Guide for Daylighting Schools



Developed by
Innovative Design

For
Daylight Dividends

Administered by
Lighting Research Center
Rensselaer Polytechnic Institute

Foreword

Daylight Dividends is a national program with a mission to help people reap the human and economic benefits of good daylighting design in buildings. After recently learning of Innovative Design's portfolio of daylit schools, we traveled to North Carolina to examine them. We independently evaluated one of these schools and will post the full results on the Daylight Dividends web site (www.daylightdividends.org). We were highly impressed that these schools were being built with no or low incremental first cost and that students, teachers, and administrators raved about the daylighting. These schools can serve as a pattern for similar success in other districts, so we asked Innovative Design to share how they do it. This Guide is the result – sound, practical advice and details for daylighting schools. Use it to guide your school's designs. You will love the results.

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DISCLAIMER

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Introduction

A well-integrated daylighting design has a greater positive impact on a school than any other sustainable design strategy. The following Guide for Daylighting Schools was developed by Innovative Design for the Daylight Dividends Program. The guideline is based upon practical experiences in designing and constructing over 40 daylit schools throughout the country.

The guide addresses the key design considerations typically confronted when designing K-12 schools from Orlando, Florida to Portland, Oregon. To achieve a successful daylighting strategy, school designers must:

Daylight Dividends is sponsored by:

- U.S. Department of Energy
- Lighting Research Center
- New York State Energy Research and Development Authority
- California Energy Commission
- Connecticut Light and Power Company
- Iowa Energy Center
- Northwest Energy Efficiency Alliance
- North Carolina Daylighting Consortium

Consider Human Factors

Daylighting is not just adding a lot of windows. If uncontrolled direct beam radiation is streaming through the classroom window and into a student's face, the teacher will simply close the blinds and negate your daylighting strategy altogether.

The most important aspect of good daylighting design is to understand how it effects human nature. In addition to the energy and maintenance benefits, daylighting done well in a school may help:

- Improve student performance
- Create a healthier indoor environment
- Increase attendance

Daylighting must be superior

For daylighting strategies to be effective, the great majority of time that teachers and students are in the particular space, the daylighting strategy must be superior to the electrical lighting. If not, the habit of walking into a space and turning on the lights will never be broken. Develop your daylighting strategy to provide superior lighting for two-thirds of the daylit hours during the year.

In determining the desired footcandle level in a particular space it is also important to understand how this requirement may change over a typical day.

Eliminate direct beam radiation

An essential component of any good daylit school design is the elimination of uncontrolled, direct beam radiation. It is critical that in all classrooms, gymnasiums, media centers, and administrative spaces, sunlight is either bounced, redirected, or filtered so that direct radiation does not enter a part of the room where this could be problematic. This is easy to say, but harder to achieve. This constraint essentially eliminates most commonly designed windows as good daylighting strategies.

Consider the need to darken individual spaces

The success of your daylighting strategy will certainly be determined by how the occupants interact with the various components of it. This is particularly true when it comes to the incorporation of blinds or shades that can be used to darken a particular space. If left closed, the daylighting contribution will never be realized. If temporarily darkening a specific space is not required functionally, don't install shades or blinds. The implementation of blinds will result in decreased performance, increased first costs, and greater long-term maintenance expenses.

If you determine that the intended function of a space will require darkening for limited time periods, consider motorized roll shades or motorized vertical blinds. It may seem like more long-term maintenance but it is actually less. The mechanical stress placed on manual operators by the students and teachers (due to uneven cranking) limits the effective life of these devices to under ten years. The inconvenience associated with the process also results in a high number of these shades being left closed. Motorized shades do cost more upfront, but will provide greater ease of operation and result in better performing daylighting design.

Only use shades if entire space needs to be darkened

In many cases you will find that teachers in a particular school still use overhead projectors. In most newer classrooms, school systems are requiring that TV monitors be installed. Both of these teaching tools require that the light level at that specific location of the screen or TV be a little more controlled (preferably under 50 footcandles).

When designing your daylighting strategy, consider the option of intentionally creating a slightly darker location(s) within the room where the projection screen or TV monitor can be located. See the section on General Recommendations for All Daylighting Options (page 20).

Don't count on view glass

Wall space is precious in schools. This results in many lower view glass windows also serving as display areas. Additionally, these windows are almost always accompanied by blinds that can readily be closed by the teachers and students. Do not count on low view glass windows for your daylighting strategy. Develop your design around roof monitors; high, south-side lightshelf apertures; or high, north glass transom windows that would be hard to reach and even harder to block.

Concentrate on the most utilized spaces

Daylighting strategies do cost money to implement so it is important to place them where they do the most good. Put them where the students are the most - in the classrooms. Gymnasium spaces are also good candidates since they are typically used both during and after school and throughout most of the year.

From a student and teacher standpoint, classrooms are the most beneficial spaces to daylight.

Design the daylighting strategy to provide natural lighting for at least two-thirds of the daylit hours in:

- classrooms;
- special needs rooms;
- gymnasium;
- cafeteria;
- media center; and
- administrative areas.

Utilize low view glass to provide visual connection to outdoors

Even if the building code does not require low view glass, incorporating a reasonable amount provides an important benefit by connecting the students to the outdoor environment.

Consider the Energy Ramifications

From an energy perspective, the worst thing that you can do is to implement a daylighting strategy that is not quite good enough. If you create a situation where there is typically insufficient daylight, resulting in having lights on, you have created a negative energy situation. All the heat produced by the lights as well as the heat created by sunlight will overheat the space, requiring more air conditioning.

If designed correctly, a daylighting strategy can reduce:

- electricity for lighting and peak electrical demand;
- cooling energy and peak cooling loads;
- maintenance costs associated with lamp replacement;
- electrical service to building; and, in some cases,
- the number of installed lighting fixtures in the school.

Orient building to maximize daylighting

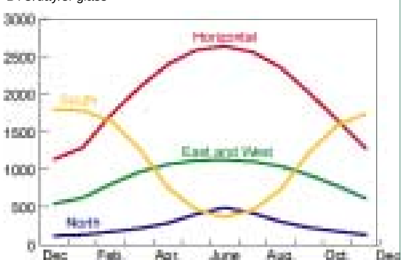
A good, cost-effective daylit school design starts with proper orientation. To maximize your opportunity for daylighting, lay out the school on an east-west axis with the majority of spaces facing either south (best) or north (second best). This will be particularly true if you are going to rely on side-lighting (versus roof monitors) as a significant daylighting strategy.

Maximize south glazing, minimize east and west facing glass

By employing south-facing apertures, you create a situation that is easy to control through the use of external window treatment strategies. It enables you to maximize winter radiation and control summer gain. As you can see from the accompanying chart that indicates the amount of radiation falling on different flat surfaces, a south-facing aperture is the only orientation that, on an annual basis, balances typical thermal needs and lighting requirements with available radiation. In the summer, the least amount of radiation hits the south, vertical surface of your school and in the winter, the most radiation strikes this surface. With few exceptions, having more solar gain entering your school in the winter is a benefit. As you can see, east- and west-facing apertures receive twice the amount of radiation in the summer as in the winter. Even north-facing apertures will see some additional direct light gain in the summer versus the winter.

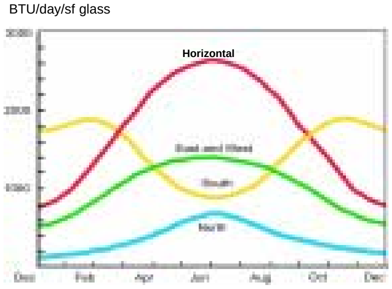
Remember that the more sunlight that you allow to enter the building to address lighting needs, the more heat you also have to deal with. By placing your apertures correctly, nature can work with you, not against you.

