak total building energy (KW)	99	92	97	112	85	126	122	122	122	119	105	103

Table I-2: *Usage After installing View Glass: WITHOUT dimmable lights*

Category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Operational HVAC electric use (KWH)	5,632	4,656	5,444	5,126	5,131	6,888	8,456	9,607	7,907	6,264	5,001	5,690
Operational HVAC natural gas use (Therms)	57	13	7	2	1	0	0	0	0	0	7	55
Lighting electric use (KWH)	8,041	7,310	8,662	7,790	8,352	8,315	7,826	8,662	7,790	8,041	7,909	7,826
Total building electric use (KWH)	27,645	24,624	28,701	26,393	27,728	29,205	29,946	32,803	29,143	28,235	26,557	27,235
Total building natural gas use (Therms)	57	13	7	2	1	0	0	0	0	0	7	55
Total building energy use (MBTU)	100	85	99	90	95	100	102	112	99	96	91	98
Peak total building energy (KW)	90	85	91	105	81	115	115	114	113	109	97	94

Table I-3: *Usage After installing View Glass: WITH dimmable lights*

Category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Operational HVAC electric use (KWH)	5,087	4,133	4,799	4,488	4,519	5,900	7,187	8,199	6,755	5,309	4,382	5,109
Operational HVAC natural gas use (Therms)	76	19	10	3	1	0	0	0	0	0	10	73
Lighting electric use (KWH)	4,633	3,728	4,017	3,299	3,530	3,434	3,307	3,876	3,718	3,865	4,353	4,550
Total building electric use (KWH)	21,681	18,691	21,245	19,318	20,206	21,257	22,201	24,443	21,972	21,093	20,405	21,421
Total building natural gas use (Therms)	76	19	10	3	1	0	0	0	0	0	10	73
Total building energy use (MBTU)	82	66	74	66	69	73	76	83	75	72	71	80
Peak total building energy (KW)	78	73	70	70	59	82	81	79	80	80	79	92

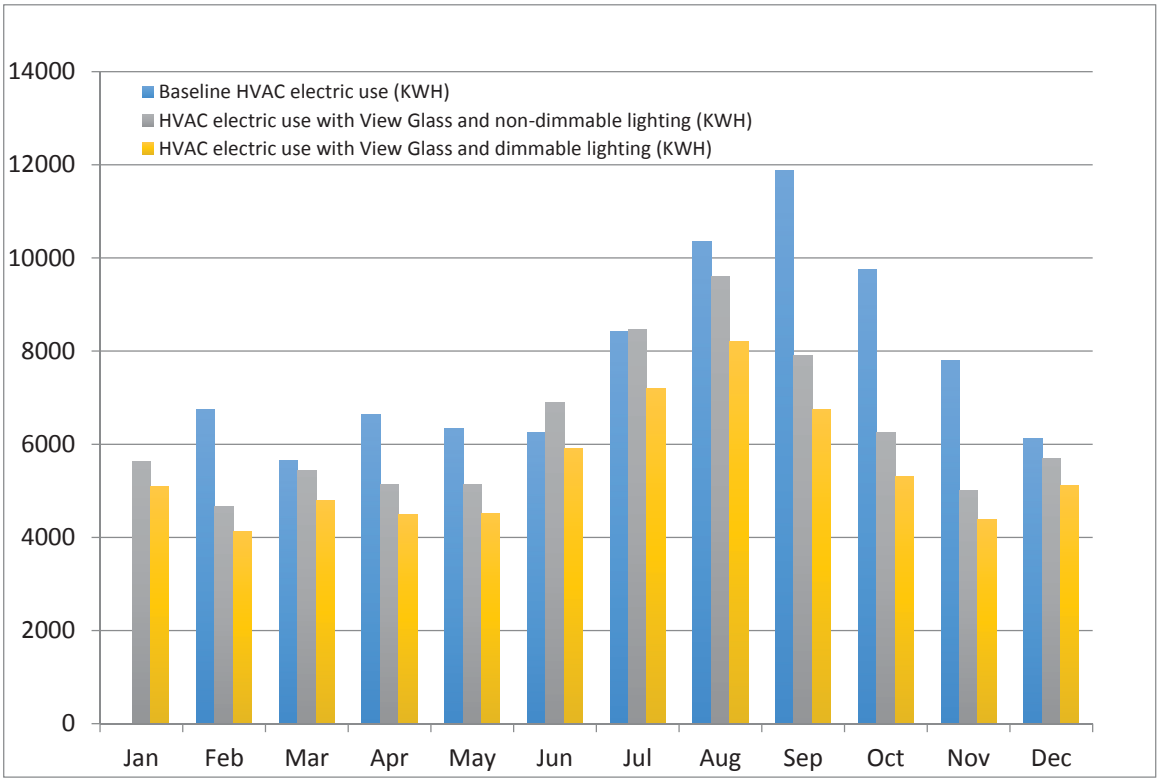


Figure I-1: *Monthly HVAC Consumption before and after dynamic glass installation*

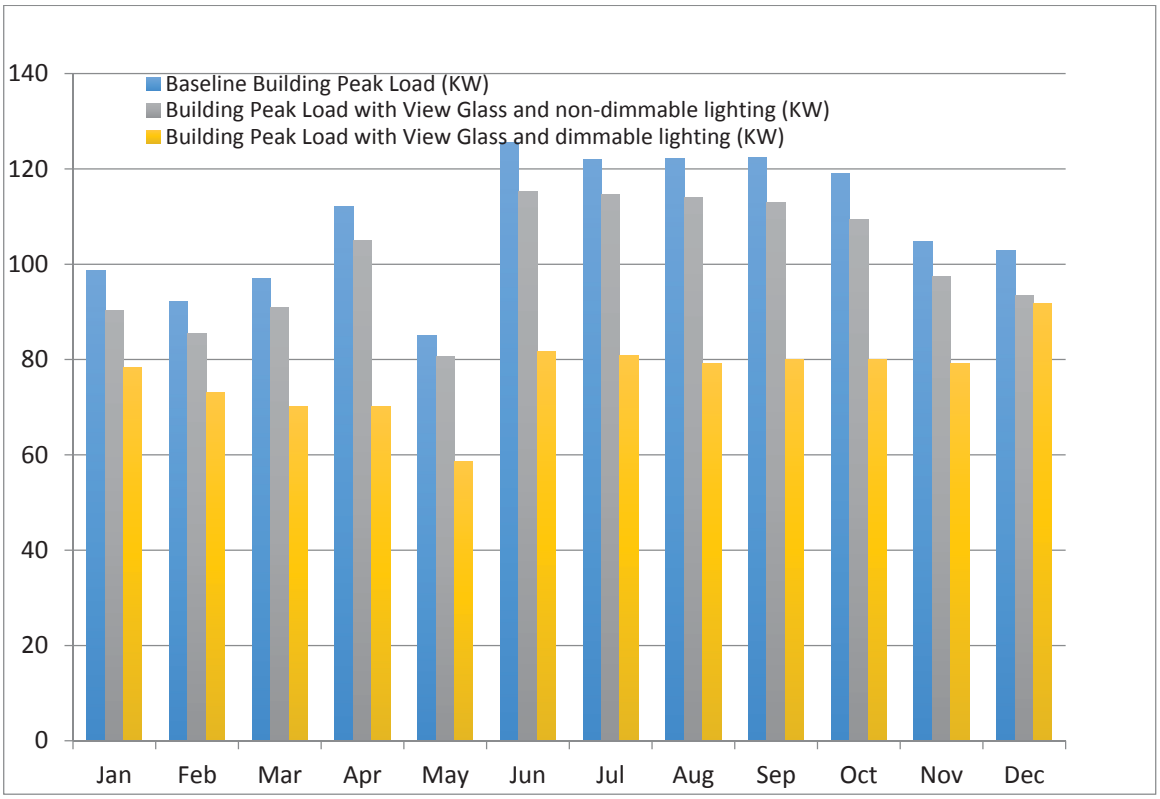


Figure I-2: *Monthly Building Peak-Load before and after installing View Glass dynamic windows.*

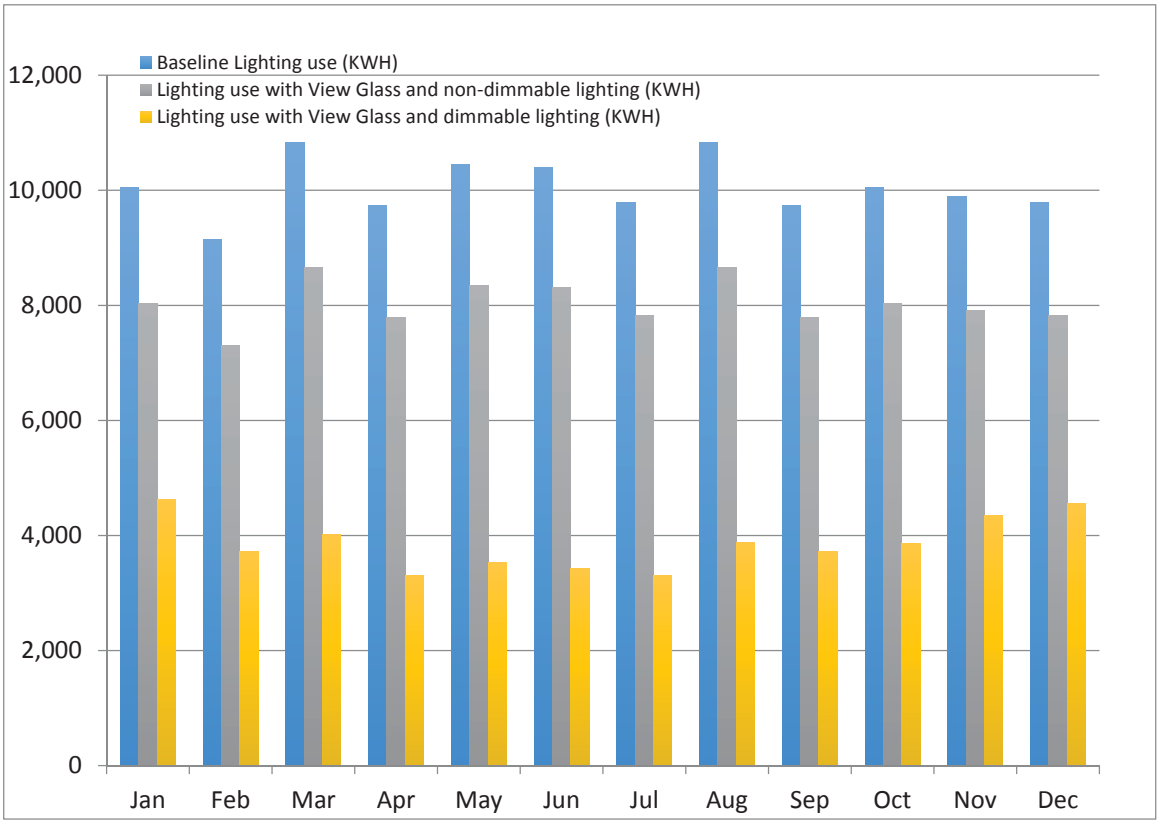


Figure I-3: *Monthly Lighting use before and after dynamic glass installation*

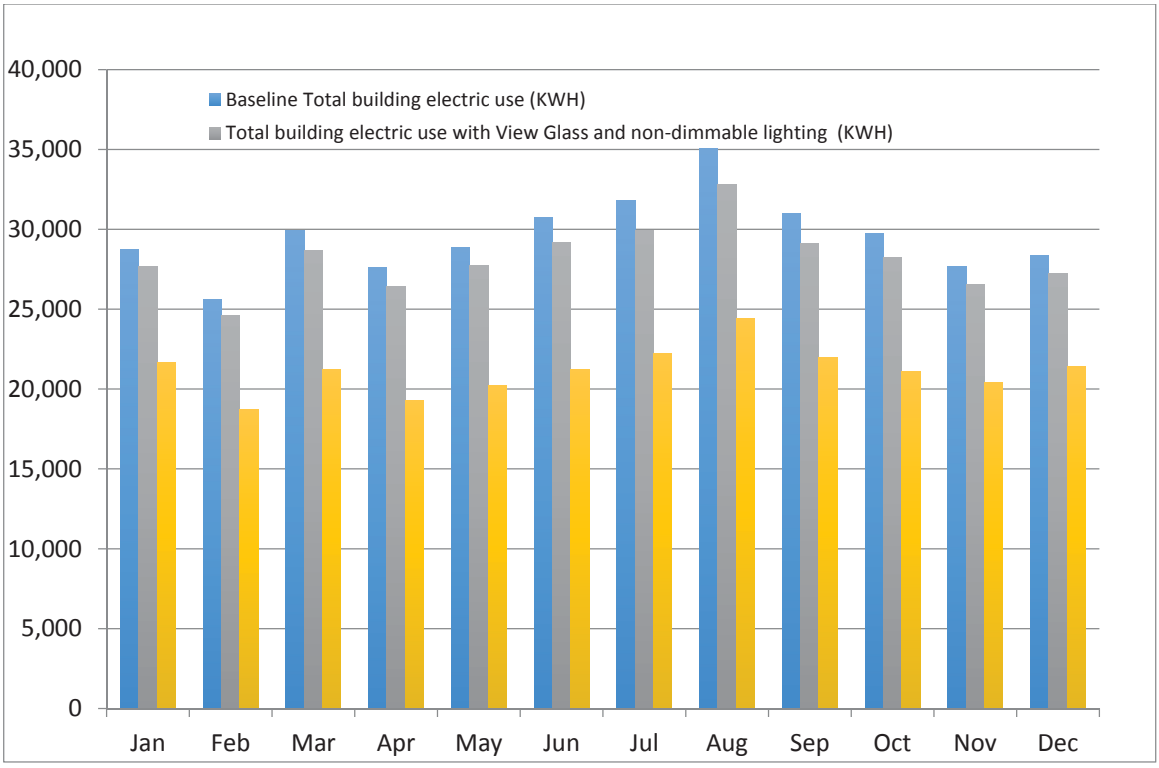


Figure I-4: *Monthly Total Building Electricity use before and after dynamic glass installation*

21.0 APPENDIX J: Anti-Terrorism Standards Certification

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Anti-Terrorism Standards Certification information starts on following page

AE Dynamics

ALUMINUM WINDOW STRUCTURAL CALCULATIONS

(Window Units A1, A2, B, B1, C, C1, D)

Project:

MCAS Miramar
San Diego, CA

Client:

Custom Engineered Openings
1055 Bay Blvd., Suite I
Chula Vista, CA 91911

AE Dynamics Job Number: 12077.00
Engineer In Responsible Charge: Scott Higinbotham, P.E.
Submittal Date: November 26, 2012

LIABILITY LIMITATIONS

AE Dynamics, LLC and the Engineer In Responsible Charge were retained in a limited capacity for this project. No responsibility and / or liability will be assumed by, or is to be assigned to the company and / or the individual engineer for items beyond those specifically shown on these pages.

129 Laura Ct, Bozeman, MT 59718
(406) 763-6375

1-877-208-8428
www.aedynamics.com

316 Maple Hill Dr, Apollo, PA 15613
(724) 472-1055

TABLE OF CONTENTS

SCOPE OF WORK 3

WINDOW ANALYSES 4
- Design Criteria
- Window System

ANCHORAGE REQUIREMENTS 4

CALCULATIONS 6
- Window Unit Diagrams (AED-01 - AED-07)
- ASTM F2248 Calculation
- ASTM E1300 Calculations
- Mullion Analysis
- Component Bending Calculations
- Anchorage Calculations

APPENDIX A – Test Reports

APPENDIX B – Fastener Data

SCOPE OF WORK:

AE Dynamics, LLC was contracted by Custom Engineered Openings to perform the structural analysis for the aluminum window assemblies being installed at the MCAS Miramar in San Diego, CA. The structural analysis includes review of the test reports supplied by the manufacturer, review of aluminum frame member capacities (where not validated by testing), and design of anchorage to the supporting substrate.

The analysis presented herein is for only the structural integrity of the window assemblies based on the provided information and criteria. The substrate for the attachment of these window assemblies is assumed to be adequately engineered in accordance with UFC 4-010-01 and in proper condition to resist the loads imparted by the window system. In addition, the analysis presented herein is not intended to address water resistance, water penetration, or air infiltration issues.

Referenced Standards utilized for this project include:

- *DoD Minimum Antiterrorism Standards For Buildings* – UFC 4-010-01, Department of Defense, 8 October 2003 (including change 1, 22 January 2007).
- *DoD Minimum Antiterrorism Standoff Distances For Buildings* – UFC 4-010-02, Department of Defense, 8 October 2003 (including change 1, 19 January 2007).
- ASTM F 2248-09, Standard Practice for Specifying an Equivalent 3-Second Duration Design Loading for Blast Resistant Glazing Fabricated with Laminated Glass.
- ASTM E 1300-12a, Standard Practice for Determining Load Resistance of Glass in Buildings.
- *Metal Curtain Wall Fasteners*, American Architectural Manufacturers Association, Report AAMA TIR A9-91, 1991.
- *Aluminum Design Manual*, The Aluminum Association, Inc., 2010

Referenced Reports utilized for this project include:

- Boyd Aluminum Shock Tube Testing for Glazing Systems, ABS Consulting
    - 2200 Fixed in Receptor – 06/25/2008
    - 2200 Fixed with snap trim – 06/25/2008
    - 2300 Fixed over Project-out in receptor – 06/25/2008
    - 2300 Fixed over Project-out with snap trim – 06/25/2008
    - 2300 Project-out in receptor – 06/24/2008

WINDOW ANALYSIS – (Window Units A1, A2, B, B1, C, C1, D):

Design Criteria:

- No project specifications provided. The following criteria have been assumed:
  - UFC 4-010-02, Department of Defense, 8 October 2003 (including change 1, 19 January 2007).
  - Charge Weight II at Stand-off Distance of 82 feet
- ASTM F2248: Equivalent 3-Second Load = 50psf (0.347 psi)
- Design for 2x ASTM E1300 Load Rating of Glass

Window System:

The window systems are based on the Boyd 2200 & 2300 Blast Series Models. The glazing is a 1" insulated glass consisting of ¼" tempered exterior glass and ¼" laminated annealed (1/8" + 0.030" PVB + 1/8") inner glass layer.

The products have been blast tested in accordance with ASTM F 1642-04. The relevant test reports can be found in Appendix A. Based on the project conditions and stated criteria, the blast testing provides adequate documentation of the window unit's ability to perform in a satisfactory manner. Our analysis therefore only addresses the vertical mullions and anchorage attaching the window units to the surrounding substrate.

