

OPTIMIZING A CLASSIC DAYLIGHTING DESIGN TO REALIZE ENERGY TARGETS OF THE TVA'S CHATTANOOGA OFFICE COMPLEX

Umesh Atre
Innovative Design Inc
850 W Morgan St
Raleigh, NC 27603
umesh@innovativedesign.net

Michael Nicklas
Innovative Design Inc
850 W Morgan St
Raleigh, NC 27603
nicklas@innovativedesign.net

David Zimmerman
Tennessee Valley Authority
1101 Market St
Chattanooga, TN 37402
drzimmerman@tva.gov

ABSTRACT

The Chattanooga Office Complex (COC), designed and built in the early 1980's, comprises of four office buildings and a data center, located in downtown Chattanooga, TN. The COC, at 1.3 million sf, is Tennessee Valley Authority's (TVA) largest office building. TVA, a federal agency and largest public power provider, is committed to customer-focused facility energy conservation and sustainable workforce practices. When originally built, the COC had many green features incorporated in its design, the most notable being daylighting. The original daylighting design was a combination of sun-lighting (tracking mirrors reflecting light to interior light scoops) and perimeter clerestories with light shelves. Though the perimeter design was adopted, the tracking systems in the atria were never installed, plus key daylighting controls put into place that could take advantage of available daylight were never fully functional. Even without the daylighting savings though, the COC can boast of having much lower building energy intensity when compared with its counterparts. Driven by its own commitment and the need to address federal energy and sustainable mandates, TVA has undertaken a recommissioning of its energy features, primarily daylighting design. As part of this undertaking, a currently ongoing analysis, initiated in April of 2010 focuses on buildings D and E - Lookout Place - representing approximately 37% of the total area of the COC (excluding the data center). Fig.1 shows exterior and interior views of the TVA Chattanooga Office Complex.



Fig. 1: North façade, south façade, interior view of atrium, and interior light scoops in atrium (clockwise, from top left)

The first phase of this analysis consisted of steps to:

- Determine the current daylighting contribution through new monitoring and past evaluations,
- Compare actual daylighting monitoring data to predicted daylighting computer simulations, and
- Develop an overall validated energy model using existing utility data.

Once the base daylighting and energy models were validated, the scope of the next set of tasks was to:

- Evaluate numerous daylighting options for north and south-facing perimeter offices, and spaces adjacent to

the central atrium on the north and south sides of the atrium,

- Evaluate existing products and systems that would allow the various daylighting strategies to be implemented and develop construction cost estimates for the various options,
- Simulate daylighting contribution with related energy uses to determine the best energy saving strategy, and
- Investigate the impact that the open floor workstation partitions have on the daylighting contribution.

1. DAYLIGHT MONITORING AND VALIDATION

With a goal to improve the daylighting in the buildings that make up the Chattanooga Office Complex (COC), a series of analyses were conducted. The first step was to validate the computer models using currently available monitoring data and/or data obtained from previous daylighting studies conducted on this building by other analysts.

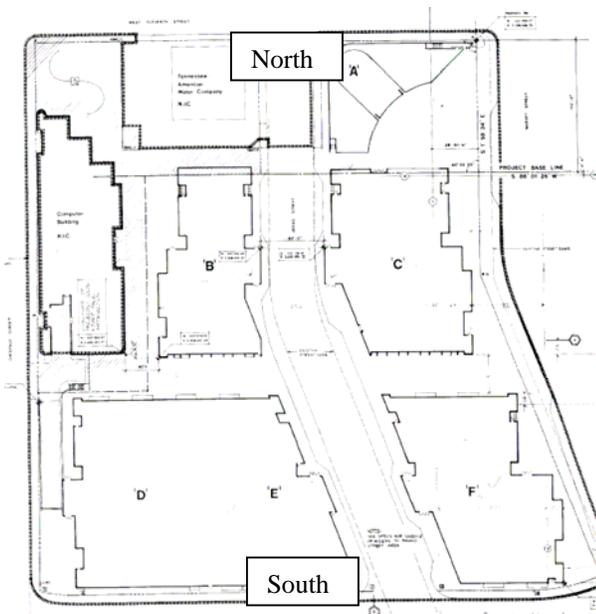


Fig. 2: Site Plan of the TVA COC showing buildings A,B,C,D,E,F, and the Computer/Data Center

Daylight monitoring equipment was set up at various points in and around the central atrium in Buildings D and E – Lookout Place – of the Chattanooga Office Complex. Fig. 2 shows a site plan of the TVA COC. Monitoring (15 min time-steps) was initialized in April 2010, and continued till August 2010. Sensors were primarily placed inside the light scoops, on the ceilings, and above interior office partitions in order to understand the source to occupant ratios of daylighting distribution. Spaces analyzed included typical 2nd floor – North of the atrium in Building D, 4th floor –

south of the atrium in Building E, and 6th floor – North of the atrium in Building D. Additional sensors were placed on the roof and below the roof to record outdoor illuminance and gauge the transmittance of the skylight glazing. Fig. 3 shows some of the installed monitoring equipment.