BTU/day/sf glass



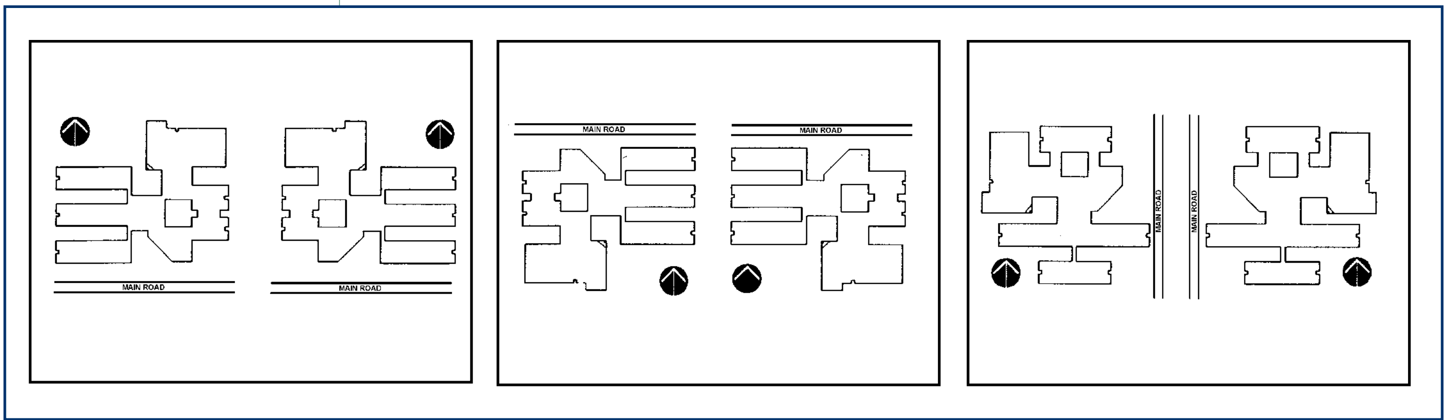
Radiation Striking Each Surface
32° latitude

BTU/day/sf glass



Radiation Striking Each Surface
40° latitude

Daylighting strategies can even be successfully implemented in prototype schools. The following prototype design was developed to address the potential of multiple orientations and entry possibilities.



As you can see, the classroom wings, under any scenario, run east-west in length with roof monitors facing south or north. The rest of the building core was developed so that square roof monitors could be rotated within the same space, always facing south.

Avoid uncontrolled skylights

Skylights are typically the worst energy choice when considering daylighting options. More than twice the radiation will enter the school through a flat skylight in the summer than in the winter, the opposite of an optimal system.

The best way to design the size of daylighting apertures is to size the glazing and overhangs so that just the right amount of radiation is brought into the school during the summer peak cooling condition. If the glazing is south-facing, this strategy will allow more and more radiation to enter the space as fall becomes winter. However, if you use a flat skylight, and you design the apertures to allow the optimum amount into the space during the summer peak, you will not have enough daylight to fulfill typical lighting needs the rest of the year.

While skylights can be designed with internal tracking louvers to produce very nice daylighting, it is still difficult to justify them when it comes to reducing cooling peak loads.

Optimally size overhangs on south-facing glazing

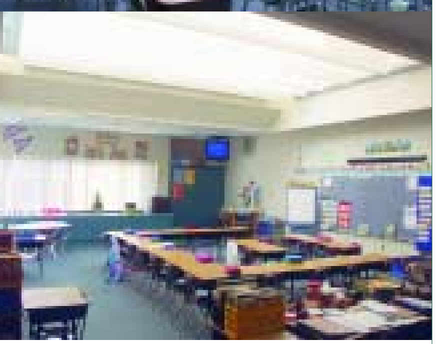
When considering your strategies to optimize daylighting versus energy, think of how the glazing can be placed and again consider the chart on page 5 showing varying radiation hitting each surface without any external shading devices or overhangs. Also consider the azimuth angles during the summer and winter, throughout the day. Several things should drive your balancing act.

Assuming you are in a location that has even a slight winter heating requirement, think about placing the overhang much as you would if designing a passive solar building. Start out by placing the outer point of the overhang on an angle about 45 degrees from horizontal, above the head of the window. This will allow most of the solar gain to enter during the winter when the altitude is low even at noon.

It is very easy to put in enough glazing to provide a very high daylighting contribution. The key is to put in as much as you can without negatively impacting the cooling loads (particularly the peak).

By moving the overhang in and out, and simulating these different conditions during peak cooling times (as well as annual simulations) you will be able to determine the optimum location. You do not want any more radiation entering the space during peak cooling times than is necessary to deliver the optimal footcandle level. If the space has higher footcandle levels than is necessary during peak cooling times, you will increase the cooling loads.

Because of the sun's very low azimuth angles that hit the east and west sides, it is very difficult and expensive to develop any strategy that can produce a "controlled" daylighting solution that maximizes winter gain and minimizes summer gain. Avoid east and west glazing unless it is very well protected.



Reduce installed lighting

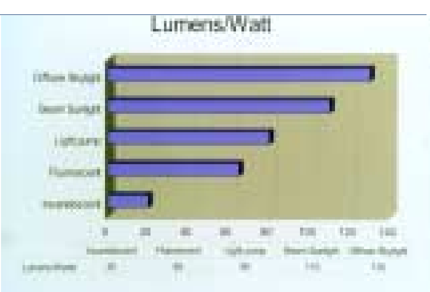
All good daylighting strategies will reduce long-term operational costs. One strategy used to lower the first costs associated with daylighting is to reduce the installed lighting in the classrooms. To achieve this, the designer needs to:

- consider how classroom usage changes from typical daytime conditions to nighttime uses;
- evaluate if there are different lighting requirements associated with different uses (e.g., during the day the school system wants 60 footcandles in the classrooms but only requires 50 footcandles at night, when parent-teacher meetings and other activities require less light);
- determine the minimum daylighting contribution during school hours; and
- determine if there is a minimum amount of daylight that can be counted on to reduce the installed lighting.

With a good daylighting strategy that is designed to provide two-thirds of the lighting needs during the daytime hours, there will often be at least 10 footcandles of natural light entering the daylit classroom even on a very overcast day. The exception could be (depending upon when the school starts classes) in December, very early in the morning, when it could still be dark outside. However, if you add up all of these hours when it is still dark outside, the total for the year would normally be less than a dozen hours. If the space lighting requirements are less for the projected nighttime use (e.g., parent-teacher meetings) and considering the few hours that are impacted, lowering the footcandle level makes good sense. The result will be one-sixth to one-fifth fewer installed lighting fixtures.

However, if the space has the same nighttime function, you will need to install the amount required to address the full footcandle demand.

Two good examples of spaces where no reduction in installed light is possible are a gymnasium, since it is used for the same function during the day and evening; and a classroom that will have night classes.



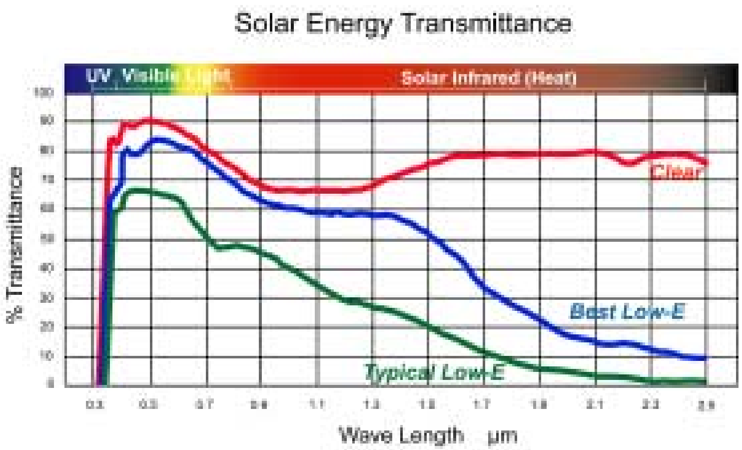
Reduce cooling loads

In the warmer months, cooling loads can be reduced by providing just the right amount of daylighting. Daylighting is sufficient and when the lights are out, the cooling load is less. This is because the lumens per watt from daylighting are twice that of fluorescent fixtures. In other words, to meet the same lighting need, daylighting produces half the heat. However, to achieve this reduced cooling it is essential that during peak cooling times:

- no more radiation is allowed to enter the building than is required to meet your footcandle objectives;
- properly sized overhangs limit the radiation to optimal amounts; and
- the lights, with the use of photosensors, are automatically dimmed or switched off.