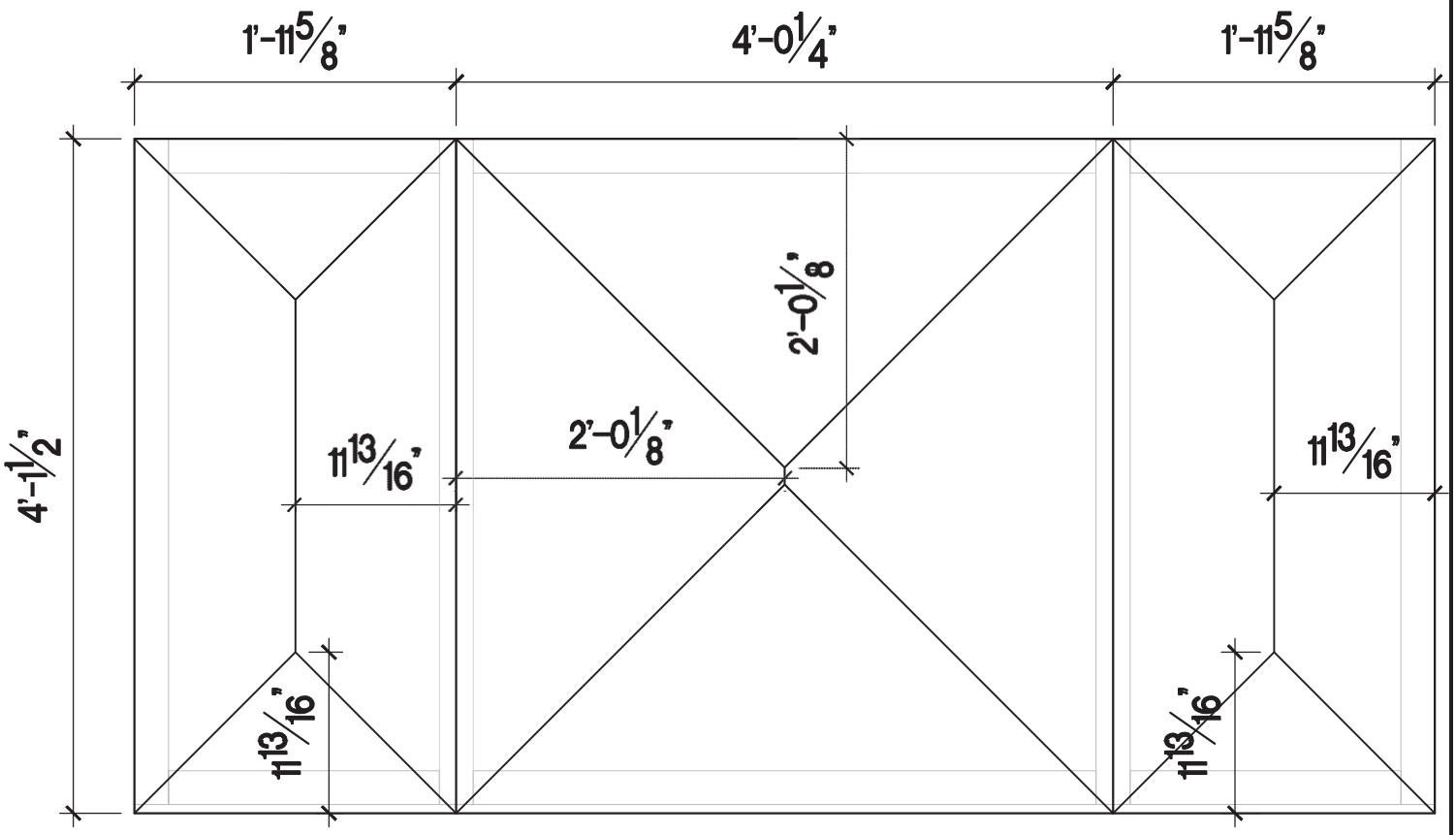
ANCHORAGE REQUIREMENTS:

Windows Units A2 & D1		
Fastener type:	Powers Fasteners - 'Tapper'	
Size:	1/4" DIA	
Substrate:	Concrete	
Typical Spacing:	6"oc max	
Min. Embedment:	1-3/4"	
Min. Edge Distance:	2"	
Corner Distance:	3" max	
Trim Clip Window Frame Anchors (Sill)	**Fastener Type:**	Elco Dril-Flex
	Size:	#12 - 14
	Typical Spacing:	12"oc max
	Corner Distance:	3" max
Shim Space:	3/8" max	
Notes:	Shim tight between substrate and clip where reducer clips into receptor to prevent bending outward	

ANCHORAGE REQUIREMENTS (CONT):

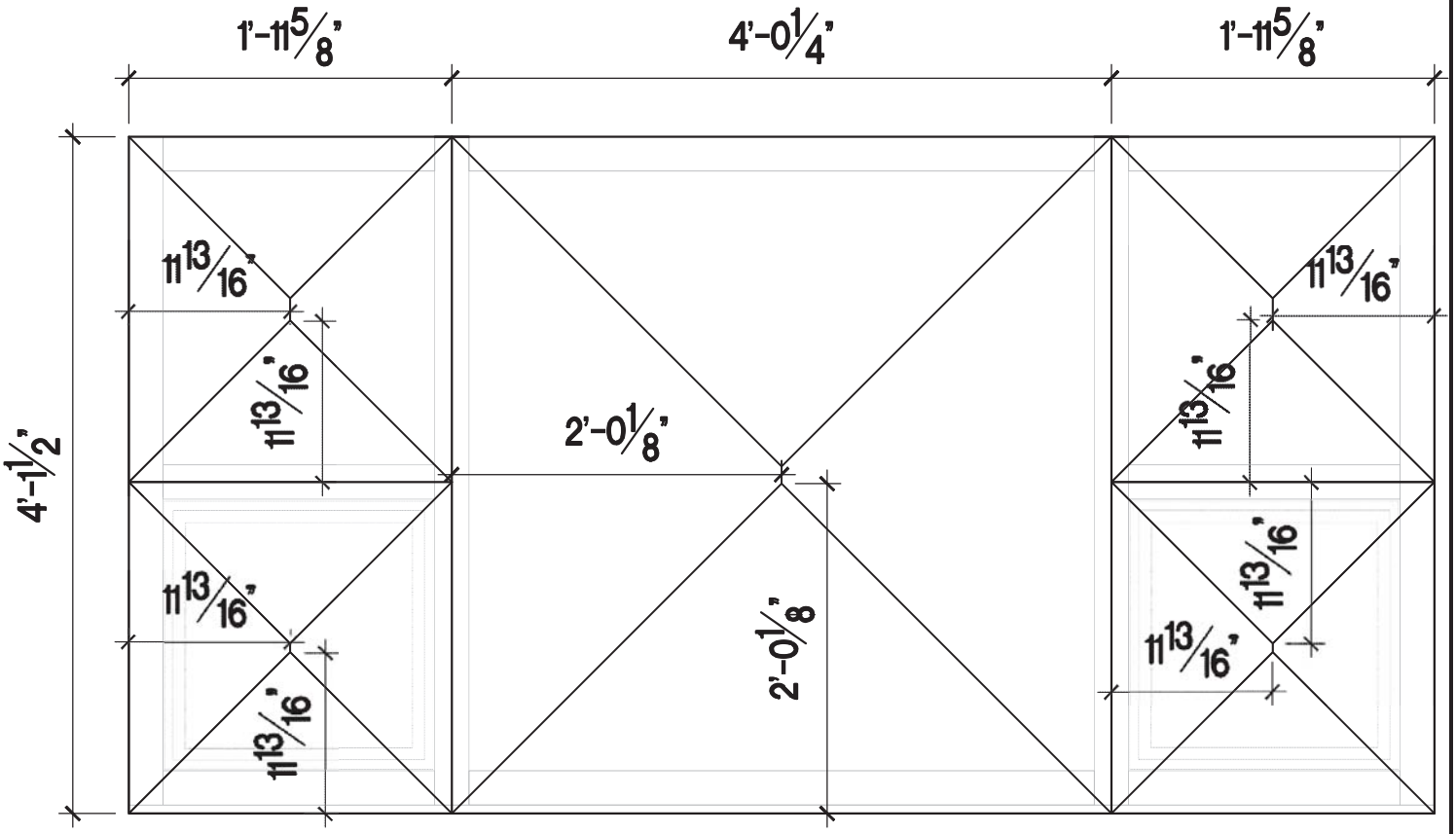
Windows Units A1, B, C1, C2, D2		
Fastener type:	Powers Fasteners - 'Tapper'	
Size:	1/4" DIA	
Substrate:	Concrete	
Typical Spacing:	10"oc max	
Min. Embedment:	1-3/4"	
Min. Edge Distance:	2"	
Corner Distance:	3" max	
Trim Clip Window Frame Anchors (Sill)	**Fastener Type:**	Elco Dril-Flex
	Size:	#12 - 14
	Typical Spacing:	12"oc max
	Corner Distance:	3" max
Shim Space:	3/8" max	
Notes:	Shim tight between substrate and clip where reducer clips into receptor to prevent bending outward	

Vertical 4PC Mullion Anchorage (Head & Sill)		
Clips:	(2) 2x2x1/8 x 2" long - Aluminum (2 Clips Each End)	
Mullion Note:	Field Cut to fit opening tight with NO SHIM SPACE	
Primary Substrate:	Concrete	
Substrate Anchors	**Fastener Type:**	Powers Fasteners - 'Tapper'
	Size:	1/4" DIA
	Quantity:	2 Anchors Per Clip
	Min. Embedment:	1-3/4"
	Min. Edge Distance:	3"
	Anchor Spacing:	1-1/4" min. apart
Clip To Mullion Anchors	**Fastener Type:**	Elco Dril-Flex (into steel plate by others)
	Quantity:	3 anchors (install completely thru both clips & mullion)
	Min. Edge Distance:	1/2"
	Min. Spacing:	3/4"
Mullion Pressure Plate Fasteners	**Fastener Size:**	1/4" Dia per Manuf.
	Spacing near ends:	3" oc first 18" from each end
	Spacing Typical:	6" oc remainder



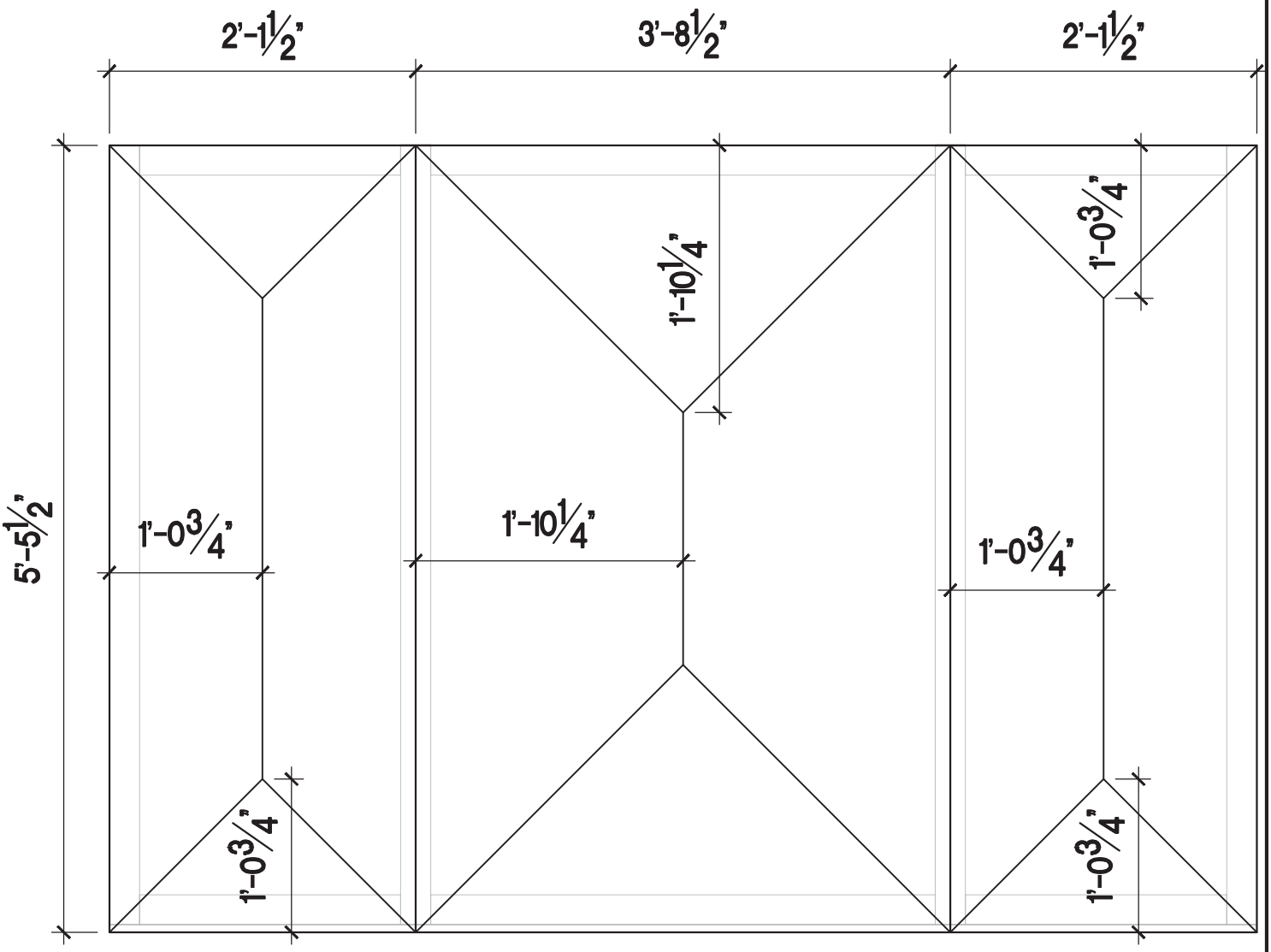
UNIT A1

	PROJECT: MCAS Miramar San Diego, CA	TITLE: PRESSURE DIAGRAM	
		SCALE: NTS	SHEET NO: AED-01
		DRAWN BY: SPH	
	PROJECT NO: 12077	DATE: 11-21-12	



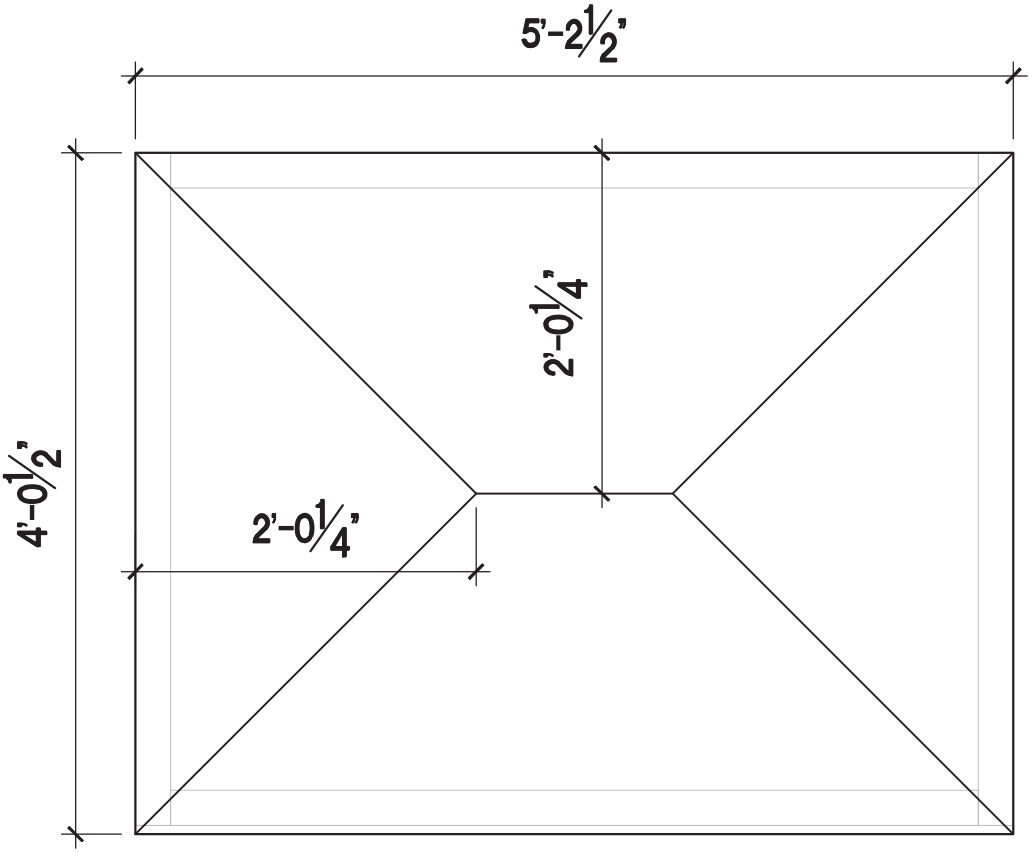
UNIT A2

	PROJECT: MCAS Miramar San Diego, CA	TITLE: PRESSURE DIAGRAM	
		SCALE: NTS	SHEET NO: AED-02
		DRAWN BY: SPH	
	PROJECT NO: 12077	DATE: 11-21-12	



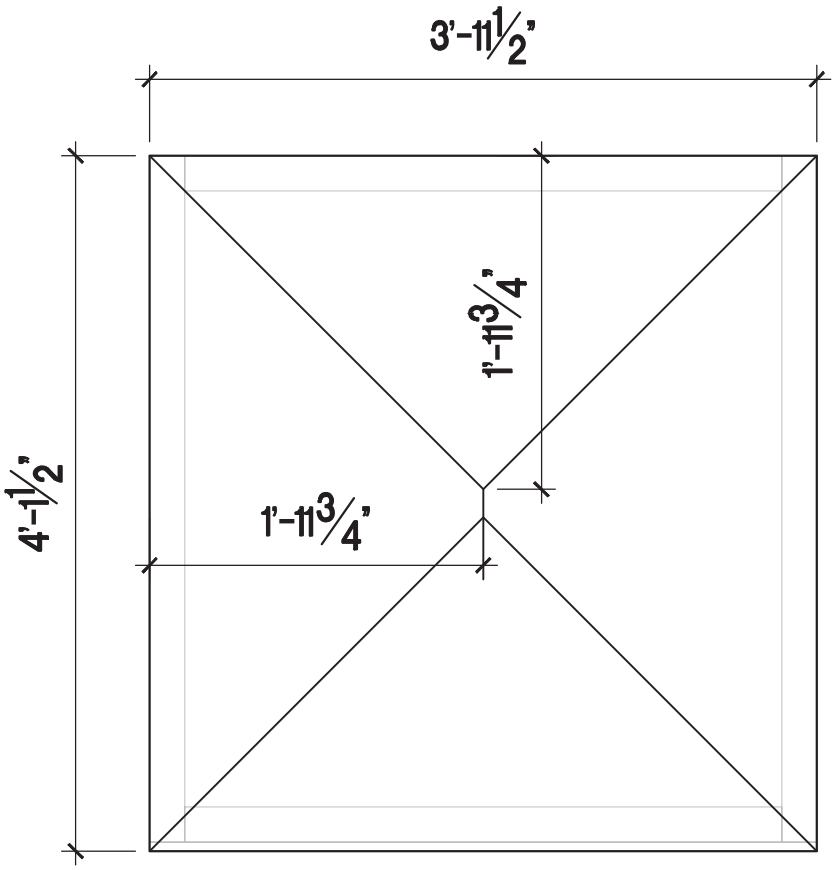
UNIT B

PROJECT: MCAS Miramar San Diego, CA	TITLE: PRESSURE DIAGRAM	
	SCALE: NTS	SHEET NO: AED-03
	DRAWN BY: SPH	
PROJECT NO: 12077	DATE: 11-21-12	



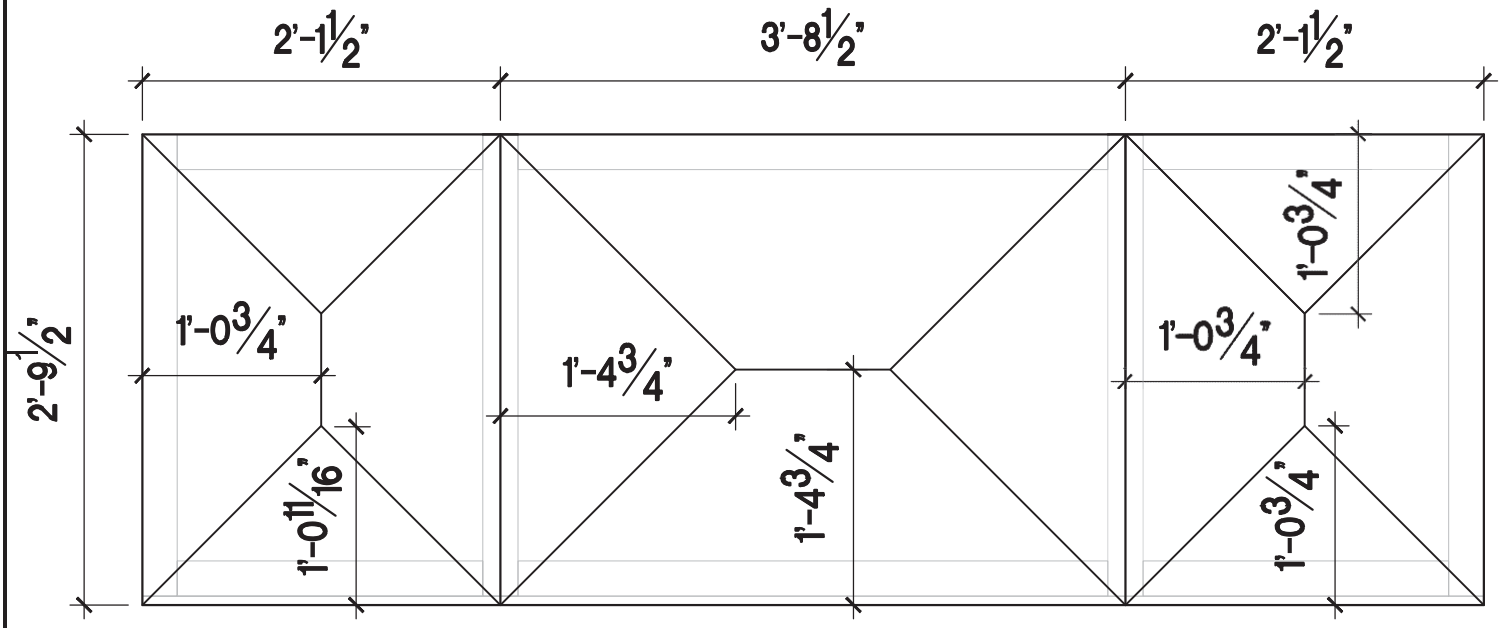
UNIT C1

	PROJECT: MCAS Miramar San Diego, CA	TITLE: PRESSURE DIAGRAM	
		SCALE: NTS	SHEET NO: AED-04
		DRAWN BY: SPH	
	PROJECT NO: 12077	DATE: 11-21-12	



