THE PRACTICAL APPLICATION OF DAYLIGHTING SYSTEMS AS AN EFFECTIVE ENERGY CONSERVATION MEASURE WITH A REASONABLE RETURN ON INVESTMENT.

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ABSTRACT

Surveys conducted by the State of **F**lorida **E**nergy **O**ffices ***E***nergy ***C***onservation ***A***ssistance ***P***rogram (***ECAP***) at the **U**niversity of **S**outh **F**lorida, over a 13 year period on a national basis, have, with repeatable results, shown that regardless of Longitude and Latitude, Passive and Active Daylight Harvesting Systems can significantly reduce conventional lighting loads with no adverse effects on a facilities originally designed HVAC systems. When such systems are properly engineered and installed, savings can be accomplished with little or **no negative effect on a facilities Architectural Aesthetics and without compromising it's Water Tight Integrity**.

INTRODUCTION

The Energy Conservation Assistance Program was created in 1989 as a joint effort between the United States Department of Energy, the Florida Energy Office and the Florida Small Business Development Center Network. Funded with Petroleum Violation Escrow Funds (PVE). The original focus of the program was to assist small business owners in being more competitive through reduced energy consumption, therefore reducing operational overheads, allowing them to be on a closer parallel with their larger corporate brothers, who statistically have a lower energy consumption per square foot due to their ability to hire professional energy specialists.

As time progressed the ***ECAP*** program has been augmented to include Environmental Surveys, Storm Mitigation Analysis, OSHA compliance assistance and most recently Blast and Emergency Operations sustainability. Our affiliation with the Department of Energy's Rebuild America, Energy Smart Schools and Federal Energy Management Programs have expanded our client base to include facilities of all types.

Our Small Business Roots, firmly implanted, with the U.S. Small Business Administration, affords us the opportunity to assist various entrepreneurs and inventors who have developed all types of Energy Conservation Devices. For the most part, these Small Business owners are normally seeking some type of technical assistance with Measurement and Verification of their product and or service to ascertain if they should proceed with having nationally recognized certification such as ASTM or other accreditation, that in some cases, **can be costly** and beyond the financial capabilities of the inventor. In other cases, the product that is in question, may be of such a design that the normally accepted test methods, such as *ASTM C 976-90, ASTM E 547-93, ASTM C 518-91, ASTM E 1105-93 and NFRC 100-91* may not be 100% applicable.

As an example, two of the most successful Daylighting Retrofit Products our office has installed in 37 individual School Buildings using Federal Grants, are, by design, **clear to allow the maximum amount of daylight to enter the room**. However, neither product allow the negative side of Daylighting Systems-i.e. , **excessive heat / cold**, to be transferred into, or out of, the controlled zone. Normally, if you rely on the Shading Heat Gain Coefficient (SHGC) number of a clear **s**kylight or window attachment, the value of clear glazing will show up as excessive, and your computer software will likely reject it as being ineffective

For an entrepreneur or inventor to qualify for the cost free assistance provided by our program they must have a Working System installed in a Commercial Facility that we can use as a Modified Climatic Chamber. All of the Daylighting Technologies discussed in this presentation underwent their initial field test using this method. 13 years of field analysis on operational systems installed and monitored by our office has shown that even recently constructed buildings (1999 to 2001) have experienced increased comfort levels, reduced energy consumption and better indoor air quality though the use of Daylighting systems.

The **Photobiological Benefits of Daylighting System** on Enhanced Student Performance, Employee Productivity and Increased Retail Sales, have, over the past 6 years, been well documented. These factors combined with the recent Terrorist Attacks on our Country, confirm the need for an Alternative Source of displacing conventional lighting loads when electrical power generation and distribution could be disrupted for weeks rather then hours. **Daylighting Systems are a Natural Alternative** to help keep a facility up and running during daylight hours.

BASIC PROCEDURES USED

This procedure outlines the ***field test methods*** used to determine the overall light levels, solar radiation admitted through, both directly transmitted, and absorbed and subsequently released inward as well as the thermal conductance and overall thermal resistance of fully assembled and installed Daylighting Assemblies in buildings. The objective of this procedure was to determine the impact of these Daylighting Assemblies on conventional electric lighting loads and any other related loads they might produce and or reduce, to heating and air conditioning systems in various large and small commercial buildings of standard construction types.