Take advantage of passive solar

Reduced electric lighting has the opposite effect in the winter. Like in the summer, the lights are off due to good daylighting levels. This means that the heat that was typically being produced by the lights is gone, creating what may seem like an increased heating load. This is simply the result of the lights being off and not producing heat, requiring the mechanical heating system to address more of the load.



If the school is heated with a gas boiler, the result will be slightly more natural gas use but much less electricity use. Typically, even with greatly increasing natural gas rates, this is a good tradeoff. If the school is heated with a heat pump, the tradeoff would likewise be smart since heat pumps are more efficient than electric lights.

However, with natural gas prices skyrocketing, it makes sense to take advantage of passive solar strategies. You can easily design a north-facing roof monitor that will, over the course of the year, provide as much daylighting as a south-facing one. But, if that same monitor was facing south, the glazing area could be about 25% less in size (resulting in less first cost as well as less conductive heat losses) and, when coupled with a well-designed overhang, could maximize winter solar gain. This strategy can do a lot to offset winter heating requirements. Remember that school heating demand is often masked by the fact that the lights are doing the heating.

Select the right glazing

In all cases, windows should be made of high-quality construction, incorporate thermal breaks, and include the appropriate glazing for the particular application. Make a clear distinction between glazing that is incorporated for views and ventilation and that which provides daylighting.

In all cases, where windows are used specifically for daylighting, clear glass has an advantage over glazing with a low-E coating. Because of the 10% to 30% reduction in visible light transmission characteristic of most low-E coatings, 10% to 30% more glass would be required to produce the same daylighting benefit.

In evaluating the trade off between the thermal benefits associated with low-E coatings and the visible light

transmission, your calculations should also consider the accompanying costs of lightshelves or roof monitors that would also have to be proportionally added if more glazing is required. Because of these other system component costs, the tradeoff, from a life-cycle approach, is seldom worth it. However, wherever low view glass windows are incorporated, low-E coatings should be used to improve comfort and save energy.

Incorporate the appropriate glazing choice for each particular application.

Application	Exposure	Type
View Glass (non-daylighting apertures)	South North East/West, unshaded East/West, shaded	Clear double, low-e Clear double, low-e Tinted double, low-e Clear double, low-e
Windows above lightshelves	South	Clear double, glass or acrylic
High windows above view glass	North	Clear double, glass or acrylic
Roof monitor	South	Clear double, glass or acrylic
Blinds-between-glazing	South	Clear double, glass or acrylic

Carefully consider the visible light, solar transmission, and insulative qualities of the particular glazing system you are considering, with emphasis on how much additional glazing will be needed to achieve the same visible light transmission. To effectively address energy at the same time you are creating a good daylighting strategy, it is important to minimize the size and maximize transmission of daylighting apertures.

Glazing Type	Solar Transmission	Equivalent U-Value
Clear, Single	75% - 89%	1.11
Clear, Double	68% - 75%	0.49
Low-e, Clear, Double	45% - 55%	0.38
Low-e, Tinted, Grey	30% - 45%	0.38
Low-e, Argon	45% - 55%	0.30

Consider reduced maintenance

When considering the energy-related life-cycle benefits associated with daylighting, don't forget the maintenance savings associated with lamp replacement. Although the fluorescent lamp life is actually decreased by employing staged dimming strategies, this is more than offset by the fact that the lamps are off the majority of the time. When comparing a typical non-daylit classroom to a daylit one, the lamps in the non-daylit space will require replacement three times more than in the daylit space.

Account for Site Constraints and Benefits

The most obvious site consideration is orientation. A design can only be maximized if oriented correctly. The potential for cost-effective daylighting is greatly enhanced by elongating the school on an east-west axis, locating high priority spaces on the north and south exposures. A one story design, while consuming more land area, also maximizes your opportunities for roof monitors.

Account for shading from adjacent buildings and trees

When integrating your building into the overall site, make sure that your daylighting apertures are not unintentionally shaded by adjacent buildings or vegetation. Likewise, verify that the school's components do not create a negative impact on others.

Consider the reflectance from adjacent surfaces

Consider the reflectance of the materials in front of the glazing areas. Using lighter roofing colors can reduce the glass area need for roof monitors, while a light colored walkway in front of a lower window may cause unwanted reflections and glare inside the classroom.

Utilize landscaping to benefit overall design

Identify and incorporate design elements that are to become teaching tools or integral aspects of educational programs.

Select Well-Integrated Daylighting Strategies

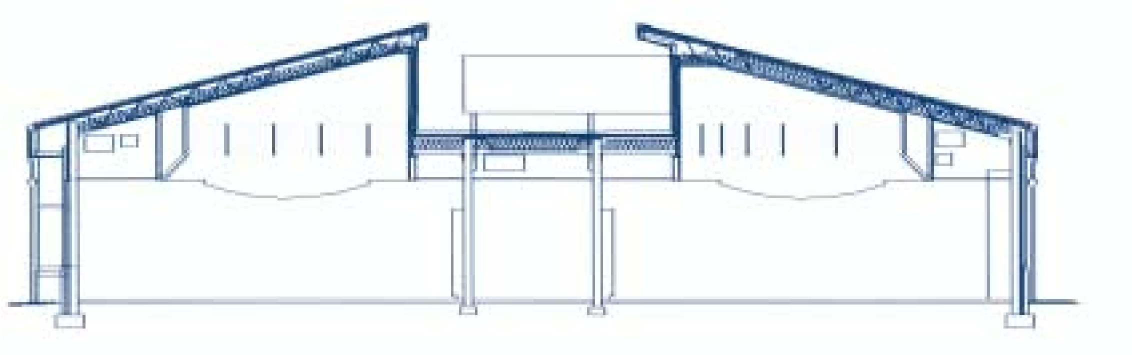
Most designers who are considering implementing daylighting strategies for the first time are very concerned that their project will be over budget and that the daylighting strategy will be deleted altogether. This mindset can actually create a negative consequence. In thinking ahead to the process of "taking the daylighting out of the design," the designers never truly integrate the daylighting components into the overall design, hurting the budget that they are trying to protect.

Do not bid daylighting as an alternate

The most economic and effective daylighting strategies are ones that are very well integrated into the design from a structural, mechanical, electrical, and architectural standpoint. Daylighting is not as simple as it may appear. To do it well, the many different interrelated aspects of the school's architecture, landscape, and engineering must be considered. If integrated, common architectural components will be serving dual functions. White single-ply roofing can serve as a waterproofing membrane at the same time it can increase radiation into a daylighting aperture, in turn reducing the glazing required. Mechanical cooling equipment can be reduced because the lighting loads are reduced. Only a comprehensive, well thought out approach will guarantee a low cost system that accomplishes the benefits you hope to achieve.

The opposite is true if not fully integrated. If designed and bid as an alternate, it is unlikely that the daylighting strategy will be nearly as cost effective or resource smart. The problem arises if the designers think that the daylighting components will have a good chance of being eliminated. When the designers have this mindset, it is very unlikely that they will risk designing a smaller mechanical cooling system, thinking that they may have to redo the design at their cost.