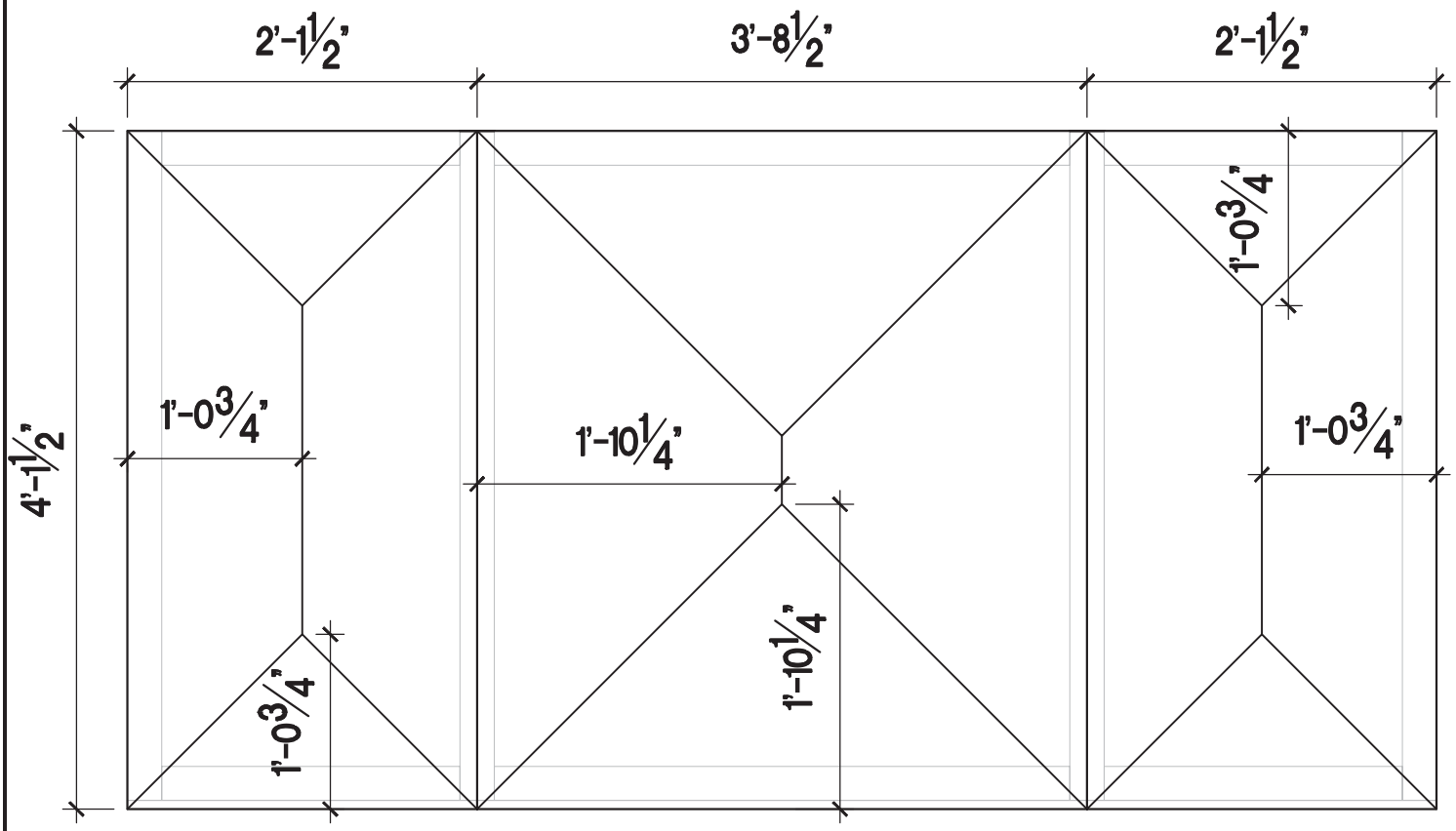
UNIT C2

	PROJECT: MCAS Miramar San Diego, CA	TITLE: PRESSURE DIAGRAM	
		SCALE: NTS	SHEET NO: AED-05
		DRAWN BY: SPH	
	PROJECT NO: 12077	DATE: 11-21-12	



UNIT D1

	PROJECT: MCAS Miramar San Diego, CA	TITLE: PRESSURE DIAGRAM	
		SCALE: NTS	SHEET NO: AED-06
		DRAWN BY: SPH	
	PROJECT NO: 12077	DATE: 11-21-12	



UNIT D2

	PROJECT: MCAS Miramar San Diego, CA	TITLE: PRESSURE DIAGRAM	
		SCALE: NTS	SHEET NO: AED-07
		DRAWN BY: SPH	
	PROJECT NO: 12077	DATE: 11-21-12	

4.2 The design load shall be used in conjunction with Practice E1300 to select the thickness(es) and glass type(s) for blast resistant glazing comprised of a single lite of laminated glass or insulating glass fabricated with laminated glass.

5. Significance and Use

5.1 This practice provides a design load suitable for sizing blast resistant glazing comprised of laminated glass or insulating glass fabricated with laminated glass.

5.2 Blast resistant glazing comprised of laminated glass or insulating glass fabricated with laminated glass shall be sized to resist the 3-second duration equivalent design loading from this standard practice using the procedures described in Practice E1300.

5.3 Blast resistant glazing comprised of laminated glass or insulating glass fabricated with laminated glass sized using the 3-second design loading determined from this practice will fracture safely in the event of a blast, thus reducing the potential for personal injury, structural and non-structural building damage, and cleanup costs should an explosion occur.

5.4 In the event a blast loading never occurs to blast resistant glazing comprised of laminated glass or insulating glass fabricated with laminated glass sized using the 3-second duration loading determined herein, the blast resistant glazing will have a probability of breakage less than or equal to 8 lites per 1000 at the first occurrence of a loading equal to the 3-second duration design loading determined herein.

5.5 Blast resistant glazing designed to resist the 3-second equivalent load as determined herein, properly supported, will perform to minimal hazard as defined in Test Method F1642.

6. Determination of Equivalent 3-Second Duration Design Loading

6.1 The chart in Fig. 1 relates the mass of an equivalent hemispherical TNT charge (sloping lines), its standoff distance from a fenestration (horizontal axes), and a 3-second duration design load (vertical axes) suitable for selecting the thickness(es) and glass type(s) of single laminated glass or insulating glass fabricated with laminated glass.

6.2 In Fig. 1 project a vertical line from the point along the horizontal axes that represent standoff distance between the high explosive charge and the fenestration to be glazed with blast resistant glazing.

6.3 From the intersection of the vertical line with the sloping line representing equivalent TNT mass, project a horizontal line. For equivalent TNT masses not represented by sloping lines, the user shall interpolate between the lines.

6.4 Read the 3-second duration design load from the vertical axes, interpolating as necessary.

7. Report

7.1 Report the following:

7.1.1 Date of calculation,

7.1.2 Mass of hemispherical TNT charge size,

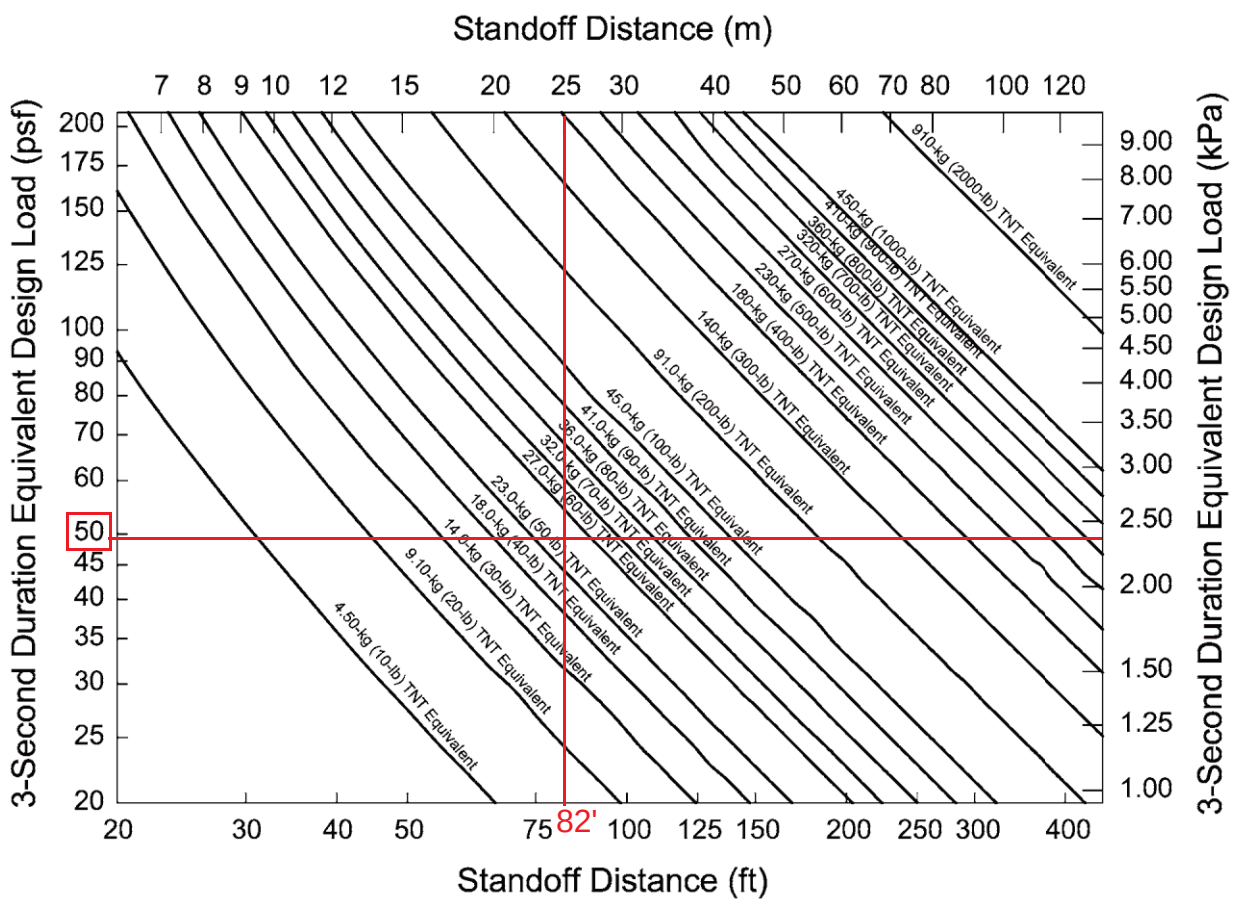


FIG. 1 Graphical Relationship Between Standoff Distance, TNT Charge Mass, and 3-Second Equivalent Design Load

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JOB #	12077
BY	SPH
DATE	11/21/12

ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	20	X	60

Outer Lite: 1/4" Tempered
Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	5.50	kPa	=>	114.95	psf
Inner Lite:	NFL2 =	4.60	kPa	=>	96.14	psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 6.067 psi
LR2 = NFL2 x GTF2 x LS2 = 1.335 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 1.335 psi **> 0.35 psi (50 psf) OK**

Design For ==> 2.67 psi

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ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	40	X	60

Outer Lite: 1/4" Tempered

Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	2.60	kPa	=>	54.34 psf
Inner Lite:	NFL2 =	2.80	kPa	=>	58.52 psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 2.868 psi

LR2 = NFL2 x GTF2 x LS2 = 0.813 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 0.813 psi **> 0.35 psi (50 psf) OK**

Design For ==> 1.63 psi

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DATE	11/21/12

ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	20	X	40

Outer Lite: 1/4" Tempered

Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	7.00	kPa	=>	146.3	psf
Inner Lite:	NFL2 =	6.50	kPa	=>	135.85	psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 7.721 psi

LR2 = NFL2 x GTF2 x LS2 = 1.887 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 1.887 psi **> 0.35 psi (50 psf) OK**

Design For ==> 3.77 psi

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ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	14	X	17

Outer Lite: 1/4" Tempered

Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	15.00	kPa	=>	313.5 psf
Inner Lite:	NFL2 =	15.00	kPa	=>	313.5 psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 16.546 psi

LR2 = NFL2 x GTF2 x LS2 = 4.354 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 4.354 psi **> 0.35 psi (50 psf) OK**

Design For ==> 8.71 psi

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ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	20	X	28

Outer Lite: 1/4" Tempered

Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	10.00	kPa	=>	209	psf
Inner Lite:	NFL2 =	9.00	kPa	=>	188.1	psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 11.031 psi

LR2 = NFL2 x GTF2 x LS2 = 2.613 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 2.613 psi **> 0.35 psi (50 psf) OK**

Design For ==> 5.23 psi

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BY	SPH
DATE	11/21/12

ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	28	X	40

Outer Lite: 1/4" Tempered

Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	5.00	kPa	=>	104.5	psf
Inner Lite:	NFL2 =	5.10	kPa	=>	106.59	psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 5.515 psi

LR2 = NFL2 x GTF2 x LS2 = 1.480 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 1.480 psi **> 0.35 psi (50 psf) OK**

Design For ==> 2.96 psi

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ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	42	X	54

Outer Lite: 1/4" Tempered

Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	3.00	kPa	=>	62.7 psf
Inner Lite:	NFL2 =	3.00	kPa	=>	62.7 psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 3.309 psi

LR2 = NFL2 x GTF2 x LS2 = 0.871 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 0.871 psi **> 0.35 psi (50 psf) OK**

Design For ==> 1.74 psi

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ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	20	X	44

Outer Lite: 1/4" Tempered

Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	6.90	kPa	=>	144.21 psf
Inner Lite:	NFL2 =	5.80	kPa	=>	121.22 psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 7.611 psi

LR2 = NFL2 x GTF2 x LS2 = 1.684 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 1.684 psi **> 0.35 psi (50 psf) OK**

Design For ==> 3.37 psi

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ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	40	X	44

Outer Lite: 1/4" Tempered

Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	3.60	kPa	=>	75.24	psf
Inner Lite:	NFL2 =	3.90	kPa	=>	81.51	psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 3.971 psi

LR2 = NFL2 x GTF2 x LS2 = 1.132 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 1.132 psi **> 0.35 psi (50 psf) OK**

Design For ==> 2.26 psi

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DATE	11/21/12

ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	20	X	25

Outer Lite: 1/4" Tempered

Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	11.00	kPa	=>	229.9 psf
Inner Lite:	NFL2 =	10.00	kPa	=>	209 psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 12.134 psi

LR2 = NFL2 x GTF2 x LS2 = 2.903 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 2.903 psi **> 0.35 psi (50 psf) OK**

Design For ==> 5.81 psi

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ASTM: E1300-12a Standard Practice for Determinining Load Resistance of Glass in Buildings

	short dim. (in.)	X	long dim. (in.)
Glass Under Evaluation:	28	X	28

Outer Lite: 1/4" Tempered

Inner Lite: 1/4" Laminated (1/8" AN + 0.030 +1/8" AN)

6.11 For Double Glzed Insulating Glass (IG) with One Monolithic Lite and One Laminated Lite Under Short Duration Load Simply Supported Continuously Along Four Sides

6.11.1 Refer to Fig. A1.6 & A1.28 Attached

Outer Lite:	NFL1 =	7.00	kPa	=>	146.3 psf
Inner Lite:	NFL2 =	7.00	kPa	=>	146.3 psf

6.11.2 Glass Type Factors (Table 2)

GTF1 = 3.8 GTF2 = 1.0

6.11.3 Load Share Factors (Table 5)

LS1 = 2.00 LS2 = 2.00

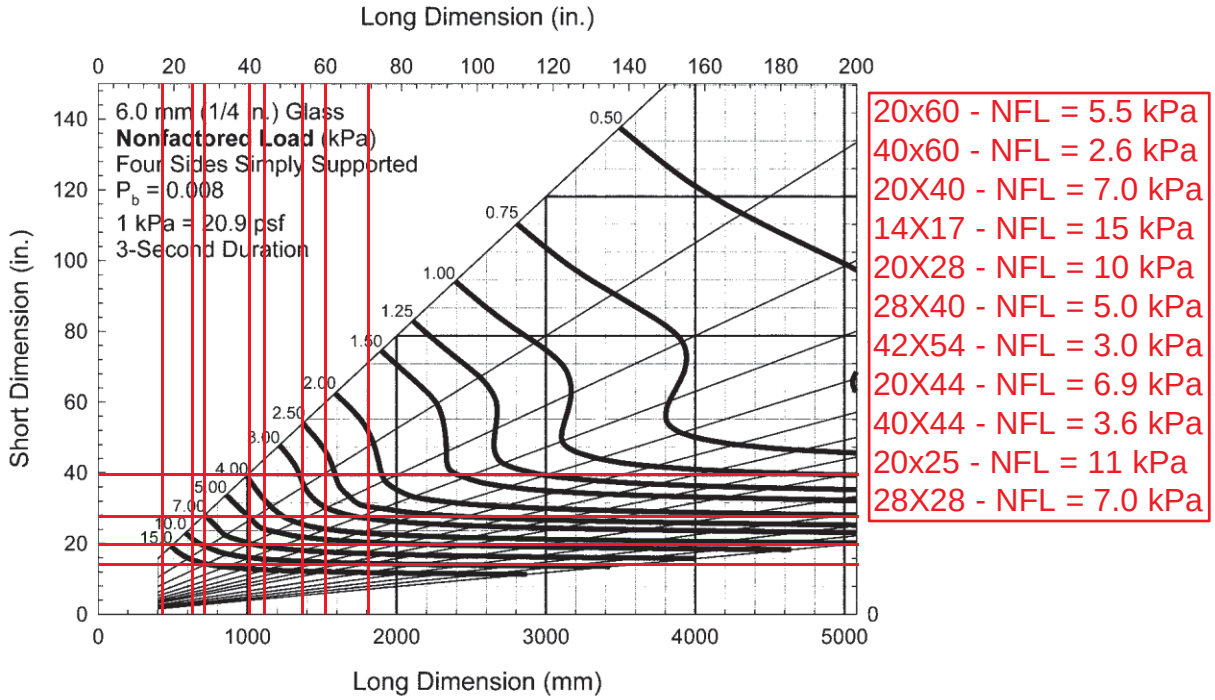
6.11.4 Load Resistance Calculations

LR1 = NFL1 x GTF1 x LS1 = 7.721 psi

LR2 = NFL2 x GTF2 x LS2 = 2.032 psi

6.11.5 Load Resistance of the Insulated Glass Unit = 2.032 psi **> 0.35 psi (50 psf) OK**

Design For ==> 4.06 psi



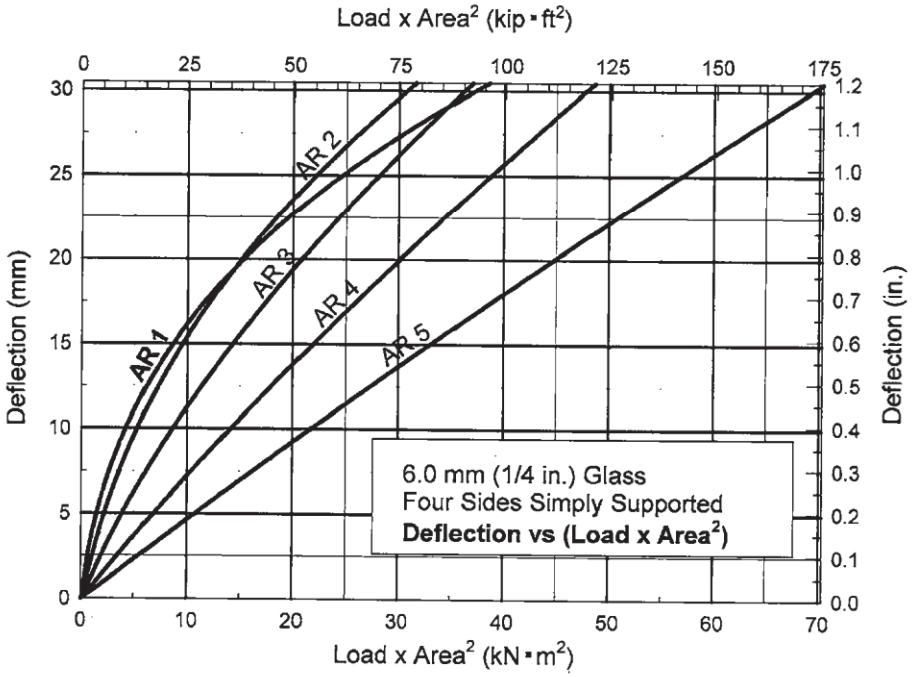


FIG. A1.6 (upper chart) Non-Factored Load Chart for 6.0 mm (¼ in.) Glass with Four Sides Simply Supported
(lower chart) Deflection Chart for 6.0 mm (¼ in.) Glass with Four Sides Simply Supported