Fig. 3: Daylight monitoring at the COC

1.1 Daylighting Model

A 3-d daylighting model representing the Lookout Place building was created using 'Google SketchUp' (v6) and was simulated using the 'Daysim' daylighting analysis software. Fig. 4 shows some views of the 3-d daylighting model.

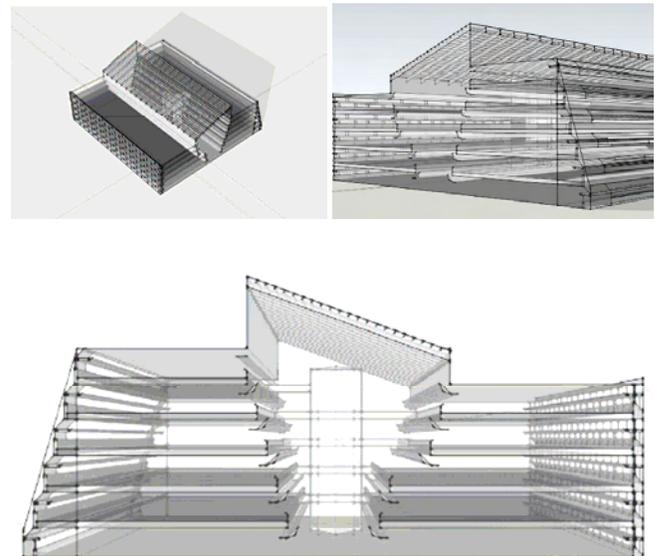


Fig. 4: Views of the daylighting model

The simulations were conducted at 15-min time-steps to correspond with the monitored data, and were later averaged out for hourly comparison. A set of 4 continuous

days was selected contingent upon a good match between the TMY3 dataset and the actual measurements.

1.2 Model Validation

Daylighting results and monitored data at all the sensor locations were numerically and graphically plotted for. The results indicated a good match between the two sets of data, and provided sufficient confidence in the modeling methodology and the daylighting software. Fig. 5 shows the comparison at 2 of the 20 sensor locations. The hours of the day are plotted along the X-axis, while the Y-axis is the illuminance in footcandles (fc).



Fig. 5: Illuminance comparison – simulated vs real

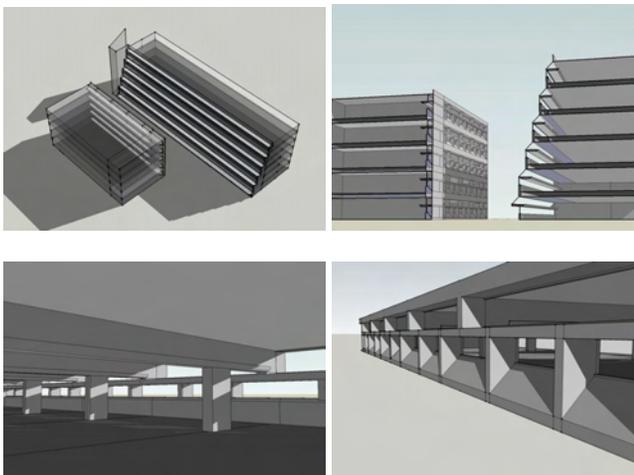


Fig. 6: Perimeter office spaces - models

Daylight monitoring equipment was not set up in the perimeter spaces, but data from previous analyses was used for comparison. The output values for horizontal illuminance from 'Daysim' computer simulations were compared with the measured values from the previously done report by another consulting firm. Fig. 6 shows views of the daylighting models created for the perimeter.