Discussion- Though our program is located in the State of Florida, through the Florida Energy Offices ***OPERATION COOPERATION***, a program that shares Solar and Alternative Energy Solutions with any interested party, the facilities included in this study, used to reach our conclusions, were located throughout the United States and included but were not limited to facilities located in;

El Paso, Texas	San Antonio, Texas
Houston, Texas	Los Angles, California
Cleveland, Ohio	Detroit, Michigan
Charlston, South Carolina	Norfolk, Virginia
Williams, Arizona	Carlstadt, New Jersey
Pensacola, Florida	Jacksonville, Florida
Miami, Florida	Tampa, Florida
Cross City, Florida	Tallahassee, Florida
Key West, Florida	Quincy, Florida

The focus of this procedure is to provide ***a comparison*** to known standards for all parties interested in using alternative energy devices, to displaced conventional lighting loads during daytime hours, until a uniform testing procedure, that is accurate and can **economically provide** similar information to the consumer can be developed and agreed upon by the engineering community. This procedure addresses the light emitting and thermal properties of the materials / products tested and has no relationship to structural building code requirements. The products that make up the majority of this study are ones that have been approved under the State of Florida, **State Negotiated Approve Purchasing System** (SNAPS) . This is the system we must use when using State / Federal Grant Dollars to retrofit Schools and Government Facilities. Thought the majority of Daylighting System Manufactures in the United States **have been invited on several occasions**, by my office, to participate in the SNAPS program, none, to date, have elected to do so limiting the pool of pre-qualified vendors available for Florida Government Projects. The information contained in this presentation is meant to be an educational guide as to the effectiveness of these Daylighting Systems and should not be construed as an endorsement of a particular product by name or design.

TYPICAL DATA POINTS RECORDED

1. Inside room temperature at ceiling level & work levels.
2. Air Conditioning discharge duct temperatures
3. Discharge Duct Air Velocity
4. Percent of Relative Humidity Dew Point
5. Abs Humidity (gm/cu.m)
6. Uncompomised Percent Relative Humidity
7. Light intensity (lumens per square foot)
8. Window Heat Flux in BTU's per square foot per hour
9. Lighting fixture Heat Flux in BTU's per square foot per hour
10. Outside ambient temperature
11. Wind speed
12. Wind direction
13. Outside wind chill temperature

Some of the equipment and instrumentation employed during the project are as follows;

1 Pete Brothers model 200 portable weather station with RS232 interface.
2 Extech Instruments CMM-15 Process Calibrator Multimeter with RS232 interface.
3 Omega Engineering Corp. HFS-1 Heat Flux Sensor Sn. 970898567, NBS traceable calibration.
4 Texas Instruments Extensa 600 CD computer for RS232 interfaces.
5 AGEMA 210 Infrared Imaging system with a –22 Deg. F to 1500 Deg. F range and a thermal resolution of 2.25 X 2.25 mrad (V&H), field calibrated to a black body standard that is NBS traceable.
6 ALNOR type 3002 Velometer with a range of 0 to 3000 feet per minute.
7 Extech Instruments Model 4077026 Light Meter / NBS traceable calibration.
8 Omega Engineering Corp. Model OS71 Infrared Thermometer.
9 ONSET Computer Corp. Model HO-006-04 Data Loggers.
10 UV-TEX A+Bidm UV Meter& Dosimeter.
11 Motorola Lighting Inc. Flicker Checker.
12 ONSET Computer Corp. Amp Probes.
13 FLIR ThermaCAM ES Infrared Imaging System.
14 SONY FD83 camera & VAIO SRX-77 Computer

Summary of Test Methods

The heat source was natural sunlight and outside ambient temperatures producing a thermal transfer to and on all outside surfaces.

The test specimen / product is installed in a ***standard constructed building envelope with a known R-Value traceable to accepted industry standards.***

The Placement of Thermal and Heat Flux transducers on the outside and inside surface of the building envelope, use a insulated blanket to protect the transducers from wind chill and direct sunlight absorption were applicable. Thermal and Heat Flux transducers on all exposed surfaces of the Test Specimen, both inside and outside of the building envelope, are protected in the same manor, from direct exposure to heating and air conditioning air flows.

A consecutive logging of data is accomplished with computer interfaces. The minimum test period is 24 hours at various locations and the average test period was 168 hours. The maximum test period was 35,040 hours at one facility. The minimum data recording time period between temperature readings at each test point is 5 minutes. All readings were taken in conjunction with each other from each test point in the same time frame.