The best way to guarantee a low cost daylighting strategy is to fight against this instinct and integrate your strategy early in the schematic design phase. With goods schematic design cost estimates that reflect the added daylighting components as well as the reduced cooling equipment and eliminated building components (that would have typically been implemented), you will soon see that the "net" daylighting costs are very reasonable.




Consider roof monitors first and lightshelves second

When considering the best daylighting strategies for a particular school, many factors will play a role in determining which ones to employ. Typically, you should place roof monitor and lightshelves at the top of that list to consider.

South-facing Roof Monitors

Roof monitors that incorporate vertical south-facing glazing, properly sized overhangs and interior baffles, have an advantage because they:

- create uniform lighting throughout the space;
- can be used to daylight spaces far from the perimeter of the building;
- create passive heating benefits by allowing more radiation to enter the space in the colder months;
- create a more diffuse, filtered lighting strategy;
- eliminate contrast and glare;
- allow heat to stratify; and
- create a more stimulating environment that allows students to be better connected to the outdoors.

The big downside of roof monitors is that they can only be employed in single story designs.

South-facing Lightshelves

Lightshelves incorporated into south glazing strategies are typically the next best option in that they:

- can be used in multi-story situations;
- can bounce sunlight to the back of most school classrooms;
- help shade view glass located below the light shelf; and
- typically cost less than monitor strategies.

Their downside is that all the light is coming from one side of the classroom, making it harder to achieve uniform lighting. There is a fairly significant drop off in light levels in rooms more than 20 feet deep. Contrast between the brighter glazed wall and the opposite side of the room also must be addressed.

North-facing Roof Monitors

North-facing monitors, while similarly effective as south-facing monitors in providing natural light, are not as energy efficient because they typically require at least 25% more glazing to achieve the same annual daylighting contribution. North monitors are clearly beneficial, but because of the additional glazing and the lack of passive heat benefits in winter, they are not as cost-effective as the south monitor.

North-facing Transom Glazing

In north-side rooms, the use of high transom glazing can also be an effective strategy in narrow rooms or used in combination with southside lightshelves or roof monitors in larger spaces.

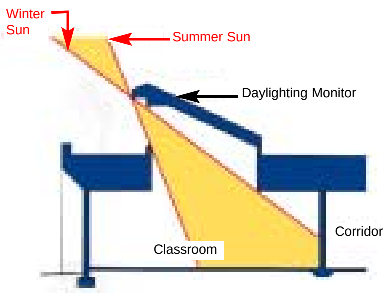
Provide proper glass-to-floor area ratios

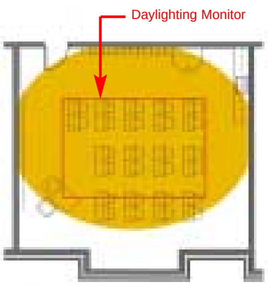
Until detailed daylighting analysis is conducted, you can use basic rules-of-thumb (for Raleigh, NC) that will help you in determining the right amount of daylighting glazing for particular systems.

	Classroom (% of floor space)	Gymnasium (% of floor space)
• South-facing roof monitor	8% to 11%	5% to 8%
• South lightshelf	8% to 11%	
• South lightshelf w/blinds between glazing	15% to 20%	
• North-facing roof monitor	12% to 15%	7% to 10%
• High, north transom glazing	15% to 20%	

Optimize the Most Appropriate Daylighting Strategies

South-facing Roof Monitors





As the primary strategy, south-facing roof monitors coupled with interior baffles can provide uniform light within the room and eliminate glare.

Minimize size by maximizing transmission

Minimize the size of the glazing by maximizing the visible light transmission value of the glass. (See chart on page 9)

Consider the passive solar benefits

Design the south-facing monitor to capture passive solar heating in the winter months. This will help in offsetting the heat not being provided when electric lights are off. Do not over-extend the overhang. It will hurt the daylighting contribution as well as the passive heating benefit.

The glazing area for a south-facing monitor is typically 25% less than a north-facing one. If you use both south- and north-facing monitors and want the profiles to be the same, you need to size the vertical wall of the monitor for the north side, since this will be a greater height.

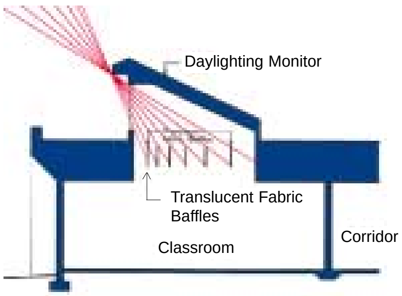
Use light colored roofing in front of monitors

Specify a light-colored roofing material to reflect additional light into the glazing. A white single-ply roofing material (aged reflectance of 69%) typically provides the best long-term reflectance. This compares to black EPDM of 6%, a gray SPDM of 23%, or a light colored rock ballast of 25%. Because single-ply roofing is smooth and without granules, it is also ideal for rainwater catchment systems.

Reflectance of Typical Roofing Materials (1)		**% Reflected**	**% Absorbed**
Single-ply Roof Membrane	Black EPDM	6%	94%
	Gray SPDM	23%	77%
	White EPDM	69%	37%
Asphalt Shingles	Black	5%	95%
	Medium Brown	12%	88%
	Green	19%	81%
	Gray	22%	78%
	White	25%	75%
Metal Roof	Aluminum	61%	39%
	Metal White	67%	33%

When white single-ply roofing (see previous page) is placed directly in front of the south-facing roof monitors, the glazing area in the monitors is able to be reduced by up to 20% because of the additional reflected radiation entering the monitor.

The white color also provides an overall benefit by reflecting solar radiation that would otherwise be absorbed and re-radiated downward into the conditioned space. Energy savings also result as a benefit of a lowered cooling load.



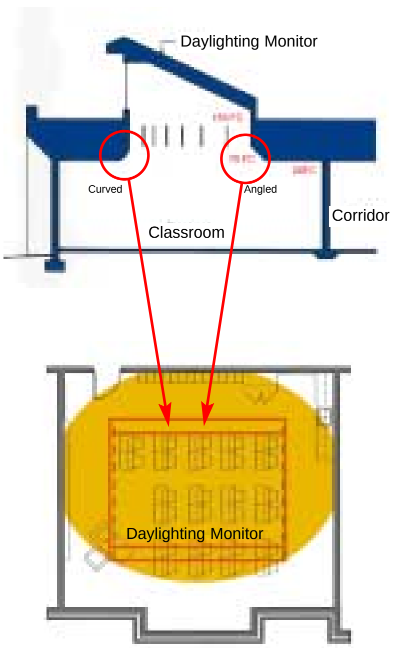
Use baffles to block direct beam radiation, diffuse light, and reduce glare

In the roof monitor lightwell assemblies, white baffles should hang parallel to the glass and be spaced to ensure that no direct beams can enter the space. The spacing and depth of the baffles should be designed to block the view of the sky from all points in the room. This will ensure that no direct beam light enters the space.

Specify fire-retardant, UV resistant baffles

The fabric baffles should be fire-retardant and UV resistant.

The baffles should be positioned so that they are located up within the well. The higher they are placed, the fewer baffles will be required.



Use translucent baffles to help reduce contrast

Light-colored translucent baffles not only reflect the sunlight into the space, but also help eliminate contrast from one side of the baffle to the other.

Minimize contrast at well-to-ceiling intersection

At the bottom of the lightwell, contrast is greatly reduced if there is a transition between the vertical plane surface and the horizontal. A 45 degree angled plane is good but a curved transition is even better. To achieve this curved effect, many designers are now using fiber-reinforced plaster curved sections that blend nicely with sheetrock.