2. BUILDING ENERGY MODELING

The base case (here being the existing building) energy model validation was conducted simultaneously with the daylighting. The energy consumption of the Lookout Place was studied using the eQUEST (DOE-2.2) software. Utility bills obtained from TVA personnel were used to compare and validate the energy model. As was seen from the building area distributions at the COC, Lookout Place (Bldgs. D and E) equaled 429,115 sf, and this was used to estimate all related energy loads as a percent of the total COC area. In order to validate this approach, the occupants/sf for all the buildings was tallied against respective building areas, and it was determined that the percentage ratios were quite constant, and thus the approach valid. All other internal loads/sf (lighting, equipment etc.) are similar throughout the complex, including the same central HVAC system shared by all. Requests were made to the building design and management teams to procure all available architectural/mechanical/electrical/interior design drawings, including building energy/lighting/equipment management schedules. Due to the COC being designed prior to the digital age, drawings had to be converted into CAD format for use with the building energy model. Fig. 7 shows SW and NE views of the eQUEST model.

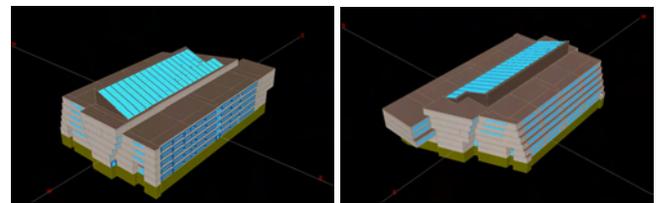


Fig. 7: Lookout Place – south-west and north-east views

2.1 Results

The whole building electricity use from the model showed a close match with the utility bill data at the monthly level. The maximum monthly variation was 10% in April, and annual average monthly variation was 5% when compared with 2009-2010 billed use. This difference could be attributed to a number of factors, the foremost being the unavailability of a model for the entire COC. A further analysis of the entire COC was recommended.

2.2 Weather-correction

Though the modeled building energy consumption follows a similar trend as the real data, a weather-correction was applied to understand the effect of difference in TMY and the actual weather for Chattanooga, TN. After weather-correction, the annual average variation reduced to 2.75%. This energy model would be used in further analyses.

3. DAYLIGHTING PROBLEM DEFINITION

3.1 Spaces Adjacent To The Atrium

The following problematic conditions were observed in the workspaces that are adjacent to the central atrium space:

- High levels of direct beam radiation from extensive glass skylights covering the large atrium spaces,
- Installation of blinds inside light scoops to block direct beam, in turn eliminating any potential daylighting,
- High contrast between the atrium and adjacent spaces,
- Excessive solar gain, insufficient light benefit,
- Originally installed light scoop acrylic sheets are worn out, yellowing, and ineffective in reflection, and
- Heavy reliance on artificial lighting.

3.2 Perimeter Office Spaces

The following problematic conditions were observed in the perimeter spaces (south and/or north):

- Direct beam radiation for the south spaces,
- Glare from the upper glazing section is in direct line of the workers, both on the south and on the north,
- Installation of blinds on both the south and the north to counter glare, eliminating daylighting benefits,
- North glazing, at limited times of the day/season reflects sunlight onto the south glazing of adjacent wing, and
- Heavy reliance on artificial lighting.

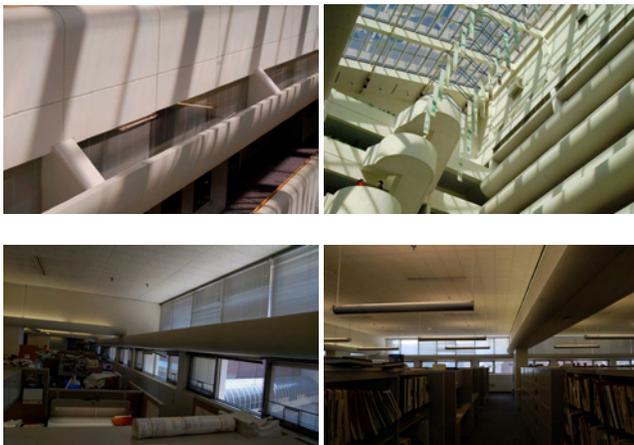


Fig. 8: Blinds inside scoops, high direct beam sunlight from atrium skylights, blinds on the south perimeter, and heavy reliance on artificial lighting (clockwise, from top left)

4. DAYLIGHTING SOLUTIONS

Lack of daylighting controls in the spaces as mentioned previously has hindered the building's energy performance and direct beam is a constant source of discomfort for the occupants.