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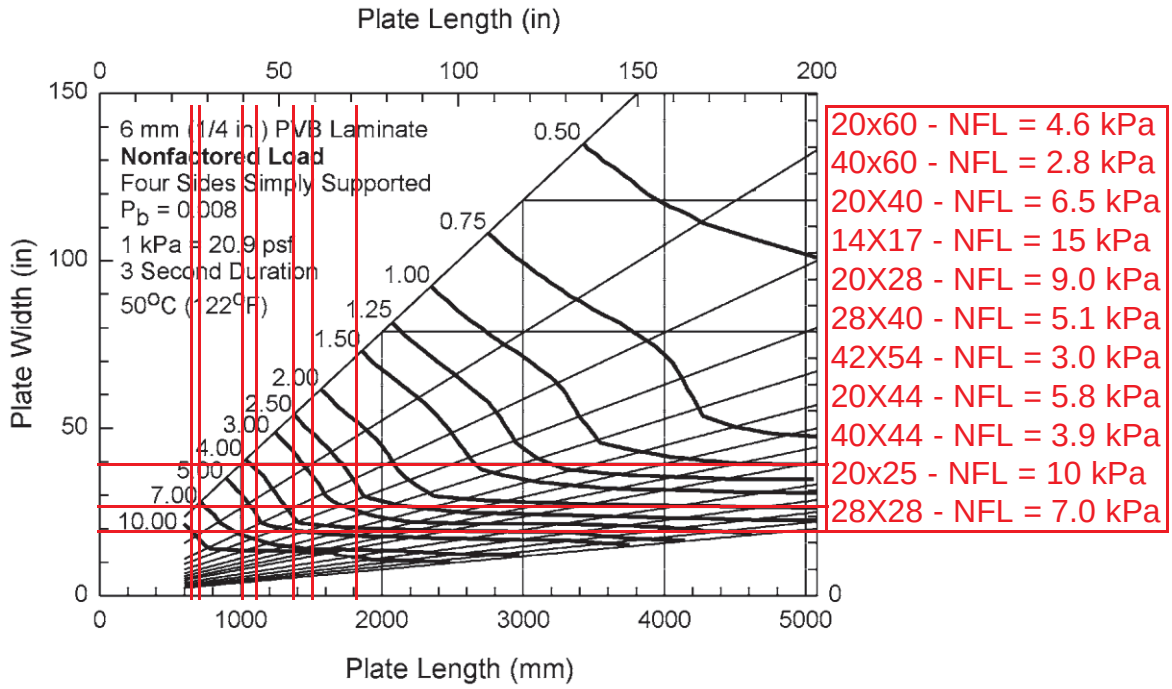

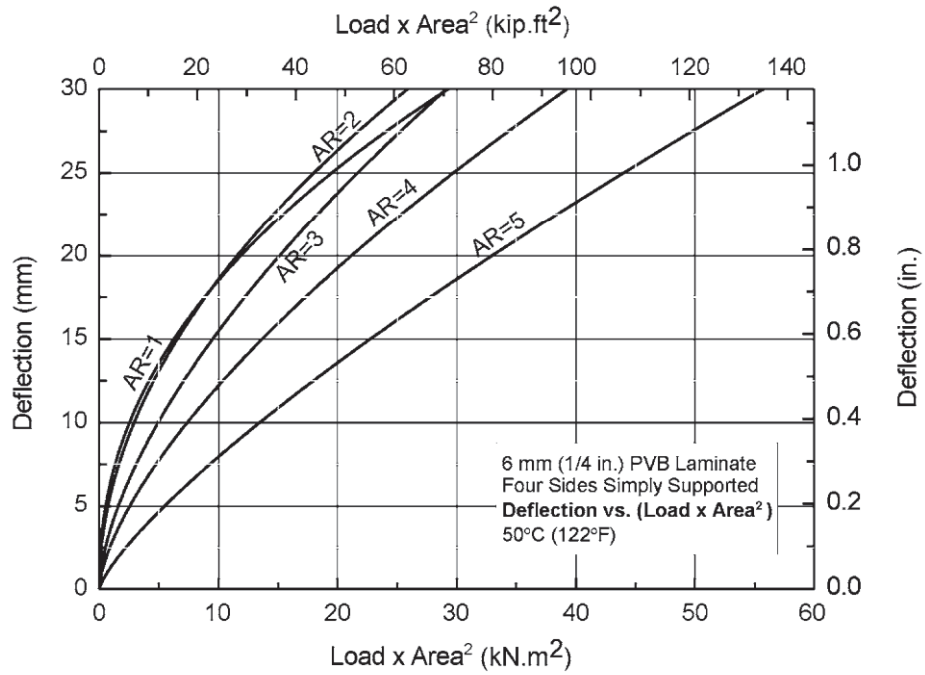

FIG. A1.29 (upper chart) Non-Factored Load Chart for 6.0 mm (¼ in.) Laminated Glass with Four Sides Simply Supported (lower chart) Deflection Chart for 6.0 mm (¼ in.) Laminated Glass with Four Sides Simply Supported

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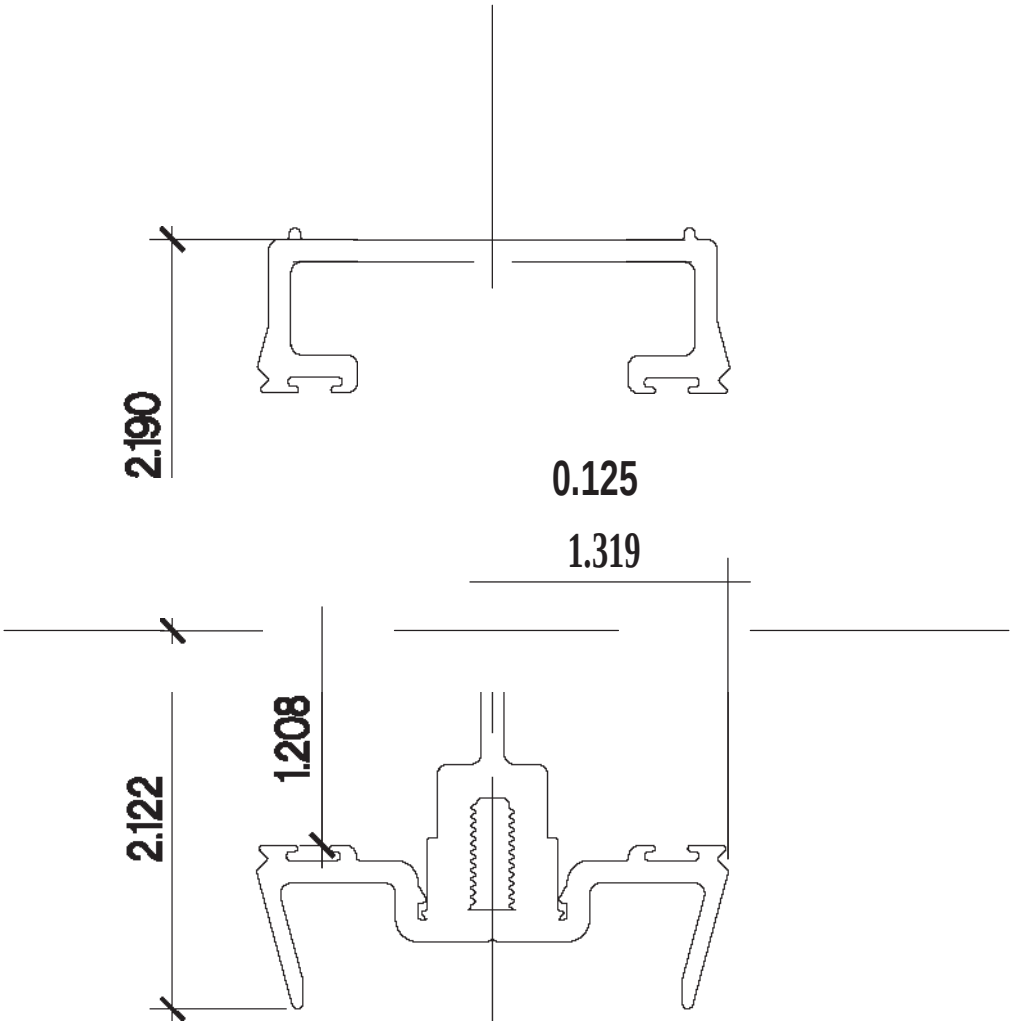


Aren: 2.0336 sq in

MoMents of inertin: X: 4.7398 sq in sq in
Y: 1.0357 sq in sq in

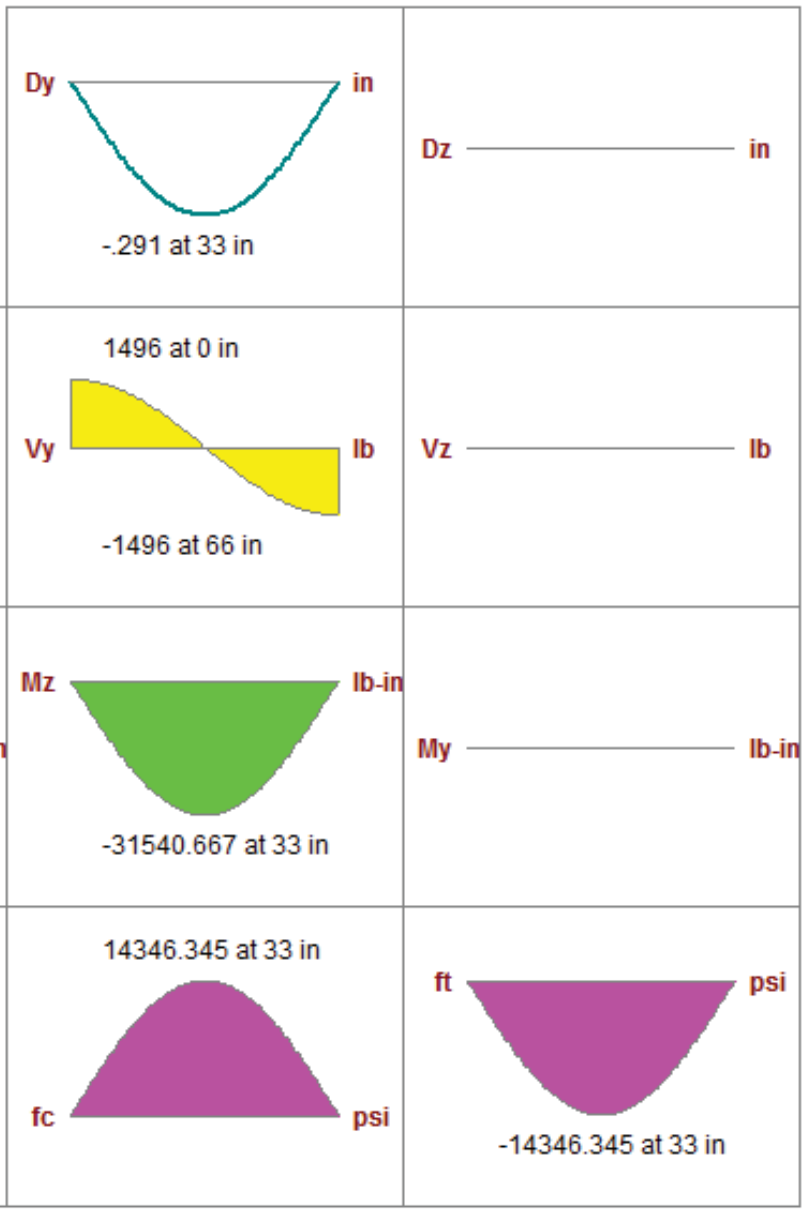
Rndii of gyrotion: X: 1.5267 in
Y: 0.7137 in

PROJECT: **MCAS Miramar San Diego. CA**	TITLE: **BOYD: 4 PIECE MULLION**	
	SCALE: NTS	SHEET NO: **AED-08**
	DRAWN BY: SPH	
PROJECT NO: 12077	DATE: 11-21-12	

Unit B – Vertical Mullion Analysis

Beam: ***M1***

Shape: **WF-Boyd4PC**
Material: **6063-T6**
Length: **66 in**
I Joint: **N1**
J Joint: **N2**
LC 1: 1
Code Check: **No Calc**
Report Based On 97 Sections



None Code Check

- Aluminum code check not calculated -

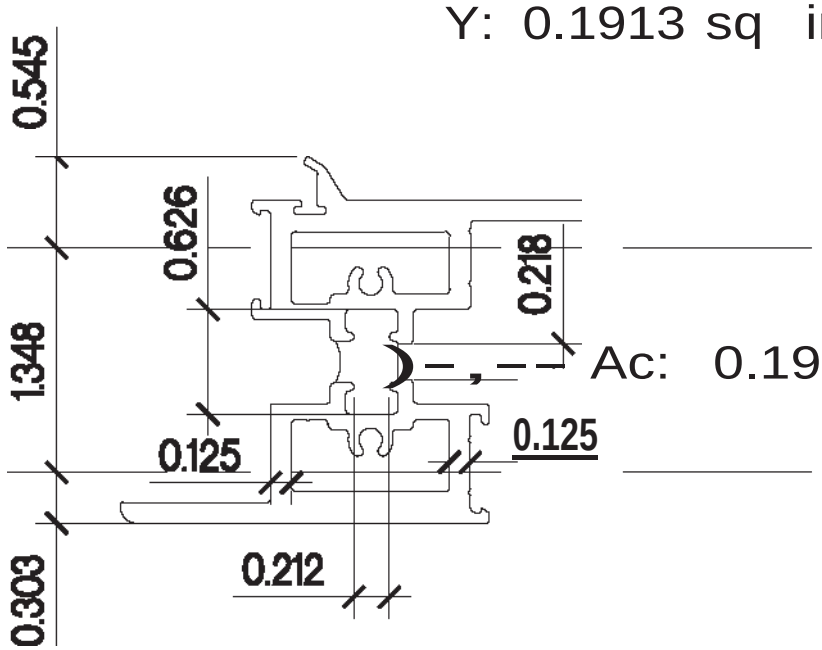
Max Defl Ratio **L/227**

Analysis convservatively ignors window frame components and only considers primary 4PC mullion

Area.: 0.6421 sq in

MoMents of inertia.: X: 0.0459 sq in sq in

Y: 0.1913 sq in sq in



Ac: 0.1952 sq in

Area.: 0.6366 sq in

MoMents of inertia.: X: 0.0443 sq in sq in

Y: 0.1910 sq in sq in

PROJECT:

MCAS Miramar

PROJECT NO: 12077

TITLE:

BOYD: P-949 HORZ.

SCALE: NTS

DRAWN BY: SPH

DATE: 11-24-12

SHEET NO:

AED-09

THE MAL A IE M LLION (COM OSITE) ST CT AL E O T

Refer to AAMA TIR A8 for Details **Report Date : 11/24/2012**

Customer : **CEO**

Test Engineer : **SPH**

roduct : **Boyd-949horizontal**

Section Properties :

Aluminium Sections :		Units	Face #1	Face #2
Cross-sectional Area	A_n	in^2	0.6421	0.6366
2nd Area Moment	Io_n	in^4	0.0459	0.0443
Centroid to Extremity	C_{nn}	in	0.545	0.303
Separation of Centroids	D	in	1.348	
Average Web Thickness	tw	in	0.25	
Profile Centroid	h_1	in	1.216	
	h_2	in	0.9799	

Core Details :		Units	
Cross-sectional Area	Ac	in^2	0.1953
Depth	Dc	in	0.626
Average Width	b	in	0.312
Minimum Width	b'	in	0.212
Debridged Gap	g	in	0.218

Analysis Results for Triangular Load :

Quantity		Units	
Aluminium Young's Mod.	E	lb/in^2	10 E6
Load : (Triangular)		lb/in	120
Span	L	in	24
Eff. 2nd Area Moment	Ie	in^4	0.2448
Eff. 2nd Area Moment	Ie'	in^4	0.2393
Maximum Deflection	y	in	0.1386

L/60 = 0.4">0.14" OK

Quantity		Units	Face #1	Face #2
Stress @ Air Side	f_{nn}	lb/in^2	- 17190	11440
Eff Section Mod.	Se_n	in^3	0.335	0.5033
Core Shear Mod.	Gc	lb/in^2	40 E3	Nominal
Max Core Shear Stress	fc	lb/in^2	1626	
Core Shear / Total Shear			0.6453	
Shear Flow	q	lb/in	344.7	

OK

Test Results :

Quantity		Units	
Aluminium Young's Mod.	E	lb/in^2	10 E6
Load : (Concentrated/Mid Span)		lb	700
Span	L	in	36
Ambient Temperature		C	
Test Temperature		C	
Maximum Deflection	y	in	0.2
Eff. 2nd Area Moment	Ie	in^4	0.3461
Eff. 2nd Area Moment	Ie'	in^4	0.3402

Quantity		Units	Face #1	Face #2
Stress @ Air side	f_{nn}	lb/in^2	- 18220	12250
Eff Section Mod.	Se_n	in^3	0.3458	0.5141
Core Shear Mod.	Gc	lb/in^2	40770	(Result)
Max Core Shear Stress	fc	lb/in^2	1018	
Core Shear / Total Shear			0.8311	
Shear Flow	q	lb/in	215.8	

Comments :

Unit A2 Horizontal

AE Dynamics
316 Maple Hill Drive
Apollo, PA 15613
724-472-1055
129 Laura Ct.
Bozeman, MT 59718
406-763-6375

JOB	Miramar
JOB #	12077
BY	SPH
DATE	11/25/12

BAM2005 + BAM926 Bending

Reference: Aluminum Design Manual - 2005 Edition

Window:	(controlling case)		
Shear	58.40	lb/in	
Thicknes	0.125	in	
s Material	6063-T6		
F allow	25000	psi	(0.2% offset yield)
Moment Arm		in	
S/in	0.00260	in^3/in	
M	51.1	lb-in/in	
ft=fc	19622	psi	**OK**

AE Dynamics
316 Maple Hill Drive
Apollo, PA 15613
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406-763-6375

JOB	Miramar
JOB #	12077
BY	SPH
DATE	11/25/12

BAM702 Bending Where BAM707 clips in

Reference: Aluminum Design Manual - 2005 Edition

Window:	(controlling case)		
Shear	70.10	lb/in	
Thicknes	0.0625	in	
s Material	6063-T6		
F allow	25000	psi	(0.2% offset yield)
Moment Arm		in	
S/in	0.00065	in^3/in	
M	13.14375	lb-in/in	
ft=fc	20189	psi	**OK**

AE Dynamics
316 Maple Hill Drive
Apollo, PA 15613
724-472-1055
129 Laura Ct.
Bozeman, MT 59718
406-763-6375

JOB	Miramar
JOB #	12077
BY	SPH
DATE	11/25/12

BAM707

Reference: Aluminum Design Manual - 2005 Edition

Window:	(controlling case)		
Shear	42.00	lb/in	
Thicknes	0.125	in	
s Material	6063-T6		
F allow	25000	psi	(0.2% offset yield)
Moment Arm		in	
S/in	0.00260	in^3/in	
M	63	lb-in/in	
ft=fc	24192	psi	**OK**

AE Dynamics
316 Maple Hill Drive
Apollo, PA 15613
724-472-1055
129 Laura Ct.
Bozeman, MT 59718
406-763-6375

JOB	Miramar
JOB #	12077
BY	SPH
DATE	11/24/12

Typical Perimeter Anchorage

Calculation Applies To: Anchorage to Concrete - Units A2 & D1

Load:	8.71	psi	Max Spacing Limit:	6	in
Load Type:	Triangular				
Length:	24	in			
Max Width:	12	in			
N/A		in	(this line for trapezoidal loads only)		

Tributary Area:	144	sq. in.	Anchor Design Load:	52.26	lbs / in

Component:	BAM-702		Substrate:	Concrete
Thickness:	0.0625	in	Thickness:	N/A
Aluminum Grade:	6063-T6			

Anchorage of Trim To Substrate:

Fasteners: Powers Tapper+ (1-3/4" embed, 2" min edge) Size: 1/4"-20

Aluminum Design Manual 2010 Checks Method: LRFD

Minimum Alum Edge Distance:	0.375	in
Minimum Alum Spacing:	0.625	in
Screw Bearing (EQ J.5-12)	468.8	lbs

Ultimate Shear (Powers Tech Guide) 1005.0 lbs

Allowable Screw Bearing Controls the Design

Max Anchor Spacing = 6.0 in (controlled by max spacing limit)

