The SCIENCE of Automated Shading

CONTEMPORARY SHADING SYSTEMS

ROLLER SHADES + LOUVER SYSTEMS

WINDOW MANAGEMENT

DAYLIGHT HARVESTING

Joel Berman

The SCIENCE of Automated Shading

CONTEMPORARY SHADING SYSTEMS

ROLLER SHADES + LOUVER SYSTEMS

WINDOW MANAGEMENT

DAYLIGHT HARVESTING

Joel Berman

C O N T E N T S

The SCIENCE of Automated Shading

CONTEMPORARY SHADING SYSTEMS

ROLLER SHADES + LOUVER SYSTEMS

WINDOW MANAGEMENT

DAYLIGHT HARVESTING

1 EXECUTIVE SUMMARY

This white paper is an effort to explain the science behind automated shading systems such as roller blinds and louvers, and the different approaches to using solar geometry and performance metrics for the appropriate positioning of shading devices. The paper offers a fuller understanding of what kinds of systems are available to control—roller shades, external fins, overhangs and louvered blinds—and the criteria necessary for a successful automated window shading program.

As a reference document, this paper will provide professionals and end-users with a technical description of how these systems function and what options are available with them. As such, some information in the sections that follow is repeated to make each section self-explanatory. Not every project needs the most expensive or technically complicated system, so the aim of this paper is to provide a functional outline of the various systems that are available.

This white paper is intended to be an evenhanded overview of the automated window-covering systems available in the industry. This paper refers to the requirements and standards of ASHRAE 90.1 to define the performance goals of each shading system, including the commissioning and verification of the system to meet performance goals, specifications and LEED-credit opportunities. Aside from MechoShade's SolarTrac, this document cannot go into detail about the performance of all manufactures of automated shading systems because the manufacturers do not publish the science behind their systems. It can only reference the technical details of the products that have been published and make logical assumptions for their other aspects.

This paper will answer high-level questions such as (a) the difference in approach between simply measuring daylight and solar evaluation, (b) articulate the differences between various automated shading systems, (c) discuss why specifications for product performance are needed to ensure proper commissioning and (d) explain how continuous monitoring of the sky condition—sunrise to sunset, 365 days a year—is better than simply determining solar angles using a less-precise lookup table. No lookup table offers the solar angles for every minute of every hour of every day, on a minute-by-minute schedule, for 365 days a year.

2 INTRODUCTION

2.1 Background: The Case for Automated Shading Systems

The evolution of automation in buildings today started with the introduction of building management systems (BMS) or building automation systems (BAS) to operate buildings efficiently by optimizing the interactions between the various systems in the building in order to reduce the use of electrical energy and minimize peak-power consumption spikes (Grondzik et al., 2010). Such spikes force utilities to increase capacity, which in turn increases fossil fuel consumption, greenhouse gasses and all that comes with an increased use of carbon-based fuels. Furthermore, cities and government want to be able to expand their business base and infrastructure without building more power plants. The primary way to grow business and infrastructure without building new plants is through energy conservation (Blakeslee, 2009).

There have been great strides in the use of lower-cost and more-efficient heating, ventilation and air conditioning (HVAC) systems, BMS energy control systems and controlled-dimming lighting systems, but little growth in automated window and skylight shading systems as a prerequisite to more effective controlled-dimming lighting systems. So it needs to be understood that the occupants of buildings are far more reactive and sensitive to the glare, heat and brightness of sunlight coming through today's high-visible-light-transmitting windows than they are to normal changes in interior temperature, lighting or humidity.

It is known that humans react "instantly" to direct sunlight though glass, whereas their responses to other changes in the room are not as immediate. This reaction, hereafter defined as a "human factor," shows that occupants can tolerate changes in interior temperature and brightness, but react swiftly to direct solar radiation through glass (Chan, 2008). Hence, direct solar radiation requires an immediate response by the solar shading system. An automated shading control program can be deployed to consider the sky condition and evaluate and respond to the solar environment within a moment, typically one minute or less. Furthermore, if automated lighting and automated shading are included in an energy-conservation program, the net effect is that both systems perform to a higher degree of efficiency, as both are synergistic, reactive systems in their individual environments. MechoShade's automated Window Management® reacts to the intensity and position of the solar ray on the glazing under consideration. Electric lighting control systems react to the level of ambient interior illumination. Automated shading can thus be used to enhance daylighting, or the use of natural light for effective internal lighting. Shades can enhance the ambient illumination, which allows for lower automated electric lighting levels. These systems work together well by responding naturally to their specific environments.

2.2 Energy Savings with Automated Lighting and Shading Systems: The New York Times Building

Stand-alone automated lighting and window shade systems can be used well in combination. An excellent example is the operating systems at the New York Times Building in midtown Manhattan, for which MechoShade provided the window management system and Lutron provided the lighting control system. A post-occupancy study by the Lawrence Berkeley National Laboratory documented the substantial energy efficiency of the two systems used together (Lee et al., 2013). Automated shading enabled reductions in energy use for both lighting and cooling, as well as reductions in peak energy demand. Annual energy savings for electricity use due to the combination of all three systems was estimated to be 24% compared to a code-compliant building. Annual heating energy use was reduced by 51%, and peak demand was reduced by 25%. The New York Times Company's investment in advanced energy-efficiency technologies was estimated to yield a 12% rate of return on its initial investment. (The Lawrence Berkeley National Laboratory report is available at http://windows.lbl.gov/comm_perf/newyorktimes.htm.)

Yet the inclusion of automated shading systems with roller screens and louvers is in its infancy for major projects. As a result, many consulting professionals do not have much history and experience in evaluating the performance of automated shading systems. MechoSystems' review of automated shading specifications and its discussions with professional consultants buttress this conclusion. There is a dearth of knowledge about, and a lack of experience with, the performance and evaluation of automated shading systems. This may because most providers of automated shading systems do not offer performance and commissioning specifications. MechoSystems' SolarTrac is an exception, as is documented herein.

One glaring omission that exists in many of the published specifications is a description of how the system will function to meet the "human factors" required by the occupants of these buildings. Too often the focus is on the hardware and mechanics, and not on the performance required to assure the comfort of occupants working near glazing. We have provided herein some of the metrics needed to verify that the installed system meets a recognized specified standard (commissioning). It also our intent to provide a guide for system integrators and commissioning engineers to ensure that the installed shading system is commissioned properly, and that its performance meets the letter of and intent of the specifications and offers its intended benefits. In the final analysis, the purpose of automated Window Management® is to assure the comfort of the occupants of a building while functioning as an energy-efficient daylighting subsystem. These are conflicting requirements—allowing more daylight inside while avoiding excessive brightness and direct radiation on the occupants—that need to be understood, incorporated into and resolved by an automated shading system.

2.3 Energy Savings with Daylighting and Automated Shading: A 2014 Study by TRC Energy Services and PG&E

In 2014, TRC Energy Services and Pacific Gas & Electric Company conducted a study comparing automated shades to manually operated shades for daylighting (Saxena, 2014). The study found that the energy savings of using automated shades was 37% higher compared to manually operated shades. In other words, the performance of a daylighting system can be improved by 37% when automated shades replace manually operated shades (Saxena, et al.). Note that SolarTrac was the operating system used for the test site. In our opinion, not all automated systems will have the same performance criteria.

Below is a figure from the study by TRC and PG&E:

TABLE 1: Table of Energy Savings and Continuous Daylight Autonomy

Continuous Daylight Autonomy cDA* (300 lux at workplane)	cDA CONTROL	cDA STUDY	% LIGHTING ENERGY SAVINGS
	Manual Shades	Automated Shades	
3 meters from Window (PDZ)	72%	88%	55%
6 meters from Window (SDZ)	43%	59%	29%
Ltg Savings (PDZ+SDZ)			37%

*cDA Calculated using weekdays between 8 am - 6 pm, and 300 lux on workplane.

This study clearly validates the ability of a properly designed automated shading system to enhance daylighting better than manually operated shades, while also assuring that no direct solar radiation—brightness and glare—impacted the occupants. The automated system was set to auto mode, which was the criteria of the test. It should be noted that the interior lighting for this test was left on continuously, and the effect of reduced HVAC was not a part of the study. This study only looked at the comparative effectiveness of manual and automated roller shade systems for daylighting. The savings resulting from the HVAC will be in addition to what is documented here. The report is available at mechosystems.com/TRC-Energy-Services-Pacific-Gas-Daylighting-Report/.

2.4 21st-Century Building Design

New, high-level technology now allows for the design and construction of high-rise building designs in shapes that previously were not conceivable. With the advent of computer-aided design (CAD) and 3-D modeling, buildings are taller than ever and may be twisted, tilted, rounded, tapered, faceted or curved. Frank Gehry's design for the Lou Ruvo Center for Brain Health in Las Vegas is but one example. The glass in such buildings may be curved and is usually glazed with low-thermal-emissivity (low-E) coatings that allow for the high transmission of visible light, which maximizes daylighting with relatively little heat gain. Such designs in turn require unique, creative shading systems.

In these new buildings, the windows may be vertical, sloped, tilted, or twisted. Shades and blinds may have to traverse windows that are sloped as much as 20 degrees from the vertical. Windows may be sloped in or out from the top (not vertical); tilted, with one side higher than the other; or twisted, in which the head and the sill of the same window are on different planes up to 20 degrees out of plumb alignment. Shades are then required that can traverse these special windows flawlessly. Some windows and facades have all of these characteristics; they require sloped, tilted and twisted shades that defy description and all traditional shading solutions.

Many of these new buildings also have large atriums with skylights. Building codes in Europe require natural light for the occupants, which is accomplished by putting an atrium in the middle or core of the building to provide natural daylight for staff who are at a distance from the window wall. These skylights may be treated as a single large unit, or may be segmented into defined skylight groups—"apertures" of glazing—for programmed shades that control solar penetration into the atrium. Each shade panel works like a camera shutter in response to the penetration of the solar ray, allowing some glazing panels to be open and some to be closed. All shading system movements are based on the defined level of direct solar radiation allowed to fall on the walls and floors of the space under the atrium. Such a shading system is able to provide solar protection while maximizing daylighting and maintaining a view of the sky.

2.5 20th- and 21st-Century Window Glazing Design

In the 1950's and 60's, the window glazing of choice was gray or bronze heat-absorbing glass. It had a shading coefficient, or SC—the measure of the heat passing through compared to clear, $^1/_8$- inch-thick glass—of around 0.5 (or 50%) and visible light transmittance, or Vlt—the amount of visible light passing through the glass—of 0.5 (or 50%). The ratio of heat-to-light transmission was 1 to 1. After the oil embargo of 1976, the glazing of choice went to glass with a much lower SC and Vlt; one example is PPG Industries' SolarBan glass with low-E reflective glazing, which has a shading coefficient of 0.20 to 0.25 and Vlt of 0.20 to 0.35. It was quickly discovered that this glazing was not energy-efficient because of the lack of daylighting. In the early 1990's, the trend went to low-iron glazing with a low-E coating, which gives an SC of 0.4 and Vlt of 0.7; the ratio of heat to light is 1 to 1.75. This glazing trend allows more light with much less heat to pass through the glass, thereby optimizing both light and heat levels.

The net effect of this change to glazing with high visible light transmission and low heat flow has allowed for a substantial reduction in the sizing of HVAC systems, which in turn makes the need for shading even more important for occupant comfort and productivity, as higher air-conditioning capacities are not available to keep the occupants close to the windows comfortable.

About 49% of solar radiation is in the infrared (heat) portion of the solar spectrum, which accounts for the heat incident on the glazing (see Figure 3). The remaining 49% of solar radiation is in the form of visible light, or daylight. Thus, the new selective glazing allows only 40% of the heat and 70% of the daylight through the glass. Because this new glazing transmits a higher percentage of visible light and solar radiation through the glass, the substantially higher levels of brightness and glare immediately affect the occupants of the building, and an effective shading system is required.

One could argue that the optimal shading control system would be able to evaluate the infrared (heat) and daylight portions of the solar spectrum, the macroclimatic sky condition and the geometry of the solar ray with reference to the building—and adjust the shade systems accordingly to optimize the benefits of daylighting without introducing too much heat or a discomforting glare.

2.6 Automated Shading with BMS and BAS Systems

Automated shade control systems with total solar evaluation are specifically designed and programmed to respect the human factors required for occupant comfort, energy efficiency and staff productivity. They are, or should be, specifically engineered to provide protection from direct solar radiation and excessive glare, and to reduce brightness values that exceed prescribed standards. The systems need to respond promptly to changes in solar conditions, with defined timing to prevent excessive shade movement. MechoShade has registered SolarEvaluation® as the name of its active algorithm component.

Current building management systems communicate with stand-alone sky evaluation/shade control systems only under emergency conditions or special environmental requirements (e.g., brownouts or overheating). No BMS or BAS can duplicate or match the day-to-day operation of a stand-alone shade control system, as controlled shading is not the purpose of the BMS (Grondzik, 2010).

2.7 Communication and Interaction Between Systems

The challenge for the engineer or the purchaser of window management and lighting management operating systems is to select the best products for each function. It is our experience and understanding that, despite claims to the contrary, "integration" of two or more operating systems does not exist.

According to Wikipedia, "in engineering, system integration is defined as the process of bringing together the component subsystems into one system and ensuring that the subsystems function together as a system." Window shading and lighting systems may indeed communicate or interact with each other, but they are not integrated. If they were truly integrated, then the combined system would operate with greater effectiveness than the two individual operating programs. However, this is not presently the case. The two systems (window management and lighting management) are currently designed as individual, stand-alone operating programs reacting to their specific enviornments, i.e. exterior and interior.

This is an important point, as some system manufacturers claim that their systems are only offered as an all-in-one "integrated" solution, which leaves the specifier no choice but to select a combination of a window management and a lighting management system. This precludes the specifier/purchaser from having the opportunity to select best-of-breed products for a facility. The operating facts are that the systems are individually reactive to their environments and may communicate with each other, but each has an independent operating program. This fact allows the specifier/purchaser to select different systems from different manufacturers to get the best product for the function intended, or to find the most cost-effective system for the project.

3 HUMAN FACTORS

Occupants near glazing who are subjected to direct solar or sky radiation will immediately sense the heat and glare regardless of the surrounding air temperature. Yet thermostats are always placed at the rear of a room, away from the windows and hence out of the solar radiation zone. Thus, their default settings are never met, and they cannot properly adjust the HVAC system.

The human response to the reflected glare and heat from the solar ray, or the shortwave radiation from sunshine, is immediate.

- Sensible heat gain from solar radiation is immediate.
- Glare: a shard of intense reflected light that debilitates immediately.

The human response to changes in ambient interior lighting and temperature is relatively slow compared to the instantaneous reaction to the heat and glare coming through glazing.

- People are generally comfortable over time with changes in temperature between 70°F and 75°F in rooms with the same radiant surface temperature.
- People are generally comfortable over time with lighting levels between 35 to 55 foot-candles (fc) with the same contrast ratio.
- Hence, the ideal shading system would be responsive in real-time every minute of every day, for 365 days a year, from sunrise to sunset.

* The ASHRAE 55 standard defines the thermal environmental conditions for human occupancy (ANSI/ASHRAE 55-2004).

3.1 Human Factors: Definition

The International Ergonomics Association defines human factors as a synonym for ergonomics.

> *"Human factors and ergonomics (HF&E) is a multidisciplinary field incorporating contributions from psychology, engineering, biomechanics, mechanobiology, industrial design, physiology and anthropometry. In essence, it is the study of designing equipment and devices that fit the human body and human cognitive abilities. The two terms,* human factors *and* ergonomics*, are essentially synonymous. Human factors and ergonomics are concerned with the 'fit' between the user, the equipment and the environment. It takes account of the user's capabilities and limitations in seeking to ensure that tasks, functions, information and the environment suit each user."*

3.2 Solar Radiation and Human Factors

The solar ray: Sunshine is shortwave radiation and is comprised of 49% visible light, 49% infrared radiation (heat) and 2% ultraviolet light (UV). Note that only 49% of the solar radiation falling on Earth is in the form of visible light.

Window glazing is transparent to shortwave radiation from the Sun. The amount of heat and light that is transmitted through the glass depends on the glazing's solar coefficient (known in Europe as its G value), and its solar optical properties—the percentages of visible light and infrared radiation that the glazing transmits, absorbs or reflects. In contemporary buildings, the shading coefficient of the glazing is likely to be 0.40 to 0.45, and the visible light transmission 0.65 to 0.70. This means that 40% of the radiant heat and 70% of the visible light is transmitted through the windows.

- 40% of radiant energy (heat) will be transmitted through this glazing
- 70% of the visible light will be transmitted through this glazing.
- The ratio of heat to light transmitted is 1 to 1.75, or 40/70.

This means that effective window management is required on an as-needed basis to control for brightness and heat and to protect occupants from direct solar radiation.

Longwave radiation: The heat coming from radiant-heated floors or ceilings is longwave radiation. When shortwave radiation impacts any surface, it is absorbed and/or reflected to a greater or lesser extent, depending on the surface's color (black absorbs, white reflects) and type of material. Materials absorb the shortwave radiation and then re-radiate it as sensible longwave heat to a greater or lesser extent. The absorption factor and emissivity (E) of the materials will determine the amount of radiation absorbed and at what temperature the material will re-radiate the longwave heat.

Glass is opaque to interior longwave radiation, trapping the heat inside the space and increasing the internal heat load. Low-E glass reduces the conductive heat loss, which adds to internal heat loads in summer but preserves heat effectively during a cold winter. This buildup of internal heat is managed by contemporary HVAC systems by utilizing the heat in winter and releasing it out of the building in summer.

When shortwave radiation impacts the building's occupants, they will immediately sense the heat gain and feel uncomfortable. This is instantaneous heat gain, and it has to be considered in the design of shading solutions. In my opinion, automated shading, which responds to environmental changes in real-time, is the only means for managing sky conditions and the solar ray on the window wall while maximizing personal comfort, daylighting and energy efficiency. Such shading systems also take into consideration the human factors required to meet those goals.

3.3 Human Factors in Automated Shading Design

A critical consideration in the design, programming and implementation of an automated window management system is to assure occupant comfort and enable energy conservation, concurrently. These are conflicting requirements that need to be understood and addressed. Today's high-efficiency glazing, with a shading coefficient in the range of 0.40 to 0.45 and visible light transmission in the 65%-70% range, gives a ratio of heat to light of 1 to 1.75. Historically, the ratio of heat to light transmitted was in the range of 1 to 1. Clear glass has a heat-to-light transmission ratio of 1 to 1. The current ratio of 1 to 1.75 reduces heat gain while offering a high percentage of visible light for daylighting. The new glazing provides a substantially increased opportunity for daylighting with reduced heat gain, but at the same time exposes occupants to much more intense window brightness, glare and solar radiation.

For comparison purposes, the heat-to-light ratio of fluorescent lighting is negative, at 1 to 0.667, compared to 1 to 1.75 for daylight. The contemplated automated shade system must recognize the conflicting human preferences for daylighting and views to the outside with protection from direct solar radiation. It is generally understood that individuals who are subjected to direct solar radiation, glare and excessive brightness in their work environment will be uncomfortable and less able to perform effectively. The issue is which automatic window system will best meet the specific requirements for any given project.

The window system must maximize daylighting and be responsive to the need for protection from direct radiation. The advantages of an effective automated shading system include daylighting for energy conservation; managed protection from direct solar radiation; and control of glare and brightness, adjusted for contrast ratios, all in real-time. (Real-time here is defined as a response within 60 seconds of an event.) The contemplated window system has to meet these defined requirements and capabilities, and demonstrate its ability to meet these standards. The system must also include the means for its performance to be verified and commissioned in order to assure occupant comfort as well as architectural uniformity.

Contrast ratio: The brightness of the work surface compared to the brightness of the window wall. (IES (Illumination Engineering Society) recommends that the contrast ratio be 1 to 7.)

