Chapter 7: Sustainable Design

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PURPOSE

The purpose of this chapter is to present guidelines for meeting the intent of OSFC Resolution 07-124 adopting LEED-Silver as a minimum standard for all OSFC projects and to provide a source of proven ideas and concepts for achieving that benchmark.

OSFC – LEED "SILVER"

On September 27, 2007, the OSFC passed resolution 07-124 which states: "For projects approved by the Commission subsequent to this date, LEED for Schools Silver Certification with a preferred investment in attaining LEED points in the energy and atmosphere category is the standard for projects participating in OSFC programs under the standards and specifications approved I nthe Ohio School Facilities Design Manual (OSDM).

Under the Commission's Green Schools Initiative, all future funded buildings will be encouraged to meet LEED Gold certification and attain Silver certification as a minimum.

LEED "RATING"

The U.S. Green Building Council (USGBC) developed the LEED (Leadership in Energy and Environmental Design) rating system in response to a growing need for defining and quantifying buildings as "green". The LEED rating system provides a nationally recognized standard and a third party certification of attaining sustainable design features.

LEED FOR SCHOOLS

The USGBC recognizes the unique nature of the design and construction of K-12 schools. Based on LEED for New Construction, ***the USGBD developed LEED for Schools*** that addresses issues such as master planning, classroom acoustics, mold prevention, ***school grounds design,*** and environmental site assessment. By addressing the uniqueness of school spaces and children's health issues, LEED for Schools is a unique, comprehensive tool for schools that wish to build green, with measurable results. LEED for Schools is the recognized third-party standard for high performance schools that are healthy for students, comfortable for teachers, ***resource efficient,*** and cost-effective.

LEED for Schools encourages project teams to use an integrated design approach and promotes improved practices in:

- Site selection and development
- Water use
- Energy use
- Environmentally preferred materials, finishes, furnishings
- Waste stream management
- Indoor air quality and comfort
- Innovation in sustainable design and construction

SUSTAINABLE FEATURES

The importance of understanding the design and construction industry's environmental impact is critical. Each year the built environment consumes significant amounts of the nation's raw materials (40%), total energy produced (33%), and fresh water use (17%). The challenge is to design intelligent, economically prudent structures that use a minimum of nonrenewable energy, produce a minimum of pollution and wastes, and are generally environmentally benign; all the while increasing the comfort, health, and safety of the people who live and work in them.

A sustainable school facility provides a healthy indoor environment for students and staff, lower life cycle costs, and lessens the environmental impact during construction and occupancy. An additional component should result – increased student achievement.

Research indicates that test scores increase when daylight is introduced to a classroom. The optimum design solution is one that effectively emulates all of the natural systems and conditions of the predeveloped site – after development is complete.

The major features of sustainable school building design are:

- Sustainable Site Planning and Landscape Design
- Renewable Energy Sources
- Integrated Day Lighting and Electrical Lighting Systems
- Energy-Efficient HVAC Systems
- Energy-Efficient Building Shell
- Environmentally Preferable Building Materials
- Indoor Environmental and Air Quality
- Water Conservation
- Construction and Occupancy Waste and Recycling Systems
- Transportation and Community Integration
- Systems Commissioning and Maintenance Programs
- Eco-Education
- Classroom Acoustical Performance
- Refrigerant Management
- Commissioning

These features support the use of the United States Green Building Council (USGBC), Leadership in Energy and Environmental Design (LEED) Green Building Rating System, but focus on principles and strategies rather than specific solutions or technologies, which are often site specific.

Many of the preceding features are being incorporated in new school facilities through criteria in the Design Manual guidelines. School districts and their Design Professionals are encouraged to recognize, perpetuate, and include sustainable features in their buildings.

According to the *Whole Building Design Guide*:

> Whole Building Design consists of two components: an integrated design approach and an integrated team process. The "integrated" design approach asks all the members of the building stakeholder community, and the technical planning, design, and construction team to look at the project objectives, and building materials, systems, and assemblies from many different perspectives. This approach is a deviation from the typical planning and design process of relying on the expertise of specialists who work in their respective specialties somewhat isolated from each other.
>
> Everybody engaged, every issue considered, early in the project.

Within LEED, there are two essential components to a successful integrated design process. The integrated team process is defined through design charettes (eco-charrettes); the integrated design approach is represented by the results of the energy modeling which begins at the very onset ***(schematic design phase)*** of the project and continues through the development of construction documents.

A. INTEGRATED TEAM PROCESS: The Eco Charette

1. The purpose of the OSFC's eco charrette is to:
   a. Understand the owner's project requirements and the options available to the design team for achieving those.
   b. Integrate the design team and assign tasks for small group collaboration.
   c. Integrate energy saving design elements and technologies into the project wherever possible.
   d. Develop community buy-in of project and increase the likelihood of the district developing their local share of the project costs (through all existing resources).
   e. Encourage greater community connectivity.
   f. Ongoing development of LEED Project Checklist.
   g. Optimize building performance.