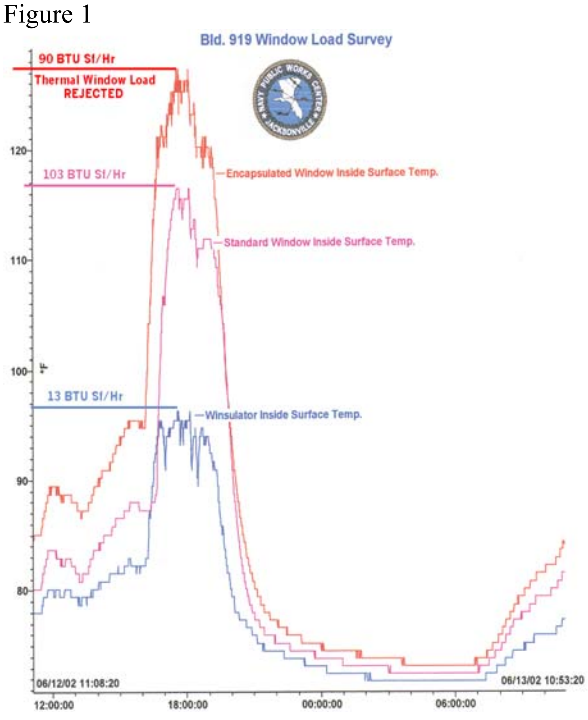
Calculating the results

The actual inside and outside surface temperatures ***of both*** the test specimen and the known *R-Value* of the Modified Climatic Chamber (the buildings actual envelope) are processed to obtain maximum and minimum temperature Delta-T and actual Heat Flux at the interface. The variables due to a natural heat source, wind chill and outside ambient conditions are considered. The area of the test surfaces, the physical size of the test specimen and other variables such as air gap between test surfaces are calculated.

The data can be expressed in ***actual or average*** readings and then used in modified calculation equations to express the ***performance equivalents*** of transmittance ***U*** and resistance ***R.*** This method was used to determine the thermal resistance **(R-Value)** of two **Passive Solar Daylighting Devices** a Tubular Skylight manufactured by Tubular Skylight Inc. of Sarasota, Florida (3 different models **TSL-13 TSL-21 & ECOSTAR-21)** and the **Winsulator Interior Storm Window System** manufactured by South Sun Energy Conservations of Sarasota, Florida, both of who's data is represented in, and the focus of, this particular paper. The results clearly indicated that the thermal resistance, of both of these systems, used as **Passive Solar Daylighting Devices** is not a unique value, but a range values found to be consistent with the tenets of Thermal Design Theory. These can be expressed in **performance equivalent values**, similar to the **accepted criterion** used to express the characteristics of other materials such as **radiant barriers**. Using this method and actual utility billing records we have proven that both of these systems **did not negatively impact** heating or air conditioning loads in the facilities surveyed.

The standard nationally accepted test methods all use a constant level heat source. We have repeatedly found that when the specimen / component is exposed to ***real life heat dynamics,*** as installed to perform its job***, the behavior is different***. Figure # 1 clearly shows these dynamics in action on the inside glass surface temperatures of a double pane insulated system that has tinted glass and a known winter U- value of .48 and a summer value of .57 with a South West exposure. The window as been retrofitted with a high molecular weight clear acrylic Interior Storm Window Daylighting Retrofit over the existing Double Glaze Insulated System .

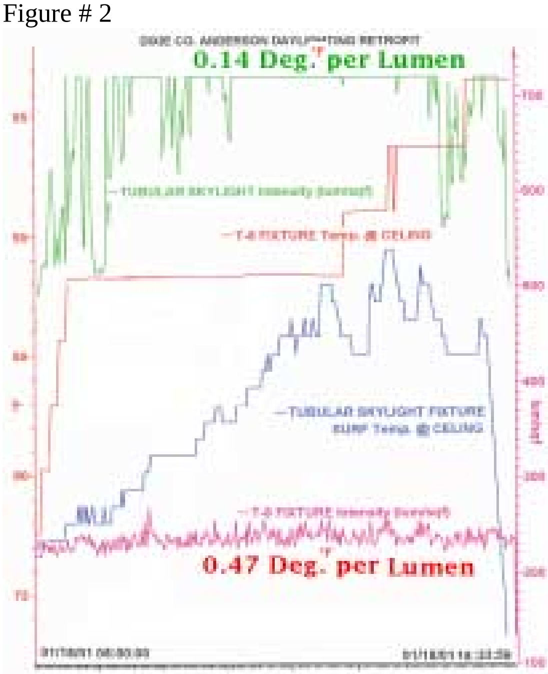
Figure 1



In case of both the these Daylighting systems, every installation was a unique case with the R-value varying within the specified, building / energy code, acceptable range and **exceeding those of normal computer software fenestration libraries used for calculations and load modeling**.