Window management has to happen in real-time to meet the conflicting requirements of maximizing daylighting and energy efficiency while providing personal comfort. A properly designed automated shading system, with defined performance standards, is the only means for meeting these complex, competing requirements.

4 SKY EVALUATION AND CLOUD TRACKING

A successful automated Window Management® system requires a detailed view and analysis of the current sky, and the position of the Sun and clouds, on a minute-by-minute basis. The most successful systems have the ability to “predict” in real-time the position of the Sun, to track the clouds in the sky from sunrise to sunset, and to track the position of solar ray on all of a building’s facades. The system should also, to some extent, have the ability to anticipate the changing sky condition over time around the building under consideration, for which purpose the system needs complete information about the current sky condition.

It should be noted that precise sky monitoring should not result in excessive changes in shade and louver positioning. Hysteresis and user-defined threshold timers should prevent over-reactive and distracting window shade movement while at the same time tracking the ever-changing sky condition, Sun position and cloud cover, and the ever-changing position and intensity of the solar ray in real-time.

New control and monitoring systems in development will increase the accuracy and predictive capability of sky conditions, and allow them to anticipate changes in the sky brightness. If sky changes can be anticipated with reasonable certainty within 10 to 20 minutes now, and soon up to 90 minutes, then the building’s subsystems can become proactive rather than reactive.

4.1 SolarEvaluation®: The Most Precise Method for Automated Shading

In the late 1980’s and early 1990’s, it became apparent that a more complete understanding was needed of the environmental conditions surrounding a building and their impact on occupants and the space inside. An automated shading system would have to respond to and meet the substantial human-factor requirements of the people inside a building while responding promptly to real-time changes in the environment.

The requirements for a better automated shading system would include:

a. knowing where the solar ray is on the building every minute of the solar day, using the standard solar geometry algorithm published by ASHRAE (ASHRAE, 1993).

b. knowing the incidence and altitude angles of the solar ray to be able to compute the heat load on the building’s glazing at all times.

c. knowing the profile angle of the solar ray to be able to determine solar penetration.

d. knowing the difference between the ASHRAE Clear Sky Radiation Curve by latitude and the building’s measured sky radiation from sunrise to sunset, in order to predict sky conditions for the day and adjust the shading systems accordingly.

e. accurately determining the regional sky/cloud condition when intermittent clear sky/cloudy/clear sky conditions exist.

f. using visible light sensor data to develop interior contrast ratio values to prevent excessive levels of brightness (optional).

This new method of environmental monitoring was developed by MechoShade in the early 1990’s. The system utilizes radiometers to measure the total solar spectrum of UV, visible light and infrared radiation, and then uses the ASHRAE Clear Sky Algorithm to compute the intensity of clear-sky radiation. With this data, a determination of the real-sky condition can be made using measured radiation values. ASHRAE formulas are used to compute the solar energy entering the building on a zone-by-zone basis, by compass and zone orientation. Incorporating this science into an automated Window Management® control system was now possible.

4.2 MechoShade's SolarEvaluation System

MechoShade's SolarEvaluation system is a software-based algorithmic program that utilizes ASHRAE Clear Sky Radiation formulas to compute the solar radiation values and the solar angle on all the facades and surfaces of the building under consideration in real time, 24/7/365.

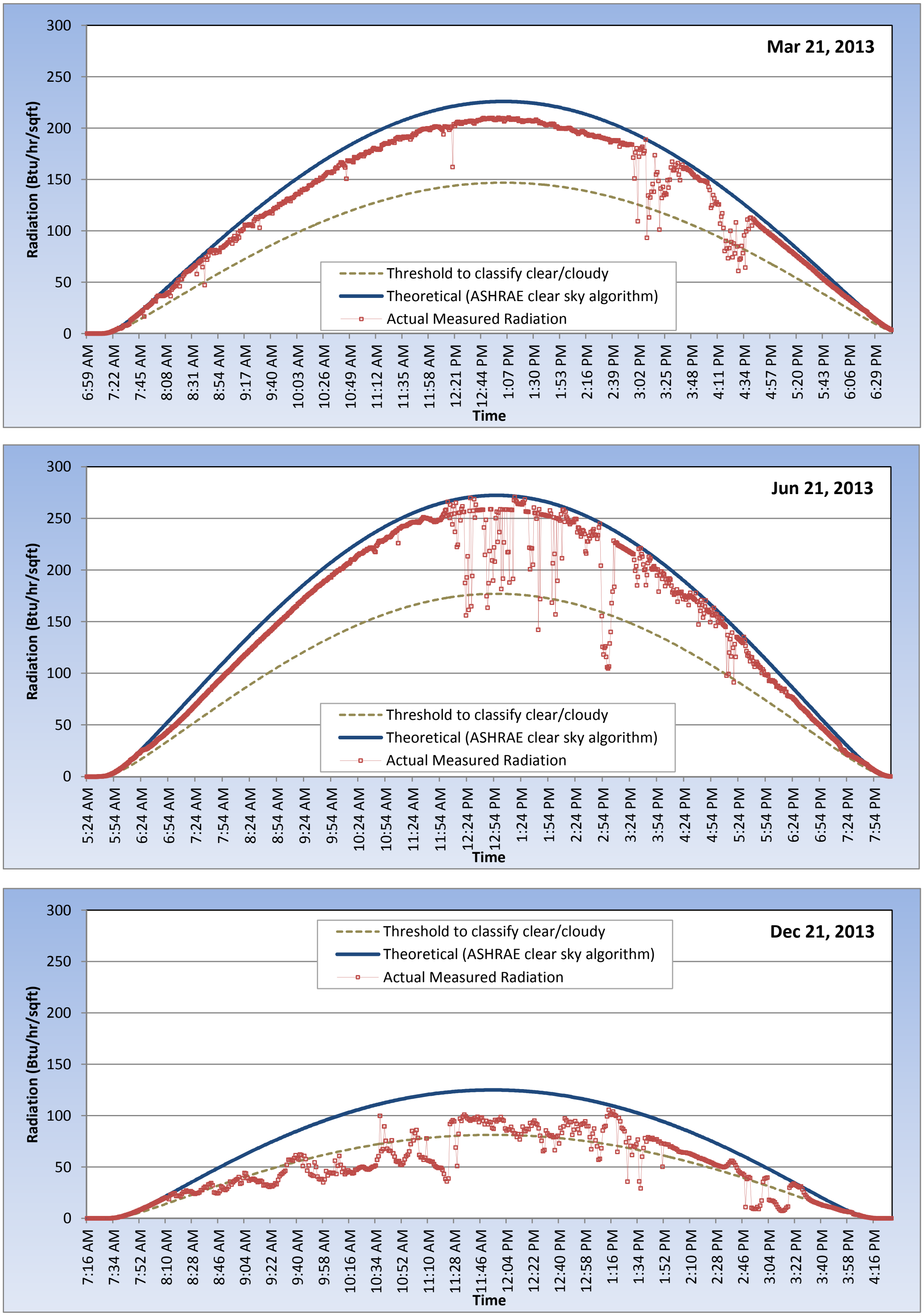
- The program uses the ASHRAE Clear Sky algorithm to compute the total solar radiation on a building, including the UV, visible light and infrared portions of the solar spectrum (98% of the solar spectrum) and the amount of radiant energy on the outside and inside of the glazing, for all surfaces and facades.
- The data used by the algorithms in the SolarEvaluation system then determines the positioning of the shading devices.
    - The SolarEvaluation system uses radiometers to measure 98%-100% of the solar radiation on the building. It then compares the theoretical radiation curve to the measured radiation values, and plots one over the other. (See Figure 1: ASHRAE Clear Sky Radiation Curves).
    - The measured data provided is developed into a sky model. This sky model is the basis for MechoShade's SolarTrac Sky Array program, which determines if the sky condition is clear or cloudy.
    - The SolarEvaluation system computes the impact of direct solar sky radiation and cloud conditions on all the facades of the building.
    - The system develops the shade positioning of the roller shades and/or louvered blinds based on one or more factors, including but not limited to: the angle of the solar ray on a surface, the heat gain in BTU/hr/ft^2 or W/m^2, the direction of the solar ray, and the incidence angle or profile angle of the solar ray.
    - The SolarEvaluation system computes the position and intensity of the solar ray in conjunction with the geometry of the windows, surfaces and skylights under consideration to determine if the shade is to be moved and where it should move to.

4.2.1 THE ASHRAE CLEAR SKY ALGORITHIM

The ASHRAE Clear Sky Algorithm is a calculation of the total solar radiation impacting the Earth under clear sky conditions (Powell, 1982). These calculations were developed and published by a group of engineers with the American Society of Heating, Refrigeration, and Air Conditioning Engineers, or ASHRAE. This standard is used by all MEP engineers for calculating heat gain and creating HVAC systems in North America. Similar algorithms were developed for other regions of the world.

4.2.2 THE ASHRAE CLEAR SKY RADIATION CURVES

FIGURE 1: ASHRAE Clear Sky Radiation Curves Compared to Actual Solar Radiation Value



Courtesy MechoSystems.

4.2.3 THE SOLARTRAC® ® MODELING PROGRAM: A SAMPLE ANALYSIS

The SolarTrac Modeling Program is an analysis tool that calculates the solar heat gain and illuminance for all the glazing on all the sides of a building, and records all shade deployments. Sample pages from a SolarTrac Modeling Program report are provided below. To see the complete report, go to: http://mechosystems.com/SolarTrac-Modeling-Program/.

SolarTrac™ Modeling Program

For Fenestration Calculating Solar Heat Gain and Illuminance

Analysis Tool Provided By: MechoSystems, Inc.

ANALYSIS SUMMARY:

Top-down: Sun Penetration

Analysis For :

Client :	40 Deg Lat
Analyzed by :	Joel and Muthu

Project :

Name :	White Paper Project
Location :	40 Degree N Latitude
Latitude :	40.0
% Average clear sky sunshine	0.90
Shade deployment direction	Top-down

Shade Position by Solar Heat Gain

Move shade by Solar Heat Gain	No
Allow SHG inside glass for Pos 0	n/a
Allow SHG inside glass for Pos 1	n/a
Allow SHG inside glass for Pos 2	n/a
Allow SHG inside glass for Pos 3	n/a
Allow SHG inside glass for Pos 4	n/a

Shade Position by Sun Penetration

Move shade position by Sun penetration	Yes
Apply SHG Go/No go decision	No
Allow SHG ins glass(Btu/Hr/Ft2)	n/a

Shade Position Override by Light Level

Move shade position by light level	No
Fixed shade pos for lgt lvl override	Variable
Prog lgt lvl inside gla: (FC)	n/a
Allow lgt lvl inside glass for Pos 0	n/a
Allow lgt lvl inside glass for Pos 1	n/a
Allow lgt lvl inside glass for Pos 2	n/a
Allow lgt lvl inside glass for Pos 3	n/a
Allow lgt lvl inside glass for Pos 4	n/a

Zone Info :

Zone #	Surface Name	Azimuth	Tilt	Glazing SC	Shade SC	Glazing VT	Shade VT
1	East Facing 40 Deg Lat	-90 E	90	0.35	0.25	0.60	0.05
2	South Facing 40 Deg Lat	0 S	90	0.35	0.25	0.60	0.05
3	West Facing 40 Deg Lat	90 W	90	0.35	0.25	0.60	0.05
4	North Facing 40 Deg Lat	180 N	90	0.35	0.25	0.60	0.05

Note: *The illuminance values were produced by converting the Btu values to Foot Candles. The conversion factor for the solar were developed by curve-fitting output data from numerous DOE-2 building simulation runs.*

Disclaimer: *Similar to SolarTrac operating system; use as a representative model for shade position, Btu levels on the glass; profile angle and position of the shades on the glass from sunrise to sunset 5 days a week for 52 weeks a year.*
*Shade position denoted by * light level override (if selected) moves the shades to a calculated position, when it exceeds the threshold*

Courtesy MechoSystems.

Yearly Shade Position | **Top-down: Sun Penetration**

Zone Information   East Facing 40 Deg Lat

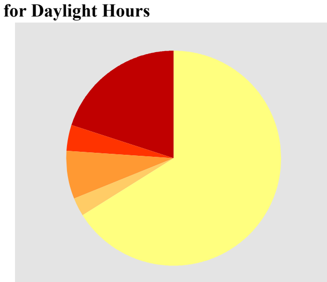
Zone Number	1	Latitude	40.0
Day of the Year	21st of each month	Top of Window (Ft)	8.0
Surface Azimuth (Deg)	-90.0 E	Bottom of Window (Ft)	2.0
Surface Tilt (Deg)	90.0	Overhang (Ft)	3.0
Shading Coeff. (w/o shade)	0.35	Ceiling Height (Ft)	10.0
Shading Coeff. (w/ shade)	0.25	Allow sun penetration (Ft)	6.0

t Solar Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5					4	4	4					
6				4	4	4	4	4				
7		4	4	4	4	3	4	4	4	4		
8	4	4	4	3	2	2	2	3	4	4	4	4
9	4	3	2	2	1	0	1	1	2	3	4	4
10	2	1	0	0	0	0	0	0	0	1	2	2
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17		0	0	0	0	0	0	0	0	0		
18				0	0	0	0	0				
19					0	0	0					

Shade position denoted by * light level override (if selected) moves the shades to a fixed or variable position, when it exceeds the programmed light level

Yearly Percent of Time for Daylight Hours

Position	%
Position 0 [0% Closed]	66
Position 1 [25% Closed]	3
Position 2 [50% Closed]	7
Position 3 [75% Closed]	4
Position 4 [100% Closed]	20
	100 %



Shade Position Report **Top-down: Sun Penetration**

March 21 (Equinox) South Facing 40 Deg Lat

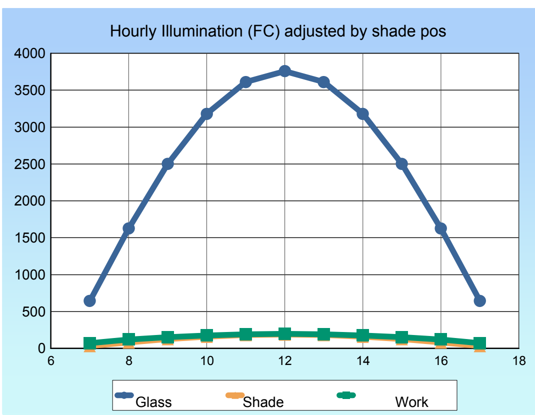
Zone Number	2	Latitude	40.0
Day of the Year	80	Top of Window (Ft)	8.0
Surface Azimuth (Deg)	0.0 S	Bottom of Window (Ft)	2.0
Surface Tilt (Deg)	90.0	Overhang (Ft)	3.0
Shading Coeff. (w/o shade)	0.35	Ceiling Height (Ft)	10.0
Shading Coeff. (w/ shade)	0.25	Allow sun penetration (Ft)	3.0

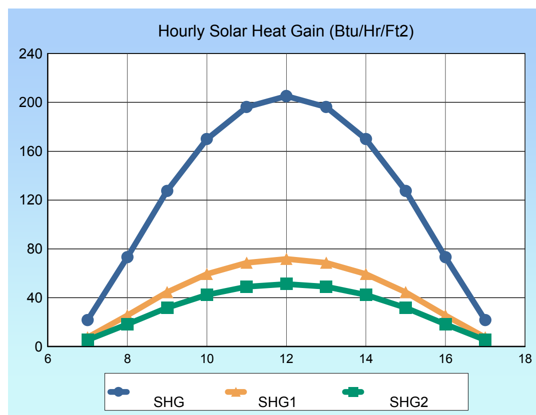
Results IP Units

Apparent Solar Time	Solar Altitude	Solar Azimuth	Surf Solar Az	Incidence Angle	Profile Angle	Total Rad	SHGF'	SHG1'	SHG2'	Shade Position
7	11.4	-80.2	80.2	80.4	50.0	40.8	22.0	7.6	5.4	3
8	22.5	-69.6	69.6	71.3	50.0	104.6	73.0	25.6	18.3	3
9	32.8	-57.3	57.3	63.0	50.0	161.7	128.0	44.6	31.9	3
10	41.6	-41.9	41.9	56.2	50.0	206.1	170.0	59.5	42.5	3
11	47.7	-22.6	22.6	51.6	50.0	234.1	196.0	68.7	49.1	3
12	50.0	0.0	0.0	50.0	50.0	243.7	205.0	71.8	51.3	3
13	47.7	22.6	22.6	51.6	50.0	234.1	196.0	68.7	49.1	3
14	41.6	41.9	41.9	56.2	50.0	206.1	170.0	59.5	42.5	3
15	32.8	57.3	57.3	63.0	50.0	161.7	128.0	44.6	31.9	3
16	22.5	69.6	69.6	71.3	50.0	104.6	73.0	25.6	18.3	3
17	11.4	80.2	80.2	80.4	50.0	40.8	22.0	7.6	5.4	3

Glass: Vertical illumination inside glass
Shade: Vertical illumination inside glass and shade
Work: Horiz illumination at work plane 9' (2.7m) from window wall, 30" (0.75m) from finished floor lvl

* Indicates that the shade position is determined by light level override
' See definitions in the legend

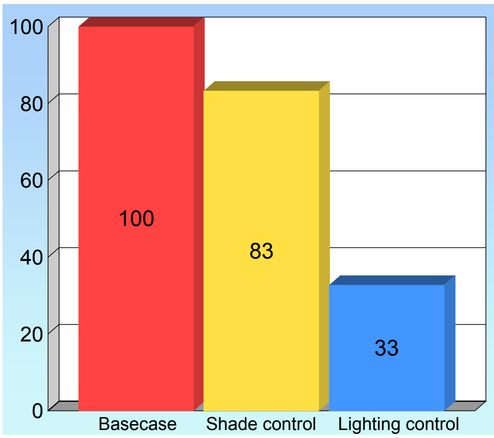




Savings Summary

# of floors:	2	Facade width (Ft) :100	Zone depth (Ft): 18

Percent Energy Use



Notes:
1. These results are provide for comparative analysis and should not be used as absolute results
2. **This analysis is not a whole building analysis. If you need that request MechoSystems eQUEST report for your location**
3. Lighting density is assumed to be 0.98 W/sf as defined by ASHRAE 90.1 (2010) for open office plan
4. Energy (BTU or W/m2) is calculated using solar optical properties of glazing and shade
5. kWh is calculated using Coefficient of Performance (COP) of 3.0 for extracting solar gain through window occupying the whole facade in a cooling dominated climate
6. No part load is assumed for HVAC system while removing solar gain through the window
7. CO2 is calculated using EPA conversion factor of 6.8956x10-4 Metric Ton/kWh
8. Barrels of oil is calculated using EPA conversion factor of 1 Barrel = 1628.2 kWh