Address the monitor design

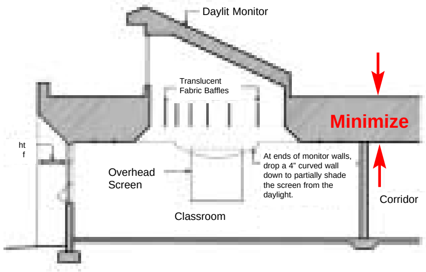
To help reduce conductive gains and losses, the walls and ceiling of the roof monitor should be well insulated and incorporate appropriate infiltration/exfiltration, moisture and radiant barriers.

Make sure that the colors used within the monitor well are very light. White is best. Any use of darker colors will result in a considerable loss in efficiency.

Also consider the acoustic issues. If acoustical ceiling material is used, make sure that the reflectance as well as the acoustical properties are high. Manufacturers often claim that the paint color is equal to the reflectance, but you also need to account for the reduced reflectance due to the fissures in the tile.

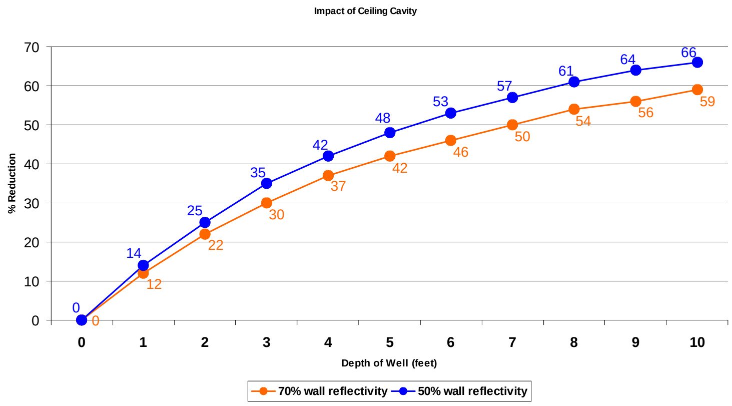
Let the heat stratify

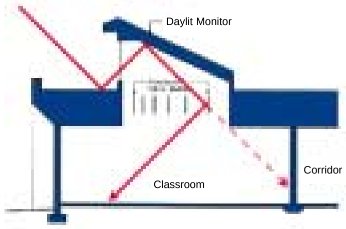
One of the keys to achieving the desired cooling reductions is to rely on the stratification of heat within the monitor itself. In that cooling loads are typically more problematic, you should not attempt to remove this heat by placing supply and return grilles in this area, but instead allow the heat to stratify. This benefit is often overlooked in designing daylit spaces and comparing one strategy to another.



Minimize the depth of the ceiling cavity

The depth of the well is very important. The deeper the well, the harder it is for the radiation to reflect down into the space. From the following chart you can see the theoretical decrease in efficiency that results from deeper and deeper wells. For example, with a seven foot deep, square skywell that has a 70% reflectance, the loss in effectiveness due to the well will be 50%.





North-facing Roof Monitors

North-facing monitors, while less energy efficient, can still provide good daylighting and a net energy benefit.

Serve as a mounting surface for a solar system

Because of the additional high costs associated with structural elements involved in supporting solar hot water systems or photovoltaic systems, the back (south side) of selected daylighting roof monitors can also serve as a mounting surface for the collectors. This "cost-sharing" keeps costs down and allows inclusion of more sustainable design components that might not otherwise be as cost effective.

Consider the elimination of baffles

Because of the orientation and limited hours that most school spaces would be used (not early or late in the summer months) baffles could be eliminated in spaces with north-facing monitors.

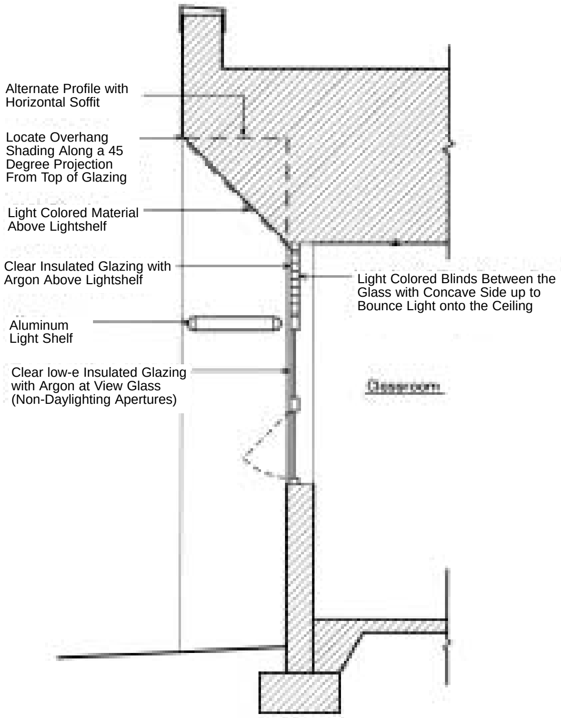
In gymnasiums, baffles may be required with north-facing monitors because this space is often utilized more during the summer.

The baffles also can help from an acoustic standpoint. Other acoustical treatment may be required.

The baffles help reduce the scale of the space, particularly in classrooms, making the ceiling appear lower.

Lightshelves on South Walls

Your choice of lightshelves will be mostly driven by the depth of the space you are trying to daylight. If the primary locations within classrooms are less than 20 feet from the south window, lightshelves can be used effectively. If the ceiling is higher, like in a multi-purpose room, it is possible to use the lightshelves to reflect the light deeper. This strategy can often be coupled with high, north transom glazing to effectively light a space.

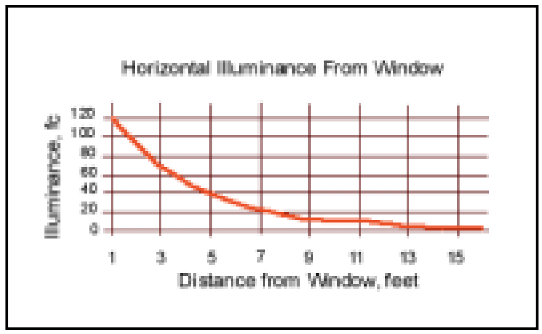


South Facing Exterior Wall Section With Lightshelf

Recognize the limitations of side daylighting

This is a very effective strategy for daylighting spaces in rooms (with 10 foot ceilings) up to 15 to 20 feet from the window and can be employed in multi-story schools or where roof monitors are not possible. The deeper the room is, the higher the ceiling has to be.

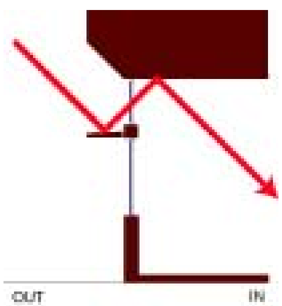
From a normal window, the illuminance levels will drop off considerably as you move away from the window. It would be common for the light level to be 120 footcandles at the window and 20 footcandles at a distance of eight feet back.

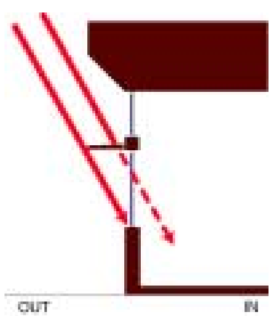


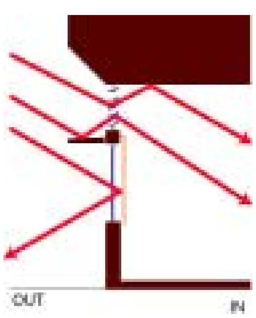
Bounce light deeper into space

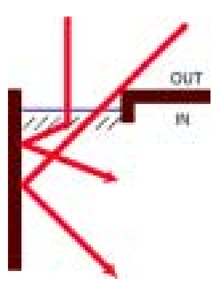
A lightshelf made of a highly reflective material will bounce the sunlight that strikes the top of the surface deep into the building. The reflected sunlight will hit the ceiling and bounce down into the room.

Don't use lightshelves on northern exposures. They provide no benefit.