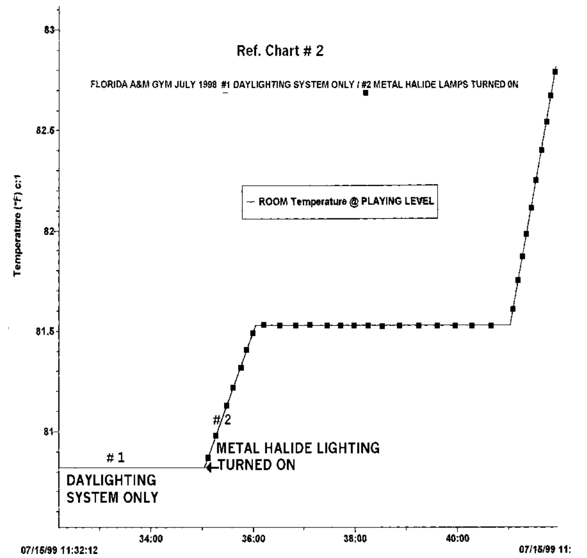
Our ***real life heat dynamics*** tests on the **TSL / Tubular Skylights** showed that the **Daylighting component** of the systems actually added less heat load to the building then the standard **T8 fluorescent fixture component** (see photo, Thermogram and Figure #2 below for Typ.).

Figure # 2



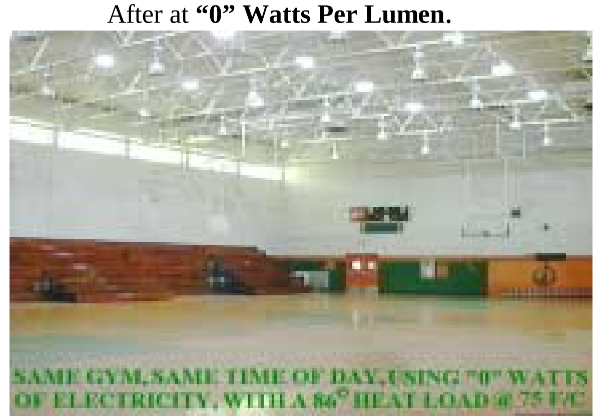
Reference Figure 3 shows the heat gain in a Gymnasium when the standard Metal Halide lighting system **is turned on** with a electrical load of 28 Watts per lumen, you will note that at playing level (5 feet from the floor) the temperature increases better than **2.6** deg. F in 6 minutes. Though not represented on the chart, the increase in foot candles when we activated the MH Lighting system was only **12%**, hardly a good trade off considering their ***is a "0" watt per lumen cost when using the Passive Daylighting system***. The following photographs were taken at the above retrofitted facility. In this case we removed the Window Film and replaced with CLEAR Interior Storm Windows and Eliminated the MAJOR SOURCE of the HEAT GAIN (Figure 3) with the use of a TSL-21 Passive Tubular Skylight System

Figure 3



Before requiring a load of
28 Watts Per Lumen.

After at **"0" Watts Per Lumen.**



The same held true for the ***real life heat dynamics*** tests conducted on the **Interior Storm Window System.** If you simply add up the accepted **published data** for a,

MATERIAL	*VALUE R*
1. WINDOW, SINGLE GLASS	0.88
2. 3/4" AIR SPACE	0.91
3. 0.120" thick HMW Acrylic sheet	4.00

Total	5.79

you can see that even using this simple method, the R Values of the interior storm window systems we tested exceeds that of most window retrofits.

When you actually install this type of retrofit over an existing system you normally end up with an air space between the glass and acrylic of at least 2 inches thus increasing the performance to even more desirable levels. Once again these assertions have been collaborated by the end users in actual energy dollar savings. When using our method and recording the performance of ***all components in a controlled zone*** a relatively accurate profile of internally generated heat loads can be establish. The following Photo and Thermogram show some typical results.