2. The eco charrette is to be interactive and address the questions: What can we do? What do we want to do? What do we need to accomplish our (owner's) goals? Who do we need to invite to the table? There are three good places where a charrette or charrette-like workshop will benefit the project:
   a. During the Planning Phase: Prior to the development of the PoR (or Owner's Project Requirements), the design team, District, and OSFC planning manager would host a community meeting and engage members of the community in a discussion of options, desires, and requirements. The goal would be to leverage the support of the community to pass levies or issue bonds to be fund the project and to bring needed support for elements of the project that would be beneficial to the community. This charrette could be facilitated by an expert in obtaining positive outcomes in community meetings.
      1) Outcome: Develop elements of the PoR that the community will support that meets the mission of the school.
      2) Outcome: Create a list of needs, including what community partners will be essential to have at the table as we move forward.
   b. During Schematic Design: The design team has developed the Owner's Project Requirements and the "Basis of Design" document. Site information is known, preliminary design concepts are clear and it is possible that they may be fully developed. Given extensive knowledge about the project and site, this charrette would encompass discussion of learning spaces, invite major stakeholder input, and completion of a LEED Project Checklist.

1) Outcome: Development of a realistic preliminary LEED Project Checklist.
2) Outcome: Development of a list of possible design elements that need research to determine viability.
3) Outcome: List of needed resources for project needs.
4) Outcome Task assignment related to LEED checklist items.
5) Outcome: Creation of small teams that will work through design elements, for example architect, mechanical engineer, and CM cost estimator working through energy modeling according to GO Specs.

c. End of Schematic Design: More of a design charrette where the design team comes together with drawings on the wall to critique, modify, optimize, and begin to finalize designs. This charrette would be facilitated by a mentor with demonstrated experience and success in designing in high performance, sustainable design, and should understand the commission's objectives with the LEED initiative.

1) Outcome: Design is optimized for daylighting, energy performance, rain water harvesting, and implementation of renewables such as solar thermal.
2) Outcome: Schematic design documents are ready for finalization and submission to OSFC for review.
3) Outcome: LEED Online Design Submission is ready to be completed. LEED Project Checklist is finalized barring any unforeseen opportunities or difficulties that arise as the project enters the construction phase.

B. INTEGRATED DESIGN APPROACH: Energy Modeling

1. Modeling During PoR and SD: Envelope Optimization

a. The goal of modeling here is to run energy usage models for your building based on square foot allotted, building orientation, shape, envelope, fenestration, and the integration of daylighting and to integrate those elements creating the optimal space possible for the allowable space to be lighted, heated, and cooled as efficiently as possible. This is similar to working the building like a block of clay and building out the space as the design team continuously runs it through a modeling software and gaining insight as to how to best optimize it for long-term energy performance.

b. For this modeling, it is essential to use software that is very robust in dealing with envelope materials and daylighting, such as the U.S. Department of Energy's eQUEST. Through the use of such software, architects and engineers work together to continually improve the performance of their building by adapting the orientation, walls, windows, and other external elements based on information learned about the interaction of the wall insulation and natural daylight penetration.

2. Modeling During DD and CD: Energy System Optimization

a. Once the building is optimized for energy performance based on the integration (or remediation) of external influences (sunlight, wind, heat gain, heat loss); the design team can move forward to begin laying out interior spaces more precisely; designing HVAC, plumbing, electric, etc. ***For this final load analysis and equipment selection, the Mechanical Engineer may elect to use commercial software such as indicated in the Systems and Materials section of Chapter 8.***

END OF SECTION

INTRODUCTION

Of all the typical sustainable design strategies that could be implemented into a school, daylighting will have the greatest positive impact. This daylighting guideline addresses those key design considerations typically confronted when designing K-12 schools in Ohio. To achieve a successful daylighting strategy, school designers must:

- Consider human factors
- Consider the energy ramifications
- Account for site constraints and benefits
- Select well-integrated daylighting strategies
- Optimize the most appropriate daylighting strategies
- Accurately simulate daylighting performance
- Verify and modify your design process.

A. CONSIDER HUMAN FACTORS

Daylighting design is not just putting in a lot of windows. If uncontrolled, direct beam radiation will stream in through your classroom window into a student's face and the teacher will simply close the blinds, negating your daylighting strategy all together. The most important aspects of good daylighting design are to understand human nature and to be realistic. Daylighting done well in a school helps:

- Improve student performance
- Create a healthier indoor environment
- Increase attendance
- Decrease energy consumption
- Reduce maintenance

1. Daylighting must be superior.

a. 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 <u>superior</u> to your 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. The examples of typical spaces provided in this guide were developed to achieve the desired footcandle level 65% to 75% of the time. The following desired footcandle levels were assumed for each type of space:

1) Classrooms ***40*** footcandles
2) Ag-Tech Labs ***50*** footcandles
3) ***Elementary Gymnasiums 30 footcandles***
4) ***Middle & High School Gyms 50 footcandles***

b. 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. For example, a classroom will require 50 footcandles of light during class periods but at night the same space may be used for parent-teacher meetings or an individual teacher's work. In these cases, 40 footcandles may be adequate if the teacher's area is lit appropriately.