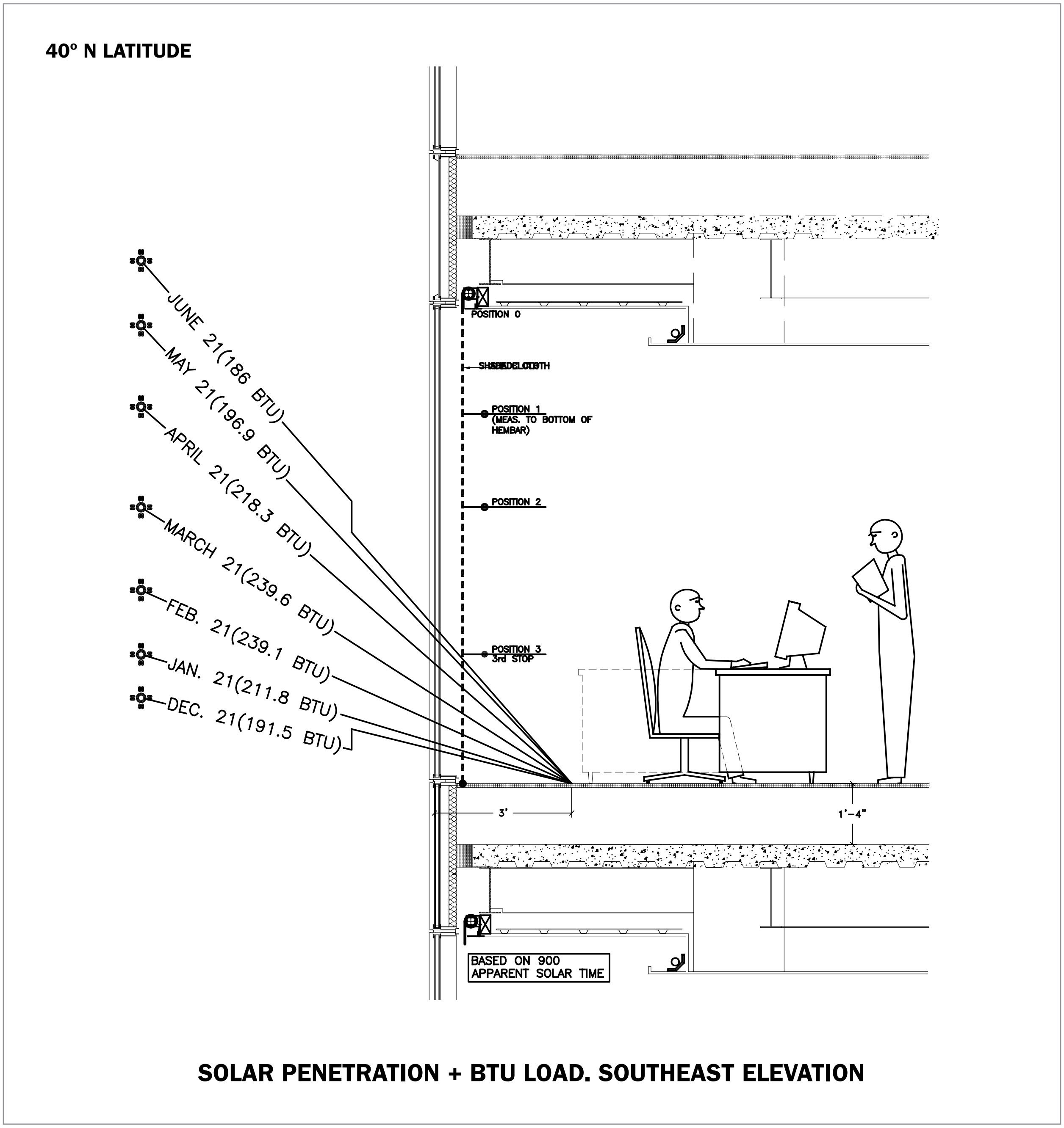
Basecase - Unshaded windows
Shade control - Automated shade (window management)
Ligting control - Shade and dimming control (window and lighting management)

#	Description	Unit	Unshaded	Window management Shade control	Shade + Lighting control
1	Energy	MBTU	177	147	58
2	Electric	kWh	51,851	43,193	16,990
3	CO2 Emissions	Metric Ton	36	30	12
4	Oil	Barrel	32	27	10

4.3 Solar Penetration: Allowing or Avoiding the Direct Solar Ray

Normally, the solar ray enters an indoor space through the vertical glazing and affects the occupants. The goal of automated shading is to maximize daylighting and the view to the outside while eliminating direct solar radiation on occupants. The shades move incrementally across the glazing, or the louvers tilt, in accordance with allowed (user-defined) levels of solar penetration. The SolarEvaluation program uses the geometry of the building, the configuration of the window and the calculated position of the solar ray to adjust the shade devices and move them to the appropriate position.

FIGURE 2. Solar Penetration and Heat Load from January to June



Courtesy MechoSystems.

4.4 Control of Heat on the Glazing with SolarEvaluation

Control of heat on the glazing occurs by computing the real-time radiation on the glazing under consideration and the solar optical properties of the glass (which may attenuate the solar load) and then moving the shading device to a specific, pre-programmed position. The shades move incrementally across the glazing, or the louvers tilt, in accordance with the allowed, user-defined heat load, or solar gain, measured in BTU/hr/ft^2 or W/m^2, and solar penetration, by using the profile angle for blinds and roller shades. SolarEvaluation programs calculate the heat load on the glazing and then determine the appropriate shade position on a window to control for solar heat gain.

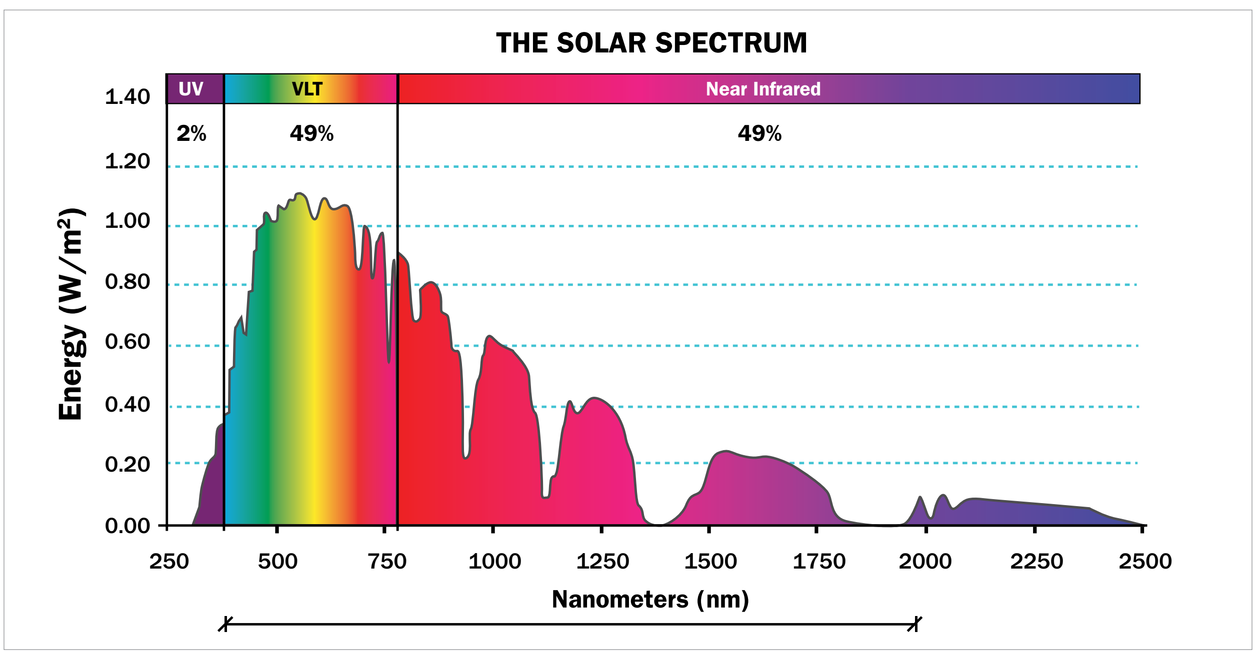
4.5 SolarEvaluation Programs for Skylights and Atriums

SolarEvaluation programs are used with skylights and atrium spaces to precisely determine which areas under the skylight and which vertical elements around the skylight are subject to direct solar penetration. A SolarEvaluation program calculates the incidence angle of the solar ray to control the position of the shading system. It computes the solar geometry of the building's skylight aperture to determine the precise impact of the solar ray, and then applies user-defined levels of allowable exposure on the floors and vertical walls surrounding the atrium to control the amount of solar radiation coming through the skylights.

4.6 Traditional Shade Control with Daylight Measuring

The traditional method of automated shading control uses daylight measuring, in which photometers, or lux sensors, are placed throughout the facade of a building to measure the intensity or brightness of the visible light (daylight). A photometer, or lux sensor, measures only the visible light portion of the solar spectrum, with wavelengths of 0.4 to 0.7 microns. The solar spectrum is shown in Figure 3 (ASTM, 1992). Figure 3 shows that the visible light portion of the solar spectrum (the portion measured by a lux daylight sensor) is approximately 49% of total solar energy. The lux sensors in daylight measuring systems are blind to 49% of the solar radiation that passes through the glazing in the form of near-infrared radiation.

FIGURE 3. Solar Spectrum Graph



Courtesy ASTM.

Lux sensors are also used in cameras to measure the amount of daylight coming through the lens and control the shutter by means of an F-stop aperture setting. An automated window-covering system with daylight measuring uses technology similar to a camera to control the shade and brightness on a solar-lit window. The automated shade system uses daylight sensors and threshold settings that act as a switch to open or close the shade(s).

The number of lux sensors used for daylight measuring determines the accuracy of the shading system. A lux sensor on each window will provide much more precise data than two or three lux sensors on a facade. In some cases, each elevation of lux sensors manages three floors, the floor above and the floor below. The granularity of the placement of sensors is directly commensurate with accuracy. (See Table 2 below.)

The negative side of adding many lux sensors for responsiveness is (a) the front-end cost (the more sensors, the greater the cost) and (b) higher costs for maintenance and calibration. In a perfect world, a sensor would be on every window, but where? In the middle? At the top, on the bottom, on the side? Perfect accuracy is not achievable. Instead of increasing the number of lux sensors, another methodology can be used: Virtual Brightness. This is an automated shading system that utilizes software to compute the illumination level. The Virtual Brightness program uses the accuracy of its total sky monitoring to reduce the number of lux sensors needed for a building.

The Virtual Brightness system utilizes three to six months of local sky data on a building, which in turn updates the Sky Evaluation database to curve-fit the window brightness to the measured sky. Tests have shown that Virtual Brightness achieves more than 90% accuracy, but even a conservative measure of 85% accuracy is exceptional and allows for much lower front-end and long-term maintence costs.

4.7 Daylight Measuring and Lookup Tables

To adjust shades for the level of brightness coming into a building, manufacturers of daylight measuring systems use (a) the local position of the building, (b) an astronomical clock, and (c) a lookup table to determine the position of the solar ray on a facade of the building given the time of day. The lookup table is used to move shades in accordance with the day program the manufacturers have selected. Manufacturers of daylight measuring systems do not specify or publish the granularity of their systems or the table they use, such as the density of the senors by floor, the number of days computed per year, and the number of checks and comparisons to a clear sky per day. As a result, the ability to verify this information for accuracy is not available for commissioning their systems.

The frequency of the lookup table may be based on either weekly (52 representative weekdays per year), biweekly (26 representative days per year), or monthly (12 representative days per year) schedules. It is reasonable in most cases to assume a lookup table based on solar data for 52 of 365 days per year, from sunrise to sunset, on the basis of one-hour increments per year-day.

The lookup table is established by an astronomical timer. The Sun, as we all know, is our clock. It should be understood that the position and path of the Sun, and therefore the angle of the solar ray, changes each day from December 21 to June 21, and then back to December 21, with each day different from either the previous or the following day because of the elliptical orbit of the Earth around the Sun.

It should be noted that daylight measuring systems that depend on lookup schedules are not precisely in sync with the solar path for each minute of each day in real-time (see Table 2). The resolution of the astronomical clock/lookup table programming appears to be very granular and is much less responsive than a system that uses “real-time,” e.g. SolarEvaluation, as the basis for action and decisions. Any program that bases shade movements on the use of a lookup table will be lacking in precision, as shown in Table 2 below.

TABLE 2: Precision of Window Management Systems Using Real-Time Calculations as Compared to Lookup Tables

Window management system	Frequency of solar radiation calculations	Number of possible adjustments per year	Penetration of solar radiation into the interior
1 **SolarTrac real-time calculations**	10 times a minute, 365 days per year	2,628,000	None
2 **Lookup table**	Hourly, using a table with 52 representative days per year	1,248	Significant
3 **Lookup table**	Hourly, using a table with 26 representative days per year	624	Severe

*The precision of the window management system is determined by the amount of time that direct radiation enters the space as sensible heat on the skin, impacting the comfort of the occupants, before the shades change position.

An automated shading system should ideally evaluate the sky condition on a minute-by-minute basis to determine if the shading system should be adjusted. This is important because in most climates there are intermittently cloudy and clear conditions. On both lightly and darkly overcast days, the level of near-infrared radiation passing through the cloud cover and then through the window wall as heat may be substantially greater than the level of daylight. As daylight measuring systems are only sensitive to the visible light portion of the shortwave radiation coming through the window wall, the lux sensors cannot “see” or “measure” the high levels of heat radiation passing through the glazing, though it is immediately sensed by the occupants subjected to the direct solar radiation. The high level of heat radiation that passes through the glazing on a cloudy day also adds a potentially huge air-conditioning load on a building. It’s easy to get a sunburn on a cloudy day at the beach!

4.8 Advantages of SolarEvaluation Compared to Daylight Measuring

A successful shading system requires a daily window-management algorithm that operates minute by minute in real-time, responding to changes in the sky condition and/or in the established threshold within 60 seconds to assure that an appropriate response can be measured and commissioned. (Real-time here is defined as an immediate response to a change in solar data, with a response in less than 60 seconds.) The most effective automated shading system uses radiometers and SolarEvaluation to compare a building’s measured microclimatic radiation with ASHRAE’s Clear Sky radiation values to accurately evaluate the sky and determine if clear or cloudy conditions exist, and to what degree.

A radiometer measures the ultraviolet (UV), visible light (VL) and heat (IR) portions of the solar spectrum, with wavelengths of 0.25 to 2.5 microns, which comprise 98% of the Sun’s energy as well as the heat and light on a building. The solar energy measured by a radiometer represents approximately 98% of the total solar energy spectrum of the Sun.

Using radiometers and SolarEvaluation instead of lux sensors and daylight measuring for an automated shade control system has other advantages, although the hardware is approximately the same cost. Only three radiometers are needed for a SolarEvaluation system, rather than the hundreds of lux sensors placed on a building for daylight measuring. Daylight measuring systems also require maintenance to keep the lux sensors clean, and some manufacturers provide battery-operated sensors that need be replaced over time. And while lux sensors measure the levels of visible light coming through the windows, they do not control or manage excessive glare and brightness.

4.9 The Thermodynamics of Solar Radiation: Understanding Radiation, Heat Gain and BTUs

- **ASHRAE Clear Sky measured solar radiation.**
  The total amount of solar radiation reaching North America on a clear day is:
  - 2% UV
  - 49% daylight
  - 49% near-infrared radiation

- **Radiation format**
  - The shortwave infrared radiation coming through modern glazing may be reduced in intensity, but it is still transmitted as shortwave radiation, which humans immediately sense as heat.

- **Heat gain by conduction**
  - Shortwave solar radiation is absorbed by opaque materials and then converted into longwave radiation and transferred by conduction through the materials as conducted heat flow, which is measured in BTUs.
  - The emissity of the opaque material determines at what temperature the heat is released or transferred. For example, metal transfers heat faster and at higher termperaturess than fabric. Other factors, such as color and reflectivity, also affect emissivity.
  - The amount of thermal energy an object will radiate is not only a function of temperature, but depends on the material itself. Emissivity describes a material's ability to emit or release the thermal energy which it has absorbed. A perfect radiator-known as a 'black body'-will emit the entire amount of absorbed energy. A real body will always emit less energy than a black body at the same temperature. Emissivity is the ratio of radiation emitted of a given object (real body) and a black body at the same temperature.

- **Heat gain by radiation: Shortwave radiation passing through glass**
  - When shortwave solar radiation is transmitted through glazing and meets an opaque body such as a human, that individual will immediately experience the shortwave radiation as heat. This is instantaneous sensible heat gain.

- **Human factors:**
  - Individuals in areas with glazing who are subjected to direct solar radiation will immediately sense the heat, regardless of the surrounding air temperature.
  - Thermostats are always placed at the rear of a room, away from the solar radiation zone, and hence the preset heat levels are never satisfied and the air conditioning system is not activated.
  - Sensible heat gain from solar radiation is immediate and is not affected by air temperature, just as glare is not affected by the level of daylight.
  - The human response to reflected glare and shortwave radiation is immediate, unique and not affected by the environment.
  - Radiant surfaces: The radiant temperature of glazing directly affects individuals near the window wall, regardless of the interior air temperature. The human body loses or gains heat through exposure to the temperature of radiant surfaces.

5 WINDOW-COVERING SYSTEMS

Cord-operated roller screens appeared in the early 1800's all over the world, using many different fabrics as the shading device. Rockefeller Center in midtown Manhattan, constructed in 1947, was one of the first major buildings to use louvered blinds as the standard building window-covering system. Draperies, curtains and two-inch-wide venetian blind louvers were the standard window-covering products for the period from 1930 to 1950. From about 1960 to 2000, the standard for window covering was the 0.5-inch venetian mini-blind. In the early 1990's, the roller shade, which had been introduced as early as 1969 in commercial office buildings, started to gain interest and popularity. Today, in 2013, the roller shade appears to dominate city center and headquarters buildings in the AA and AAA class. The following is an overview of the design and mechanics of each system.

5.1 Venetian Blinds

The critical characteristics of the venetian blind are the spacing between the slats and their cutoff angle, or the angle at which the slats prevent direct solar penetration. Generally, the space between the slats is slightly less than the width of the slat, with a 42° cutoff angle. Thus, when the altitude of the Sun is at 42° or greater above the horizon, there is no direct solar penetration through the horizontally positioned slat. However, light and heat will still be reflected into the space. For a reflected ray, the relationship is: the angle of reflectance equals the angle of incidence. With the louvers in a horizontal position, there may be no direct penetration of the solar ray, but there will be almost the same amount of heat gain as for an unshaded window (Nicol, 1966).

When the altitude and/or profile angle of the solar ray drops below the louvers' 42° cutoff angle, the slats are tilted down to the next position to eliminate direct solar penetration. The tilt, then, diminishes the horizontal view through the blinds and reduces daylighting.

5.2 Louvered Blinds for Clerestory Windows

Reverse-contoured louvered-blind slats, with concave-up or special slat profiles, are used in clerestory windows to reflect radiation onto the ceiling for daylighting by reflected illumination. Depending on the solar position, the blinds have to be tilted to get the maximum radiation reflected onto the ceiling. These blinds, too, should be automated to maximize the efficiency of ceiling-reflected illumination in a facility.

5.3 Perforated Louvers

To avoid the darkness of tilted or closed blinds, the industry responded by perforating the louvers. This is effective for maintaining some view to the outside when closed, but it does little for daylighting and is only effective if the slats are fully closed. If the slats are tilted, then the perforations in the slats are viewed at an angle that renders them visually opaque for most tilted angles. To control the solar radiation coming through the glazing and the shade, the perforation density (openness factor) of the slats is important. With perforated blinds, the better the view to the outside, the greater the transmission of direct solar radiation. Perforated slats can cause discomfort when the pinholes of light in the opaque slats are in the occupants' line of sight. The color of the opaque slats will directly affect the contrast ratio between the pinholes of light and the slat background. The darker the color of the slats, the greater the contrast and the light/dark values, creating glare or visual discomfort. The lighter the color, the greater the amount of reflectivity.

Additionally, the perforated slats in the tilted position allow solar penetration onto the next lower slat, which is then reflected into the space, increasing the heat gain, surface brightness and daylighting. The degree of heat gain and illuminance is dependent on the color of the slats plus the openness factor of the slat perforations.

5.4 Fabric Roller Shades

Roller shades were developed in the early 1800's in Scotland (Gordon, 2013). Their purpose was to provide privacy, daylight management and sun control. The shade cloth was made from translucent coated linen, or a starched cotton fabric with a natural resin coating so that it would be waterproof, not ravel when cut, and remain stable against the window. The Victoria & Albert Museum in London utilized roller shades made from resin-coated Egyptian cotton. The shade was either rolled up into a tube at the head of the window with a cord-and-reel assembly, or rolled from the bottom with a series of rollup cords that caused the round tube or wood shaft at the bottom to roll up inside the shade cloth. The roller shade became a ubiquitous standard, with many types of woven fabrics, hemp and straw used as the shade material.