The prior Photo and Thermogram is of a **Interior Storm Window Daylighting Retrofit** at a U.S. Naval Station, you will note some of the Load Data Recording devices are still attached to the building envelope. The following Figures, 4 & 5 show a synopsis of some of the results from this field survey. We have obviously made a positive impact on light levels without adding any additional discomfort factors.

Figure 4

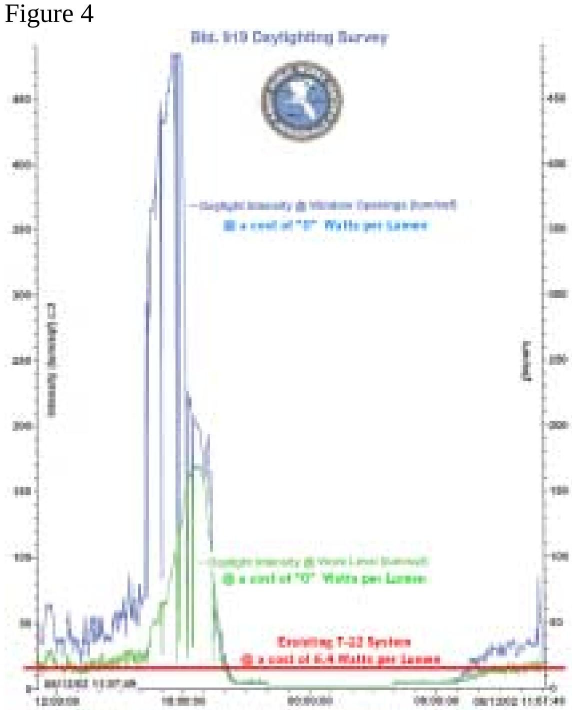
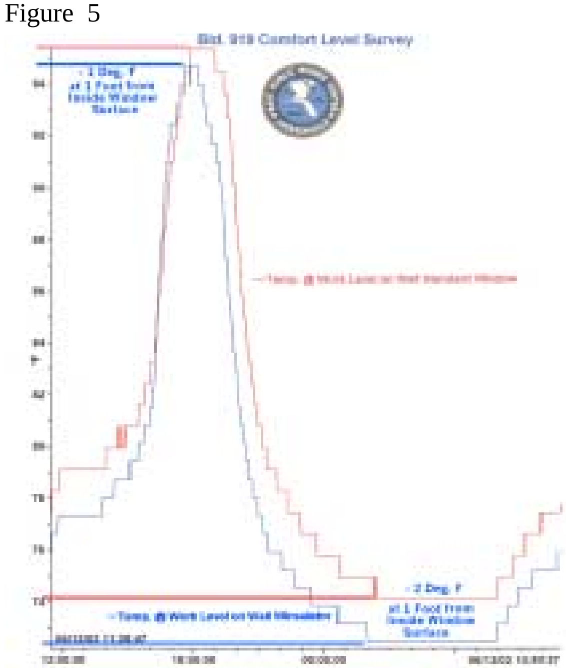


Figure 5



Unfortunately using these same test methods on other materials and building component produce results that can be perplexing. As an example windows treated with different types of films and internal coatings, rejected heat and solar gain on work level surfaces such as desks and carpeting, however, our field test indicated that the interior surface of the filmed and coated glass, the side exposed to the HVAC system**,** had, in most cases, a significant heat gain. This poses the question of what percent of the typical advertised and accepted reduction in window loads are actually being realized when the inside surface of the filmed / coated glass is generating a higher thermal transfer then anticipated?

Additionally, field testing on window systems, even identical systems, manufactured by the same company with NFRC ratings, never perform the same way, with repeatable results, at different locations. **Even when the facilities are of exactly the same construction type and less than one mile apart, with identical window orientation** and all the data is being gathered consecutively the performance curves are always **signifincantly different.**