<u>Check screw bending across shim space:</u>

Shim space gap:	0.375	in	fv / Fv =	0.085	
Load Per Anchor:	314	lbs	Sx =	0.001534	in^3
Screw Diameter:	0.25	in	fb =	76653.5	psi
			fb / Fb =	0.83319	

fv/Fv + fb/Fb = 0.918 **OK**

AE Dynamics
316 Maple Hill Drive
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129 Laura Ct.
Bozeman, MT 59718
406-763-6375

JOB	Miramar
JOB #	12077
BY	SPH
DATE	11/24/12

Typical Perimeter Anchorage

Calculation Applies To: Anchorage to Concrete - Typical conditions

Load:	3.77	psi	Max Spacing Limit:	10	in
Load Type:	Trapezoidal				
Length:	48	in			
Max Width:	12	in			
Center Length:	24	in	(this line for trapezoidal loads only)		

Tributary Area:	432	sq. in.	Anchor Design Load:	33.93	lbs / in

Component:	BAM-702		Substrate:	Concrete
Thickness:	0.0625	in	Thickness:	N/A
Aluminum Grade:	6063-T6			

Anchorage of Trim To Substrate:

Fasteners: Powers Tapper+ (1-3/4" embed, 2" min edge) Size: 1/4"-20

Aluminum Design Manual 2010 Checks Method: LRFD

Minimum Alum Edge Distance:	0.375	in
Minimum Alum Spacing:	0.625	in
Screw Bearing (EQ J.5-12)	468.8	lbs
Ultimate Shear (Powers Tech Guide)	1005.0	lbs

Allowable Screw Bearing Controls the Design

Max Anchor Spacing = 10.0 in (controlled by max spacing limit)

<u>Check screw bending across shim space:</u>

Shim space gap:	0.375	in	fv / Fv =	0.092	
Load Per Anchor:	339	lbs	Sx =	0.001534	in^3
Screw Diameter:	0.25	in	fb =	82945.95	psi
			fb / Fb =	0.901586	

fv/Fv + fb/Fb = 0.994 **OK**

AE Dynamics
316 Maple Hill Drive
Apollo, PA 15613
724-472-1055
129 Laura Ct.
Bozeman, MT 59718
406-763-6375

JOB	Miramar
JOB #	12077
BY	SPH
DATE	11/26/12

Mullion Anchorage

Calculation Applies To: Vertical Mullions (Unit B Controls)

Load:	1685	lbs	Clip Thickness:	0.125	in
Mullion Web Thickness:	0.125	in	Clip Legs:	2	in
Aluminum Grade:	6063-T6		Clip Length:	2	in

Connection To Mullion:

Fasteners: Elco Dril-Flex — Size: #12-14

Aluminum Design Manual 2010 Checks — Method: LRFD

Minimum Alum Edge Distance:	0.324	in
Minimum Alum Spacing:	0.540	in
Screw Bearing (EQ J.5-12)	810.0	lbs / screw
Ultimate Screw Double Shear (AAMA TIR-A9-91):	2965.0	lbs / screw

Screws Required: **3** screws through clips and mullion

Clip Angles (5052-H32 Alum):

Load:	842.5	per angle
M:	842.5	in-lb
Sx:	0.167	in^3
fs:	3370	psi
ft:	5055	psi

(fs/Fs)^2+(ft/Ft)^2 = 0.26 **OK**

Substrate Anchors:

Powers Tapper+ (1-3/4" embed, 3" min edge)

Anchors Per Clip:	2	
Anchor Spacing:	1.25	in

Max Shear Per Anchor =	421.3	lb
Max Tension Per Anchor =	674.0	lb

Vult =	1050	lb	Per Powers Tech Guide with Spacing & Edge Adjustments
Tult =	1335.6	lb	Per Powers Tech Guide with Spacing & Edge Adjustments

V/Vult + T/Tult = 0.906 **<=1.0 OK**

Appendix A
Referenced Reports

ABS Consulting
RISK CONSULTING DIVISION

ABS Shock Tube Testing Report

Pretest Information

Test Information

Client:	Boyd
Model Number:	2300
SPECIMEN Number:	G
Description:	Project Out
Test Date:	6/24/2008
Test Number:	3
Test Report Number	
Report Date	
Test Location:	ABS Test Range

Test Method:
- GSA "Standard Testing Method for Windows and Glazing Systems Subject to Dynamic Overpressure Loadings"
- ASTM F-1642-04 "Standard Test Method for Glazing and Glazing Systems Subjected to Airblast Loadings"

Notes: Boyd Model #2300
Project Out - Hinge Top
Mounted in Receptor Frame All Sides

Frame Information

Width (in):	48.00
Height (in):	66.00
Width:	2-3/8
Material:	Aluminum
Frame Support:	Captured at head and sill in ABS sub-frame.

Glazing Information

Multiple Lites? No

	Lite 1	Lite 2	Lite 3
Width (in):	41.75		
Height (in):	59.75		
IGU?	Yes	Air Gap:	1/2

	Inner Lite	Outer Lite
Thickness (in):	1/8 X 0.03PVB X 1/8	1/4
Glass Type:	Annealed-Laminated	AG
Notes:	Receptor (4) sides	

Temperature

Ambient (F):	97.4
Glass Surface (F):	97.4

Blast Pressure Information

	Gauge Number 1	2	3	4	5	6	Average
Peak Reflected Pressure (psi)	6.7	6.1	5.2	6.1	5.5		5.9
Positive Phase Duration (ms)							#DIV/0!
Positive Phase Impulse (psi-ms)	43.2	42.1	37.6	39.1	43.3		41.1

Glazing Damage Summary

	0 - 40 in	40 - 120 in
Notes:	Dusting	None
United Dimension (in):	N/A	N/A

	Interior	Perimeter	Sum
Tears and Pullout (%):	0	0	0

	Low Hazard/Zone 4	High Hazard/Zone 5
Witness Panel Perforations:	N/A	N/A
Witness Panel Indents:	N/A	N/A

Notes: Both lites fractured - no tears - no pullout

GSA Performance Condition: **2**

ASTM F-1642 Hazard Level: **Minimal Hazard**

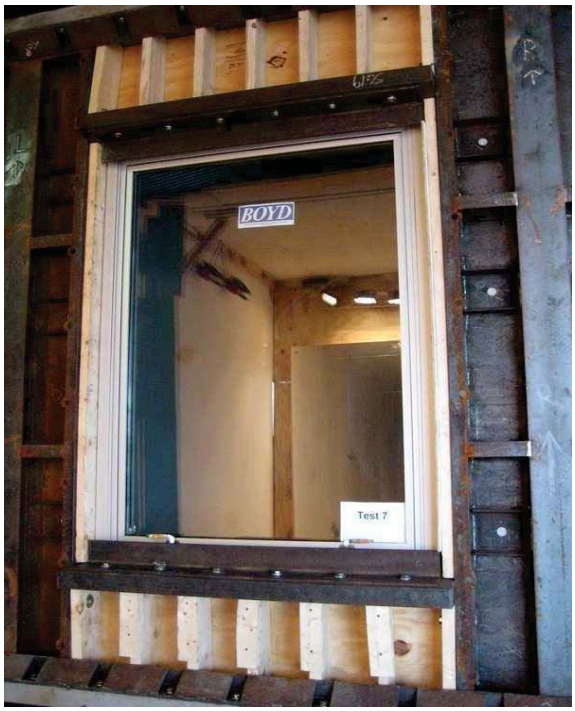
Test Certification per UFC 4-010-01 Jan 2007 (Table 2-1)

Test Pressure per ASTM F1642:	6
Glazing Performance:	Minimal

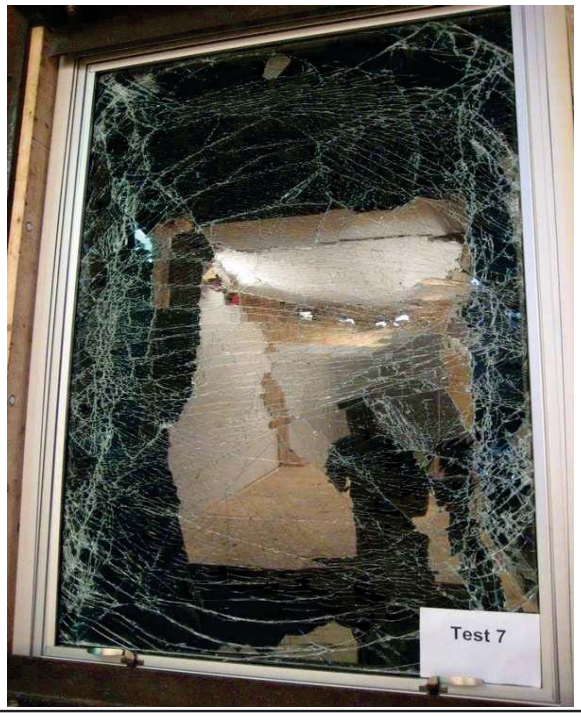
Specimen Number:	3
Other Specimens:	5,6

ABS Consulting
RISK CONSULTING DIVISION

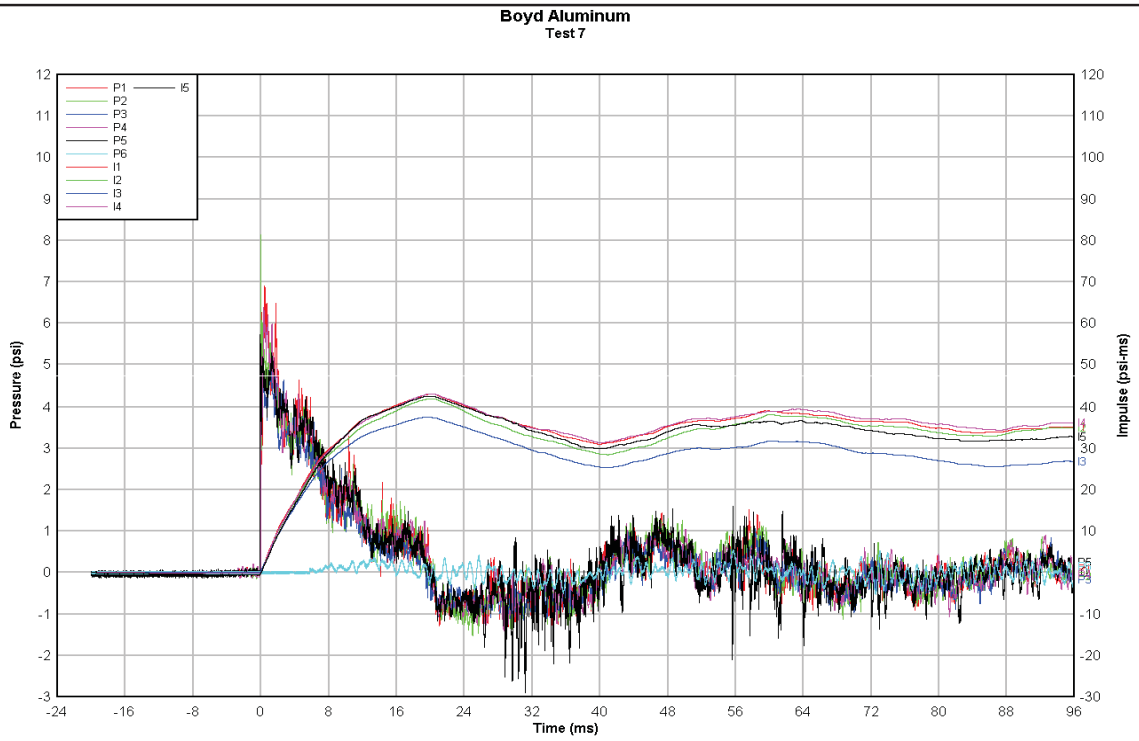
Pre-Test Photograph



Post-Test Photograph



Blast Trace



ABS Consulting
RISK CONSULTING DIVISION

ABS Shock Tube Testing Report

Pretest Information

Test Information

Client:	Boyd
Model Number:	2300
SPECIMEN Number:	I
Description:	Fixed / Project-out
Test Date:	6/25/2008
Test Number:	9
Test Report Number	
Report Date	
Test Location:	ABS Test Range

Test Method:
- GSA "Standard Testing Method for Windows and Glazing Systems Subject to Dynamic Overpressure Loadings"
- ASTM F-1642-04 "Standard Test Method for Glazing and Glazing Systems Subjected to Airblast Loadings"

Notes: Boyd Model #2300 Fixed / Project-out
Snap trim stop on all sides
#6 self-tap screws at 9" o.c. at head and sill
#6 self-tap screws at 28" o.c. at jambs

Frame Information

Width (in):	48.00
Height (in):	66.00
Width:	2-3/8
Material:	Aluminum
Frame Support:	Captured at head and sill in ABS sub-frame.

Glazing Information

Multiple Lites? Yes

	Lite 1	Lite 2	Lite 3
Width (in):	44.00	41.75	
Height (in):	26.00	30.25	
IGU?	Yes	Air Gap:	1/2

	Inner Lite	Outer Lite
Thickness (in):	1/8 x 0.03PVB x 1/8	1/4
Glass Type:	Annealed-Laminated	AG
Notes:	2-piece snap trim (4) sides	

Temperature

Ambient (F):	89.4
Glass Surface (F):	90.4

Blast Pressure Information

	Gauge Number 1	2	3	4	5	6	Average
Peak Reflected Pressure (psi)	6.8	6.6	5.3	6.2	5.4		6.1
Positive Phase Duration (ms)							
Positive Phase Impulse (psi-ms)	44.7	43.7	39.1	44.1	41.2		42.6

Glazing Damage Summary

	0 - 40 in	40 - 120 in
Notes:	None	None
United Dimension (in):	N/A	N/A

	Interior	Perimeter	Sum
Tears and Pullout (%):	0	0	0

	Low Hazard/Zone 4	High Hazard/Zone 5
Witness Panel Perforations:	N/A	N/A
Witness Panel Indents:	N/A	N/A

Notes: No lites fractured - Frame deflected and frame joint at CL partially opened - Not operable

GSA Performance Condition: **2**

ASTM F-1642 Hazard Level: **No Hazard**

Test Certification per UFC 4-010-01 Jan 2007 (Table 2-1)

Test Pressure per ASTM F1642:	6
Glazing Performance:	Minimal

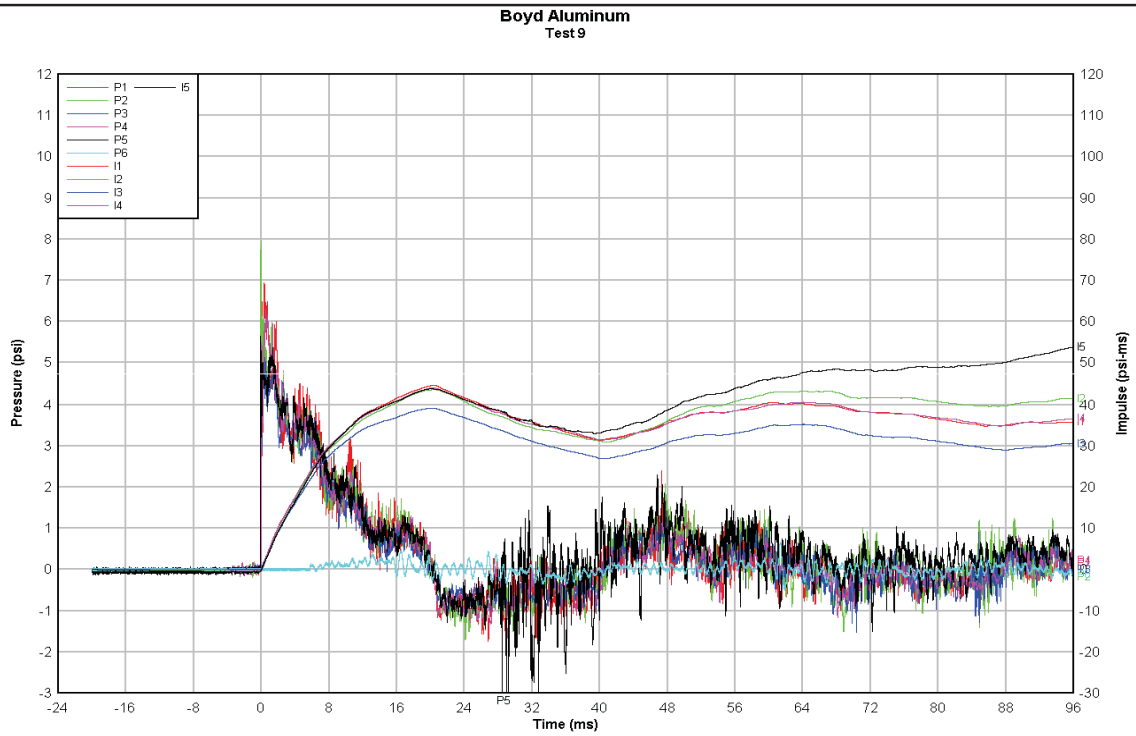
Specimen Number:	1
Other Specimens:	11,14

ABS Consulting
RISK CONSULTING DIVISION

Pre-Test Photograph

Post-Test Photograph

Blast Trace



ABS Consulting
RISK CONSULTING DIVISION

ABS Shock Tube Testing Report

Pretest Information

Test Information

Client:	Boyd
Model Number:	2300
SPECIMEN Number:	K
Description:	Fixed / Project-out
Test Date:	6/25/2008
Test Number:	11
Test Report Number	
Report Date	
Test Location:	ABS Test Range

Test Method:
- GSA "Standard Testing Method for Windows and Glazing Systems Subject to Dynamic Overpressure Loadings"
- ASTM F-1642-04 "Standard Test Method for Glazing and Glazing Systems Subjected to Airblast Loadings"

Notes: Boyd Model #2300
Fixed over Project-out
Mounted in Receptor Frame All Sides

Frame Information

Width (in):	48.00
Height (in):	66.00
Width:	2-3/8
Material:	Aluminum
Frame Support:	Captured at head and sill in ABS sub-frame.