In 1969–70, MechoShade designed, developed and installed the first commercial roller shades in the Trust Company of Georgia Building in Atlanta. The design utilized a sprocket and chain borrowed from the vertical blind industry and a roller shade of warp-knitted modacrylic fabric made from a fire-retardant yarn. The density of the fabric was such that there was a certain amount of see-through, with a minimum amount of solar gain, brightness and glare. The hardware was simple, with no brake or clutch system. It was basically a free-running sprocket with a bead chain, and a holding system mounted to the wall so that the chain could be clipped and held at any position.

MechoShade's next major project was the retrofitting of all of the windows in the Irving Trust Company Tower on lower Broadway in Manhattan, a 45-floor 1920 building with punched double-hung windows. The shade cloth used was the first to utilize vinyl-coated yarns, which then became the basis for MechoShade's ThermoVeil fabric. The system was the first MechoShade system with a chain, clutch and brake system to allow the shades to stop anywhere on the window. Subsequent improvements included a means of selecting either a system with a brake that could stop anywhere, or a free-running design with a wall-mounting clip that allowed the shades to be positioned only at predetermined locations on the window. This style provided uniformity of design and controlled solar penetration. It is important to note that all buildings constructed up to the early 1930's had high sills and high ceilings, with windows that extended close to the ceiling. This design maximized the amount of daylight that could enter a room, as the distance of daylight penetration increased with the window height.

6 SHADE CLOTHS

6.1 Characteristics of Shade Cloths

The common feature of all shade cloths is that they can be cut to size from a larger piece of fabric with a knife or sonic cutter and not ravel or shred. An additional requirement is that the cloths hang "flat," though in reality no fabric can hang absolutely flat. (And the larger the fabric panel, the greater the potential that the fabric will hang "less flat.")

Among the original solar shade cloths, the other common feature was the use of an opaque yarn, either one with a fiberglass core that was then dipped and coated in polyvinyl chloride (PVC), or one with a polyester core that was coated with vinyl through an extrusion process.

The operable word to understand is that most shade cloth yarns are opaque. The industry has followed MechoShade's lead in using the "openness factor" of the fabric with opaque yarns, in conjunction with its color, to determine which shade cloth is appropriate for a project (Yellot, 1983). The "openness factor" simply refers to how tight the weave is; the percentage of openness varies from 0.01 to 0.05. The amount of light let in through the fabric is the percentage of openness plus the color of the fabric. Dark fabrics transmit less light; lighter fabrics transmit more light. White fabrics are not recommended due to their propensity for high surface brightness. Medium-value colors in the mid-gray range appear to have the best attributes of surface brightness and daylight transmission. A low openness factor means that the fabric is tightly woven and there is less visibility through the shade, giving it low daylight availability while cutting down on heat and glare. Testing samples of fabric with the glazing that is to be used is a critical and recommended effort.

Fabric openness and color are good tools to use to determine which opaque-yarn shade fabric is best for a project. However, openness factor as a criterion for shade cloth selection is only applicable to fabrics made with opaque yarns. Screen cloths made from translucent, 100% polyester yarns that are not vinyl-coated will not provide the same protection from brightness and direct solar radiation as fabrics made with opaque yarns. Screen cloth made of opaque yarn that is 3%-5% open will have a visible light transmission of approximately 2%-5%, depending on the fabric's color.

However, a polyester screen cloth made of translucent yarns that is 3%-5% open will have a visible light transmission of 30% to more than 40%. The color of the screen cloth determines how much light gets through. The color of the screen cloth determines how much light gets through.

The manufacturers of 100% polyester screen cloths promote an aluminum backing that renders the yarn opaque and increases the price significantly. These companies suggest that the addition of a low-E aluminum coating to the back of the fabric is a benefit. However, there are many instances in which the low-E coating on the shade fabric competes with the low-E coating on the glazing and hence does not contribute much to energy efficiency. It is our opinion that the purpose of the aluminum coating is to create an opaque backing for the shade fabric so that it is similar to fabrics made with opaque yarns, which better manage light and heat transmittance, at much higher cost.

The aluminum-backed fabric is offered as an energy-conserving enhancement, but it does not function well as such. Low-E glazing is already offered to reduce conductive heat flow. Conductive heat flows downhill, from "hot" to "less hot" or "cold." Most buildings that have low-E glazing will not benefit from shades that also have a low-E coating. In order to truly evaluate the benefit or liability of adding a shade cloth to windows with a low-E coating, it is necessary to model the building's energy efficiency using an approved program such as eQUEST or EnergyPlus. From our research, the liability and additional cost of aluminum-backed polyester shades outweigh the benefits in most cases. This conclusion can be verified by running a building modeling program with a life-cycle cost-benefit analysis.

Fabric made of fiberglass yarn coated with polyvinyl chloride (PVC) has the distinction of having less stretch; fiberglass yarn does not stretch. However, the weaving process creates a matrix of yarns on an X-Y grid (warp and weft) which, due to the weaving process, has mechanical extensibility, which means that under tension or weight, the fabric will mechanically stretch in length and "hourglass" in width. This "hourglass" effect is defined as a distortion at the interstices of the warp and weft yarns of the fabric.

Fabric made from extruded polyester yarn with a vinyl coating has the distinction of higher tensile strength and is generally the most robust type of fabric. This fabric is typically used for seating and lawn furniture as well as shade cloths. An additional advantage to fabrics made from vinyl-coated polyester-core yarn is that both the vinyl and the polyester are thermoplastics. When this fabric is cut with hot knives or sonic cutters, or sealed by high-friction crush-slitting, the edge of the fabric fuses, and the vinyl and polyester are melted together in an almost invisible bead that prevents the cut edge from raveling. It should be pointed out that shade fabric can only be joined with a horizontal seam. No vertical seams are possible, as they distort the shade cloth when it is rolled up by changing the thickness of different sections of the shade band as it rolls up. Thus, no side hems or vertical seams are possible.

Both shade cloth types—whether made with PVC-coated fiberglass yarns or vinyl-coated polyester yarns—are finished in a high-heat, fabric-tensioning oven in which the fabric is stabilized to be square to the X-Y grid. The warp (long) and the weft (side) yarns are fused under heat and pressure into a matrix that stabilizes the fabric and prevents the raveling of the shade cloths when they are cut.

6.2 PVC-Free Shade Cloths

There are two fabrics on the market that are certified as free from polyvinyl chloride, or PVC, which tends to off-gas. The first is EcoVeil by MechoShade. MechoShade started developing this PVC-free fabric in the late 1990's, but ran into technical problems and had to conduct new polymer research. The project resumed in early 2000, and MechoShade worked with a mill partner to develop a new thermoplastic olefin (TPO) yarn. EcoVeil fabric utilizes a core TPO yarn with an opaque TPO coating, which makes it recyclable. In the recycling process, the TPO filament and the TPO coating are reduced to the basic TPO chemistry, which allows for its reuse. Thus, EcoVeil is a "green," sustainable material. However, MechoShade still has to use a small amount of flame-retardant additives in EcoVeil to meet building code requirements. There is a research program underway to find a flame retardant that is "green," but to date no one has found an additive that both meets green standards and current building codes. Still, EcoVeil is almost completely free of cancer-causing chemicals and is certified as a Cradle to Cradle™ recyclable by McDonough Braungart Design Chemistry (MBDC). Thanks to the compatibility of the core TPO yarn and the TPO coating, the fabric can be recycled and reused. This fabric can be considered a "sustainable nutrient" in industrial designs, as described by the book *Cradle to Cradle: Remaking the Way We Make Things* (Braungart & McDonaugh, 2002).[1]

Phifer Inc. also produces a PVC-free fabric, Infinity™, which we understand is also made from TPO yarn. The fabric has characteristics similar to screen cloths with PVC; it utilizes a core TPO yarn that is coated with an opaque TPO with fire-retardant additives. It is also recyclable.

6.2.1 POLYESTER SHADE CLOTHS WITH TRANSLUCENT YARNS

There is a group of screen fabrics made from 100% polyester. The fabric yarns are translucent rather than opaque, and the price is generally lower than for fabrics made from opaque, vinyl-coated polyester or fiberglass yarns. Because these yarns are translucent and not opaque, they have higher visible light transparency, as much as 10 times higher, compared to fabrics with a similar openness factor and color. Thus, the fabric selection guidelines developed by MechoShade in the late 1970's for screen cloths (openness factor) with opaque yarns are not applicable to fabrics with translucent yarns. The tools and formulas for fabric selection guidance used historically for selecting opaque-yarn screen cloths do not apply to 100% polyester fabrics, or to any screen cloth made with translucent yarns. In general, it is easy to determine if the yarn is opaque or translucent. If a 3% open fabric in a medium-gray color has a Vlt of 3%-5%, the yarn is opaque. If a 3% open fabric has a Vlt of 20%-40%, the yarns are translucent. For polyester fabrics, the lighter the color, the higher the visible light transmission.

The polyester screen cloths on the market today fall into two categories.

- All new polyester material with known additives
- Recycled polyester with unknown additives

6.2.2 CONTENTS OF RECYCLED POLYESTER SHADE CLOTHS

There is a growing interest in recycled materials and in reusing materials instead of dumping them into a landfill in order to help the planet. However, manufacturers of recycled polyester screen cloths cannot say (and do not know) what chemical or fire-retardant additives may be in the recycled materials they use. Thus, recycled polyester screen cloths may or may not contain contaminants. As we understand it, the additives in recycled materials are unknown and may or may not be "green" as we understand the meaning of "green." The PVC-free EcoVeil fabric from MechoShade and Infinity fabric from Phifer use all new materials, and the ingredients are of a known quantity and value.

6.3 Selection Criteria for Shade Cloths

The selection of shade cloths requires an evaluation of (a) the transmission of heat and visible light through the glazing, as measured by the shading coefficient or G factor of the glass; and (b) the solar optical properties of the shade cloth, including its solar transmission (Ts), solar reflection (Rs), solar absorption (As) and visible light transmission (Vlt).

6.3.1 SOLAR OPTICAL PROPERTIES OF SHADE CLOTHS

The methodology used to determine the solar optical properties of glazing is also used for screen cloths. The solar optical properties of screen cloth—namely, Ts, Rs, As and its openness factor—are used to calculate the net heat and light transmission through the glazing and a shade fabric window treatment. It needs to be noted here that not all screen cloths have the same light- and heat-transmitting factors. Historically, screen cloths have been made of opaque yarns coated with PVC (or, more recently, TPO). Since the early 1980's, the standards for selecting a shade fabric based on its openness factor to work with the Vlt of

[1] *McDonough Braungart Design Chemistry advises companies on integrating Cradle to Cradle principles into products, operations, and corporate strategy to regenerate the economy, ecology and equity.*

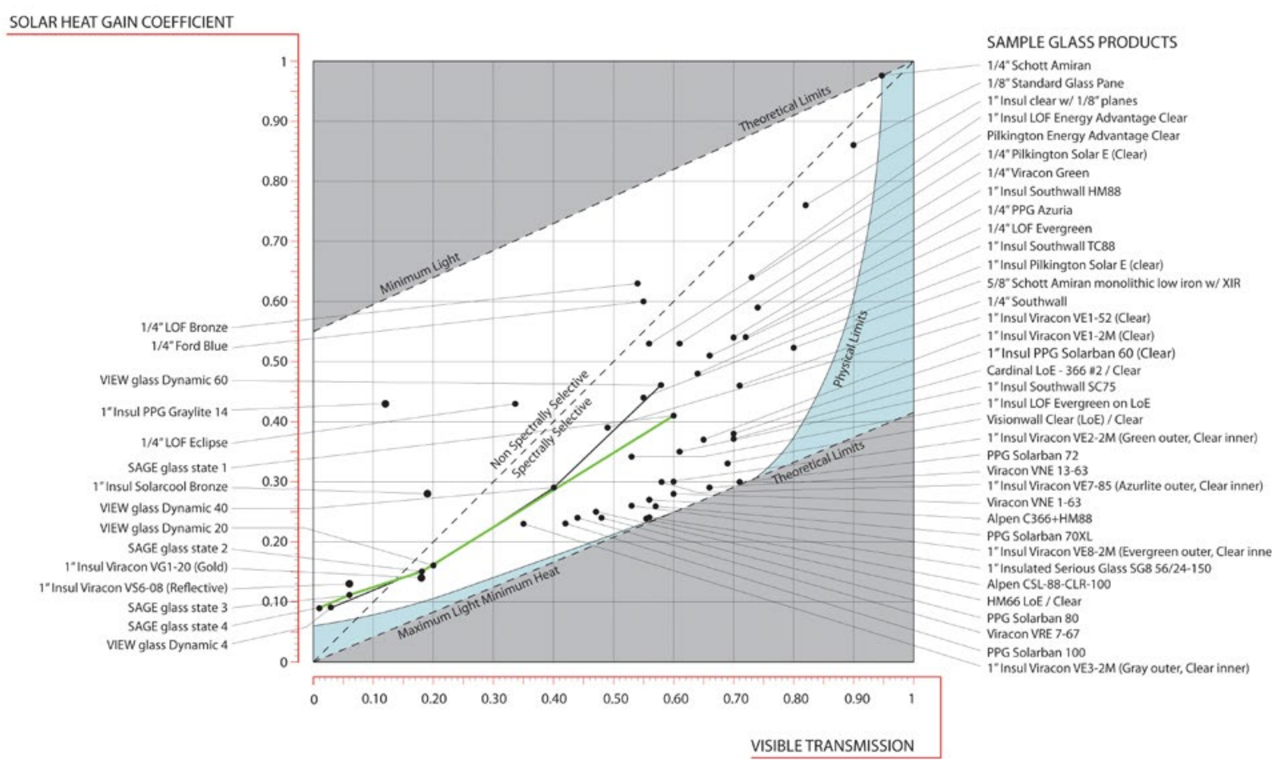
the glazing were known and used. This research was conducted in 1978 by Dr. John Yellot at Arizona State University for the Arizona Solar Testing research program, sponsored by Mecho-Shade. (The report is available at: http://mechosystems.com/Yellot-U-Value/).

Now, however, the range of polyester screen cloths made with translucent yarns has rendered previous standards null and void. Uncoated polyester screen cloths made with translucent yarns offer as much as 10 times higher VIt compared to fabrics made from opaque yarns.

6.3.2 SELECTION CRITERIA FOR GLAZING WITH A SCREEN CLOTH

As modern high-tech glazing has a low heat flow in the 40% range and visible light transmission in the 65%-70% range, the critical criteria for selecting an opaque-yarn screen cloth are its openness factor and its transmission values (see Figure 4 below). If the shade cloth is too open, solar protection from the direct solar ray and incoming radiation will be diminished, causing discomfort to occupants and affecting performance. The current standard for opaque-yarn shade cloths, when used with glazing with a shading coefficient of about 0.45 and visible light transmittance of 0.60 to 0.65, is 3% open fabric and a Vlt of 2%-5%. If the Vlt of the glazing is in the 70% range or higher and the color of the shade is light, then the openness factor of the fabric may be best in the range of 1%-2%. In any case, the color and thickness[2] of the fabric will affect the shade protection values for glare, surface brightness and heat. It is recommended that side-by-side testing with the type of glazing to be used, using individuals at a work table with computer monitors, should be included in the analysis to arrive at the final decision.[2]

FIGURE 4. Heat and Visible Light Transfer Through Different Types of Glazing



Courtesy Loisos & Ubbelohde.

6.3.3 SELECTION OF SHADE CLOTHS FOR TRANSPARENCY AND COLOR SELECTION

The ability to "see through" a fabric, thereby affording a view to the outside, is affected by two properties of the fabric: its color and its density. Dark colors are easier to see through, while light colors are more reflective of light and thus harder to see through. Also, the more open (less densely woven) the fabric, the easier it is to see through (i.e., 3%-5% open fabric is easier to see through than 1%-2% open fabric). Thus, the combination of color and density affects the view to the outside. Fabrics should be tested visually in different colors and densities as part of a full-size mockup.

[2] *Thin screen cloths do not have the same cutoff angle for preventing direct solar penetration as thicker fabrics with the same openness factor. Thus, thin fabrics may have to be denser to achieve the same result. One should first determine if the yarns are opaque or translucent for proper comparison.*

The characteristics of the glazing will determine the density and color of the selected screen cloth. If a lighter color is required for the interior finish, then a denser screen cloth may be considered. If a darker color is required for the interior, then a screen cloth with a higher openness factor may be considered. In any case, the two or three considered screen cloths should be installed side by side for comparative evaluation.

7 AUTOMATED SHADING SYSTEMS

A new interest in sustainable design has dramatically increased the need for, and the advantages of, automated shading systems in buildings in order to increase the productivity and comfort of occupants, improve building efficiency, promote energy conservation, and reduce carbon emissions and global warming. To meet this desire for sustainable design, buildings use high-tech glazing that has a low heat gain (a low shading coefficient or G factor) and high visible light transmittance in order to maximize ambient illumination and daylighting. The new glazing, in turn, allows for dimming or turning off electric lighting in the 15- to 18-foot perimeter space near the window wall. The daylighting effect depends on many factors, but the height of the glazing above the floor directly affects the distance of the daylighting zone from the window wall.

The energy-conserving effect of window-wall daylighting, and dimming or turning off electric lights in the daylighting zone, is not merely 1 to 1 but roughly 1 to 1.25. That is, for every kilowatt (kW) of lighting energy conserved, there is an additional savings, because the heat that would be emitted from the lighting fixture amounts to about 0.25 kW, which the air-conditioning system is then required to offset. This results in a total energy savings of 1.25 kW for every 1 kW of lighting electrical energy conserved.

TABLE 3: Enery Efficiency of Different Illumination Sources

Light Source	Efficiency (in Lm/W)	AC Load (in tons/10,000 Lm)
Daylight	106	0.27
Red LED bulb	72	0.45
Fluorescent bulb	60	0.63
Incandescent bulb	20	1.90

* Lm/W is lumens per watt

The advantages of lower heat gain and increased illumination from daylighting are self-evident from the table above (DiLaura, 2011). The light-to-heat ratio for daylighting is approximately 65% light to 35% heat when using glazing with an SC of 0.35 and a Vlt of 0.70. The light-to-heat ratio for fluorescent electric lights is approximately 40% light to 60% heat, which is the component of electric lighting that adds to the air-conditioning load. LED bulbs have roughly the same ratio of heat to light as fluorescents, but at a lower amperage for the same amount of light.

The control of direct sunlight and/or sky brightness for daylighting cannot be managed efficiently by building occupants using manually operated shades. In fact, a 2014 study by TRC Energy Services and PG&E found that using automated shades for daylighting resulted in 37% higher energy savings compared to manually operated shades (Saxena, et al.). Daylighting can only be managed by an automated system with a timely, effective and appropriate response to constant changes in sky condition and solar position.

The following are some of the key factors for evaluating an appropriate automated window management system. Occupant comfort is described in the section on human factors.

7.1 Requirements for Automated Shade Performance

In order to fulfill the requirements for optimizing energy efficiency and human comfort, an automated shading system should react in real-time to changes in the environment and be user-friendly in terms of accessibility and definition. Real-time is defined to be a reaction in a computer to a change in conditions "as it happens," or within less than one minute of the change. Furthermore, the program should be configurable for fine-tuning over the long term and provide flexibility, a critical element for occupant satisfaction.