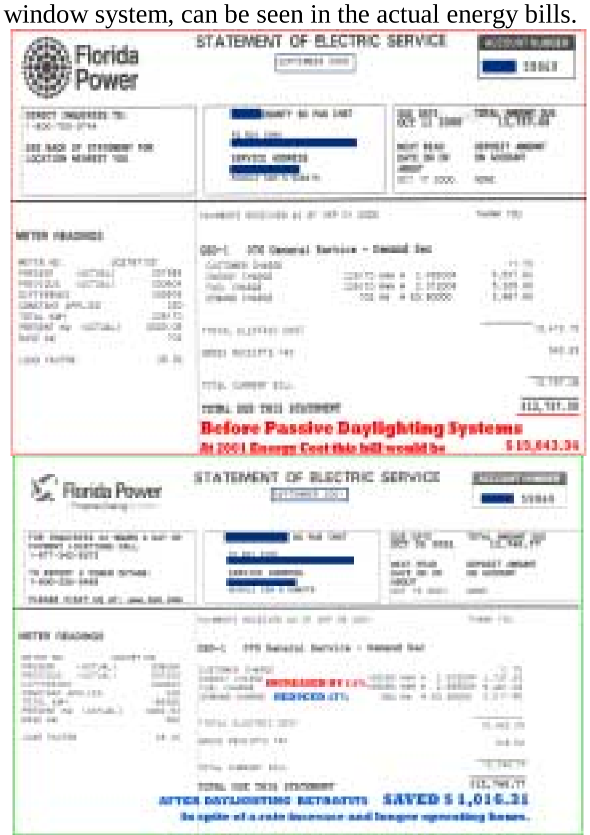
METHODS EMPLOYED IN CONDUCTING DAYLIGHTING FEASABILITY SURVEYS

Due to the advances made in these particular Tubular Skylight and Interior Storm Window products, as previously demonstrated, Lighting and Energy Conservation Professionals are no longer restricted to bouncing window light off the ceiling to incorporate Daylighting in any facility.

The first hurdle you must overcome is equating usable Lumens with Electrical Load and Building Envelope Heat Gain or Loss. As seen in the prior charts, photos and Thermograms, if you choose a properly engineered product, letting the "**Sun Shine In" is not necessarily synonymous with Increasing Heating or Cooling Load Levels.**

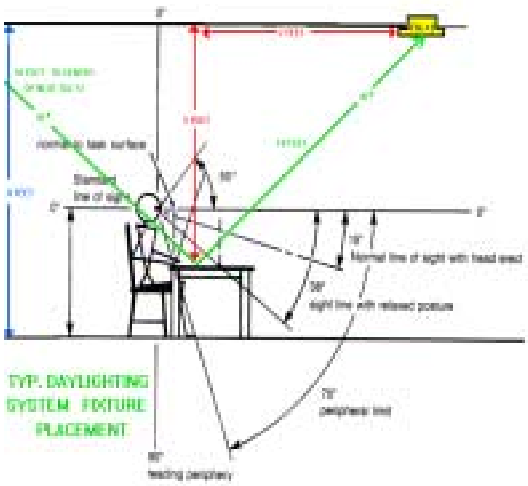
This next facility is a perfect example, it has a higher then normal **Window to Wall Ratio** making it a perfect candidate for a ***Passive Daylighting*** retrofit. The facility was under contract to a large well known National ESCO that had implemented all of the standard Energy Conservation Measures (ECM's) at their disposal two years prior. This ***Winsulator Daylighting Retrofit*** was the **ONLY additional enhancement to the facility**.

The end result from, removing failing window films and high maintenance deteriorating Mini-Blinds and reducing the Infiltration Factors caused by normal structural settling and shrinking window seals, combined with eliminating the need to use the 1/3 of the conventional lights in close proximity to the window system, can be seen in the actual energy bills.



If you incorporate the **available Daylight from CLEAR windows** (free of dark tints, heavy shades and closed blinds) as the starting point of a feasibility study and then work towards the center of the facility, by employing some of the data we have compiled it is relatively easy to design a **Successful Daylighting Retrofit by combining both Widow Treatments and Tubular Skylights**. Figure 6 shows the typical, simple calculations needed.

Figure 6



Using the existing window system as a starting point reduces the number of Tubular Skylights needed and the total project cost. As can be seen in the following examples the results can be dramatic.

The School Cafeteria (above) is using both Interior Storm Windows and a **Daylight Harvesting System** . This type of system uses **self dimming T-8 electronic ballast to reduce electric lighting loads**. The total conventional T-8 lighting electrical load **would have been 135 Watts with the dimmers engages** at the time of this picture, however, in this instance, the staff elected not to use the T-8 system (due to the more then adequate light levels) and the load is **"0" watts**.

This library (photo below) employs both Interior Storm Windows and a **Passive Daylighting System** (no electronic controls on the conventional lighting system). **"0" Watts per Lumen**

Similarly, this classroom (below) has been retrofitted with a Passive Daylighting System.