Glazing Information

Multiple Lites? Yes

	Lite 1	Lite 2	Lite 3
Width (in):	44.00	41.75	
Height (in):	26.00	30.25	
IGU?	Yes	Air Gap:	1/2

	Inner Lite	Outer Lite
Thickness (in):	1/8 x 0.03PVB x 1/8	1/4
Glass Type:	Annealed-Laminated	AG
Notes:	Receptor (4) sides	

Temperature

Ambient (F):	89.4
Glass Surface (F):	90.4

Blast Pressure Information

	Gauge Number 1	2	3	4	5	6	Average
Peak Reflected Pressure (psi)	6.7	6.5	6.1	6.1	5.4		6.2
Positive Phase Duration (ms)							
Positive Phase Impulse (psi-ms)	43.4	42.2	44.6	43.1	41.8		43.0

Glazing Damage Summary

	0 - 40 in	40 - 120 in
Notes:	Dusting	None
United Dimension (in):	N/A	N/A

	Interior	Perimeter	Sum
Tears and Pullout (%):	0	0	0

	Low Hazard/Zone 4	High Hazard/Zone 5
Witness Panel Perforations:	N/A	N/A
Witness Panel Indents:	N/A	N/A

Notes: Only protected side plate of lami broke - Frame deflected - Frame joint at CL opened - Not operable

GSA Performance Condition: **2**

ASTM F-1642 Hazard Level: **Minimal Hazard**

Test Certification per UFC 4-010-01 Jan 2007 (Table 2-1)

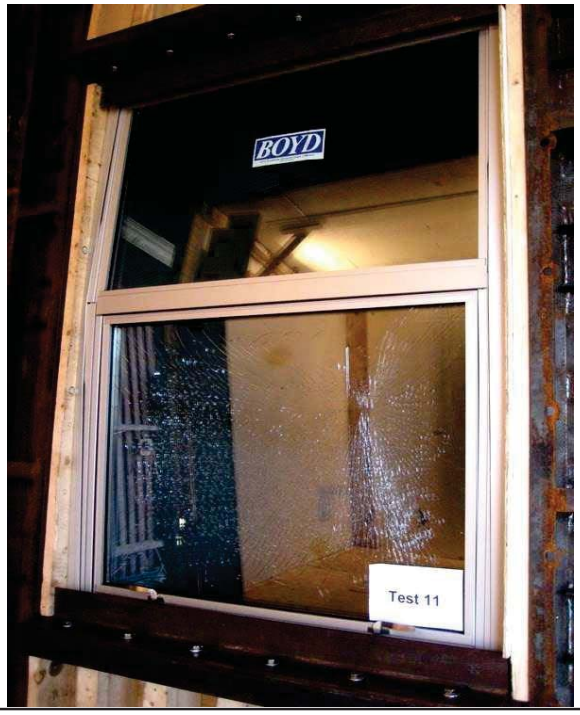
Test Pressure per ASTM F1642:	6
Glazing Performance:	Minimal

Specimen Number:	2
Other Specimens:	9,14

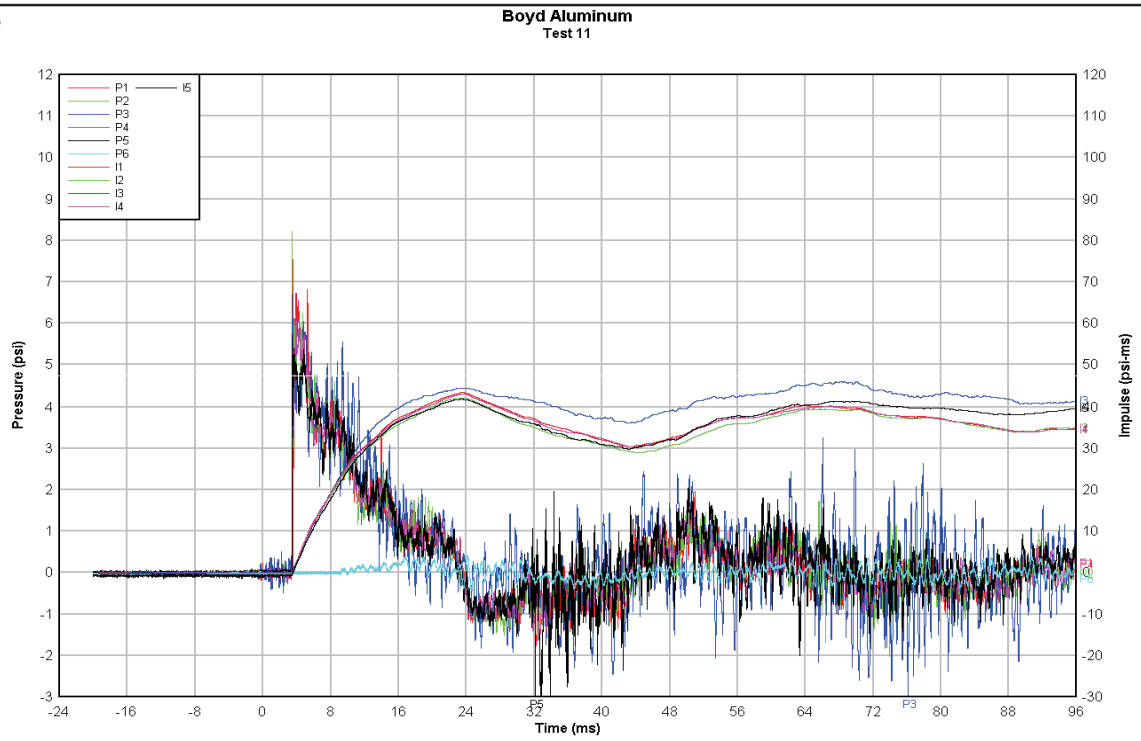
ABS Consulting
RISK CONSULTING DIVISION

Pre-Test Photograph

Post-Test Photograph



Blast Trace



ABS Consulting
RISK CONSULTING DIVISION

ABS Shock Tube Testing Report

Pretest Information

Test Information

Client:	Boyd
Model Number:	2200
SPECIMEN Number:	J
Description:	Fixed Lite
Test Date:	6/25/2008
Test Number:	10
Test Report Number	
Report Date	
Test Location:	ABS Test Range

Test Method:
- GSA "Standard Testing Method for Windows and Glazing Systems Subject to Dynamic Overpressure Loadings"
- ASTM F-1642-04 "Standard Test Method for Glazing and Glazing Systems Subjected to Airblast Loadings"

Notes:
Boyd Model #2200 Fixed Lite
Snap trim stop on all sides
#6 self-tap screws at 9" o.c. at head and sill
#6 self-tap screws at 20" o.c. at jambs

Frame Information

Width (in):	48.00
Height (in):	66.00
Width:	2-3/8
Material:	Aluminum
Frame Support:	Captured at head and sill in ABS sub-frame.

Glazing Information

Multiple Lites? No

	Lite 1	Lite 2	Lite 3
Width (in):	41.75		
Height (in):	60.00		
IGU?	Yes	Air Gap:	1/2

	Inner Lite	Outer Lite
Thickness (in):	1/8 x 0.03PVB x 1/8	1/4
Glass Type:	Annealed-Laminated	AG
Notes:	2-piece snap trim (4) sides	

Temperature

Ambient (F):	88.7
Glass Surface (F):	88.1

Blast Pressure Information

	Gauge Number 1	2	3	4	5	Average	6
Peak Reflected Pressure (psi)	6.8	6.6	5.3	6.2	5.4	6.1	0.4
Positive Phase Duration (ms)							
Positive Phase Impulse (psi-ms)	44.7	43.7	39.1	44.1	41.2	42.9	

Glazing Damage Summary

	0 - 40 in	40 - 120 in
Notes:	Dusting	None
United Dimension (in):	N/A	N/A

	Interior	Perimeter	Sum
Tears and Pullout (%):	0	0	0

	Low Hazard/Zone 4	High Hazard/Zone 5
Witness Panel Perforations:	N/A	N/A
Witness Panel Indents:	N/A	N/A

Notes: All plates and all lites fractured - Frame sustained some plastic deformation

GSA Performance Condition: **2**

ASTM F-1642 Hazard Level: **Minimal Hazard**

Test Certification per UFC 4-010-01 Jan 2007 (Table 2-1)

Test Pressure per ASTM F1642:	6.1
Glazing Performance:	Minimal Hazard

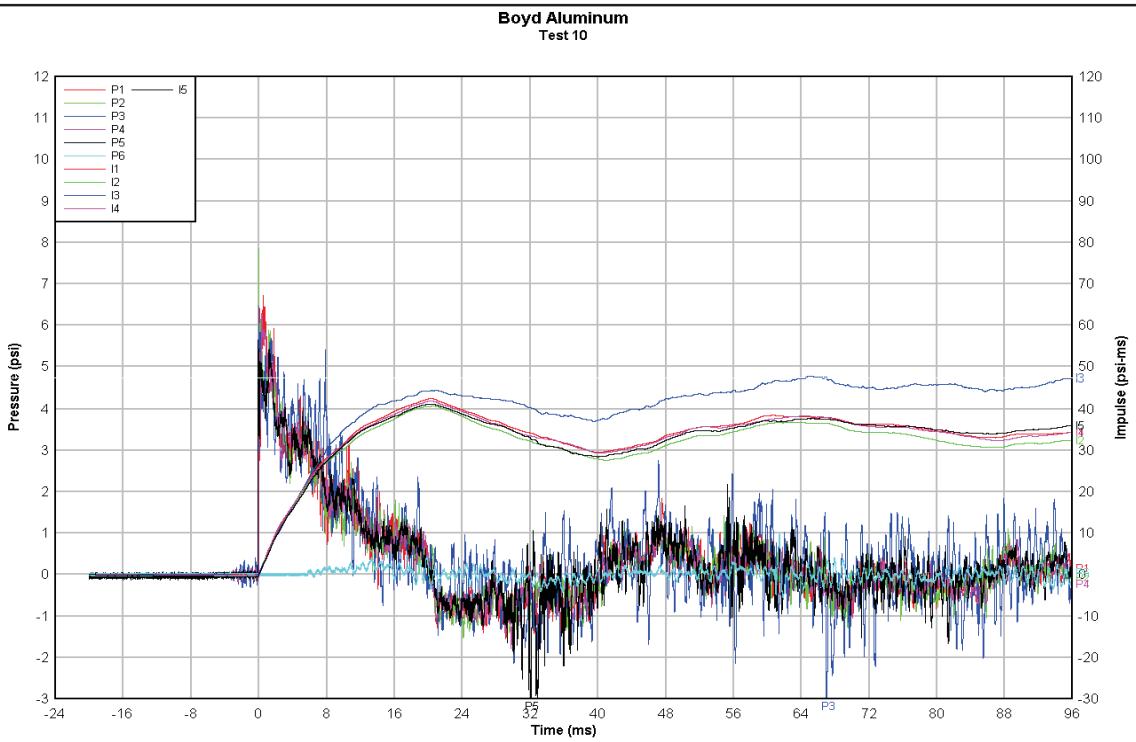
Specimen Number:	1
Other Specimens:	12,13

ABS Consulting
RISK CONSULTING DIVISION

Pre-Test Photograph

Post-Test Photograph

Blast Trace



ABS Consulting
RISK CONSULTING DIVISION

ABS Shock Tube Testing Report

Pretest Information

Test Information

Client:	Boyd
Model Number:	2200
SPECIMEN Number:	L
Description:	Fixed Lite
Test Date:	6/25/2008
Test Number:	12
Test Report Number	
Report Date	
Test Location:	ABS Test Range

Test Method:
- GSA "Standard Testing Method for Windows and Glazing Systems Subject to Dynamic Overpressure Loadings"
- ASTM F-1642-04 "Standard Test Method for Glazing and Glazing Systems Subjected to Airblast Loadings"

Notes: Boyd Model #2200
Fixed Lite
Mounted in Receptor Frame All Sides

Frame Information

Width (in):	48.00
Height (in):	66.00
Width:	2-3/8
Material:	Aluminum
Frame Support:	Captured at head and sill in ABS sub-frame.

Glazing Information

Multiple Lites? No

	Lite 1	Lite 2	Lite 3
Width (in):	41.75		
Height (in):	60.00		
IGU?	Yes	Air Gap:	1/2

	Inner Lite	Outer Lite
Thickness (in):	1/8 x 0.03PVB x 1/8	1/4
Glass Type:	Annealed-Laminated	AG
Notes:	Receptor (4) sides	

Temperature

Ambient (F):	96.9
Glass Surface (F):	94.6

Blast Pressure Information

	Gauge Number 1	2	3	4	5	Average	6
Peak Reflected Pressure (psi)	6.7	6.5	6.0	6.0	5.5	6.1	0.4
Positive Phase Duration (ms)							
Positive Phase Impulse (psi-ms)	41.1	40.6	43.6	41.3	39.6	41.7	

Glazing Damage Summary

	0 - 40 in	40 - 120 in
Notes:	1" Slivers	None
United Dimension (in):	5	N/A

	Interior	Perimeter	Sum
Tears and Pullout (%):	0	0	0

	Low Hazard/Zone 4	High Hazard/Zone 5
Witness Panel Perforations:	N/A	N/A
Witness Panel Indents:	N/A	N/A

Notes: Both lites fractured - First frame lip on left side pushed past receptor

GSA Performance Condition: **2**

ASTM F-1642 Hazard Level: **Minimal Hazard**

Test Certification per UFC 4-010-01 Jan 2007 (Table 2-1)

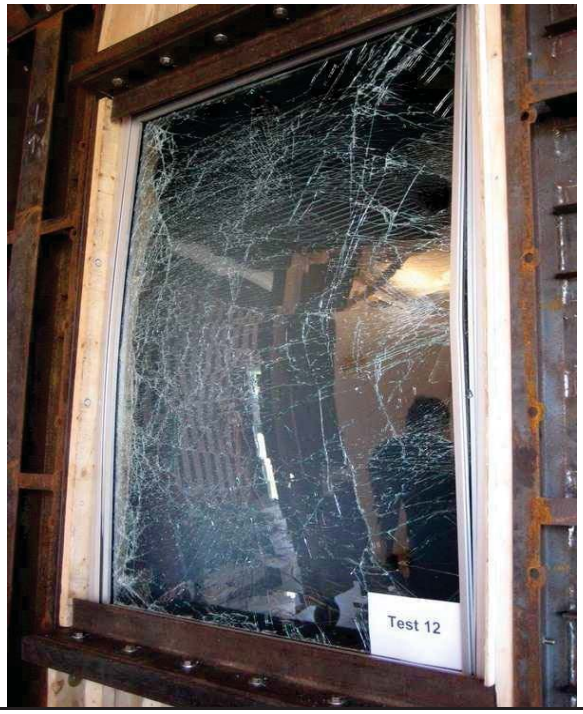
Test Pressure per ASTM F1642:	6.1
Glazing Performance:	Minimal Hazard

Specimen Number:	2
Other Specimens:	10, 13

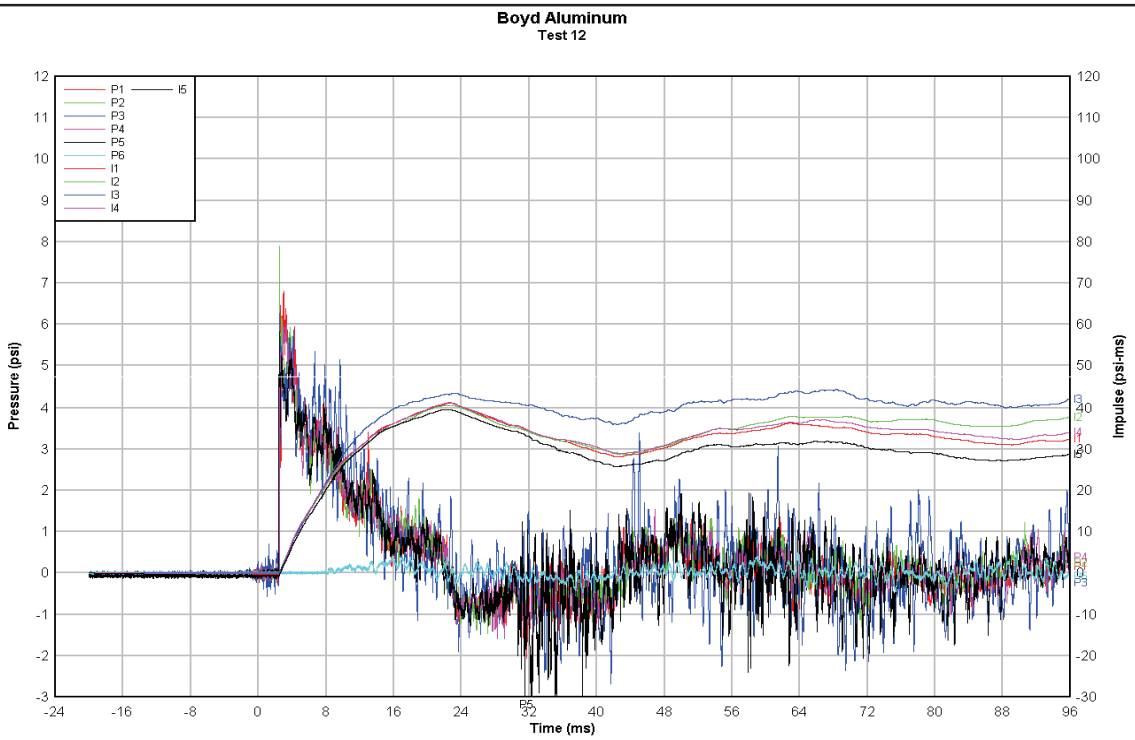
ABS Consulting
RISK CONSULTING DIVISION

Pre-Test Photograph

Post-Test Photograph



Blast Trace



Appendix B
Fastener Data

MECHANICAL ANCHORS

Tapper+ *Concrete Screw Anchor*

PRODUCT DESCRIPTION

The Tapper+ fastening system is a complete family of screw anchors for light to medium duty applications in concrete, masonry block, brick, and wood base materials. The Tapper+ is fast and easy to install and provides a neat, finished appearance. The Tapper+ screw anchor is engineered with matched tolerance drill bits and installation lools designed to meet the needs of the user and also provide optimum performance. The Tapper+ features a gimlet point for self-drilling into wood base materials without pre-drilling.

The Tapper+ screw anchor is available in carbon steelwith a Perma-Seal climate coating in several colors. Head styles include a slotted hex washer head, Phillips flat head, trim Phillips flat head and Hex flange washer head.

GENERAL APPLICATIONS AND USES

Perma-SealTappers+

- Window installations
- Interior hand rails
- Metal door frames
- Joint flashing
- Storm shutters
- Interior lighting fixtures
- Thresholds
- Screened Enclosures

FEATURES AND BENEFITS

+ Available in several head styles
+ Several colors and finishes to match application
+ Removable (reusable in wood)
+ High-low thread design for greater stability and grip
+ Does not exert expansion forces
+ No hole spotting required
+ Good corrosion protection with Perma-Seal coating
+ Gimlet point for self drilling into wood base material

APPROVALS

International Code Council, Evaluation Service OCC-ES), ESR-3068 for uncracked concrete. Code compliant with the 20091BC, 2009 1RC, 20061BC, 20061RC, 2003 IBC, 2003 IRC and 1997 UBC
Compliant with the 2007 Florida building code (Building and Residential)
Tested in accordance with ACI355.2 and ICC-ES AC193 for use in structural concrete, ICC-ES AC106 for use in masonry. ICC-ES AC233 for use in wood, and ICC-ES AC257 for use in pressure treated lumber
Evaluated and qualified by an accredited independent testing labortatory for reliability against brittle failure, e.g. hydrogen embrittlement
Miami-Dade County Notice of Acceptance (NOA) 10-0505.05

GUIDE SPECIFICATIONS

CSI Divisions: *03151-Concrete Anchoring, 04081-Masonry Anchorage* and *0509Q-Metal Fastenings.* Concrete Screw Anchors shall be Tapper+ anchors as supplied by Powers Fasteners, Inc., Brewster, NY.

MATERIAL SPECIFICATIONS

Anchor Component	Perma-Seal Tapper
Anchor Body	Case hardened carbon steel
Coating/Plating/Finish	Perma-Seal coating (various colors)

SECTION CONTENTS Page No.

General Information 1
Installation Specifications 2,3
Performance Data 4-6
Ordering Information..... 1·8

Perma-Seal Coated Carbon Steel Tapper+

ANCHOR MATERIALS

Carbon Steel with Perma-Seal Coating

ANCHOR SIZE RANGE (TYP.)

3116" diameter x 1-1/4" length to 1/4 • diameter x 6• length

SUITABLE BASE MATERIALS

Normal-weight Concrete
Structural Lightweight Concrete
Grouted Concrete Masonry (CMU)
Hollow Concrete Masonry
(Lightweight & Normal weight)
Solid Brick Masonry
Wood

This Product Available In PDA®
Powers Design Assist
Real Time Anchor Design Software
www.poignas.skf.com

INSTALLATION SPECIFICATIONS

Perma-Seal Carbon Steel Hex Head Tapper+

Dimension	Anchor Diameter, *d* 3/16"	1/4"
Tapper Drill Bit Size, *dbir* (in.)	5/32	3/16
Fixture Clearance Hole. *dh* (in.)	1/4	5/16
Head Height (in.)	7/64	9/64
Hex Head Wrench/Socket Size	1/4	5/16
Washer O.D., *dw* (in.)	11/32	13/32
Washer Thickness. (in.)	1/32	1/32

1/4 • nange hex head parts have a washer 0.0.o139/64 •.

Perma-Seal Carbon Steel Flat Head Tapper+

Dimension	Anchor Diameter, *d* 3/16"	1/4..
Tapper Drill Bit Size, *dbir* (in.)	5/32	3/16
Fixture Clearance Hole, *dh* (in.)	1/4	5/16
Phillips Head O.D., (in.)	3/8	1/2
Phillips Head Height, (in.)	9/64	3/16
Phillips Bit Size (No.)	2	3

1/4 • *rrrm* R at head pans have a head herght of 5132" and a head wsdth of 13/32".

Installation Procedure

1.) Using the proper Tapper+ drill bit size, drill a hole into the base material to the required depth. The tolerances of the Tapper+ bit used must meet the requirements of the published range in Table t.

2.) Remove dust and debris from hole using a hand pump. compressed air or a vacuum to remove loose panicles left from drilling.

3.) Anach a Tapper 1000 installation socket tool for the selected anchor size to a percussion drill and set the drill to rotary only mode. Mount the screw anchor head into the socket For flat head versions a phillips bit tip must be used with the socket tool.

4.) Place the point of *the* Tapper+ anchor through the fixture into the predrilled hole and drive the anchor until it is fully seated at the proper embedment. The socket tool will automatically disengage from the head of the Tapper+.

Nott.Step tl and *112* not applitable for wood baSI' materials drill bit not app cable for mod base mattrlals.