The system shall react in real-time in order to:

a. manage solar radiation

b. reduce excessive brightness

c. assess when established thresholds for heat load have been exceeded

d. assess changes in the sky condition (clear or cloudy)

e. maximize human comfort while supporting energy-efficient systems

f. interface with third-party BMS/BAS systems such as BACnet, KNX and Lonworks

g. interface with third-party lighting control systems (occupancy sensors, demand control, work schedule control, etc.)

h. provide a browser-based GUI for remote-user access

i. provide a user-friendly shade-position override

j. provide configurable settings for fine-tuning over time

7.2 SolarEvaluation Systems with Louver Blinds

Recently, there has been increasing interest in the development of precise control for automated louver blinds. MechoSystem's SolarEvaluation system calculates the profile angle and intensity of the incoming solar ray on the louvered window and adjusts the louvers to the appropriate angle to maximize daylighting and prevent direct solar penetration. Once the system has calculated all of the solar data and the geometry and orientation of the louvers, it compares the geometry of the solar ray with the geometry of the window, and then adjusts the louvers to maximize daylighting and the view while blocking direct solar radiation.[3]

7.2.1 TRADITIONAL DAYLIGHT MEASURING SYSTEMS WITH LOUVER BLINDS

In traditional daylight measuring systems for louvered blinds, analog, non-intelligent daylight sensors are placed behind the slats, and a timing program moves the slats when a sensor is illuminated. When sunlight activates a sensor, it sends a signal to the system that jogs the slats to the next position, which in turn puts the sensor in shadow. If the sensor is again subjected to daylight, the system jogs the slats to the next position. In some designs there are two sensors: one to determine rain or shine, and a second to react to direct solar penetration if a clear sky is detected. The costs of this design soon become prohibitive due to the need to install and maintain a large number of sensors.

7.3 SolarEvaluation Systems with Roller Shades

Most of the engineering and design efforts in automated shading systems to date have gone into the development of systems for roller shades. Some reasons for the development of automated systems for roller shades are listed below.

[3] *It is recommended that the motors used to control the louvered blinds operate at 10-12 rpm and have an encoder with at least 365 reference points and a microprocessor that is accessible via a serial port.*

A roller shade operates in the same way that an awning shades a window. It provides a shadow to prevent direct solar penetration, but it also allows a substantial amount of daylight to enter through the unshaded portion of the window to increase the ambient illumination. The efficacy of daylight is high, at 65% light and 35% heat compared to artificial light (see Table 3 above), so daylighting saves energy by requiring less artificial lighting and reducing the use of air conditioning.

Shade cloths also trap heated air in the shade plenum, the space between the shade and the glazing. By capturing this solar gain in the plenum, the shade plenum directs the solar heat into the return-air ceiling plenum, increasing the temperature difference between the return-air plenum and the chillers, which makes the AC system more efficient and saves energy. Solar heat is now evacuated at the window wall and no longer mixes with the chilled air being delivered into the space by the AC system.

New shade cloths have been developed that both provide protection from the solar ray and allow for visibility through the screening fabric.

7.3.1 AUTOMATING TOP-DOWN ROLLER SHADES

Roller shades appear to be the first form of a manufactured roller shade product utilizing a fabric screen cloth. Roller shades are usually installed at the top of a window and lowered, depending on the altitude or height of the Sun above the horizon, to block the penetration of the solar ray. Invariably, roller shades were used to screen the upper portion of the window, leaving the lower portion open to admit natural light—now called daylighting—and views to the outside.

By reviewing the geometry of the Sun and the solar ray on a typical vertical window, it becomes apparent that the roller screen is similar to an awning in that it provides shading, solar protection, daylight and a view, all at the same time. Both systems—awnings and top-down roller shades—provide daylight and shading with a view.

The SolarTrac SolarEvaluation® system adjusts the roller shades incrementally on the window in accordance with the profile angle of the Sun, the penetration of the solar ray and a user-defined default value. The system automatically integrates the sky condition (clear or cloudy) with the position of the solar ray in real-time, and then adjusts the roller shade to the appropriate intermediate position on the window.

An additional advantage in buildings where the glazing extends to the floor is to stop the roller screens at +/- 28 inches above the floor and use the peripheral floor area as a light-diffusing light shelf, which increases ambient illumination and offers more effective daylighting.

7.3.2 USING BOTTOM-UP ROLLER SHADES

A shift in the architectural design of buildings has created a range of unusual window shapes that slope and tilt from the vertical. Some are trapezoidal windows in which the windows are wider at the bottom and narrower at the top. For these windows, shades need to move from the bottom up to intersect the solar ray. In this configuration, a high-angle Sun condition requires the roller shades to be fully deployed from bottom to top, whereas a top-down shade may only need to cover 25%-50% of the window. For a bottom-up shade to meet the criterion that it block the solar ray in the upper section of the window, it must be completely closed, bottom to top. This shading can be modeled or simulated in advance with MechoShade modeling programs to determine the best solution for a project. When the window wall slopes in, or tilts left or right from the vertical, these special shading solutions are required.

7.4 Emerging Technologies: Electrochromic Glazing

It is now possible to use automated shading technology in conjunction with electrochromic glazing (ECG) or photochromic glazing to provide protection from direct solar radiation while providing a view to the outside and daylighting for energy efficiency. This can be accomplished by electrically charging either the entire glazed panel or different sections of the ECG window for different degrees of light and heat transmission. For example, the upper third of the window may be darker, the middle third lighter and the lower third clear.

Will electrochromic glazing replace window shading for energy and light control? It may be possible in the distant future, but it will be a while before it becomes a ubiquitous solution, for several reasons: (a) it is generally much more expensive; (b) there are limits on the size of the glass panels; (c) it takes time to change from 90% to 50% Vlt; and (d) the glazing can endure only an unknown number of duty cycles. It needs to be understood that outside air temperatures may affect the time it takes for the electrochromic glass to change its light- and heat-transmission values. The colder the temperature outside, the longer it takes the glazing to change. Manufacturers claim that the time delay for adjusting light and heat transmission has been reduced, but it has not yet approached the 60-second standard that is now available with automated window shade systems. We are advised by electrochromic glazing manufacturers that the time and density factors required to reduce heat gain and brightness with EC glazing are being shortened, especially to the point of 50% transmission. (See Figure 4 below).

7.5 Emerging Technologies: Predictive Sky Analysis

A great deal of work, time and effort is being invested around the world to develop systems that can scan the sky from horizon to horizon to predict local sky conditions with 80%-85% accuracy, 30 to 90 minutes in advance of a sky event.

These predictive systems use high-definition cameras, a combination of lux sensors and radiometers, proprietary algorithms, and in some cases data from weather satellites and national weather bureaus. The advantage of knowing, with a reasonable degree of accuracy, the heat gain on all surfaces of a building in advance of a sky event allows for an entirely new approach to the energy management of buildings. This information will be invaluable to the manufacturers of building management and building automation systems by allowing for a proactive program that anticipates heat gain or loss, rather than a reactive program that senses heat, thereby improving response times.

MechoSystems has a test system in operation now, SkyView, which can be used in parallel with the SolarTrac radiometer system for total solar measuring and the Virtual Brightness program.

8 SOLAREVALUATION: SOLAR SCIENCE APPLIED

8.1 The SolarTrac® SolarEvaluation® Program

SolarTrac is a predictive, logic-based system utilizing a clear-sky SolarEvaluation program that works in near real-time, with an almost instantaneous response to changing environmental conditions. The system considers and evaluates the current sky condition, the geometry of the Sun, the solar intensity (heat gain), and the position of the solar ray in conjunction with the building's orientation and the geometry of the windows under consideration.

Solar radiation-measuring radiometers, which measure global horizontal solar radiation, continuously monitor the sky, utilizing theoretical clear sky values to determine, in real-time, the building's microclimatic sky condition. This data is used to adjust the roller shades to the required incremental height on the glazing, or to adjust the louvers' tilt position, within 60 seconds of crossing any of the established thresholds. This assures protection from direct solar radiation while maximizing views to the outside and enhancing daylighting. The solar path changes each minute of each day throughout the year, which is tracked continuously in real-time by SolarTrac, every minute of every day, 365 days per year, from sunrise to sunset.

8.2 The SolarTrac® Window Management® System

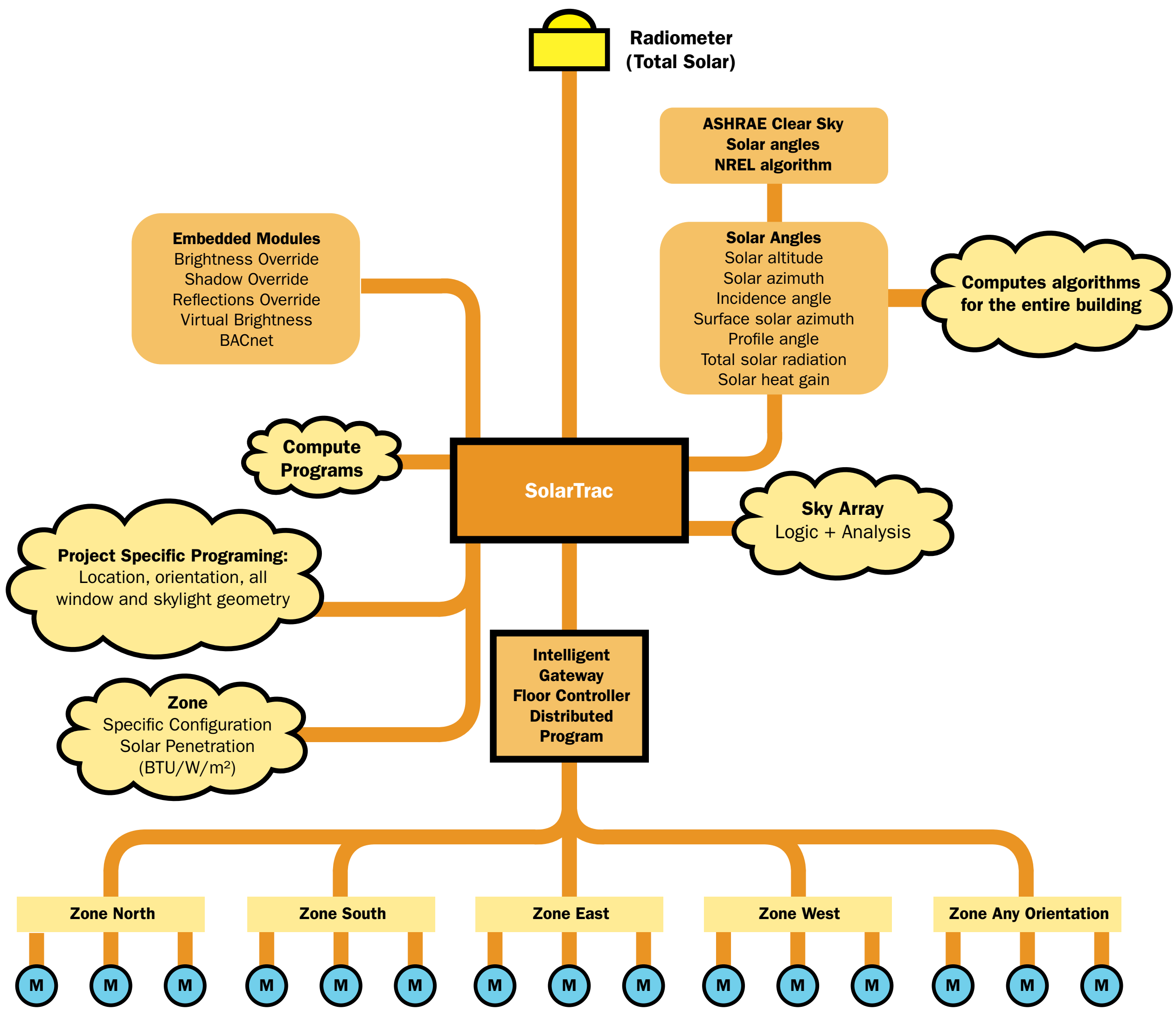
MechoSystem's automated shade/louver Window Management control system, SolarTrac, utilizes ASHRAE's Clear Sky algorithm (Powell, 1982) to mathematically calculate the clear sky radiation. Certified mathematical formulas compute the solar radiation values on the building's window surfaces in real-time. Additional mathematics (ASHRAE, 1993) use a building's geometry and location information—such as latitude, longitude, year day, time of day and facade orientation—to compute the heat load on the glazing in BTU/hr/ft^2 or W/m^2; the profile angle (shadow angle) of the solar ray; and the incident, solar altitude and surface solar angles. This solar data is used for computing the required positioning information for the shades or louvers. The result is scientific Window Management on a minute-by-minute basis.

SolarTrac's Sky Array algorithm determines the current sky condition—clear or cloudy—by utilizing solar radiation values that are continuously measured by solar radiometers, aggregated over time, and compared in real-time with the computed ASHRAE Clear Sky values to determine the current microclimatic sky condition from sunrise to sunset. This system affords a response time of less than a minute after crossing a defined threshold.

Shade positioning is accomplished by analyzing the project's glazing geometry vis-à-vis the solar geometry to control the penetration of the solar ray into the building's interior by adjusting the position of the shade bands on the glazing in accordance with user-defined requirements.

The shade or louver positions are adjusted incrementally on the window and skylights to assure the human-factor requirements of personal comfort, daylighting, and architectural uniformity.

FIGURE 5. SolarTrac® Automated Shading Flowchart



Courtesy Loisos & Ubbelohde.

8.3 SolarTrac® Performance Factors

SolarTrac's scientific method of automated window shading offers a high degree of performance and resolution. The system's accuracy, precision and performance are measurable and verifiable for and during commissioning. Solar radiometers measure the sky radiation in real-time, and this data is compared to the ASHRAE Clear Sky radiation values. Radiometers combined with MechoShade's Virtual Daylight Brightness™ program eliminate the need for daylight measuring sensors on the building's windows, thereby substantially cutting costs for installation and maintenance. Radiometers provide complete, timely and accurate solar values compared to daylight sensors alone (see Table 2 above).

8.4 Solar Data

Solar data and mathematical formulas allow SolarTrac to adjust the shades and/or louvers in accordance with a variety of factors. The SolarEvaluation system calculates how, where and when the window covering needs to be adjusted.

The ASHRAE Clear Sky radiation formula is used to determine radiation values by latitude, the position of the Sun, and the position of the solar ray to any point on Earth or the building's facade, every minute from sunrise to sunset, given the atmospheric turbidity, or clearness value.

a. profile angle: the "shadow angle" that determines solar penetration through a vertical surface.

b. incidence angle: the angle used to calculate the heat load, in $BTU/hr/ft^2$ or W/m^2, using a combination of the altitude and the surface solar angles.

c. altitude angle: the position of the Sun above the horizon.

d. surface solar angle: the position of the solar ray in relation to a line perpendicular to the glazing.

e. project-specific measured solar radiation: the heat gain from sunrise to sunset for all the glazing, regardless of its slope, pitch or tilt.

8.5 SolarTrac's Performance and Repeatability

The SolarTrac system's consistent performance has been verified and detailed in the Lawrence Berkeley National Laboratory's post-occupancy review of the New York Times Building in Manhattan, as published on the lab's website: http://windows.lbl.gov/comm_perf/newyorktimes.htm.

The press release is available at:

http://eetd.lbl.gov/news/article/30598/big-energy-savings-in-the-new-york-times-building-confirmed-by-berkeley-lab-study.

8.5.1 SOLARTRAC'S BROWSER INTERFACE

The graphical user interface (GUI) on SolarTrac's™ browser allows remote IP access, with the ability to change settings and put required user overrides into effect. Access to the database and standard reports are available via the browser interface.

All standard browsers are supported, including Microsoft IE, Mozilla Firefox, Apple Safari and Google Chrome. Security is implemented so that users entering through the browser interface must enter login credentials in order to access the protected features of SolarTrac™.

The interface offers a standardized method for integrating the SolarTrac™ graphical user interface into the BMS.

The browser interface supports simultaneous multi-user access to SolarTrac™ and provides the appropriate, secured-access level to each user. The Administrator level can create users and determine which functionality they may access. For example, the building administrator may grant access to a particular person on a particular floor so that that individual can override certain shades in defined zones.

The browser interface supports the following SolarTrac™ functions:

a. floor, zone and shade position overrides
b. floor, zone and shade position reporting
c. real-time sky analysis to report the current the sky condition
d. an event scheduler for building wakeup and sleep times, and an override cancel timer
e. zone properties (e.g. maximum solar penetration, BTU thresholds, cloud position, brightness override threshold, etc.)
f. global properties (e.g. clear-to-cloudy timer, cloudy-to-clear timer, clear sky threshold, etc.)
g. maintenance mode
h. event log (historical data)
i. real-time sensor data
j. sensor logs (historical data)
k. reports

8.5.2 MOBILE DEVICE APPLICATION

With the proliferation of applications for mobile devices, there is an expectation that access and control of automated shading systems can be done through an app. The SolarTrac app allows a facilities manager to remotely access the system from anywhere, inside or outside the facility.

The app can be used, for instance, to allow an office occupant the limited capability to temporarily override his or her shade. Another use would be to allow for the control of blackout shades in a conference room. The SolarTrac app offers this type of customized control, and will soon be available for iPhone, Android and other mobile devices.

8.5.3 BMS INTERACTION

SolarTrac provides sky, solar and shade position data to the BMS system, which may shift the BMS from being a reactive system to being a system that incorporates predictive sky and solar data, including the thermal (heat) and solar radiation loads on the building. The BMS system can use this data to anticipate changes in the exterior thermal environment and adjust thermostat settings to increase or decrease the air flow into the perimeter zones, well before the sensors pick up on the changes. This creates the opportunity to improve the efficiency of the BMS.

8.5.4 INTERACTION AND COMMUNICATION WITH THIRD-PARTY SYSTEMS

It is necessary that third-party systems, such as lighting control and HVAC, be able to communicate with the Window Management system. The sharing of data may be very helpful in maintaining an optimal environment as different circumstances arise.

For example, lighting control systems often utilize occupancy sensors in order to reduce electric lighting in areas that are unoccupied. SolarTrac can also use that occupancy information to modify the shade positioning rule in a given area. When an area is occupied, the shade-positioning algorithm takes human factors into account by maximizing natural light, minimizing glare and affording a view. When the same area is unoccupied, the emphasis shifts to the energy efficiency of the building's operations. The thermal issues to be managed are: (a) conductive heat gain or heat loss, (b) solar heat gain, and (c) the need to reduce solar heat loads in summer and minimize heat loss in winter.

A second example of useful coordination between lighting and shading systems is to manage light pollution. It may be necessary to deploy shades at night so that light from a building does not create unnecessary brightness in the surrounding neighborhood. This may be more necessary in winter than in summer, when foliage may mitigate much of the light escaping from a building.

In any case, SolarTrac has the capability to share information with other building systems in order to fully optimize the Window Management system.

8.5.5 SOLARTRAC'S SOFTWARE MAINTENANCE

As part of the cost of the project, MechoShade's SolarTrac program includes six months or one year of online support and fine-tuning. This support includes the initial training for the operations staff. The end-user is also encouraged to order either a three-year or a five-year software maintenance and support agreement before the end of the fine-tuning time period. This agreement offers: (a) a reduced price when making changes to zones, if and when the interior spaces are reconfigured, (b) online support, (c) a reduced price for on-site support, (d) standard reports, and (e) a once-a-year project survey with the operating staff and additional training for each year of the software maintenance contract.

8.5.6 SOLARTRAC'S WINDOW-COVERING MAINTENANCE PROGRAM

MechoShade provides a master hardware maintenance agreement for the owner to secure from an authorized dealer. This agreement includes, among other elements: (a) an annual full building inspection, (b) fixed costs for non-warranty products, (c) fixed costs for changes, and (d) a training package for the window-covering dealer and electrical maintenance firm so they can inspect and service the system, from the SolarTrac module to the motor, in the event of the failure of a part of the system.

It should be noted that all motors have a disconnect plug, which allows for the immediate testing of the motor outside of the system to verify if the motor is operating or not. If the motor is functioning properly with a remote tester, then the troubleshooting starts from that point back to the central connection, and then back to the control system, which is checked to verify that it is sending communication signals appropriately.

8.5.8 BACNET COMMUNICATION PROTOCOL

The SolarTrac Infinity and SolarTrac 50 systems offer BACnet, an embedded communication protocol that meets ASHRAE, ANSI and ISO standards. BACnet is one of the most popular communication protocols between a building's BMS/BAS energy control and management systems and a third-party system. BACnet utilizes I/O (input/output) points to communicate, and the number of points included in the system indicates the degree of communication that is possible between components. The following is a summary of the current capability of SolarTrac's BACnet communications, which can support up to 65,000 points.