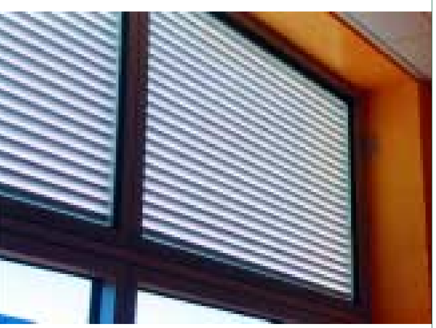
Select durable but reflective lightshelf material

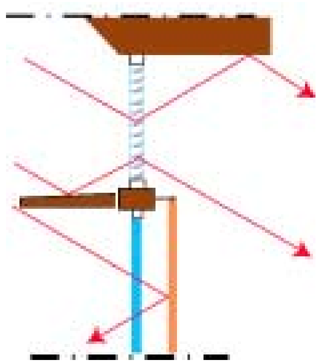
Select durable materials for both interior and exterior lightshelves and design them to carry the weight of a person.

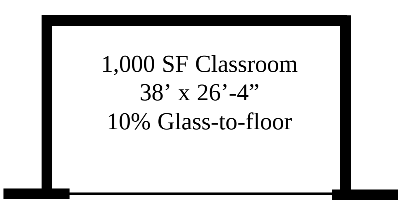
Specify aluminum exterior lightshelves as a good compromise between good reflectance, little or no maintenance, and cost.

Shade lower view glass

The lightshelf also serves the vital role of shading the window below, keeping out heat gain and glare.







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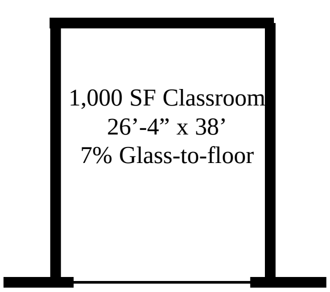


Stop direct beam with directional blinds

The use of a lightshelf will shade much of the view glass below the shelf but does not stop direct beam radiation from coming through the top section of glazing and into someone's face. One option is to incorporate an interior light shelf, but this option often requires a significant width to effectively block low altitude sunlight. A better option is to incorporate directional blinds to intercept this light and either reflect it up to the ceiling or toward the walls.

If the lightshelf area is narrow and located adjacent to the perpendicular walls, vertical blinds can be employed to bounce the sunlight outward, towards the walls.

When installing vertical blinds, make sure that one continuous blind is not installed that covers both the top lightshelf area and the view glass. Install separate blinds. Having one continuous blind has a negative effect on the performance of the lightshelf, generally only making it effective in the months where the lightshelf can effectively shade the lower view glass.

When sizing the glazing area, it is critical to account for the loss in sunlight coming into the space due to the window treatment.

Use horizontal blinds between glazing

If the lightshelf glazing is located near the middle of the space and further away from perpendicular walls, use horizontal blinds to allow the light to be reflected up toward the ceiling and bounced deep into the space.

If the lightshelf area is more extensive, and is the primary feature lighting a space, the design requires that the light be bounced deeper into the room. Horizontal blinds will help achieve that.

For horizontal blinds to be effective, they should have either flat or curved blades. If curved, they should be turned opposite of the way they are normally installed, so they are curved upward. Additionally, because of potential dirt build-up and maintenance, they should be placed between the glazing.

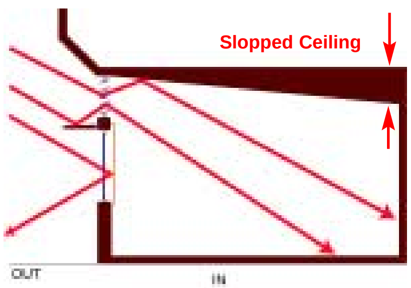
When sizing the amount of glazing required, make sure to account for the loss in transmission due to the internal shades.

Most shades available today are operable and can be closed completely. However, if the space does not need to be temporarily darkened, the angle of the internal blinds can be fixed, angled up to the ceiling (approximately 45 degrees). By fixing the angle and not allowing the occupants to operate the blinds, there will be less opportunity for the daylighting to be negated.

If the internal blinds do need to be operated for darkening purposes, it is desirable to have one setting (at 45 degrees upward) that optimizes the gain while still intercepting direct beam radiation, and a second "closed" position. Motorized blinds are best suited for this purpose, as the setting can be fixed.

Elongate room to maximize glazing opportunity

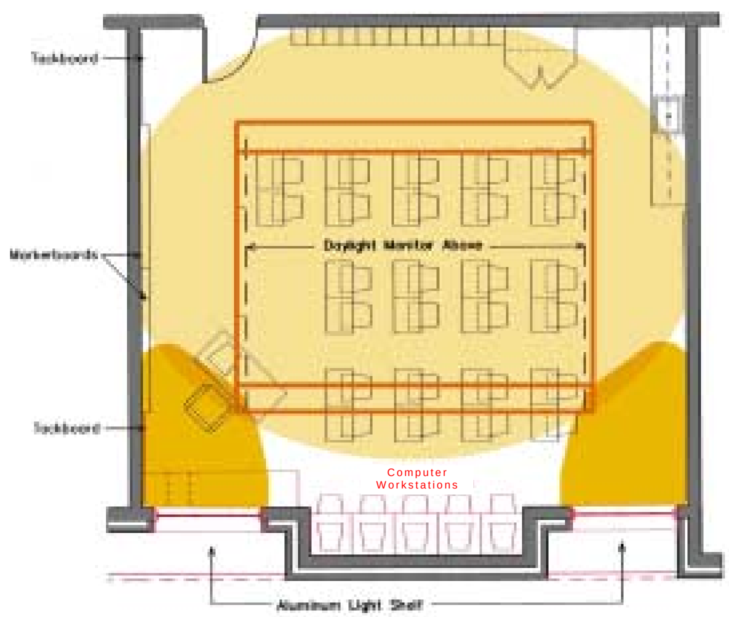
The more elongated your classrooms and offices are in the east-west direction, the more opportunity there will be to achieve an adequate daylighting strategy that employs lightshelves. Let's take an example of a typical 1,000 square foot classroom (38' x 26'-4") in Raleigh, NC, that uses a lightshelf, the bottom of which is 7 feet above the floor. You will need approximately 10% glass-to-floor area ratio, or about 100 square foot of clear glass in the lightshelf area. If the space



has a 38 foot outside wall, a 38' x 2'-8" aperture will provide enough glass. However, if the 26'-4" dimension is on the outside wall, and the glass is still 2'-8" tall, you will only be able to achieve a 7% glass-to-floor area ratio - not enough to effectively daylight the space.

Slope ceiling from top of lightshelf down to back of room

To maximize the ability to bounce light deep into a space using a lightshelf, you should consider the advantages of sloping the ceiling from the top of the south-side lightshelf to the back of the room (north wall of space). The efficiency, in comparison to a flat ceiling, will be improved by 10% or more.



When sloping the ceiling from the outside wall down to the back of the space it is often possible to encroach into the ceiling cavity space just at the window area, not increase floor-to-floor dimensions, and still have enough space for ductwork. A good example might be comparing a classroom with a flat ceiling at ten foot versus one that might be 11'-4" at the lightshelf and 9'-0" at the back of the classroom.

Implement lightshelves to complement roof monitors

Lightshelves on south-facing windows can be very effective in complementing the daylighting provided by the roof monitors. If you place one window on each end of the south wall, they will balance the daylighting within the space.

High Transom Glazing on North Walls

High, north transom glazing can provide a good daylighting option in spaces that are not too deep. Like north-facing roof monitors, a transom takes more glazing than would a south lightshelf to achieve the same annual contribution, hence the energy performance is not quite as good. The most significant advantage is that controlling direct beam radiation is not usually a problem.