Tapper+ Anchor Detail

(Siooed hexhead .UsmpKtll'ed. flat head kng\tl measured from bcXlom *d* head to tp *d* ancha)

Head Marking

Legend
'P' Marking = Powers Tapper +
'+' Symbol = Strength Design Compliant Anchor length Identification Mark

Matched Tolerance System

Per coating provdes proteCIIOrl againS1 corrosion

SelfTapping Hi-low thread

Gimlet Point

Designed and tested as a system for consistency and reliabi lity

Tapper+ Length Code Identification System

Length ID marking on head		O	A	B	C	D	E	F	G	H	I	J
Overall anchor length eanch• (inches)	From	1	1-112	2	2-1/2	3	3-112	4	4-1/2	5	5-112	6
	Up to but not induding	1-112	2	2-1/2	3	3-1/2	4	4-1/2	5	5-112	6	6-112

MECHANICAL ANCHORS

INSTALLATION SPECIFICATIONS

Installation Table for Tapper+ in Concrete (Design Provisions of ACI 318 Appendix D)

Anchor Property/Setting Information	Notation	Units	Nominal Anchor Size (in.)	
			3/16	1/4
Nominal outside anchor diameter	d (d_{o})[1]	in. (mm)	0.145 (3.7)	0.185 (4.7)
Nominal drill bit diameter	d_{bit}	in. (mm)	3/16 Tapper+ bit	1/4 Tapper+ bit
Tapper+ bit tolerance range	-	in.	0.170 to 0.176	0.202 to 0.207
Minimum nominal embedment depth	h_{nom}	in. (mm)	1-3/4 (44.4)	1-3/4 (44.4)
Effective embedment	h_{ef}	in. (mm)	1.23 (31.2)	1.23 (31.2)
Minimum hole depth	h_o	in. (mm)	2 (50.8)	2 (50.8)
Minimum concrete member thickness	h_{min}	in. (mm)	3-1/4 (82.5)	3-1/4 (82.5)
Minimum edge distance	c_{min}	in. (mm)	1-3/4 (44.4)	1-3/4 (44.4)
Minimum spacing distance	s_{min}	in. (mm)	1 (25.4)	2 (50.8)
Critical edge distance	c_{ac}	in. (mm)	3 (76.2)	3 (76.2)

Installation Table for Tapper+ in Masonry

Anchor Property/Setting Information	Notation	Units	Nominal Anchor Size (in.)	
			3/16	1/4
Nominal outside anchor diameter	d	in. (mm)	0.145 (3.7)	0.185 (4.7)
Nominal drill bit diameter	d_{bit}	in. (mm)	3/16 Tapper+ bit	1/4 Tapper+ bit
Tapper+ bit tolerance range	-	in.	0.170 to 0.176	0.202 to 0.207
Minimum nominal embedment depth	h_v	in. (mm)	1-1/2 (38.1)	1-1/2 (38.1)
Minimum hole depth	h_o	in. (mm)	2 (50.8)	2 (50.8)

Installation Table for Tapper+ in Wood

Anchor Property/Setting Information	Notation	Units	Nominal Anchor Size (in.)	
			3/16	1/4
Nominal outside anchor diameter	d_o	in. (mm)	0.145 (3.7)	0.185 (4.7)
Nominal drill bit diameter	d_{bit}	in. (mm)	Pre-drilling is not required for Tapper+ into wood	

1. Notation in parenthesis is for the 2006 IBC.

MECHANICAL ANCHORS

STRENGTH DESIGN PERFORMANCE DATA

TENSION DESIGN INFORMATION FOR TAPPER+ ANCHOR IN CONCRETE
(For use with load combinations taken from ACI 318, Section 9.2)u.l.•.s.'·7·u

Design Characteristic	Notation	Units	Nominal Anchor Size (Inch) 3/16	1/4
Anchor category	1.2 or 3	-	1	1
Nominal embedment depth	*hnom*	in. (mm)	1-3/4 (4.4)	1-3/4 (4.4)
STEEL STRENGTH IN TENSION[4]				
Minimum specified ultimate tensile strength (neck)	*fura*[8]	ksi (N/mm 2)	100 (689)	100 (689)
Effective tensile stress area (neck)	*ASP,N tAseJ*[9]	in2 (mm2)	0.0162 (10.4)	0.0268 (17.3)
Steel strength in tension	N_{sa}a	lb (kN)	1,620 (7.2)	2,680 (12.0)
Reduction factor lor steel strength3		-	0.65	
CONCRETE BREAKOUT STRENGTH IN TENSION[7]				
Effective embedment	*het*	in. (mm)	1.23 (31.2)	1.23 (31.2)
Effectiveness factor for concrete breakout	*kuna*		24	24
Modification factor lor cracked and uncracked concreteS	'I'(,Ng	-	1.0 See note 5	1.0 See note 5
Critical edge distance	(ii(	in. (mm)	3.0 (76.2)	3.0 (76.2)
Reduction factor for concrete breakout strength3		-	0.65 (Condition 8)	
PULLOUT STRENGTH IN TENSION[7]				
Characteristic pullout strength, uncracked concrete (2,500 ps1)6	*Np,una*	lb (kN)	635 (2.8)	940 (4.2)
Reduction factor for pullout strength3		-	0.65 (Condition B)	

For Sl: 1 inch = 25.4 mm, I ksi = 6.895 N/mm2. I lbf = 0.0044 kN.

1. The data in this table Is intended to be used v.1th the design provisions of ACI 318Apj)fndix 0.
2. Installation must comply with published instructions and det.ails.
3. All values of were determined from the load combinations of UBC Seaion 1605.2.1, UBC Seaion 1612.2.1, or ACI 318 Section 9.2. 1f the load combinations of UBC Section 19022 or ACI 318 Appendix C are used, the appropriate value of IP must be determined in accordance with ACI 318 0.4S. For reinforcement that meets ACI 318 Appendix 0 requirements lor CondiUon fl. see ACI 3180. 4.4 for the appropriate factor.
4. The Tapper+ anchor is considered a brittle sreel elemenr as defined by ACI3 18 0.1. Tabulated values for steel srrength in tension must be used for design.
5. For all design cases use '!' N = 1.0. The appropriate effeaiveness faaor for uncracked concrete (k"") must be used.
6. For all design cases use '!'<P = 1.0. For calculation of Npn, see Section 4.1.3 of this repon.
7. Anchors are petmined to be used in struClural sand-lightweight concrete in accordance with Section 4.1.10 of this repon. Provided the modification factor 1for concrete breakout strength is taken as 0.6. 1n addition, the pullout strengm, Nf.unamust be muliplied by 06. as applicable. for ACI 318-05, the values No and N?.una must be multiplied by 0.6, in Lieu of ACI318 0.3.4
8. For 2003 IBC. fur> replaces fu1. N<> replaces N and '!'a; replaces '!'.1.
9. The notation in parenlhesis is for the 20061BC.

d

PERFORMANCE DATA

SHEAR DESIGN INFORMATION FOR TAPPER+ ANCHOR IN CONCRETE
(For use with load combinations taken from ACI 318, Section 92)u.3.•.s.ua

Design Characteristic	Notation	Units	Nominal Anchor Diameter	
			3/16"	1W
Anchor category	1, 2 or 3		1	1
Nominal embedment depth	*hnom*	in.	1-3/4	1-3/4
STEEL STRENGTH IN SHEAR•				
Steel strength in shears	*Vsa*	lb (kN)	810 (3.6)	1,180 (5.3)
Reduction factor for steel strength3	¢	-	0.60	
CONCRETE BREAKOUT STRENGTH IN SHEAR'				
Load bearing length of anchor (hef or 8d0 whichever is less)	*{e*	in. (mm)	1.23 (32)	1.23 (31)
Nominal anchor diameter	*da(do)*	in. (mm)	0.145 (3.7)	0.185 (4.7)
Reduction factor for concrete breakout3	¢		0.70 (Condition B)	
PRYOUT STRENGTH IN SHEAR'				
CoEHicient for pryout strength (1.0 for hef < 2.5 in., 2.0 for hef <:: 2.5 in.)	*kcp*	-	1.0	1.0
EHective embedment	*her*	in. (mm)	1.23 (31.2)	1.23 (31.2)
Reduction factor rot pryout strength3	¢		0.70 (Condition B)	

For Sl: I inth = 25.4 mm, I lbf = 0.0044 kN.

1. lhe data in this table is intended to be used with the design provisions of ACI 318 Appendi 0.
2. Installation must comply with published instructions and details.
3. All values of ¢ were determined from the load combinations of UBC Section 1605.2.1, UBC Section 1612.2.1, or ACI 318 Section *9.2*. If the load combinations of UBC Se<tion *1902.2* or ACI 318 Appendix C are used, the appropriate value of ¢ must be determined in accordance with ACI318 0.4.5. For reinforcement that meets ACI 318 Appendix D requirements for Condition A, see ACI 318 0.4.4 for the appropriate ¢ factor.
4. The Tapper+ anchor is considered a brinle steel element as defined by ACI 318 0.1.
5. Tabulated values for steel strength in shear must be used for design.
6. Anchors are permined to be u d in suuctural sand-lightweight concrete. for ACI318 05. the values V_c must be multiplied by 0.60, in lieu of ACI 318 0.3.4.
7. For 2003 IBC, V..replaces V,; and *t*,replaces *t*.
8. lhe notation in parenlhesis is for the 2006 IBC.

MECHANICAL ANCHORS

PERFORMANCE DATA

Ultimate Load Capacities for Tapper+ in Normal-Weight Concrete[1].

Anchor Diameter d in. (mm)	Minim um Embedment Depth in. (mm)	Minimum Concrete Compressive Strength							
		f'c = 2.500 psi (17.3 MPa)		f'c = 3.000 psi (20.7 MPa)		f'c = 4,000 psi (27.6 MPa)		f'c = 6,000 psi (41.4 MPa)	
		Tension lbs. (l<N)	Shear lbs. (l<N)	Tension lbs. (kN)	Shear lbs. (l<N)	Tension lbs. (l<N)	Shear lbs. (I:N)	Tension lbs. (kN)	Shear lbs. (kN)
3/16 (4.8)	1 3/4 (44.4)	1,240 (5.5)	985 (4.4)	1,310 (5.8)	985 (4.4)	1,430 (6.4)	985 (4.4)	1,615 (7.2)	985 (4.4)
1/4 (6.3)	1 3/4 (44.4)	1,855 (8.3)	1,500 (6.7)	1,995 (8.9)	1,500 (6.7)	2,235 (10.0)	1,500 (6.7)	2,630 (11.7)	1,500 (6.7)

I.Tabulated load values are lor anchors installed in concrete. Concrete compressive strength must be at the specified minimum at the tirnt! of installation.
2.Ultimate load capadties must be reduced by a minimum safety lactor of 4.0 or greater to determine allowable working load.

Allowable Load Capacities for Tapper+ in Normal-Weight Conaete[1].u

Anchor Diameter d in. (nun)	Minimum Embedment Depth in. (mm)	Minimum Concrete Compressive Strength							
		f'c = 2,500 psi (17.3 MPa)		f'c = 3.000 psi (20.7 MPa)		f'c = 4,000 psi (27.6 MPa)		f'c = 6,000 psi (41.4 MPa)	
		Tension lbs. (kN)	Shear lbs. (kN)	Tension lbs. (kN)	Shear lbs. (l<N)	Tension lbs. (kN)	Shear lbs. (kN)	Tension lbs. (kN)	Shear lbs. (kN)
3/16 (4.8)	1 3/4 (44.4)	310 (1.4)	245 (1.1)	325 (1.4)	2-15 (1.1)	360 (1.6)	245 (1.1)	400 (1.8)	245 (1.1)
1/4 (6.3)	1 3/4 (44.4)	460 (2.0)	375 (1.7)	495 (2.2)	375 (1.7)	555 (2.5)	375 (1.7)	655 (2.9)	375 (1.7)

I.Allowable load capacitieS listed are calculated usrng and applied safety lae101 ol 4.0. Cooslderauon ol safety lact01s of 10o1 higher may be necessary depending on the opplication, such as file safety 01 ove head.
2. linear interpolation may be used to det!rmtne allowable loads 101intermeciate compressM suengths.
3. Allowable load capacities are muhiplied by load adjustment lact01s found n anchOI spacing or *edge* drstancts are less than cn11ul dtst.ances.

Load Adjustment Factors for Normal Weight Concrete

Edge Distance, Tension (FN)			
Dia		3116	1/4
'a		3	3
'min		1	1
Vi'oj·cu g u oj c:·9·i5 o·1	1	0.73	0.56
	1.25	0.76	0.62
	1.5	0.79	0.67
	1.75	0.83	0.73
	2	0.86	0.78
	2.25	0.90	0.84
	2.5	0.93	0.89
	2.75	0.97	0.95
	3	1.00	1.00

Spacing Distance, Tension (FN)			
Dia		3116	1/4
Scr		3.75	3.75
Smin		1	2
...oj·u:§.'...oj c: fl i5 2' ;...-I v1	1	0.76	-
	1.25	0.78	-
	1.5	0.81	-
	1.75	0.83	-
	2	0.85	0.72
	2.25	0.87	0.76
	2.5	0.89	0.80
	2.75	0.91	0.84
	3	0.94	0.88
	3.25	0.96	0.92
	3.5	0.98	0.96
	3.75	1.00	1.00

Edge Distance, Shear (Fv)			
Dia		3/16	114
'cr		3	3
'min		1	1
v1 oj·cu g u,el c: O".g w	1	0.58	0.35
	1.25	0.63	0.43
	1.5	0.68	0.51
	1.75	0.74	0.59
	2	0.79	0.67
	2.25	0.84	0.76
	2.5	0.89	0.84
	2.75	0.95	0.92
	3	1.00	1.00

Spacing Distance, Shear (Fv)			
Dia		3/16	1/4
sa		3.75	3.75
Smin		1	2
Vi' oj·cu §, oj c: fl 10 o1 c: ;;;; 10 a+	1	0.70	-
	1.25	0.73	-
	1.5	0.76	-
	1.75	0.78	-
	2	0.81	0.95
	2.25	0.84	0.95
	2.5	0.87	0.96
	2.75	0.89	0.97
	3	0.92	0.98
	3.25	0.95	0.98
	3.5	0.97	0.99
	3.75	1.00	1.00

d

MECHANICAL ANCHORS

[redacted]

PERFORMANCE DATA

Ultimate and Allowable Load Capacities for Tapper+ Anchors Installed into the Face of Hollow Concrete Masonrt[2,)]

Anchor Diameter *d* in. (mm)	Mimmum Embed. hv in. (mm)	Minimum Edge Distance in. (mm)	Minimum End Distance in. (mm)	ASTM C-90 Block Type	Ultimate Loads		Allowable Loads	
					Tension lbs. (kN)	Shear lbs. (kN)	Tension lbs. (kN)	Shear lbs. (kN)
3/16 (4.8)	1 (25.4)	2 (50.8)	2 (50.8)	Light Weight 4	340 (1.5)	460 (2.1)	65 (0.3)	90 (0.4)
	1-1/4 (31.8)			NormalWeight s	575 (2.6)	700 (3.1)	115 (0.5)	140 (0.6)
1/4 (6.4)	1 (25.4)	2 (50.8)	2 (50.8)	light Weight 4	495 (2.2)	530 (2.4)	100 (0.4)	90 (0.4)
	1-1/4 (31.8)			NormalWeight 6	950 (4.2)	740 (3.3)	190 (0.8)	150 (0.7)

1. Tabulated load wlues *ae* for anchas rnstalled in minrnum 8" wde. Grade N.T)lle H.tight-weight or norma wei!ln concrete masauy units ronfarnng to ASTM C 90 that have readied the mirif111JT1 designated liim;ne compressive strength at the timt! of Dation (fm > 1700 psi). CeDs rna'ybe !)'outed.
2. Alowable load CIIJI(ldties fisted arc caWated U5ln!l an i!!Ilted safety factor of 5.0. Consideration of safety factors *ci* 10or highef may be necessary dependi1g on the aJdc;aDon, such astife safety or we head.
3. I'llowal* shea. loads 11to Ore face shel of a masonry wall may be aWJed in <rtf lfrrection.
4. The talxilated values for the 3/1&-inch and 114-inch lf amelet Tawer+ in light-weight block are applrccl:le fa anchors Installed at a aitical spadng between anchors of 16 times the *ancha* diametet fhe anchors may be redlced lo*a* mirimum spadng lf!SlanCe *ci* 8times the ancho!lframeter JlcMded the alloY.OOie tensi(llloads are redlced by 12 percent AlcN.llble shear loads do not need lO be rediCfd.
5. The tabulated vakJes fa the 3/l&inch ciameter Tawer+ in noonal weight block are a ble fa anchors installed at a critical spacing between anchors of Slimes the anchor diametet
6. The tabulated vakJes for the 1J4.inch Tapper+ in nonnaJ weight block <wu appl e for anchors instaDed al a oiticiil spadng between anchors of 16limes the anchor diametec. The anchors may be reduced to a mitimum spacilg cfistance of 8times the anchor diameter prO'lided the alo.val:le tension 1ocds are reduced lJj 20 percenL AlfcNiaije shear loads do 001 need to be ed.

Allowable Load Capacities for Tapper+ Anchors Installed in Clay Brick Masonryul.4

Anchor Diameter *d* in. (mm)	Minimum Embed. *hy* in. (mm)	Minimum Edge Distance in. (mm)	Minimum End Distance in. (mm)	Installation Location	Tension lbs. (kN)	Shear lbs. (kN)
3/16 (4.8)	1-112 (38.1)	1-3/4 (44.5)	1-3/4 (44.5)	Face	380 (1.7)	165 (0.7)
3/16 (4.8)	1-1/2 (38.1)	1-3/4 (44.5)	1-3/4 (44.5)	Mortar Joint	300 (1.3)	190 (0.8)
114 (6.4)	1-1/2 (38.1)	1-3/4 (44.5)	1-3/4 (44.5)	Face	605 (2.7)	270 (1.1)
1/4 (6.4)	1·112 (38.1)	1-3/4 (44.5)	1-3/4 (44.5)	Mortar Joint	200 (0.9)	155 (0.7)

1. Tabulated load values are for anchors Installed rn multrple wythe, mlnmum Grade SW, sohd day bndc masonry walls confonmng to ASTM C 62. Mortar must be m10rmum Type N. Masonry compreSSIVe strength must be at the specified minimum at the time of installation (f., 1,500 i).
2. Allowable load capacities liSled are calculated calculated and applied safety factor of 5.0. Consideration of safety factors of 10or higher may be necessary depending upon the application such as life safety or overhead.
3. Allowable shear loads into the face or mortar joint of the brick maSOilry wall may be applied in any direction.
4. The tabulated values are applicable for anchors installed at *a* critical spacing between anchors of 12 times the anchor diameter.

Average Withdrawal Capacity and Average Bending Yield Moment of Tapper+ in Wood'

Anchor Diameter *d* in. (mm)	Minimum Embed. *hv* in. (mm)	Minimum Edge Distance in. (mm)	Withdrawa l Capacity[1] lbs. (kN)	Bending Yield Moment psi (MPa)
3/16 (4.8)	1 (25.4)	1-3/4 (44.5)	540 (2.4)	67,000 (464)
3/16 (4.8)	1-112 (38.1)	1-3/4 (44.5)	820 (3.7)	67,000 (464)
1/4 (6.4)	1 (25.4)	1-3/4 (44.5)	680 (3.0)	107,000 (740)
114 (6.4)	1-112 (38.1)	1-3/4 (44.5)	1,050 (4.7)	107,000 (740)

1. Tests In Oouglas-Fn larch with Spedhc Gravny of 0.42; strew onented tangental to wood gram.

ORDERING INFORMATION

(HWH)

(PFH)

BLUE PERMA-SEAL TAPPER - SrANnARr PACK*				
Cat No.		Screw Size	Quantitres	
HWH	PFH		Box	Carton
270050	274050	3/16" x 1-1/4"	100	500
270250	274250	3/16" x 1•3/4"	100	500
270450	274450	3/16" x 2-1/4"	100	500
270650	274650	3/16" x 2-3/4"	100	500
270850	274850	3/16" x 3-1/4"	100	500
271050	275050	3/16" x 3-3/4"	100	500
271250	275250	3/16" x 4"	100	500
272050	276050	1/4" x 1-1/4"	100	500
272250	276250	1/4" x 1·3/4"	100	500
272450	276450	1/4" x 2-1/4"	100	500
272650	276650	1/4" x 2-3/4"	100	500
272850	276850	1/4" x 3-1/4"	100	500
273050	277050	1/4" x 3-3/4"	100	500
273250	277250	1/4" x 4"	100	500
273450	277450	1/4" x 5"	100	100
273650	277650	1/4"x6"	100	100

BLUE PERMA-SEAL TAPPER • MASTER PACK**					
Cat No.		Screw Size	Quantities	Drill Bit References	
HWH	PFH			Straight	SDS Hex
947450	948850	1/4" x 3-3/4"	1000	2787	2797
947550	948950	1/4" x 4"	1000	2787	2797
	949050	1/4" x 5"	1000	2788	2797
	949150	1/4" x 6"	1000	2789	2797

HWH=-Hex Washer Head (slotted); PFH = Phillips Flat Head; TFH = Trim Flat Head; FHH = Flange Hex Head.
Tapper+ parts have an 'SO' designation added to the catalog number.
* - One Tapper+ drill bit included in each standard box.
** - Drill bit not included with master pack.
Shaded catalog numbers denote sizes which are less than the mmimum standard anchor length for strength design.