The BACnet protocol considers each input/output (I/O) point as a single parameter, such that a solar zone's current position or a motor's current position can be a BACnet point. With SolarTrac, a zone encompasses a multitude of real-time values associated with the solar zone: current mode of operation (auto, override, night, maintenance); calculated BTU load; solar penetration; profile and incident angles, etc. Therefore, since we do not know exactly which parameters the Window Management system will be allowed to access, or which are required, or which parameters are of interest to the BMS, we use 10 as the typical number of zone parameters that can be shared as BACnet points per zone, and 10 as the number of parameters for each motor. This is likely to be far more that any BMS/BAS requires.

The number of points associated with each motor will likely be fewer, since most of the pertinent parameters that SolarTrac maintains are solar zone-related. But even if we allow 10 points per motor, we can still manage it well within our 65,000 points:

(200 zones @ 10 points/zone) + (1,000 motors @ 10 points/motor) + (200 sensors* @ 1 point/sensor) + 10 global points = 12,210 points vs. 65,000 points of communication available

** The SolarTrac Brightness Override module only requires up to 15 sensors for calibration, not 200. However, systems from other manufacturers do utilize a plethora of sensors and thus those are included in our calculations.*

8.6 SolarTrac's Solar Penetration/Heat Load Module

All SolarTrac models—SolarTrac Infinity, SolarTrac 50 and SolarTrac 12—incorporate a Solar Penetration/Heat Load module within the base operating program. This module manages both the penetration of the solar ray into a building and its heat load in real-time.

The Solar Penetration module measures the profile angle of the solar ray and the geometry of the window to adjust the position of the shade or the tilt of the louvers in accordance with user-defined values for solar penetration.

The Heat Load module computes the heat load (in BTU/hr/ft^2 or W/m^2) on all the glazing in real-time, working in conjunction with a Sky Array™ determination of whether the sky is clear or cloudy, to find the appropriate shade or louver positioning.

The system changes the position of the shades or the tilt of the louvers based on either the profile angle of the solar ray or the calculated heat on the glazing under consideration. In either case, there is a Go/No-Go default setting that needs to be exceeded before either of the module's components is activated. The solar penetration and heat load default values are user-defined, globally or by zone.

The Solar Penetration/Heat Load module has been designed for glazing with any orientation, slope or tilt.

For managing vertical windows, the SolarTrac module:

- computes the geometry of the window and the solar ray, and compares them with the user-defined default settings for solar penetration.
- computes the heat load on the glazing to move a shading device to the appropriate default position, all in real-time.
- For horizontal, sloping or tilted skylights, or for roof glazing, the SolarTrac system computes the position of the solar ray and its impact in the building and compares these with the allowed solar penetration profile angles. It also computes the heat on the glazing and adjusts the shading device to the appropriate position to control the heat flow into the space below the glazing.

8.7 SolarTrac's Optional Embedded Modules

All SolarTrac operating programs offer ASHRAE Clear Sky and Sky Array analysis for use in conjunction with the solar penetration/heat load module for roller shade or louver positioning. As well, four additional, optional modules are embedded in the program:

a. Brightness Override modules, both sensor-based and software-based

b. 3-D Urban Shadow module

c. Reflectance module (available only with the 3-D Urban Shadow module)

d. Suburban Shadow module

When required, these embedded modules can be activated and programmed to increase the scope and effectiveness of the SolarTrac system, based on the needs of the building and its occupants at any time, now or in the future. Project-specific programming may be required.

8.7.1 SOLARTRAC'S BRIGHTNESS OVERRIIDE MODULES

SolarTrac's Brightness Override modules adjust the window-covering position of roller screens or louvers based on the level of window luminance. The purpose of the system is to inhibit excessive brightness between the illuminated window and an individual's work surface or computer screen, inside the 60° viewing angle of the occupant of that work area. The modules assure the visual comfort of occupants by managing the contrast ratio between the brightness of the window and the illumination of the work surface. The current recommended contrast ratio for visual comfort is 1 to 7, though historically the preferred contrast ratio was 1 to 10. With glazing that has a Vlt of 0.65 to 0.70, and computer screens that have a brightness of 2,000 cd/m^2 (nits), a good starting point is 2,000 cd/m^2 at the glazing.

8.7.2 SENSOR-BASED BRIGHTNESS OVERRIDE MODULE

Using exterior lux photometers and hard-wired interior sensors, the SolarTrac sensor-based Brightness Override module measures and compares the visible light portion of the solar spectrum falling directly on the building and through the glazing. Photometers are used to calibrate the sensor system in case the window glass is dirty. When the measured illuminance inside exceeds a predetermined default value, the shade/louvers are moved to a predetermined, user-defined position. Commissioning and fine-tuning after occupancy are recommended.

8.7.3 SOFTWARE-BASED BRIGHTNESS OVERRIDE MODULE

SolarTrac's InfiniteBrightness™ Module, a software-based illuminance program, determines the brightness of the glazing based on radiometer measurements that have been curve-fitted to compute the indoor illumination level. The program then manages the positioning of shades and louvers to control brightness. The software-based InfiniteBrightness Override module eliminates almost all of the otherwise necessary lux sensors in a building, which in turn substantially minimizes the costs of front-end installation and ongoing maintenance. A few sensors are used for calibrating the curve fit and the predetermined shade/louver intervals. This system is included in the commissioning process and is fine-tuned after occupancy.

8.8 SolarTrac's 3-D Urban Shadow Module

The 3-D Urban Shadow module employs a digital 3-D model of the building and the surrounding area to predict, with substantial precision and repeatability, where and when the surrounding structures and the environment will cast shadows on the building. The system determines which parts of the building are in shadow and allows the shades to be opened, allowing as much usable daylight into the space as possible. The system distinguishes between the shadows cast by other buildings and the shadows cast by clouds.

The 3-D Urban Shadow module predicts when and how long the shadow will be on any particular window or zone. The sky condition is monitored and reported continuously in real-time. If the sky is determined to be clear, the system then calculates whether a shadow will fall on any part of the building. If the sky is cloudy, there will be no such shadows or shade movements.

Performance precision is within 0.05°. Response time is within one minute of exceeding an established threshold. The 3-D Urban Shadow module is generally required for urban areas with uneven, undulating landscapes. This module eliminates "rainy day" and "sprinklers watering the lawn in the rain" conditions. Project activation is required.

8.8.1 REFLECTANCE MODULE

The Reflectance module, a subset of the 3-D Urban Shadow module, adjusts shades and louvers to veil the glare and prevent or minimize the impact of shards of reflected light from nearby buildings or bodies of water. It measures first-generation specular reflections from adjacent buildings and the surface of lakes and rivers, which are incorporated into a 3-D model of the environment around the building. The Reflectance program requires activation of the 3-D Urban Shadow module, and a current 3-D model of the local region and the surface reflectivity of adjacent structures is required and may be provided by the owner. Precision is within 0.05°, and the response time is within one minute of a required response.

8.9 SolarTrac's Suburban Shadow Module

The Suburban Shadow module provides shade and shadow management for projects in suburban areas, on low-rise campus sites, or on project sites where the surrounding terrain is reasonably uniform. The module utilizes an adjusted false horizon, by zone, based on the landscape of the project and its solar orientation. It does not require the 3-D model needed for urban sites, and hence is very cost-effective.

8.10 Methodologies for Shade Positioning

Control and management of solar penetration and/or heat load (SHG) through all glazing is accomplished by utilizing the ASHRAE-calculated position and intensity of the solar ray and computing profile angles for all windows. By precisely managing solar penetration and/or heat load, the optimal shade position can be achieved, thereby maximizing the natural daylight in the space without excessive glare or discomfort. It should be understood that both shade and louver control methods, including electrochromic glazing density, may be employed at the same time on different widows or zones.

8.10.1 SHADE POSITIONING TO MANAGE SOLAR PENETRATION

The Solar Penetration module positions shades and louvers in order to limit the penetration of direct sunlight onto the floor for every window zone, including, but not limited to, vertical, sloped or horizontal glazing. This provides protection from the direct solar ray's radiation, maximizes daylighting, promotes energy efficiency, improves views to the outside and allows for architectural alignment of the window coverings.

Precision of the penetration of the solar ray through the blind louvers shall be within one degree, and within one inch at the floor of defined threshold by zone for roller shades, all in real-time. Every zone and blind type shall have a defined solar penetration value that may be modified by the user.

8.10.2 SHADES TO MANAGE SOLAR HEAT GAIN

The Solar Heat Gain (SHG) module adjusts shades and louvers based on the calculated heat gain on the glazing under consideration. Shades and louvers are moved to different incremental positions on the glazing—whether vertical, horizontal or sloped—in accordance with user-selected heat gain thresholds (in BTU/hr/ft^2) for each of the shade/louver positions required on the glazing, for each window group. The Solar Penetration and Heat Control modules both utilize heat-level default values for Go/No-Go for all shading systems, including electrochromic glazing and individual panels of EC glazing.

8.10.3 SOLAR CONTROL FOR SKYLIGHTS

There are numerous skylight configurations, sizes and orientations, with various shading systems employed to provide required shading. The skylight may be a grid of glazing modules with shades or louvers. Special low-heat and high light-transmitting glazing is often used in skylights because of the increased heat load and brightness. In some cases, a porcelain frit is added to the glazing in a predetermined pattern that affects the openness factor of the glazing. The patterned frit will reduce the heat gain and brightness, but generally not in a dense enough pattern to provide personal solar protection. There is a direct correlation between the density of the frit on glazing and the density of the shade cloth for solar protection. It is our understanding that the main purpose of adding the frit to the glazing is to reduce heat gain and not for personal protection from the solar ray.

Management and control of these different skylight configurations and shading is accomplished by controlling either each individual glazing module or the entire skylight as a single shading element, as was traditionally done. The intent is to provide solar protection, maximize daylighting and offer a view of the sky.

The program requires the parties to develop a range of profile angles, or allowable heat gain, for the area under the skylight. The skylight shading may be organized to maximize the view to the sky and meet the allowable solar penetration or heat gain requirements. Defined profile angles for controlled solar penetration and no penetration are used to lay out the most effective skylight configurations to minimize closing of the individual skylight shade systems. SolarTrac is used to adjust shade positions to meet the defined objectives of maximizing the view of the sky with protection from the solar ray and excessive heat gain. Special programming is required and is project-specific.

8.10.4 MANAGING THE SOLAR INCIDENCE ANGLE FOR SKYLIGHTS

Parameters to consider for skylight incidence and managing the angle of the solar ray:

a. Defining the allowable and not-allowable areas for solar ray penetration into the space under the skylight.

b. Establishing the range of profile angles that meet the allowable and not-allowable areas of solar ray penetration.

c. Analyzing the structure of the skylight and determining the most effective skylight shade layout to maximize the skylight openings and provide protection from the solar ray for the areas under the skylight.

The skylight shades will be managed by SolarTrac to offer a maximum view of the sky without allowing penetration of the solar ray, as specified. The skylight shades perform as a shutter. Special programming is required and is project-specific.

8.10.5 SHADE POSITIONING IN SKYLIGHT TO CONTROL SOLAR HEAT GAIN

SkyLight Management may be based on a user-defined heat load (in BTU/hr/ft^2 or W/m^2), or on the heat value settings integrated with the incremental shade positions on the skylight. In its current form, the SolarTrac zone for skylight shading may be programmed to move the shading system or adjust the louvers incrementally based on preset default values in BTU/hr/ft^2 or W/m^2. There are three intermediate positions available on the override switch, with a still larger number of incremental shade positions available on the SolarTrac system. Each incremental shading position is controlled by its default BTU setting.

8.11 Fine-Tuning the User-Configurable Settings

The SolarTrac system is designed to be configurable and flexible in order to meet the specific requirements of the occupants in large and small buildings. The following is a list of some of the configurable settings.

TABLE 4: SolarTrac Settings Configurable by Users

Category	Sub-Category	Function
Overrides	Floor	Shade/louver position
		Return to auto
		Maintenance mode on/off
	Zone	Shade/louver position
		Return to auto
		Maintenance mode on/off
		Recapture/uninhibit shades/louvers
	Shade	Shade/louver position
		Return to auto
		Maintenance mode on/off
Scheduler	Floor	Add, delete, modify floor move events
	Zone	Add, delete, modify zone move events
	Shade	Add, delete, modify shade/louver move events
Properties	Global	Clear-to-cloudy timer
		Cloudy-to-clear timer
		Clear sky threshold
	Zone	Enable/disable automation
		Maximum allowable solar penetration
		Cloud position
		Brightness override threshold
		Brightness release threshold
		Brightness time delay
		Brightness release time delay
		Night position
		Sleep position
		Sleep time
		Wake position
		Wake time
Security		Add users (with equal or lower access level)

9 WINDOW AND LIGHTING MANAGEMENT

9.1 Daylighting: Synergism of Automated Shading and Lighting

Automated shading (Window Management®) and automated lighting (Lighting Management®) are independent reactive systems that interact to maximize ambient illumination and daylighting while providing comfort from solar penetration and radiant surfaces. MechoSystem's automated shading technology, SolarTrac, reacts to the microclimatic sky condition and adjusts shade heights and/or louver positions to maximize and harvest daylight while protecting occupants from direct solar radiation. Saving 1 kWh of lighting energy yields a total savings of 1.25 kWh in electrical energy for lighting and HVAC.

Daylighting is enhanced through the increased use of curtain walls, windows, skylights and illumination beamed into the building with light shelves. Automated shading is used to manage the amount and quality of natural light during the day so that the natural light provides effective internal lighting without the negative effect of excessive brightness and/or direct radiation. The current use of high-transmission glazing, with a heat gain value of 0.40 and visible light transmission of 0.70, allows for more daylight and less heat through the glazing. Particular attention is given to daylighting when designing a building in which the aim is to maximize visual comfort and reduce energy use. Energy savings can be achieved by reducing the use of electric lighting through the interaction of an automated window-shading system and the implementation of an automated lighting-control system.

The efficacy of daylighting is much higher than artificial lighting. Artificial lighting generates more heat per watt of energy. See Table 3 above to compare the efficacy of various types of artificial light to daylight. Because of the increased heat generated by artificial lights, the air-conditioner tonnage required to keep the building cool increases. Approximately 40% of the energy consumed by fluorescent and LED lighting becomes visible light; a full 60% becomes heat, which contributes to the interior heat load and needs to be evacuated by the HVAC system. Thus, every kilowatt of lighting energy conserved creates an energy savings of 125% and a heat-to-light ratio of 3 to 2.

9.1.1 THE EFFICACY OF DAYLIGHT

Daylight is comprised of 33% heat and 67% visible light, for a heat-to-light ratio of 1 to 2. The type of glazing used in a building changes the final daylighting effect, as glazing with an SC of 0.40 and Vlt of 0.70 will substantially increase the ratio of heat to light.

9.2 Window Management®

MechoSystem's proprietary term for the automated control of sunlight and heat through a window is Window Management®. This automated system:

a. maximizes daylighting and views to the outside.

b. measures solar radiation and utilizes solar science to adjust the shading on the glazing in accordance with a prescribed set of rules.

c. protects people from direct shortwave solar radiation.

d. manages window brightness.

e. manages the contrast ratio in brightness between the window and the work surface, which is generally assumed to be nine feet away from the window wall.

f. balances and adjusts the competing requirements of maximizing daylighting and offering protection from shortwave solar radiation.

g. responds to changes promptly, within a minute, if the changes cross a set threshold.

9.3 Lighting Management®

MechoSystem's proprietary term for the management of natural and electric light sources is Lighting Management®. Such systems:

a. position shades and louvers to maximize daylighting and reduce artificial lighting and HVAC energy consumption.

b. utilize various lighting-control strategies depending on occupant use, including, but not limited to, dimming and load shedding.

c. eliminate artificial lighting where it is not needed.

9.4 Automated Lighting Control Systems for Energy Reduction

Automated lighting control systems:

a. offer daylight harvesting with linear dimming control based on available daylight illumination.

b. feature on/off switches.

c. feature time scheduling.

d. feature programmed linear dimming with a minimum lighting set point that defaults to 50 foot-candles.

e. provide information about occupancy to the window management system.

f. offer task tuning.

g. offer load shedding based on a demand signal.

h. activate upon entrance.

9.5 Methodology of Window and Lighting Management

Automated shading control (Window Management) and automated lighting control (Lighting Management) are independent reactive systems used in conjunction with each other in order to realize their full energy-saving potential. The two systems are connected only by their reactions to the ambient illumination and the solar environment.

With the correct application of an automated shading and automated lighting control system, a building can maximize energy savings while maintaining a glare-free, comfortable visual environment for occupants. Failure to implement either one of these two automated systems can lead to unacceptable contrast ratios, occupant discomfort and the loss of potential energy-saving capability.

9.6 Conflicting Requirements for Shading and Dimming

SolarTrac monitors many aspects of the environment and adjusts the position of shades and louvers to balance conflicting requirements. The order of priority between various parameters is defined in SolarTrac based on MechoSystems' 34 years of experience with roller shade and louver control. The shades and louvers are moved in real-time in response to outside conditions and expected indoor comfort. Some of the parameters that are followed in these integrated control systems are described below.

9.6.1 CONTRAST RATIO: A VISUAL PREREQUISITE

The contrast ratio is the relative degree of brightness (or luminance) of a window compared to the luminance of the work surface within an occupant's 60° field of vision. It is measured in candelas per square meter, or cd/m^2. Based on the performance of SolarTrac in the New York Times Building, our experience indicates that a contrast ratio of 1 to 10 or higher was appropriate and preferred in some sections of the building.

To manage contrast ratios, the system measures the illuminance of the work surface at 30 inches (76 cm) above the finished floor. The SolarTrac system uses this data to move the shades and louvers to a predetermined position when the brightness values at the window wall fall within a defined contrast-ratio threshold of 1 to 7, or 1 to 10, as determined on site.

For optimum contrast ratios, IES specifies 1 to 7, although historically the contrast ratio has been 1 to 10. Alternatively, the contrast ratio can be established by the building management staff.

9.6.2 AUTOMATION OF CONTRAST RATIOS

Window Management® automation is required for monitoring the brightness of all the windows. It compares the brightness of the windows to the established illuminance of the work surface (measured in foot-candles or cd/m^2), and determines if and when the shades and louvers should be repositioned to decrease excessive brightness from the unshaded portions of the windows. This protects the occupants from excessive bright spots.

10 CONTROL METHODOLOGIES

10.1 Distributed Intelligence with a Central Server

Currently, and looking into the future, major buildings are designed for "mixed occupancy." Tenants in the building may have substantially different requirements, all of which need to be supported. Every one of these tenants may need an automated window management operation that meets their specific needs. Such mixed-occupancy buildings may include office space, hotels, public restaurants, residential apartments and mechanical floors. All of these requirements can be met by using SolarTrac Infinity™ in conjunction with an intelligent floor controller, which is a server-based, multitasking sub-control system for major projects. The central server must be able to communicate with the rest of the building's energy-operating systems, specifically with and through the BMS or BAS energy-management and security systems. BACnet appears to be the most ubiquitous system used today, although KNX appears to be becoming popular in Europe.

10.2 Open-Architecture Communication Between Operating Systems

The selected system should have open communication between the BMS/BAS energy management systems and the central server, which in turn should have an open-communication architecture between the automated window covering system server and the motorized systems it controls.

The communication datagram between the central server and the operating window-covering systems will vary between shading system manufacturers. It is important that the control datagram between the central server and the motors operating the shading device have an open and accessible architecture to allow for the control of many window-covering products from different manufacturers in the same building. For example, the central server may be controlling the tilt angle of louvers on some windows, adjusting the position of roller shades on others, and moving the shade modules on a skylight in accordance with a solar-ray-control strategy.