4.1 South-facing Perimeter Office Spaces

The solutions evaluated (both visually and through computer simulation) for the south-facing perimeter spaces included replacing existing glazing with translucent panels, use of translucent or solid light shelves inside the spaces, installing blinds-between-the-glazing or exterior blinds/shades, and installing translucent vertical fabric baffles running the full length of the windows.

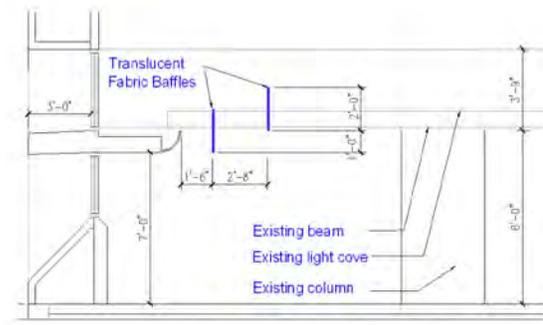


Fig. 9: Section showing the interior fabric baffles

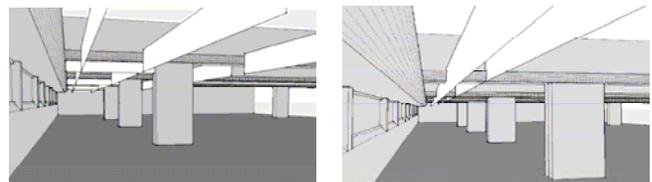


Fig. 10: Fabric baffles on the south – 2 options

In order to reduce glare and block the direct gain coming from the high glazing areas, the daylighting design team recommended installing two white, translucent, UV resistant, fire retardant baffles that would be positioned to block the direct gain (as well as block direct sight lines of glazing), filter the light entering the space and still allow light to reach the ceiling and bounce back further into the spaces. This solution would require very little maintenance and does not necessitate any additional glazing modifications to the existing windows. The daylight levels resulting from this retrofit were favorable in comparison to the other options listed above. From previous project experience, it was noted that this aesthetically pleasing solution could also improve the sound/acoustic quality in the spaces. The section in Fig. 9 shows the positioning of the fabric baffles. As seen in Fig. 10, the

baffles could also all be aligned at the same height from the floor level, in which case 3 baffles would be required.

4.2 North-facing Perimeter Office Spaces

Solutions similar to the south-facing offices were evaluated (both visually and through computer simulation) for the north-facing perimeter spaces, excluding the light shelves. Although direct beam radiation entering the north-facing glazing was not the concern, the same baffle solution was recommended as on the south because the baffles block the worker’s view of this glazing, currently the main cause for glare and contrast issues. Use of anti-reflective glazing or films was suggested to prevent hot-spots/glare resulting from reflected light, but was not analyzed in detail at this stage.

4.3 Spaces Adjacent To The Atrium

The spaces adjacent to the atrium were some of the most critical analysis areas. The following solutions were evaluated:

- Fixed and tracking exterior and interior louver products as well as new designs that could be incorporated into current product lines
- Varying amounts of reduced skylight area with varying transmissions as well as solid sections where PV (photovoltaics/solar) could be incorporated
- Fixed and tracking blinds-between-the-glazing products as well as new designs that could be incorporated into current product lines
- Translucent glazing systems with varying transmissions and insulation values
- Interior translucent fabric baffles
- Varying geometric configurations of reflectors located within the existing scoops at each floor, used to reflect light up to the ceiling and back into each floor
- Combinations of the above

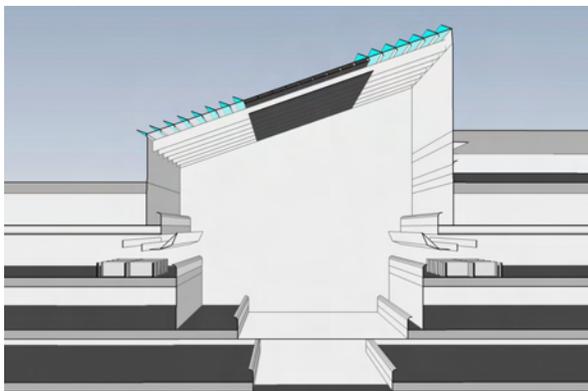


Fig. 11: Recommended solution for the atrium – enhanced option (base option would be without the fixed exterior sun louvers)