"0" WATTS PER LUMEN

This system is producing 75 Lumens a square foot of FLICKER FREE 98 CRI natural lighting at a cost of **"0" Watts per Lumen** with a heat load that was 14 degrees cooler then the existing T-8 system. You will notice that the Teacher has ***VOLUNTARILY TURNED OFF ALL OF THE T-8 STANDARD FIXTURES***. Our experience has been that once a Teacher or Employee see the dramatic difference between even the highest end conventional lighting CRI's and the Daylighting system, the conventional lighting becomes a point of aggravation and they elect to not use them, even without automated controls.

The resent studies completed on the amount of light that the human eye actually sees in comparison to Light Meter Readings has been confirmed by our surveys. The importance of a proper Color Rendering Index and it's relationship to Daylighting Retrofits can clearly be seen in the fowling Photos. This retrofit used A TSL/ ECO-STAR **Daylight Harvesting System** to replace a LPS system in a School Districts Maintenance facility.

BEFORE S/P RATIO= 0.4 CRI= 20
@ 58 WATTS PER LUMEN

AFTER S/P RATIO= 2.47 CRI =98
@ 2.3 WATTS PER LUMEN

CONCLUSION

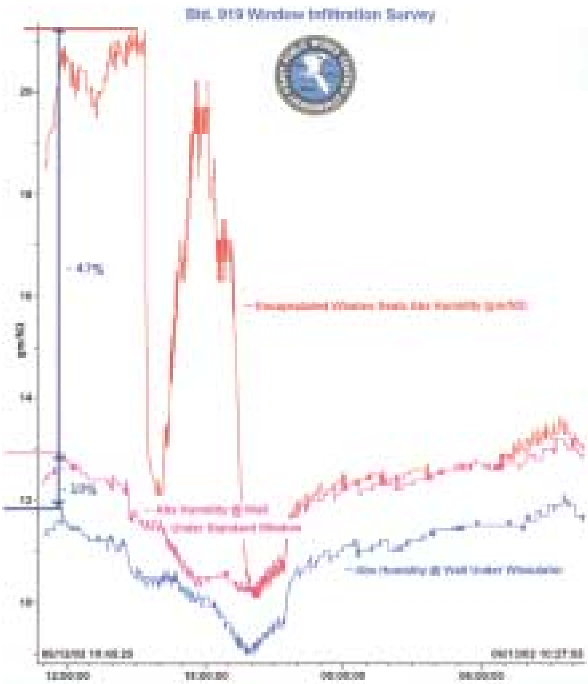
Regardless of the type system that you may have under consideration, a totally **Passive Daylighting System or a Hybrid Daylight Harvesting System**, it has been our experience that Daylighting Retrofits have a simple Return On Investment (ROI) that normally fall within a three to seven year period. When you consider some of the other benefits of both these products, such as;

1. Better then standard window and skylight thermal resistance and transmittance thus reducing a facilities existing fenestration loads..
2. Reducing existing fenestration noise levels to a higher STC of 35 to 40.
3. Reducing harmful UV by 98%.
4. Eliminating the need for costly hazardous materials abatement .
5. Reducing PDM cost (Painting, Maintenance & Decorating).
6. Reducing bulb and ballast inventory levels.
7. Increasing IAQ quality (mold and mildew normally will not grow in natural sunlight).
8. Reducing the size of emergency generation equipment and fuel consumption .

all of which have been other reasons some of our clients have chosen these retrofits and in some cases the only reasons. In case after case even when the retrofits ***were funded with Federal and State Grants, the End Users purchased and installed addition product using their own budget dollars when Grant dollars were no longer available***. In other cases Nationally recognizable clients (Banks, Hotels etc.) have actually changed their New Construction Specifications to include these products in their newly constructed buildings.

When we have chosen the **Interior Storm Window Retrofit,** we do not consider window orientation has a major factor. Our field test clearly indicate that **North and East** facing Windows allow more than an acceptable amount of natural light to enter a facility. Combining this with our data, that clearly shows that these types of **Interior Storm Window systems significantly reduced the thermal transfer, in both directions through the existing fenestration system,** as well as **reducing window frame and seal Air Leakage (AL) factors,** (see Figure 7 for Typ.) the overall **total load reductions** are more than acceptable as savings factors.

Figure 7



Therefore, the standard practice of addressing only South and West facing Windows, becomes a moot point. The addition of self dimming ballasts to the lighting fixtures closest to the window system also, in some cases, reduces the ROI. With the 324 facilities we have retrofitted with this particular technology the average installed cost has been less then $ 10.00 a square foot of glazing and frame surface encapsulated. Additionaly, in older facilities, when environmental problems –i.e. lead paint, asbestos based building materials etc., may add abatement cost, because this type of retrofit **Encapsulates the existing system**, the cost of abatement can be eliminated.