In some cases, the window-covering operating system may be tasked to control various third-party motorized building components—e.g., audio/video systems—or to open and close air vents or motorized windows for ventilation purposes. In these cases, the logic for moving air-related devices may be initiated by the HVAC or air-quality systems via the BMS/BAS system to the window-management control system, which has control modules and systems at the window wall. In the case where audio and video components are integrated with a shading system, the command may come from an integrated control system that manages several elements to create the appropriate setup for a meeting.

There are various system communication protocol choices: RS232/485, Lonworks, KNX and other technologies. The selected system should be able to accommodate all these protocols for system operations. For future service and maintenance, the vendor owes the general contractor/building owner the documents for the address tables and the matrix mapping of all the systems, with a pre-priced programming fee base.

10.3 Intelligent Motor Controllers for Every Floor

For the purposes of backup and redundancy, a distributed, intelligent floor-management system stores each day's solar program, with direct access to the array of radiometers for sky evaluation. In the rare event that the central controller fails, the entire system will continue to operate from the local program. Each day's program is downloaded into the floor controller. Each floor controller will continue to manage the window-covering devices for which it is responsible. The floor controllers can be accessed and managed from anywhere on the network. Diagnostics are performed remotely over the network through a two-way communication system. There is a floor controller for each floor, or for multiple floors, as required.

Multi-functional intelligent floor controllers provide backup and redundancy. The "floor controllers" communicate with the motor-control devices and intelligent motors on each floor through a "gateway" in the risers, and also store backups of the year/day program used.

The features of these floor controllers include:

a. communication, through the gateway in the risers, with the SolarTrac central server.

b. communication, through the gateway in the floor network, with the motor controllers and the motors.

c. storage of the latest year-day solar programs for operation.

d. communication with the radiometers.

e. storage of year-day operational data. In the event of a loss of communication with the riser or the central server, the floor controller has stored the last solar day program and will continue to use it. The system can operate with or without input from the radiometer. Without input from the radiometers, the system will operate in a clear-day mode until communication is restored.

10.4 IT and Internet Requirements

The successful installation of a window management system, with ongoing post-occupancy support, requires remote monitoring of the system by the manufacturer over the internet. It is suggested that the window-management system be on a separate network from the company's internal business network. Online and telephone support is a critical element in the fine-tuning of the project after occupancy in order to meet specific requests from personnel.

11 SOLARTRAC MODELS & PRODUCTS

All SolarTrac operating models call on the same combination of programs and formulas, including but not limited to: ASHRAE Clear Sky mathematical calculations, solar characteristic algorithms, radiometer monitoring of total solar sky radiation and subsequent analyses. The SolarTrac core program creates a continuous year day sky model to provide appropriate window management for each SolarTrac model.

11.1 SolarTrac Infinity

SolarTrac Infinity is designed to support large projects and incorporates a complete, comprehensive, intelligent automated shading management system, utilizing ASHRAE Clear Sky algorithms with real-time measurements. For all practical purposes, SolarTrac Infinity can support an unlimited number of control zones.

SolarTrac Infinity incorporates daylighting and the science of Window Management, which includes the basic ASHRAE Clear Sky calculations, the computed load of radiation and heat on all glazing surfaces, a microanalysis of the sky above the building, and predictive sky and heat analyses. SolarTrac Infinity includes a user-defined heat load threshold in BTU/hr/ft^2 or W/m^2 to activate the system, programmed either by zone or globally. Shading may be controlled to manage the heat and solar radiation load, given the geometry of the windows, as well as the intensity of the solar ray and solar penetration. The system includes expanded BACnet support for communication with the BAS.

11.1.1 SOLARTRAC INFINITY: FEATURES AND CAPABILITIES

a. manages 1,000 or more shade and louver zones, with continuous minute/day/year resolution

b. makes individual, continuous, 365-day-per-year solar calculations

c. offers expansive local accessibility for changes to the user-defined set points, which include but are not limited to:

    1. adjusting the shade recapture time after a manual or BMS override
    2. adjusting the heat gain in $BTU/hr/ft^2$
    3. scheduling both repetitive and non-repetitive events by motor group, hour, day, week, month and year

d. offers prompt, adjustable response times as sky conditions change from cloudy to clear and clear to cloudy

e. compares Clear Sky radiation values to the actual sky condition, using the Sky Array logic to determine whether it is a clear or cloudy day

f. makes changes to motor groups (as part of an optional, additional software-maintenance agreement)

g. creates access to the structured query language (SQL) database for expanded custom reports

h. offers BACnet support for BMS/BAS integration

i. manages roller shades and louvered blinds

j. responds to environmental changes within 60 seconds

The system has some embedded modules that are only programmed if the project requires them. These modules are:

a. a Brightness Override module that utilizes Solar Analysis software to manage daylighting

b. a Brightness Override module that utilizes hardwired lux sensors to manage daylighting

c. a 3-D Urban Shadow module for city-center projects that utilizes a 3-D model of the building and its built surroundings. Based on the accuracy of the 3-D model, it offers a precise shadow solution with a resolution of 0.05°.

d. a Reflectance module, a separate subset of the 3-D Urban Shadow module. Controls first-generation reflections from other buildings and nearby bodies of water.

e. a Suburban Shadow module that is based on the specific landscape of the project and utilizes virtual zone horizons.

11.2 SolarTrac 50

Solartrac 50 is a new, expanded, cost-effective program intended for medium-sized projects with up to 50 zones. SolarTrac 50 offers full SolarTrac capability with continuous minute/year/day resolution, for 365 days a year of solar programming.

The system:

a. manages up to 50 shade zones

b. includes SolarTrac's sky analyses, predictive logic and shade positioning

c. tracks and monitors the sky condition

d. predicts and adjusts the shade-band heights according to solar default values

e. determines whether it is a clear or cloudy sky

f. supports the software-based Brightness Override module for daylighting, on a project-specific basis

g. supports the Surburban Shadow module, based on the landscape of the project and utilizing virtual zone horizons

h. utilizes unique, 365-year-day adjustments for shade positioning

i. utilizes up to three radiometers
j. integrates with BacNet and BMS programs
k. permits intranet access for user-defined defaults
l. does not include the 3-D Urban Shadow module or the Reflectance module

11.3 SolarTrac 12

The SolarTrac 12 system, formerly known as the SunDialer, is for new or retrofitted smaller projects. The system covers up to 12 zones of operation, with full SolarTrac sky analysis with radiometer input. However, the optional modules are limited. It does not include the Brightness Override module, though it can perform an optional Suburban Shadow analysis by utilizing zone-based artificial horizons. The precision of the shadow analysis is to be determined and is based on the landscape of the project. The SolarTrac 12 system:

a. manages up 12 shade zones
b. uses individual solar calculations for 52 days per year, one day each midweek
c. provides full ASHRAE Clear Sky solar evaluation with radiometer sky analysis
d. tracks and monitors the sky condition
e. predicts and adjusts the shade band heights according to solar position default values in real-time
f. determines whether the sky is clear or cloudy using the Sky Array analysis program
g. includes SolarTrac's predictive logic, sky analyses and shade positioning
h. can operate in a "clear sky mode" all of the time when the radiometers or photo sensors are not available
i. offers intranet control of user-defined default values

11.4 SunDialer 50 Brightness™

The SunDialer 50 Brightness system utilizes photometers to measure the daylight portion of the solar spectrum, which makes up 49% of solar energy. These sensors are not as precise as radiometers, which measure +/- 98% of the solar energy of the Sun. However, the SunDialer 50 Brightness system is more advanced than other daylight measuring systems. The SunDialer 50 Brightness develops a year-day program for 365/52 days a year and responds to changes in threshold settings in real-time, or within 60 seconds of a change, without the need for an hourly lookup table.

The SunDialer 50 Brightness system measures changes in the amount of daylight on the glazing to adjust shades to the required position. Its daylight measuring system is used in conjunction with a program that determines the location of the Sun as part of its shade/blind-positioning solar penetration program.

Optional embedded modules may be activated on a project-specific basis:

a. a software-based Brightness Override module utilizing solar analysis
b. a Suburban Shadow module, based on the landscape of the project and its solar zone
c. management of up to 50 shade zones

The SunDialer 50 Brightness system:

a. monitors sky conditions in real-time
b. predicts and adjusts the shade-band heights according to user-defined solar penetration or heat load default values
c. determines if the sky is bright or dark
d. offers a Brightness Override module

e. offers a Suburban Shadow module

f. utilizes a unique, 365 day/52 year day program, five (5) times a minute each day, sunrise to sunset, for precise shade positioning

g. utilizes solar radiometers

h. uses up to four photometers as well as local lux sensors, as required

i. integrates with BacNet and BMS programs

j. offers intranet access for user-defined defaults

k. does not offer the 3-D Urban Shadow and Reflectance modules

11.5 SunDialer 12 Brightness™ Performance Factors

MechoShade's SunDialer 12 Brightness system utilizes a combination of lux sensors, hard-wired window sensors and radiometers with an integrated software program that computes the amount of daylight by solar zone in real-time, eliminating the need for a large number of lux sensors. This unique combination of lux sensors, which measure the daylight portion of the solar spectrum, with radiometers, which measure the entire UV, daylight and infrared portions of the solar spectrum, uses a very limited number of lux sensors for verification and calibration of the system.

Generally, the degree of accuracy when utilizing daylight sensors is directly dependent upon the number of sensors installed, given the square footage of the surface of the building. Some manufacturers claim to use daylight measuring sensors that determine brightness, shadow and cloud conditions. SolarTrac uses radiometers to measure the total UV, heat and light on the building, and to determine whether the sky condition is clear or cloudy by comparing ASHRAE Clear Sky radiation values to the measured values to determine the sky condition.

The SunDialer 12 Brightness system uses lux sensors for special conditions. The position of the solar ray on the building's glazing is calculated, in conjunction with the geometry of the window, to determine the position of the Sun on every window, in real-time, to manage shade positioning. The degree of accuracy for managing solar penetration into the interior space is plus or minus three inches, plus or minus the deviance of the changes in the position of the solar ray from day to day. The system's response time for resolving solar penetration is within three minutes of exceeding the selected value.

The accuracy of the system's response time to shadows falling on the building will be determined, by zone, after installation. The number of solar zones is limited to 12.

12 IMPLEMENTATION OF AN AUTOMATED SHADING PROJECT

12.1 Project Kickoff

A good start begins with preliminary meetings between the installation and operational groups. These may include but are not limited to:

a. a general contractor

b. a window-covering contractor

c. an owners' representative

d. a facilities or IT director

e. an electrical contractor

f. others as determined by the owner and the main contractor

12.2 Pre-Occupancy Training for Facility Staff

On-site training requires the participation of at least two people from the facility who will be operating the system software. This is end-to-end training for the entire control system, which includes, but is not limited to, a program for troubleshooting the system in the event of a component failure. MechoShade recommends a minimum of two to three full days for the facilities people to work with the commissioning team to learn the entire system. End-to-end training covers everything from the central server to the motors, with all controls in between—including, but not limited to, troubleshooting the system and its components. In addition, there should be a detailed review of the system's hierarchy and operational philosophy to fully understand its design concept, features and capabilities. Furthermore, there needs to be a full review of the user-accessible default settings to assure appropriate system performance.

a. A five-year software maintenance agreement is offered and suggested upon the termination of the fine-tuning warranty period.

b. A three-year hardware maintenance agreement with the dealer of record is recommended for the annual inspection and servicing of the window-covering hardware and its operation.

c. A three-year hardware maintenance agreement is required with a trained, certified dealer when Hi-Bay and Monumental shades are part of the project.

12.3 Verification of the Shading System's Connectivity

A key element of the training program is to assure connectivity between all the components within the control system. This process requires the cooperation of the window-covering dealer and electrical contractors for the line voltage and low-voltage wiring in order to assure connectivity from the motors to the floor controller to the riser, and from the riser to the central controller.

In the event of a loss of communication with, or loss of control of a motor, the first step would be to disconnect the plugs on the motor and test its separate functioning, using a portable test cable or switch system. If the motor is operating properly, then the connectivity of the system, from the gateway back to the server system, needs to be inspected, and continunity verified by an electrical contractor or a technician, which can be done locally or online by the system vendor.

12.4 Training for Maintenance of the Shading System

The maintenance training program is established based on the size and complexity of the system provided. A minimum of two full days for two facility employees is recommended to work with the commissioning team to learn the entire system from end to end. This extends from the server to the motor and all controls in between, including but not limited to changing the user-defined default values on the system and troubleshooting the entire system.

12.5 SolarTrac and Performance Criteria: Commissioning Standards

TABLE 5: Performance Criteria for Various SolarTrac Systems

#	Performance Criteria	SolarTrac Infinity	SolarTrac 50	SolarTrac 12
1	Computing power	Server-class machine, 64-bit	Desktop class machine, 32-bit	Microcontroller, 16-bit
2	Solar tracking/radiation calculation method	ASHRAE solar geometry, Clear Sky algorithm, NREL for sunrise/sunset time	ASHRAE solar geometry, Clear Sky algorithm, NREL for sunrise/sunset time	ASHRAE solar geometry, Clear Sky algorithm, NREL for sunrise/sunset time
3	Solar angle calculation precision	0.5°	0.5°	3.5°
4	Response time	Less than 1 minute	Less than 1 minute	Less than 3 minutes
5	Precision of angle calculation for solar penetration	1 inch	1 inch	3 inches
6	Year-day program	365	365	52
7	Number of zones	Unlimited	50	12
8	SolarTrac program with solar geometry to position shades/louvers and control solar penetration	Included	Included	Included
9	SolarTrac program for control of heat gain and positioning of shades/louvers	Included	Included	Included
10	Included additional modules (activation is project-specific)	(a) sensor-based Brightness Override module, (b) software-based Brightness Override module, (c) 3-D Urban Shadow module, (d) Reflectance module, (e) Suburban Shadow module	(a) software-based Brightness Override module, (b) Suburban Shadow module	N/A
11	Method of determining sky condition	Every 5 seconds, with an inertia period of 90 seconds	Every 5 seconds, with an inertia period of 90 seconds	Every 30 seconds, with an inertia period of 90 seconds
12	Reaction to changes from clear to cloudy	60–1,800 seconds (user-defined)	60–1,800 seconds (user-defined)	60–600 seconds (user-defined)
13	Reaction to change from cloudy to clear	60–600 seconds	60–600 seconds	60–600 seconds
14	Manual override	Yes	Yes	Yes
15	Override recapture timing	User-defined (with a 2-hour default)	User-defined (with a 2-hour default)	Midnight every day
16	Reaction time to shadows	2 minutes, based on the accuracy of the 3-D model	5 minutes, based on the horizon setting	N/A
17	Reflection reaction time	2 minutes, based on the accuracy of the 3-D model	N/A	N/A
18	Radiometers (#)	Required (3)	Required (3)	Required (2)
19	Photometers	Optional	N/A	In place of radiometer
20	Lux sensors	Required for the sensor-based Brightness Override module	N/A	N/A
21	Training	2 days for 2 facility employees	1 day for 2 facility employees	1 half-day for 1 facility employee
22	Distributed controller	Yes	Yes	No

23	Data logging	Sensor and event log	Sensor and event log	Sensor and event log for the previous two weeks
24	Reporting	Built-in	Built-in	Offline/custom
25	Database	SQL server	SQL server	None
26	Browser/GUI	Yes/yes	Yes/yes	No/yes

12.6 Post-Occupancy Fine-Tuning and Performance Review

A six-month fine-tuning period, with an online review of the performance of the operating program, is required to assure the system is accommodating the special requirements of the tenant. The fine-tuning process is in addition to on-site training and includes a detailed, in-depth software review. Fine-tuning support is for six months for SolarTrac Infinity, four months for SolarTrac 50, and two months for SolarTrac 12.

12.7 SolarTrac Standards & Specifications

TABLE 6: SolarTrac Specifications

Description	Specification
Radiometer sampling frequency	5 Hz.
Radiometer values	0–400 BTU/hr/ft^2
Solar altitude precision	0.5° (20% of 1°)
Solar azimuth precision	0.5° (20% of 1°)
Sky condition determination	Every 6 seconds
Cloudy-to-clear response	60 seconds
Clear-to-cloudy response	User-defined, 60–600 seconds
Brightness sensor precision	As per project specifications
Scheduled event precision	60 seconds
Manual override response	0.5 seconds
Override recapture time	User-defined

13 SOLARTRAC REPORTS

The ability of any automated shade control system to collect and store data is a critical aspect of the system. Historical information about changing sky conditions, shade movements, local overrides and sensor data is used to evaluate the performance of the system over time. Careful analysis of historical data reveals trends in the operation and interaction of the system with the building's occupants. This, in turn, allows for adjustment of the user-defined settings in order to modify and optimize the performance of the system.

SolarTrac utilizes state-of-the-art SQL database technology to store an extensive array of information. This information includes all shade movements, sky condition changes, local overrides and sensor data. With simple interrogations of the database, the user can understand when a particular shade moved and why.

13.1 Standard Reports

SolarTrac has several standard reports that are available to the end-user. These reports allow the user to analyze specific zones and groups of zones for purposes of troubleshooting, trend analysis and optimization. The following reports are available:

a. zone event log by day

b. sensor log by day

c. zone/day clear sky preview report

d. shade positions by date period by floor

e. shade positions by date period by elevation

f. shade positions by date period by building

g. local overrides by date period by floor

h. local overrides by date period by elevation

i. local overrides by date period by building

j. ratio of user override to automatic shade movement

13.2 Custom Report Writing

SolarTrac utilizes structured query language (SQL) database technology to store and access historical shade movement data on sky conditions and the performance of most aspects of the system. This data includes all shade moves, all overrides, sky condition changes, sensor data, radiometer and clear sky data.

An end-user or third-party integrator may utilize read-access to the SolarTrac database in order to create custom reports for various building management-related purposes. For example, the data may be used to support an energy-conservation dashboard.

14 CONCLUSIONS

The time and effort to research and consider the many aspects of automated shading for this white paper have made for an exhilarating learning experience. It is very clear that modern office buildings with dynamic sky and solar enviornments require dynamic operating subsystems to satisfy the human factors required for a successful project. To achieve this goal, it is necessary to understand and select automated systems which analize the changing sky condition and allow for energy-efficient design and operation, ultimately, zero-energy buildings, without sacrificing the comfort of the occupants.

People are at least ten times more reactive to the Sun's heat and glare than to other elements in the building, such as temperature or lighting levels. As a result, there is a much higher need for automated window shading than for other subsystems such as HVAC, BMS and lighting control. Yet those systems are standard in most projects, whereas automated window shading and lighting are not. One goal of this white paper is to explain the varieties of automated shading systems and the superior performance characteristics and advantages of the best-of-breed, interoperative, automated window and lighting systems now available to consultants and end-users. Our purpose is to allow them to select the individual systems that meet the goals of enlightened design, within their budget.

This effort has convinced MechoSystems, more than ever, that automated shading systems for corporate office buildings, multiple-dwelling units, hospitals, government facilities and higher education facilities, will eventually be as ubiquitous as automatic door locks or automatic windshield wiper systems in cars. It is just a matter of time and further good experiences with these systems. Then there will be trust that these systems are very effective and really work.

15 Acknowledgements

I would like to thank Alex Greenspan and Muthu Ramalingam for their research, Michele Albright for copy editing, and Brigid Kavanagh for design. Without their invaluable assistance, guidance, technical expertise and support, this document would not have seen the light of day.

16 References

ANSI/ASHRAE 55 (2004). Thermal environmental conditions for human occupancy. American Society of Heating Refrigerating and Air-Conditioning Engineers.

ASHRAE (1993). *ASHRAE Handbook of Fundamentals*. American Society of Heating Refrigerating and Air-Conditioning Engineers.

ASTM E891-87 (1992). Tables for terrestrial direct normal solar spectral irradiance. Tables for air mass 1.5. ASTM International.

Blakeslee, T. R. (2009). Energy saving: Much cheaper than building power plants! http://www.renewableenergyworld com/rea/news/article/2009/11/energy-saving-much-cheaper-than-building-power-plants.