Considering maintenance and first cost objectives, the team focused their attention on non-tracking solutions that were relatively easy to install and maintain while allowing skylight area reduction by up to 40%. It should be noted that the existing skylight glazing that covers the whole sloped roof only admits around 18% visible light transmittance, thus providing the opportunity to reduce the glazing amount by up to 40% through use of better, high-performance glazing. Several tracking options were evaluated that could provide similar or even slightly better lighting results by reflecting sunlight directly down to the scoops but it was found that there are currently no products that could provide the exact characteristics that were needed to effectively block all direct beam from entering into adjacent areas at the same time adequate sunlight reached the original light scoops at every floor. Likewise similar problems were encountered when the COC was under construction resulting in the tracking system not being installed and a switch to low visible light transmittance glass to reduce the heat gain. The solution recommended could be viewed as one that has a base level of improvement as well as an enhanced performance level. Both utilize fixed, low-maintenance solutions that incorporate the implementation of more reflective scoops at each floor level as well as baffles, similar to those incorporated on the North and South sides of the building.

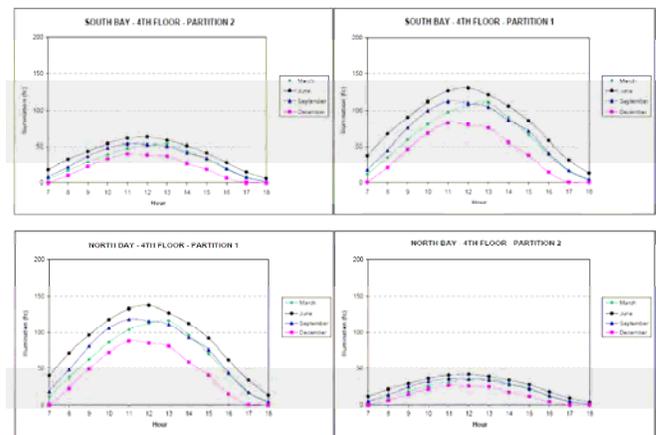


Fig. 12: Base Option – Average daily results for 4 representative months – March, June, September, December

The base recommendation utilizes a 3-inch thick translucent, double-glazed glass unit with 30% visible light transmission to reduce the negative impact of direct beam radiation reaching the work surfaces and computer screens. The glazing is additionally insulated with fiberfill insulation, enabling the assembly to achieve R-5 (or alternatively upto R-20 if using ‘Aerogel’) thermal properties. Adequate diffuse light is allowed to reach the scoops where it is then reflected back into the spaces on both sides of the atrium.

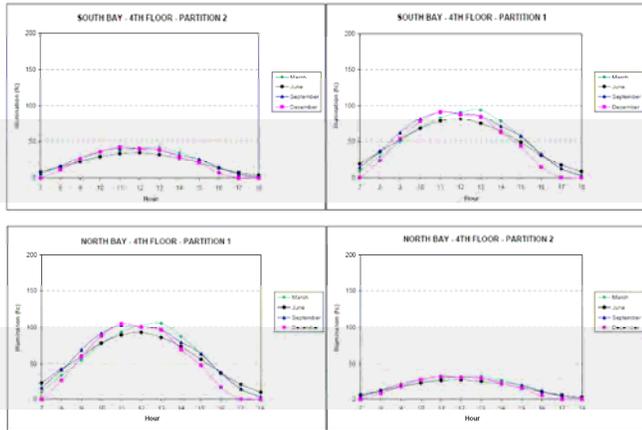


Fig. 13: Enhanced Option – Average daily results for 4 representative months – March, June, September, December

Fig. 11 shows a section through the daylighting model with the translucent glazing in the skylight, exterior louvers (enhanced option), and the vertical fabric baffles in spaces adjacent to the atrium. In the enhanced option the team recommended installing fixed, exterior louvers that are carefully positioned to maximize winter gain and establish more uniform solar gain conditions that will further decrease peak summer cooling. In this case the visible light transmission was increased to 40% to compensate for the exterior louver shading. This enhanced case, while costing more provides very uniform lighting conditions throughout the year and reduces peak cooling loads. Figs. 12 and 13 show the simulated average daily illuminance for the base and enhanced options at 4 sensors. The sensors are located at the top of 5'-0" office partitions, 2 on the south and 2 on the north, the first sensor being 11'-0" in from the atrium and the second at 20'-0" from the atrium on both sides. It was observed that the levels averaged around 75-100 fc at the first sensor and 35-50 fc at the second sensor respectively. The significant difference between the base and enhanced options was the drop in light level around mid-day during the summer cooling months (month of June if representative of summer season), which might indirectly represent a peak cooling load reduction.