In choosing a **Tubular Skylight System** other factors should be taken into consideration. **We do not disregard multistory facilities** when suggesting this type of retrofit, this is due to the higher load factors that normally exist on the top floor of the structure closest to the roofing system. By incorporating the Tubular Skylight system and reducing the loads closest to the roof, even retrofits to multistory buildings can have an acceptable the ROI.

Obviously any single story facility is a perfect candidate for Tubular Skylight retrofits. Depending on the existing light source we have experienced return on investments between 2.6 and 7 years using this technology. Some of the other considerations that come into play concerning these types of through the roof technologies are the clients needs concerning;

1. Necessity to turn off lights during daytime hours.
2. Actual facility operating hours.
3. Foot candles required by law (OSHA etc.)
4. Obstacles blocking sun path (trees, highway overpasses, tall buildings etc.)
5. Conducting training classes to familiarize the facility occupants to the difference between constant level light sources, electric lighting, & variable level light sources (daylighting).

Fortunately their are attachments and accessories for Tubular Skylight systems that can overcome most of these scenarios. ***We personally prefer the totally Passive Tubular Skylight systems***, obviously these are less-expensive to install (from the electrical perspective) and have a shorter ROI .

Our office has been instrumental providing feasibility studies that resulted in a in installing both **Passive and Hybrid Tubular Skylighting Systems** in over 66 facilities consisting of private sector Manufacturing and Commercial facilities, private and public Schools, State and Federal government buildings and Military bases. The installations ranged in size form retrofitting a single 400 square foot room with a totally **Passive System** to retrofitting an entire 60,000 square foot botteling facility with a **Hybrid Daylight Harvesting System**.

The average installed costs, per square foot of inside lighting area retrofitted, of these Tubular Skylight projects has been as low as;

$ 0.68 for Totally Passive systems.

$ 2.44 for Hybrid Daylight Harvesting Systems that included fixture replacement / retrofitting to T-8 systems with electronic self dimming ballast.

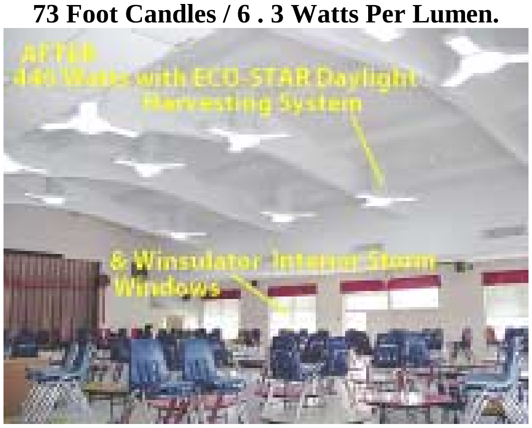
In some extremely rare cases, due to antiquated electrical systems that needed to be upgraded to modern day codes or odd configurations in roofing structures and materials these costs can vary. The highest single cost ever encountered by our office due to such factors has been $ 6.81 square foot. In some of our School Projects retrofitting to the **Passive Daylighting Systems** and leaving the existing fixtures in place was **$ 0.49 per square foot less expensive** then retrofitting the fixtures to standard T-8's and electronic ballast. We have experienced **no problems with roof leak complaints** concerning any of our installations some of which are approaching **their 10th year of service**.

CLOSING COMMENTS

We have had the opportunity to Field Test several different types of Tubular and other Skylighting Systems along with an array of Inside Window Treatments over the years, not all the systems we tested had the same performance curves. You must be particularly cautious in choosing systems ***that will not add THERMAL and INFILTRATION loads*** to the facilities existing HVAC system. As " a picture is worth 1,000 Words" the following **results** speak for themselves.

113 Watts Per Lumen Electric Load

73 Foot Candles / 6 . 3 Watts Per Lumen.



60 Foot Candles / "0" Watts Per Lumen

25 Watts Per Lumen Electric Light Load.

BEFORE 1 Non-Insulated Steam Lines, Steam Leaks and MH Lighting.

1.99 Watts Per Lumen Electric Light Load.

AFTER, Insulated Steam Lines, Steam Leaks Repaired and **Daylight Harvesting System at a cost of 1. 99 Watts Per Lumen.**

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