Braungart, M., & McDonough, W. (2002). *Cradle to Cradle: Remaking the Way We Make Things*. New York: North Point Press.

Chan, M. Y., & Mak, C. W. (2008, December). Thermal comfort levels in a room with solar radiation. *Indoor and Built Environment 17*(6): 516-524.

DiLaura, D., Houser, K., Mistrick, R., & Staffy, G. (eds.) (2011, July 30). *The Lighting Handbook: Reference and Application* (10th ed.). New York: Illuminating Engineering Society.

Gordon, N. (2013, February 28). *History of the Roller Shade*. Retrieved from http://www.dwfcontract.com/Drapery–Window-Covering-Blog/bid/87071/History-of-the-Roller-Shade.

Grondzik, W. T., Kwok, A. G., Stein, B., & Reynolds, J. S. (2010). *Mechanical and Electrical Equipment for Buildings* (11th ed.). John Wiley & Sons, Inc.

Lawrence Berkeley National Laboratory. (2015) Daylighting The New York Times Building. http://windows.lbl.gov/comm_perf/newyorktimes.htm.

Lee, E. S., et al. (2013, January). A post-occupancy monitored evaluation of the dimmable lighting, automated shading, and underfloor air distribution system in the New York Times Building. Report LBNL-6023E. Lawrence Berkeley National Laboratory. http://buildings.lbl.gov/sites/all/files/lbnl-6023e.pdf.

Nicol, J. F. (1966). Radiation Transmission Characteristics of Louver Systems. Building Science 1: 167-182.

Powell, G. L. (1982). The ASHRAE Clear Sky Model: An evaluation. *ASHRAE Journal, American Society of Heating Refrigerating and Air-Conditioning Engineers 24*: 32-34.

Saxena, M., Berkland, S., & Turnball, P. (2014) Measuring the Daylighting Impact of Automated and Manually Operated Shades. In: *Advanced Building Skins*. Conference Proceedings of the 9th Energy Forum, Bressanone, Italy.

Yellott, John, I. (1977) Window Management: A Realistic Approach to Energy Conservation by Daylighting, Sun Control, Insulation. http://mechosystems.com/Yellot-Window-Management/.

Yellot, John I. (1983) U-Value Determination of Single and Dual Window Shades in Various Open/Closed Positions. Yellot Solar Energy Laboratory, Phoenix, AR. Report No. 8340-1. http://mechosystems.com/Yellot-U-Value/.

17 Appendix: International and U.S. Units

Measure	SI Unit	IP Unit
Temperature	Celsius	Fahrenheit
Solar penetration	meters	feet
Illumination	lux	foot-candles
Luminance	candela/m^2	foot-lamberts
Radiation	W/m^2	BTU/hr/ft^2
Heat gain	Watts	BTU/hr

18 Glossary

ALGORITHMS/ANALYSIS

ASHRAE sky geometry: The ASHRAE sky geometry equations and Clear Sky algorithm incorporated in the SolarTrac program compute the total radiation by latitude for every minute of the solar day, sunrise to sunset, to create a Clear Sky model. Additional solar values are computed by comparing the building's orientation and geometry to the ever-changing position of the solar ray, every minute of every day of the year. The algorithm assesses the constant changes in (a) the solar radiation levels on every facade, measured in BTU/hr/ft^2 or W/m^2, (b) solar penetration (solar angles), (c) profile angles, (d) incident angles and (e) surface solar angles, measured minute by minute in real-time.

curve-fitting solar analysis: This system computes the amount of daylight on a window and consists of a radiometer with a few lux sensors for calibration and verification. A research program compares the real-time radiometer data to lux sensor data and converts this into an operating algorithm. This system allows for brightness override with high resolution at a fraction of the cost of installing many lux sensors on a building.

IES: Illumination Engineering Society

solar schedule: The solar schedule allows for timed programming of shade movements. It can be programmed to move the shade bands on an hourly, daily, weekly or monthly schedule. It tracks the Sun's position in the sky from sunrise to sunset. The system schedule may be repetitive or not.

CONTROL

adjusted horizon: An adjusted horizon for each solar zone on a building allows for a cost-effective shadow-control system for buildings in suburban areas, on campuses, or on sites where the surrounding terrain is reasonably uniform. For suburban projects, the SolarTrac adjusted-horizon shadow-control module avoids the cost of the 3-D shadow model required for buildings in urban settings.

analog control: The data sent from the radiometers to the shading system's Sky Array algorithms. The data is transmitted by modulating a continuous transmission signal, which is used to determine appropriate shade positions according to solar zone and the orientation of the facade.

BACnet: A communications protocol for building automation and control networks. The BACNet protocol is set to meet ASHRAE, ANSI and ISO standards.

BAS, BMS: Building automation systems (BAS) and building management systems (BMS) are centralized, interlinked networks of hardware and software that monitor and control the environment in commercial, industrial and institutional facilities. By managing various building systems, the building automation system ensures the operational performance of the facility as well as the comfort and safety of its occupants.

Brightness Override: A SolarTrac Window Management function that optimizes comfort by alleviating undesirable sky brightness or glare when these conditions exceed luminance levels specified by the IES. In the event of excessive glare, such as when the sky is overcast but bright, photo sensors alert the SolarTrac system, and the shades are lowered to protect against glare while still permitting the entrance of daylight and views to the outside.

BTU set points: A proprietary process developed by MechoSystems for automatically controlling shades in extreme environmental conditions. This process controls shade heights according to the BTU load on the window glass. (Other methods control shade heights according to sunny or cloudy sky conditions.) Shade heights are automatically adjusted through the proprietary SolarTrac computer-control system. Shades are fully raised below a predetermined BTU load, lowered halfway (or at some other chosen height) when the BTU load is within a certain range, and fully lowered when the BTU rises above another set point.

daylight harvesting: Daylight harvesting systems use daylight to offset the amount of electric lighting needed to properly light a space, in order to reduce energy consumption (Wikipedia).

daylight measuring: Measurement of the daylight levels (Vlt) in a space through lux photo sensors in order to control the movements of an automatic shading system.

heat load module: A proprietary process developed by MechoSystems for automatically controlling shades in extreme environmental conditions. This process controls shade heights according to the heat load, measured in BTUs or watts, on the window glass. (Other methods control shade heights according to sunny or cloudy sky conditions.) Shade heights are automatically adjusted through the proprietary SolarTrac computer-control system. Shades are fully raised below a predetermined BTU load, lowered halfway (or to some other chosen height) when the BTU load is within a certain range, and fully lowered when the BTU rises above another set point.

logic: Fine-tuned sequencing of the solar ray with the geometry of the building is used to determine and prioritize the shade positions based on not one factor but on multiple factors, such as specific profile of the building, the type of glazing, the formatting of the occupants' space and user requirements.

precision: Clearly defined performance criteria are used to verify and commission all projects.

predictive solar penetration: SolarTrac uses solar geometry to predict solar penetration into an interior every minute of every day, which allows for appropriate shade or louver positioning.

real-time: When an event or function is processed instantaneously, it is said to occur in real-time. To say something takes place in real-time is the same as saying it is happening "live" or "on the fly." For example, the graphics in a 3-D action game are rendered in real-time by the computer's video card. This means that the graphics are updated so quickly, the user experiences no noticeable delay. While some computer systems may be capable of rendering more frames per second than other systems, the graphics are still being processed in real-time.

repeatability: Verification of consistent post-occupancy performance, as in the post-occupancy verification done by the Lawrence Berkeley National Laboratory on the New York Times Building (Lee, et al. 2013) and published on the LBNL website, http://windows.lbl.gov/comm_perf/newyorktimes.htm.

response time: The SolarTrac system response time is less than 60 seconds after a default setting is exceeded. SolarTrac continuously monitors the position of the solar ray and impact on the project hundreds of times per minute, from sunrise to sunset.

shade position: The calculated level at which a shade should be positioned in order to optimize daylighting and outdoor visibility while controlling for glare, heat gain and the penetration of solar radiation.

shadow override module: A SolarTrac module used for buildings in urban centers that predicts clear-sky shadows and then raises the shades in the zones that are in shadow. The module uses a 3-D model of the surrounding cityscape to account for all adjacent structures that cause shadows to fall on a facade. When a facade is in shadow for a user-determined time frame, the system raises the shades to maximize daylighting and the view.

solar logic: The science incorporated into SolarTrac's enhanced solar tracking, which uses various algorithms to position shade heights to meet a prescribed standard, every minute of every hour of every day. Shade positions are based not on one factor but on multiple factors, including the specific profile of the building and occupant requirements. Shade positions are determined by a fine-tuned sequencing of the solar ray with the geometry of the building. The data computed include ASHRAE clear-sky modeling, microclimatic sky modeling, and solar- and window-geometric computing programs.

SolarEvaluation: The continuous evaluation of ASHRAE Clear Sky values and the measured project sky in real-time, every minute of every hour of every day.

SolarTrac embedded modules: SolarTrac provides many mandatory and optional modules to perform its functions. Some of the embedded modules are: solar penetration, BTU set points, brightness override, urban 3-D shadow, suburban shadow, reflection, darkness, virtual brightness.

window shapes: Roller shades can be used with windows up to 20° out of plumb alignment in any direction. Windows in the newest architectural styles may be sloped in or out at the top of the window; tilted to one side or the other, left or right; or twisted so that the head and sill of the window are on different planes.

Window and Lighting Management: The interoperability and automatic control of a Window Management system and a dimmable electric lighting system, depending on the level of daylighting available, occupancy and other factors. The lighting control system can dim or shut off lights when the space is not occupied, when daylighting is available, or according to load-shedding strategies.

Window Management: The control of the heat and light coming through window glazing by means of an automatic microclimatic solar modeling system. The system controls the adjustable shade devices to maximize daylighting and the view while minimizing direct solar radiation on the occupants.

HEAT GAIN

instantaneous heat gain: Heat is transferred into space in three modes: conduction, convection and radiation. In conduction and convection, the heat transfer happens using a medium like air or a wall, and in that process the shortwave radiation from the Sun is absorbed and then reradiated, after a time lag and at lower intensity, as longwave radiation. So the impact of heat gain is felt slowly. On the other hand, heat transfer through radiation happens without a medium. The human body absorbs the radiation directly, and the impact of the heat transfer is sensed immediately.

sensible heat gain: Heat gain that changes the temperature of the human body without involving a phase change, such as converting water into vapor.

solar heat gain: Solar heat gain is the heat, measured in BTU/hr/ft^2 or W/m^2, that passes through an unshaded sunlit window; it varies according to the type of window glazing under consideration.

ILLUMINATION

ambient illumination: The average of the direct and indirect luminance, measured in foot-candles or lux, on the walls, floor and ceiling of a space.

diffused radiation: The solar radiation, measured in BTU/hr/ft^2 or W/m^2, falling on a surface after some amount of it has been diffused by atmospheric particles such as water vapor, dust particles and pollutants.

illuminance: The total amount of visible light illumination, coming from all directions, on a surface; it is measured in foot-candles or lux.

power density, foot-candle levels: Today's recommended lighting level in an office space, according to IES lighting standards, is 35-40 foot-candles, or approximately 0.9 W/m^2. This is a significant reduction from the recommendation about a decade ago, which was 1.5 W/m^2.

LIGHTING

brightness: The luminance value of an illuminated surface.

contrast ratio: The relative amount of brightness (or luminance of a window) compared to a work surface's luminance, in cd/m^2, within an occupant's 60° field of vision. Based on MechoSystem's experience with the performance of SolarTrac Infinity in the New York Times Building, a contrast ratio of 1 to 10, or higher, was appropriate and preferred in many sections of the building.

glare: A narrow, intense reflective beam or shard of light that reflects off a surface. If the contrast ratio in the field of vision is greater than 15 to 1, the eye cannot focus to see the darker area behind the reflected ray.

luminaire coefficient of utilization: A luminaire is a complete lighting unit consisting of one or more electric lamps and all of the necessary parts and wiring. The coefficient of the utilization of a luminaire is the difference between a lamp's light output without a luminaire and the light output with a luminaire. Generally, the best performance that can be expected is a lighting output of 85%. A coefficient of utilization of 65%-75% is normal.

luminance: The visible light from a source such as the Sun, a bright window illuminated by the Sun, a light fixture, or a computer screen: all are light sources. It is measured as the amount of visible light leaving a point on a surface in a given direction (measured in foot-lamberts or cd/m2 or nits).

PERFORMANCE

commissioning: The act of installing and configuring a system to ensure that it is working as expected and meeting all of its performance specifications.

electrochromic glass: Also known as smart glass or electronically switchable glass, this glazing allows users to control the amount of heat or light that passes through the glass, giving them the ability to regulate temperatures or create privacy by applying electrical power to the glazing. SolarTrac can adjust the density of EC glazing in accordance with (a) heat load, (b) solar penetration, (c) position of the panels of glass from top to bottom, with a different densities applied for each section.

G value: It is the coefficient commonly used in Europe to measure the solar energy transmittance of glass and is sometimes called a "solar factor" in the literature. For instance, 58% = 0.58.

human factors: The study and design of equipment and devices so that people can use them easily, comfortably and safely. A synonym for human factor is *ergonomics*; additional terms are *wellness* and *human-centric*. The study of human factors and ergonomics is multidisciplinary and incorporates contributions from psychology, engineering, biomechanics, mechanobiology, industrial design, physiology and anthropometry.

performance verification: A review of the post-occupancy performance of the SolarTrac system in the New York Times Building was conducted by the Lawrence Berkeley National Laboratory and is published on its website: http://windows.lbl.gov/comm_perf/newyorktimes.htm.

reflection: The visible light that is redirected off a surface.

savings from reduced use of lighting and HVAC: According to current assumptions, an additional 25% of HVAC can be saved for every 1 kWh of lighting saved. This may be both a benefit and a liability, depending on local climatic conditions. In winter, heat is generated for heating the interior of a building. In summer, an HVAC system removes excess heat. However, today's office buildings generally generate excessive internal heat loads even in winter. This means that additional air conditioning may be required, even in winter, especially on the south side of a building.

shading coefficient: The ratio of solar energy from direct sunlight passing through a piece of glass compared to the solar energy that passes through 3 mm-thick clear float glass. It is used as an indicator of how well the glass itself is thermally insulating (shading) the interior when there is direct sunlight on the panel or window. Window standards have moved away from using a shading coefficient to using a solar heat gain coefficient (SHGC), which is defined as the fraction of incident solar radiation that actually enters a building, through the entire window assembly, as heat gain. To perform an approximate conversion from SC to SHGC, multiply the SC value by 0.87.

solar heat gain coefficient: The fraction of incident solar radiation admitted through a window, both directly transmitted, or absorbed and released inward later. SHGC is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits. The nationally recognized rating method by the National Fenestration Rating Council (NFRC) is for the whole window, including the effects of the frame. Alternately, the center-of-glass SHGC is sometimes referenced, which describes the effect of the glazing alone.

solar heat gain factor: This number represents the amount of solar radiation falling on a building facade on an average clear day. ASHRAE has produced charts that list these figures for various latitudes. The charts are broken down by month, time of day and solar orientation.

solar penetration: The distance that solar radiation extends into a building's interior, in feet or meters. In the Northern Hemisphere, solar penetration is greatest in winter due to the low angle of the Sun. (See Figure 2: Solar Penetration and Heat Load from January to June.)

system integration: In engineering, it is defined as the process of bringing together component subsystems into one system and ensuring that the subsystems function together as one system.

RADIATION

diffused radiation: The light level that comes as diffused light after being scattered by clouds on its way from the Sun to Earth.

direct normal radiation: Radiation, measured in BTU/hr/ft^2 or W/m^2, falling directly on a surface lying perpendicular to the solar ray. In other words, the incidence angle is zero.

direct radiation: Radiation falling directly on the surface at the incidence angle without being diffused or reflected.

longwave radiation: Shortwave radiation from the Sun warms the surface of Earth. As Earth warms, the energy in the ground is re-emitted as longwave radiation, in the form of infrared rays. Earth emits longwave radiation because Earth is cooler than the Sun and has less energy to give off.

reflected radiation: Some amount of direct radiation falling on the surface of the Earth may be reflected; for example, white snow on the ground reflects much more radiation than barren ground.

shortwave radiation: The Sun is very hot and emits shortwave radiation, with wavelengths in the visible (VIS), near-ultraviolet (UV) and near-infrared (NIR) parts of the solar spectrum.

solar radiation, insolation, irradiation: The total amount of solar radiation energy received on a given surface area during a given time, measured in BTU/hr/ft^2 or W/m^2.

total radiation: The total amount of radiation, including direct, diffused and reflected components.

SENSOR

photometer, lux sensor: A photometer measures the visible light (daylight) portion of the solar spectrum, which is +/- 49% of solar radiation

radiometer: A radiometer measures the total solar radiation falling on a building, including the visible light, infrared and ultraviolet portions of the solar spectrum, which is +/- 98% of solar radiation

SOLAR ANGLES

incident angle: The incident angle is the angle used to calculate the heat load on a vertical surface, in BTU/hr/ft2 or W/m2, using a combination of the solar altitude and surface solar azimuth angles.

profile angle: The "shadow angle" that determines solar penetration through a vertical surface.

solar altitude angle: The position of the Sun above the horizon.

solar azimuth angle: The solar azimuth angle is the angle between the north-south line and the horizontal projection of the solar ray. The convention for solar angles is 0° for true south, 180° for north, -90° for east, and +90° for west.

surface solar angle: The position of the solar ray in relation to a line perpendicular to the glazing.

SKY CONDITION

cloud trends: The pattern of clouds in the sky dome at any point in time and its movement over a period of time.

microclimatic sky condition: A real-time sky model developed by the SolarTrac Sky Array program to determine not only whether the current sky condition is clear and cloudy, but also how clear and how cloudy, as well as predicting the sky condition to come. A real-time model of the current sky condition, clear or cloudy, created by SolarTrac's Sky Array program; it can predict the solar condition to come.

Sky Array: A logic-based algorithm that uses data from solar radiometers to determine the current sky condition over a building in real-time. It measures UV, Vlt, or and IR many times a minute; or monitors the current sky condition over time; and compares microclimatic sky data (clear or cloudy) to ASHRAE Clear Sky radiation values.

sky condition: The condition of the sky, specifically the type, amount, location, size and transmittance of the clouds in the sky dome.

sky monitoring: The monitoring of cloud conditions over time and their impact on the levels of solar radiation and lighting inside the space.

TEMPERATURE

effective temperature: The effective temperature, as it is commonly understood, is a combination of the temperature and the relative humidity of a space in one index. More technically, it is the temperature of an enclosure at 50% relative humidity in which the environment has the same sensible plus latent heat exchange as a person inside it. The effective temperature effects the thermal comfort of people in an enclosed space; it is more relevant as a human factor than mean radiant temperature or operative temperature.

mean radiant temperature: The surface temperature of an imaginary black body, or enclosure, with which a person, also assumed to be a black body, exchanges the same amount of heat by radiation as in the actual environment. The mean radiant temperature impacts thermal comfort in an enclosed space, and is a human factor.

operative temperature: The uniform temperature of a radiantly black enclosure in which an occupant exchanges the same amount of heat by radiation plus convection as in the actual non-uniform indoor environment. Numerically, it is close to the average of indoor dry-bulb and mean radiant temperatures. This measure has significance for thermal comfort in an enclosed space; it is a slightly better measure than mean radiant temperature when assessing human factors.

TIME

apparent solar time: Apparent solar time is based upon the apparent motion of the Sun across the sky. Time is read using a sundial, not a watch.

daylight savings time: In North America, Europe and many other countries, the clock is artificially moved ahead one hour in March to take advantage of the daylight for energy savings. China, India, Japan, and the Middle East do not make this adjustment to the clock.

local standard time: Local standard time is the actual time observed at a location, the time read from a watch throughout the year. Some locations adjust for daylight savings and some do not.

 The Science of Automated Shading