Don't use lightshelves on north wall

Because of the lack of direct beam radiation on the north, lightshelves do not provide any benefit and should not be used.

Employ many of the same optimization strategies as with south-facing lightshelves

Place the glazing high in the room with the head of the glazing at the ceiling.

Utilize sloped ceilings to enhance performance.

It is very important to elongate the rooms in an east-west direction so that there is more exposed wall area in which to place the glazing.

Window treatments should only be used to provide a strategy to temporarily darken a space. Make sure that the blinds can be fully retracted so that they block the least light possible.

As with glazing in lightshelf areas, do not use low-E glass in the high, designated daylighting apertures. It will reduce visible light transmission, in turn requiring more glazing.

Use lower glass areas as a last resort

When implementing a daylighting strategy in classrooms that face both north and south, it may be difficult to establish an optimum ceiling height. On the south side you can use lightshelves that generally require less glazing than high, north transom apertures. However, if you use blinds-between-the-glass, the height of the south aperture will pretty closely match the height of north transom glazing. To avoid different ceiling heights, some of the lower view glass may be considered as an integral part of your daylighting strategy. Because blinds would typically not be used by the students or teachers to block direct beam radiation, it is logical to assume that this lower view glass be considered. The big drawback is that the teacher might still use the window area as a display board and block the light.

Assuming that lower northside view glass is considered in your daylighting strategy, it is advisable for comfort reasons to use low-E glass in this case, sacrificing the 10% to 30% reduction in visible light benefit. In this case, it will be very important to select a low-e glass that has a high visible light transmission.

General Recommendations for All Daylighting Options

Minimize contrast

The success of your daylighting strategy will be determined, to a great degree, by the amount of contrast that exists within the space. Your design should attempt to eliminate contrast between bright surfaces and darker surfaces by avoiding bright, visually exposed windows.

Roof monitors help considerably in bringing more uniform light into a space because not all the daylighting apertures are located on one wall.

If you do use lightshelves, consider using blinds-between-the glass to eliminate any glare.

Select light colors for interior finishes

The color of the ceiling, walls, floor, and furniture have a major impact on the effectiveness of your daylighting strategy. When considering finish surfaces, install light colors (white is best) to insure that the daylight is reflected throughout the space. In order of importance, the lightest colors should be installed at the skywell, ceiling, wall, furniture and floor.

All have an impact. The darker these surfaces are, the more glazing will be required to achieve the same net effect.

Select highly reflective ceiling tile

Consider a ceiling tile or surface that has a high reflectivity. Make sure that you account for any fissures in acoustical tiles and how this will impact the amount of light absorbed. Don't assume that the color of a tile alone dictates its reflectance.

When selecting a tile, question the product manufacturer regarding the listed reflectance. Most will list the reflectance as if it were the paint color reflectance.

Use continuous dimming controls

To enhance the economic benefits and provide a smooth transition between varying light conditions, dimmable lighting controls should be used in most cases. In setting your lighting photosensor controls, consider the lower limit to which the ballast can be dimmed (typically, 10% to 20%.)

Depending upon the daylighting strategy employed, photosensor controls should be used to dim logical groupings of lights.

Implement a lighting fixture layout and control wiring plan that complements the daylighting strategy.

If a lightshelf strategy is used, photosensors should control each bank of lights (running parallel to the outside glazing wall) as they progressively move back deeper into the space. Because of the strong difference in light levels that will occur close to the window and further back from the window, having each bank controlled individually will help balance out the space.

In a space that has a roof monitor, you may prefer to install one photosensor that controls all the perimeter lights and a second that controls all the lights within the monitor well.

In gymnasiums, using ganged-fluorescent fixtures coupled with dimmable ballasts effectively eliminates the problems typically associated with the long restrike time of metal halide fixtures.

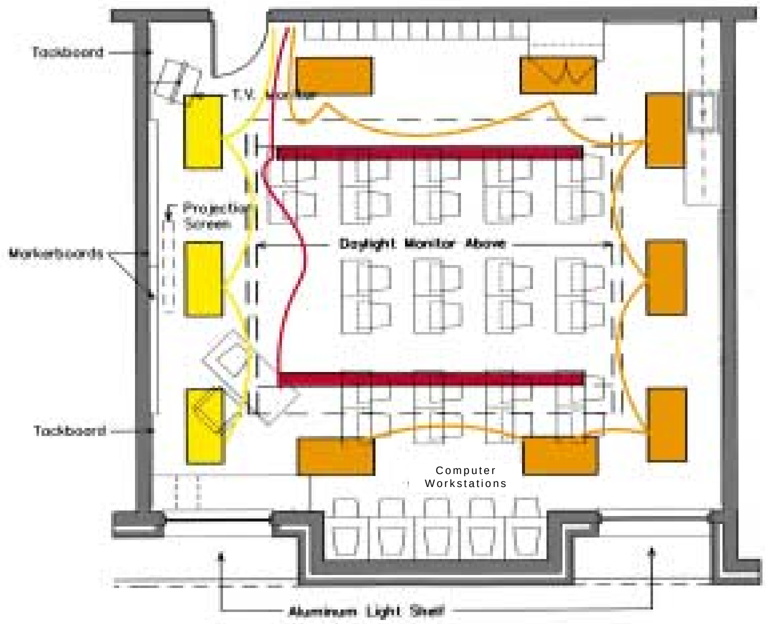
Locate your photosensors correctly

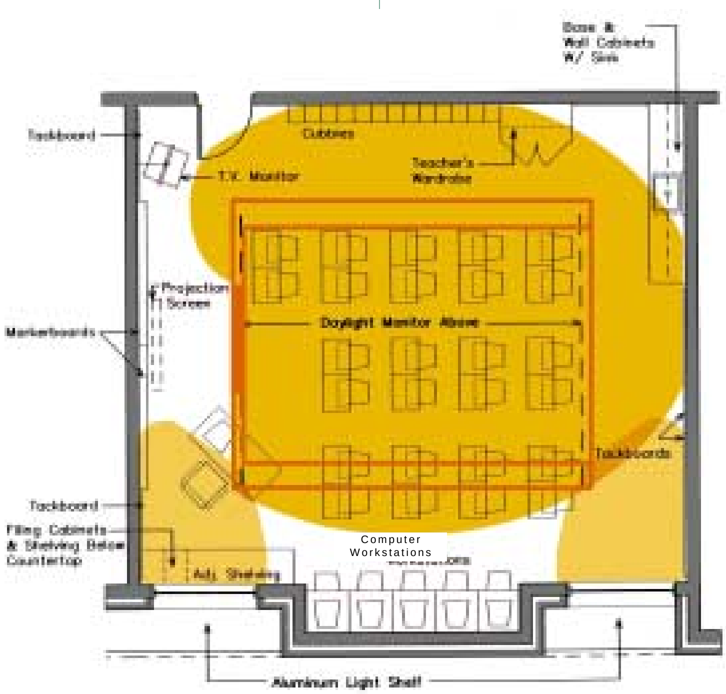
Mount the photosensors in locations that will allow them to closely simulate the desired light level (or can be set by being proportional to the light level) at the work plane.

Provide a means and convenient location to override daylighting controls in spaces that are intentionally darkened to use overhead projectors or slides.

Select compatible light fixtures

First consider using indirect lighting fixtures that closely represent the effect of daylighting. Since this light is reflected off several surfaces and from various sources, the fixtures will provide high quality light that is more uniform and less glaring.