Carbide Drill Bits for Perma-Seal TAPPER+ - Straight Shank				
Cat. No.	Size	Usable Length	Std. Tube	Wt./ 10
278150	5/32" x 3·1/2"	2	10	1/4
278250	5/32" x 4-112"	3	10	1/4
278350	5/32" x 5-Jn"	4	10	1/4
278550	3/16" x 3-112"	2	10	1/4
278650	3/16" x 4-1/2"	3	10	1/4
278750	3/16" x 5-112"	4	10	1/2
278850	3/16" x 6-1/2"	5	10	1n
278950	3/16" x 7-1/2"	6	10	1/2

Carbide Drill Bits for Perma-Seal TAPPER+ - Hex Shank SDS-Pius				
Cat. No.	Size	Usable Length	Std .Tube	Wt./ 10
2793	5/32" x 5"	3	1	1
2794	5/32" x 7"	5	1	1
2796	3/16" x 5"	3	1	1
2797	3/16" x 7"	5	1	1

ACCESSORIES

		length	Length		

• This tool cannot be used with SDS Drill Bits or PFH screws.

MECHANICAL ANCHORS

ORDERING INFORMATION

(HWH)

(PFH)

(FHH)

(TFH)

(HWH)

(PFH) f:1

(FHH)

(TFH)

WHITE PERMA-SEAL TAPPER+ • STANDARD PACK*						
Cat No.				Screw Size	Quantities	
HWH	PFH	FHH	TFH		Box	Carton
240050	244050			3/16" x 1-1/4"	100	500
240250	244250			3/16" x 1-3/4"	100	500
240450	244450			3/16" x 2-1/4"	100	500
240650	244650			3/16" x 2·3/4"	100	500
240850	244850			3/16" x 3·1/4"	100	500
241050	245050			3/16" x3-3/4"	100	500
241250	244950			3/16" x 4"	100	500
242050	246050			1/4" x 1·1/4"	100	500
242250	246250	870650	871050	1/4" x 1-3/4"	100	500
242450	246450	870750	871150	1/4" x 2-1/4"	100	500
242650	246650	870850	871250	1/4" x 2·3/4"	100	500
242850	246850	870950	871350	1/4" x 3-1/4"	100	500
243050	247050		871450	1/4" x 3-3/4"	100	500
243550	247250			114" x 4"	100	500

WHITE PERMA-SEAL TAPPER+ • MASTER PACK**					
Cat No.		Screw Size	Quantities	Drill Bit References	
HWH	PFH			Straight	SDS Hex
	919150	3/16" x 1 1/4"	2000	2781	2793
	919250	3/16" X 1·3/4"	2000	2781	2793
	919350	3/16" X 2·1/4"	2000	2782	2793
	919450	3/16" x 2-3/4"	2000	2782	2793
	919550	3/16" x 3·1/4"	1000	2783	2794
	919650	3/16" x 3·3/4"	1000	2783	2794
	919750	3/16" X 4"	1000	2783	1794
992350	995150	1/4" x 1-1/4"	2000	2785	2796
992450	995250	1/4" x 1-3/4"	2000	2785	2796
992550	995350	1/4" x2-114"	1000	2786	2796
992650	995450	1/4" x 2-3/4"	1000	2786	2796
992750	995550	1/4" x 3-1/4"	1000	2787	2797
992850	995650	1/4" x 3-3/4"	1000	2787	2797
9929SD	9957SD	1/4" x 4"	1000	2787	2797

Shaded catalog numbers denote sizes which are less than the minimum standard anchor length for strength design.
Flange Hex Head parts are not included in the scope of ESR-3068

- TAPPF[--STANDARD PACK"						
Cat No.				Screw Size	Quantities	
HWH	PI-H	FHH	TFH		Box	Carton
	249850			3/16" x 1-1/4"	100	500
	250050			3/16" x 1-3/4"	100	500
	250150			3/16" x 2-1/4"	100	500
	250250			3/16" x2-3/4"	100	500
	250350			3/16" x3-1/4"	100	500
	250450			3/16" x 3-3/4"	100	500
	250550			3/16" x 4"	100	500
248650	250650			1/4" X 1-1/4"	100	500
248850	250750	871550	871950	1/4" x 1-3/4"	100	500
249050	250850	871650	872050	1/4" x 2·1/4"	100	500
249250	250950	871750	872150	1/4" x 2·3/4"	100	500
249450	251050	871850	872250	1/4" x 3·1/4"	100	500
249550	251150		872350	1/4" x 3-3/4"	100	500
249650	251250			1/4" x 4"	100	500

– SiElfPACK'''					
Cat No.		Screw Size	Quantities	Drill Bit References	
HWH	1'FW			Straight	SDS HeX
	875750	3/16" x 1-1/4"	2000	2781	2793
	875850	3/16" x 1-3/4"	2000	2781	2793
	875950	3/16" X 2·1/4"	2000	2782	2793
	876050	3/16" x 2·3/4"	2000	2782	2793
	876150	3/16" X 3·1/4"	1000	2783	2794
	876250	3/16" x 3-3/4"	1000	2783	2794
	876350	3/16" X 4"	1000	2783	2794
875050	876450	1/4" x 1-1/4"	2000	2785	2796
875150	876550	1/4" X 1-3/4"	2000	2785	2796
875250	876650	1/4" X 2-1/4"	1000	2786	2796
875350	876750	1/4" X 2-3/4"	1000	2786	2796
875450	876850	1/4" x 3·1/4"	1000	2787	2797
875550	876950	1/4" x 3-3/4"	1000	2787	2797
875650	877050	1/4" x 4"	1000	2787	2797

(PFH)

(FHH)

BRONZE PERMA-SEAL TAPPER ·STANDARD PACK"				
Cat No.		Screw Size	QuantitieS	
PFH	FHH		Box	Carton
997550	997750	1/4" x 1-3/4"	100	500
997650	997850	1/4" x 2-114"	100	500

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Dril-Flex Structural Fasteners

ELCO®

Dril-Flex® Structural Self-Drilling Fasteners

Offers virtual immunity to hydrogen-assisted stress corrosion cracking for maximum performance in the field

Product Information

Dril-Flex® Structural Self-Drilling Fasteners

Dril-Flex® fasteners are specially designed and processed to help prevent hydrogen-induced brittle failures. Each fastener undergoes the unique Flex Technology® dual-hardening process to ensure the optimal combination of ductility and hardness required for maximum performance in the field.

Testing of this product, in accordance with ASTM standards, has proven that Dril-Flex® fasteners provide the same resistance to hydrogen-assisted cracking (HAC) as a Grade 5 fastener.

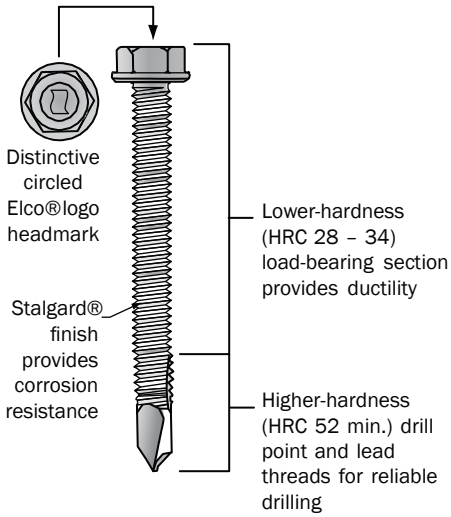
Unique Hardening and Finishing Processes Provide High Performance

Hydrogen-Assisted Stress Corrosion Cracking (HASCC) refers to a time-delayed failure that is aggravated or accelerated by hydrogen generated in the application. This is most often encountered and associated with dissimilar metal applications through the galvanic corrosion process. Most self-drilling fasteners, including 410 fasteners, are case or similarly hardened, which provides the necessary hardness for drilling and tapping, but leaves the screws vulnerable to HASCC due to their high surface or core hardness.

Dril-Flex fasteners offer the unique Flex Technology® dual-hardening process. The self-drilling point and lead tapping threads are selectively hardened to a minimum of HRC 52. The load-bearing portion of the screw is held at or below the critical HRC 34 level. This reduced hardness level also meets SAE J429 Grade 5 and ASTM A449 strength and ductility standards.

Dril-Flex fasteners are then coated with silver Stalgard® finish to provide superior corrosion resistance and enhanced galvanic compatibility. Fasteners coated with Stalgard® finish typically show no red rust or other base metal corrosion on significant surfaces even after 800 hours of 5% neutral salt spray exposure (ASTM B117).

The combination of this unique dual-hardening process and Stalgard® finish results in a strong, reliable fastener that can be used where other self-drillers would fail. Dril-Flex self-drilling fasteners are the ideal fastening solution for demanding construction applications.



Features

- Self-drilling point
- Higher hardness (HRC 52 min.) point and lead threads
- Lower-hardness (HRC 28 – 34) load-bearing threads
- Silver Stalgard® multi-layered corrosion resistant finish

Benefits

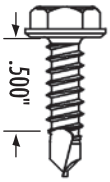
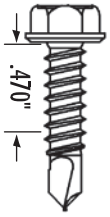
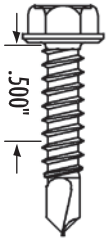
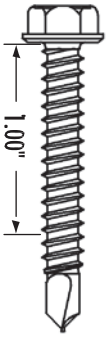
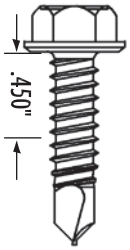
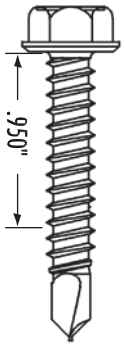
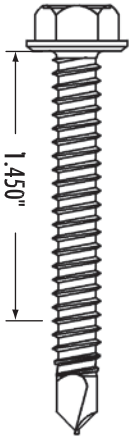
- Virtually immune to delayed HASCC brittle failures found with other hardened fasteners
- Provides the same high resistance to hydrogen-assisted failure as a Grade 5 fastener
- Precision self-drilling point ensures consistent, reliable drilling and tapping
- Eliminates separate drilling and tapping operations
- Corrosion resistance superior to zinc- or cadmium-based finishes
- Provides enhanced galvanic compatibility in dissimilar metal applications
- Approvals: ICC ES ER-4780 Legacy Report; COLA (City of Los Angeles) Research Report #25095

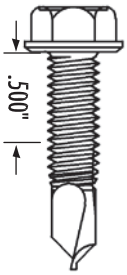
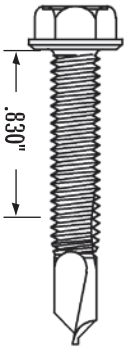
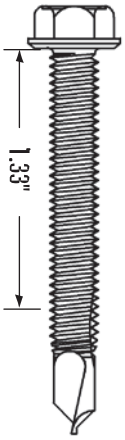
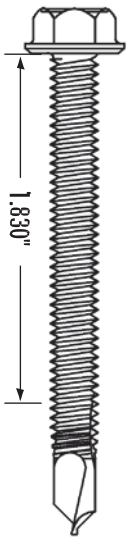
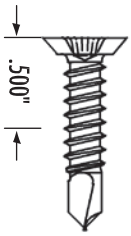
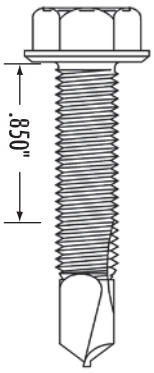
STAFDA ASSOCIATE

ALUMINUM ASSOCIATION OF FLORIDA INC. AAF

Dril-Flex® Structural Fasteners

SELECTION GUIDE*

Size	10-16	12-14	12-14	12-14	12-14	1/4-14	1/4-14	1/4-14
Length	3/4"	7/8"	1"	1-1/2"	2"	1"	1-1/2"	2"
Head Style	HWH #3	HWH #3	HWH #3	HWH #3	HWH #3	HWH #3	HWH #3	HWH #3
Application Use	steel and aluminum	aluminum only	steel and aluminum	steel and aluminum	steel and aluminum	steel and aluminum	steel and aluminum	steel and aluminum
Drilling Capacity	.150"	.187"	.187"	.187"	.187"	.210"	.210"	.210"
Catalog Number	AF 430	AF 621	AF 641	AF 681	AF 690	AF 816	AF 841	AF846
Maximum Load-Bearing Area Indicated By Arrows**								

Size	1/4-20	1/4-20	1/4-20	1/4-20	12-14	5/16-24
Length	1-1/8"	1-1/2"	2"	2-1/2"	1"	1-1/2"
Head Style	HWH #4	HWH #4	HWH #4	HWH #4	Undercut Flat Head #3	HWH #4
Application Use	steel and aluminum	steel and aluminum	steel and aluminum	steel and aluminum	steel and aluminum	steel and aluminum
Drilling Capacity	.210" to .312"	.210" to .312"	.210" to .312"	.210" to .312"	.187"	steel: 0.187" aluminum: 0.25"
Catalog Number	AF 865	AF 876	AF 886	AF 890	BL 215	AF960
Maximum Load-Bearing Area Indicated By Arrows**						

* Fasteners shown are in-stock. Other head styles, threads, lengths and drilling capabilities can be produced to meet specific application needs.

** IMPORTANT: to ensure proper performance, only the load-bearing area should be engaged in the material being fastened.

Dril-Flex® Structural Fasteners

COMPARISON TO STAINLESS STEEL FASTENERS

300 series stainless steel fasteners will not rust, and, because of their low hardness, they also provide high resistance to hydrogen embrittlement failures. However, because stainless steel is galvanically incompatible with certain building materials – including steel and aluminum – it can cause other problems (see chart) when combined with these materials. Stainless steel fasteners trigger a sacrificial action in the aluminum or steel panel, which can lead to degradation of the panel and loosening of the fastener.

The dual-hardening process allows Dril-Flex fasteners to provide high strength and resistance to hydrogen embrittlement failures. Their unique Stalgard® finish provides corrosion resistance several times greater than other commonly-used finishes. Fasteners coated with Stalgard finish typically show no red rust or other base metal corrosion on significant surfaces even after 800 hours of 5% neutral salt spray exposure (ASTM B117).

If the environment is corrosive enough to significantly affect the Stalgard® finish, the potential for significant degradation of the aluminum/ stainless steel assembly would also exist.

Galvanic Series

Anodic End	
Metal/Alloy	*EMF (v)*
Magnesium	-1.60
Zinc	-1.10
Alum (5000, 6000, 7000)	75
Iron, Low Alloy Steels.	70
Alum (2000).	60
Lead.	55
18% Chromium Steel.	35
Naval Brass.	30
Brass, Bronze.	25
Austenitic Stainless (300 Series).	20
Nickel.	15
Silver	0
Gold	+15
Cathodic End	

In the presence of moisture, materials higher on the list will be sacrificial to materials lower on the list. The greater the EMF differential, the greater the sacrificial action of the anode to the cathode in a galvanic cell.

EMBRITTLEMENT TESTING

Embrittlement testing of Dril-Flex fasteners was performed in accordance to ASTM F1624-06, "Standard Test Method for Measurement of Hydrogen Embrittlement in Steel by the Incremental Loading Method". Fastener lots were tested to determine their Threshold Stress Limits for both Internal Hydrogen Embrittlement and Environmental Hydrogen Embrittlement. Threshold Stress Limit is the stress level below which no time-dependent cracking will occur. Above this level, subcritical cracking that leads to time-delayed fracture or embrittlement may occur if the fastener is exposed to a hydrogen environment.

Embrittlement Test Results

- Dril-Flex fasteners have a hardness range of HRC 28 – 34, which is roughly equivalent to a SAE Grade 5 fastener (HRC 25 – 34).
- Dril-Flex fasteners showed resistance to the effect of hydrogen-assisted cracking when loaded to 75% of their tensile strength. This is within accepted industry guidelines for in-service loading conditions.
- Dril-Flex fasteners showed no degradation or failures in tensile strength below their Ultimate Tensile Strength.

SHEAR AND PULL-OUT VALUES

Pull-out Tests – Steel

Pull-out values shown are in lbs.

Screw Size	Point Type	Drill Cap	Steel							
			18	16	14	12	1/8	3/16	1/4	5/16
10-16	3	.150	396	501	634	1595	1693			
12-14	3	.187	396	527	710	1678	2061	2898		
1/4-14	3	.187	398	530	686	1950	2264	3919		
1/4-20	4	.312		516	649	1912	2296	2928	3561	4488
5/16-24	4	.312				2148	2573	4226	5424	6622

Pull-out Tests – Aluminum

Pull-out values shown are in lbs.

Screw Size	Point Type	Drill Cap	Aluminum 6063-T5		
			1/8"	1/4"	3/8"
10-16	3	.150			
12-14	3	.187	939	2286	
1/4-14	3	.187	1003	2424	
1/4-20	4	.312	897	2075	3683
5/16-24	4	.312	1043	2566	

Shear Tests – Steel

Shear values shown are in lbs.

Screw Size	Point Type	Drill Cap	Steel						
			18-18 gage	18-14 gage	16-16 gage	14-14 gage	1/8"-3/16"	3/16"-1/4"	1/4"-12 gage
10-16	3	.150	1362	1733	1462				
12-14	3	.187	1315	2118	1655	1816			
1/4-14	3	.187	1395	2313	1681	2417	2600		
1/4-20	4	.312	1350	2086	1582	2450	2814	2810	2706
5/16-24	4	.312					5486	5283	4761

Shear Tests – Aluminum

Shear values shown are in lbs.

Screw Size	Point Type	Drill Cap	Aluminum 6063-T5	
			1/8" - 1/8"	1/8" - 1/4"
10-16	3	.150	1466	
12-14	3	.187	1797	2483
1/4-14	3	.187	1996	2883
1/4-20	4	.312	2006	2926
5/16-24	4	.312	1849	2926

NOTE: All test setups and dimensions were as limited and outlined in AISI Test Method for Mechanically Fastened Cold-Formed Steel Connections (CF92-1) document. Performance values listed are ultimate values obtained under laboratory conditions. Appropriate safety factors should be applied for design purposes.

SPECIFICATIONS

Application:
Metal (including aluminum) to steel structurals

Short Form Specification:
Dual-hardened fastener with self-drilling point and self-tapping thread that meets SAE J429 Grade 5 and ASTM A449 strength and ductility requirements, which provides a maximum load-bearing area of_____.

Approvals/Listings:
- ICC ES ER-4780 Legacy Report
- COLA (City of Los Angeles) Research Report #25095

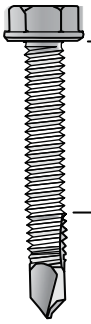
Diameters:
#10, #12, 1/4", 5/16"

Head Styles:
Hex washer head, undercut flat head; custom heads styles available

Thread Form:
Self-tapping

Point Type:
Self-drilling

Material:
Special alloy steel

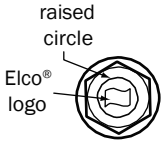


Actual load-bearing area varies per fastener size. Please refer to chart on page 2 of this brochure for more information.

Finish:
Silver-colored Stalgard® corrosion-resistant finish withstands a minimum of 800 hours salt spray per ASTM B117 standards

Installation Tools:
Standard 4.5 min. amp screw gun that has a torque-limiting and/or depth-sensitive nose piece

Inspection
In-place inspection can be made by identifying the special Dril-Flex® headmarking. This is a combination of two markings: an Elco®logo surrounded by a raised circle.



hex washer head shown

DESIGNING WITH DRIL-FLEX FASTENERS

Download CAD files from our web site at www.elcoconstruction.com or contact Elco Construction Products for a free disk containing CAD drawings and specifications of Dril-Flex fasteners.

QUALITY CONTROL

Dril-Flex fasteners are produced under lot control conditions. Each production run is sampled and checked for two key conditions. First, that the lower hardness zone extends down the shank to the length specified, and second, that the hardness in that zone is per the specifications. Documentation is retained for a period of five years. Lot numbers are marked on every box of product.

QUALITY PRODUCTS

A number of other high-quality products for construction are available from Elco Construction Products, including:

- Self-drilling fasteners
- UltraCon®Masonry Fasteners in 3/16", 1/4" and 5/16" diameters
- ConFlex®Masonry Fasteners in 3/8" and 1/2" diameters
- Crete-Flex®SS4 Masonry Fasteners
- HangerMate®Threaded Rod Anchoring System
- Fab-Lok™ Vibration-Resistant Fasteners

For more information on our wide selection of products, visit our web site at www.fastenersforconstruction.com or contact your Elco Construction Products representative.

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