4.4 Interior Light Scoops

It was proposed that the existing acrylic sheets, which have aged over the years, be replaced with new, reflective panels, either metal, or filmcoated. This proposed change, though effective in reflecting daylight farther into the spaces, might be an eyesore and a glare hotspot if within the occupants' direct line of vision. In order to prevent this discomfort situation, the recommended option was to use fabric baffles in front of the scoops. The baffles eliminate direct view of the scoops while themselves acting as daylight diffusers due to their semi translucent nature. The

baffles were modeled in all the daylighting simulations, and were accounted for in the cost benefit analyses.

All of the solutions for the atrium and the perimeter spaces, though studied for just one building -Lookout Place - at the moment, are applicable to all of the buildings within the TVA Chattanooga Office Complex, and would not only result in an energy reduction, but improve the quality of the workplace environment.

5. DAYLIGHTING BENEFITS AND ENERGY SAVINGS

The next phase of the building energy analysis focused on studying the effects of daylighting on the building energy consumption. Of particular interest was the effect on lighting and cooling end-use. Hourly daylighting schedules generated from the daylighting analyses were incorporated into the previously validated baseline building energy model. This revised model represents the effect of the following daylighting measures:

- Interior fabric baffles in the perimeter spaces,
 - Translucent glazing in the skylights with and without the exterior sun shading louvers,
 - High reflectance ceilings,
 - New reflective light scoops, and
 - Interior fabric baffles in the spaces adjacent to atrium
- All other simulation parameters were maintained similar to the basecase model.

A further analysis studied the effect of using new energy-efficient interior lighting systems replacing existing lighting. The ambient average lighting intensity was 1.0 w/sf, which follows in line with goals of past and recently ongoing retrofit testing undertaken by TVA building energy management personnel. The ambient light set point is 30-35 fc for both daylight and artificial light.

5.1 Results and Conclusions

Currently, while uncontrolled daylighting is flooding many parts of the building, it is not contributing to any energy savings. In fact, because of the glare issues (and, in turn, the installation of blinds) and lack of daylighting controls on the electrical lighting, the lights remain on and the radiation only adds to the cooling load. By the fact that the proposed daylighting strategies would control glare issues, provide a more uniform and diffuse lighting condition and be coupled with automated dimming strategies, it is reasonable to expect that, within the areas 20 feet from the sides and atrium, 59% to 61% of the time during daytime hours (7am to 6pm) the 35 footcandle ambient light objective would be achieved from natural lighting alone. By zone, the percentage of time when the ambient light level from controlled daylighting exceeds 35 footcandles was 67% in

the north perimeter spaces, 53% in the south perimeter spaces, and 60% (average) in the spaces adjacent to the atrium. These savings were based on monthly average daylighting contributions, calculated irrespective of interior lighting design, for a depth of 20'-0" in the perimeter offices and on either sides of the atrium. This represents approximately 110,000 square feet of space. However, it should be noted that diminishing levels of daylighting are reaching further back into the spaces beyond 20 feet and realizable contributions will occur when dimming light controls are finally implemented.

The salient energy cost analysis results from use of daylighting in the Base recommended design were:

- Reduction in whole building energy use: 12.2%
- Simple payback with/without energy inflation: 14/13
- Reduction in peak cooling load: 34 tons (not included in cost/payback savings at this time due to measures being applied in an existing application; potential for future savings)
- Reduction in whole building energy consumption from the use of daylighting with efficient lighting: ~22%

The salient energy cost analysis results from use of daylighting in the Enhanced recommended design were:

- Reduction in whole building energy use: 14.3%
- Simple payback with/without energy inflation: 18/16
- Reduction in peak cooling load: 88 tons (not included in cost/payback savings at this time due to measures being applied in an existing application; potential for future savings)
- Reduction in whole building energy consumption from the use of daylighting with efficient lighting: ~25%

Finally, it is expected that the quality of the occupants' work environment will be greatly enhanced by the introduction of measures that will:

- Reduce glare and contrast by eliminating direct beam radiation from reaching workstations, and
- Improve light quality, acoustics, and worker productivity.

6. FUTURE WORK

This is an ongoing project, and is currently in the detailed analysis and design implementation phase. This next set of analyses focuses on evaluating the effects of other building energy saving strategies related to mechanical and electrical system design, building envelope, and renewable energy (photovoltaics are being considered), besides refining and actual products identification on the daylighting.