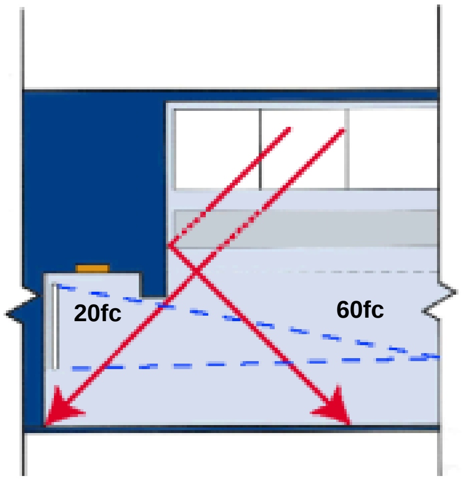
Consider the furniture and space layout

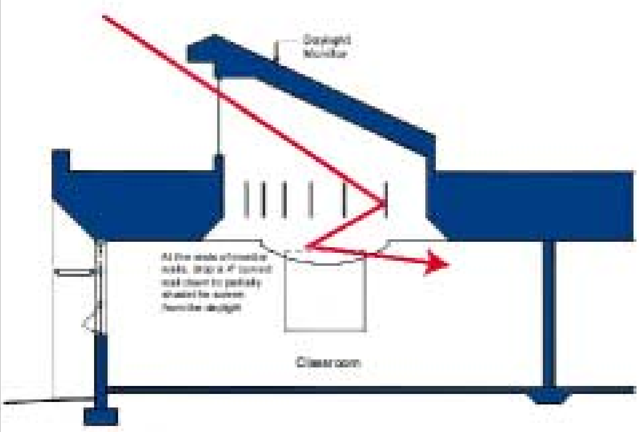
When laying out the classrooms, consider where the light is coming from and the potential for glare. The characteristics of the space will be much different if the daylighting is accomplished with a roof monitor or a lightshelf.

The teaching wall will have key teaching aids that have unique lighting requirements. The teaching wall is normally the location for the overhead projection screen, white board, and TV monitor. Each of these elements has different lighting needs and should be addressed separately.

Students optimally would be seated facing the teaching wall with the lower view glass windows, lightshelf windows, and high north glass to the side or back of the students. In no case should the students face the outside windows.

A good location for computer stations in the classrooms is on the outside wall, between two view glass windows.





Intentionally darken select spaces within classrooms

The TV monitor should be placed in a location that eliminates glare on the screen. This is typically easy to accomplish by locating the monitor high in a corner of the space and not adjacent to a window.

White boards need sufficient light but should not have excessive glare. Since they are often in the same location as the overhead projection screen, this can be problematic if the design doesn't incorporate operable blinds. The overhead projection screen requires that the light level be below 50 footcandles for viewing unless the projector has increased lamp capability. The white board could benefit by having much higher levels (as long as glare is reduced). To address both of these needs you need to intentionally darken the area of the teaching wall that has the screen and then use electric lighting to brighten the wall when the white board is in use.

Below you can see how the wall is intentionally shaded by dropping the edge of the roof monitor well in front of the teaching wall. At Millbrook Elementary School, in Raleigh, NC, the wall in front of the shading device is effectively darkened by at least 40 footcandles more than the area less than ten feet away.

Accurately Simulate Daylighting Performance

Daylighting Analysis

To determine the optimum daylighting and glazing strategy for each application, the designer should conduct detailed daylighting computer simulations that compare options. The program variables should allow you to input different locations (TMY data for various cities) as well as component configurations including exterior fins, overhangs, glazing types, window treatments, lightshelf design, surface reflectances, space configurations, ceiling heights, glazing placements, mullion sizes, dirt build-up, dimming options, and time-of-use schedules.

Simplistically, the goal in conducting this evaluation should be to establish the optimum amount of glazing, regardless of the strategy, that does not ultimately produce overheating and best creates a uniform light distribution. This is most easily done early in schematic design, by looking carefully at the peak cooling months and seeing if excessive radiation is entering the space during key peak times. If during these peak times more gain is entering the space than is necessary, either reduce the glazing, adjust the overhangs, alter the depth of the ceiling cavity, or change the overall strategy.

Analyze your daylighting strategies by conducting computer simulations of each key representative space. You should analyze numerous points within each space for hourly, monthly, and yearly contributions. It is important to understand the range in lighting achieved as well as the average for the space. Once this process is accomplished, you should take all the hourly points within one space and produce one generic point that best represents the hourly performance of the space in general.

This process should be accomplished for each different "typical" space until a condition exists where no more radiation enters the space during the peak cooling times than is needed to achieve the desired footcandle level. The goal should be to achieve a daylighting strategy that reaches a "design" footcandle level two-thirds of the daytime. Experience has shown that it is very difficult to achieve the desired footcandle level more than 70% or 75% of the time without overheating.

Once this is completed, the hourly data (by month) for each representative space should be input into the US Department of Energy's DOE-2 program, much like a very extensive lighting schedule. This will result in a detailed assessment of how the daylighting strategy interacts with the other building components and systems. The output, taking into account the varying performances of the different spaces, produces a very dynamic model of how the school performs and most accurately accounts for the typical cooling load reduction of 10% to 20%.

The following represents the cooling load reductions that were achieved at six schools due to daylighting and modified roof assemblies:

School	Location	Peak Cooling Reduction	Lighting Savings	Total Energy Reduction
Millbrook Elementary School	Raleigh, NC	11%	59%	22%
Heritage Middle School	Wake Forest, NC	24%	43%	25%
Smith Middle School	Chapel Hill, NC	19%	64%	16%
Kenton County Middle School	Kenton, KY	9%	34%	10%
Riverside High School	Greenville, SC	27%	7%	20%
Edmonson Gymnasium	Detroit, MI	18%	44%	12%

DOE-2 Whole-Building Energy Analysis

Once you have completed your daylighting analysis, it is essential that you utilize a comprehensive, whole building energy stimulation tool that can adequately factor the true impacts of the daylighting. The best program available to do this is the US Department of Energy's DOE-2 program. The energy simulation should evaluate the entire school to determine interrelationships of key energy-saving measures to the daylighting strategies being considered.   The DOE -2 simulation will help you in evaluating hourly, daily, monthly and yearly energy consumption in relationship to space cooling, space heating, fan energy, pump energy, ventilation energy, lighting, and other miscellaneous electrical loads.

The following PC versions of DOE-2 have been developed and are available commercially:

- ADM-DOE.1E , ADM Associates, Inc., www.adm-energy.com
- ENERGYPRO, EnergySoft, Inc., 415-833-5900, www.energysoft.com
- EZDOE (2.1), Elite Software, Inc., 800-648-9523, www.elitesoft.com
- FTI/DOE2, Scott Henderson, 907-333-8937, www.finite-tech.com
- POWER-DOE (2.2), James J. Hirsch & Associates, www.DOE2.com

Build Physical Models

Another excellent method of better understanding how spaces within your school will perform is by building and measuring scaled models of particular spaces. There is not a computer model that has been developed that can simulate performance as well as an actual scaled model.

Verify and Modify your Design Process

After your daylit school design has been constructed, it is essential that you visit the school and measure the light levels within each of the different spaces at different times of the day and year and compare the performance with your computer and physical models. Every computer program has particular aspects that can not be simulated as accurately as other areas. To improve your future designs it is important to understand the strengths and weaknesses of the program that you are using and how you may modify your runs to achieve better accuracy.

Part of your post-occupancy analysis should also be an evaluation of how well the human factors were addressed. Every project offers you a new opportunity to improve your next one.

Daylight Dividends

Daylighting reduces the need for electric light by introducing natural light into a building. The Daylight Dividends program was established to build market demand for daylighting as a means of improving indoor environmental quality; to overcome technological barriers to effectively reap the energy savings of daylight; and to inform and assist state and regional market transformation and resource acquisition program implementation efforts.

>> Building Owners and Developers
Research evidence for the benefits of daylight, with full references

>> Architects and Engineers
Authoritative guidance on the effective use of daylighting

>> Case Studies
Perspectives supporting the use of natural light in commercial and educational settings

For more information about the program or about the Lighting Research Center, visit:

www.daylightdividends.org

or

www.lrc.rpi.edu

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