1) Daylit Classroom

2) Daylit Gymnasium

2. Eliminate direct beam radiation

a. 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, ag-tech lab spaces, media centers, and administrative spaces, the design strategies bounce, redirect, or filter the sunlight so that direct radiation does not enter a space where it could be problematic. This is easy to say, but harder to achieve. This constraint essentially eliminates most commonly designed windows as good daylighting strategies.

3. Consider the need to darken individual spaces

a. The success of your daylighting strategy will certainly be determined by how occupants interact with the various components of your daylighting strategy. This is particularly true when it comes to the incorporation of blinds or shades that can be used to darken a particular space. If the blinds are 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.

b. If the intended function of the space requires darkening for limited periods of time, 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 (do to uneven cranking) limits the effective life of these devices to under ten years. The inconvenience associated with the process also results in a number of these shades being left closed. The implementation of motorized shades, while more expensive to install, will provide the teachers and students with greater ease of operation and result in a better performing daylighting design.

4. Only use shades if entire space needs to be darkened

a. Today's classrooms commonly use digital projectors and TV monitors that are best viewed in locations with lower than normal light levels. When designing your daylighting strategy, consider creating a darker location(s) in the room for the projection screen or TV monitor. See the section on Optimization. This strategy will allow the majority of the classroom to remain well daylit while still providing good viewing.

b. Only utilize darkening shades if the entire space requires darkening.

5. Don't count on view glass

a. Wall space is precious in schools. This unfortunately 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. In designing your daylighting strategy, 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.

6. Concentrate on the most utilized spaces

a. 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 typically used more, longer into the day and most of the year.

b. From a student and teacher productivity standpoint, classrooms are the most beneficial spaces to daylight. Design daylighting strategy to provide natural lighting for at least two-thirds of the daylit hours in:

1) the majority of the classrooms
2) special needs classrooms
3) gymnasium
4) ag-tech labs
5) cafeteria
6) media center
7) administrative areas

7. Utilize low, view glass to provide visual connection to outdoors

a. Regardless of building code requirements, you should incorporate a reasonable amount of low view glass for the students' benefit of a visual connection to the outdoors.

B. 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 that typically has insufficient natural sunlight, resulting in lighting not being turned off as planned, you have created a negative energy situation. The spaces will gain all the heat produced from the lights as well as the heat created by sunlight.

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
- in some cases, the number of installed lighting fixtures in the school

1. Orient building to maximize daylighting

a. A good, cost-effective daylit school design starts with good 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 important if you are going to rely on side lighting (versus roof monitors) as a significant daylighting strategy.

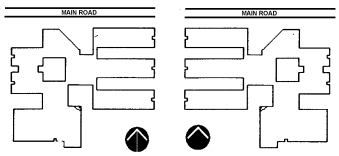
2. Maximize south glazing; minimize east and west facing glass

a. By employing south-facing apertures, you create a strategy that is much easier to control through the use of external window treatment strategies. It enables you to maximize winter radiation and optimize summer gain. As you can see from the accompanying chart that indicates the amount of radiation falling on different flat, non-shaded 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, although very slight, will also see a slight gain in the summer versus the winter.

b. Remember that the more sunlight that you allow to enter your building to address your lighting needs, the more heat you also have to deal with. By placing your apertures correctly, nature will be working with you versus against you.

c. 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.

1)



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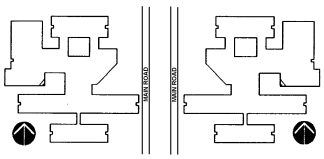

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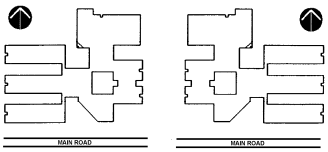
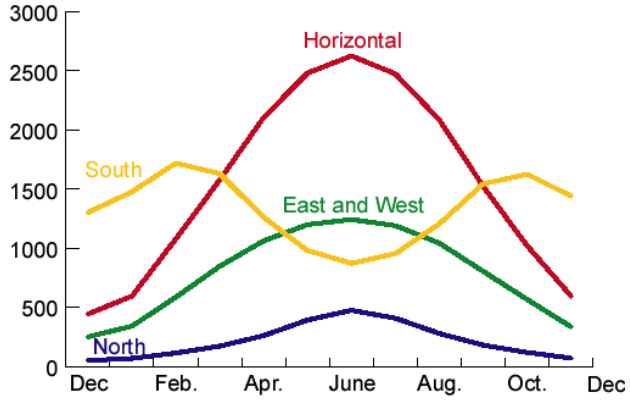


d. As you can see, the classroom wings, under any scenario, run east-west in length with roof monitors facing south or north. The rest of the building core was developed so that square roof monitors could be rotated within the same space, always facing south.



1) Radiation striking each surface at 40^0 latitude
(Btu/sf of unprotected glass/day)

3. Avoid uncontrolled skylights

a. The worst energy choice a designer can make is to implement skylights. The warmer months get the most radiation, just when it should be avoided. More than twice the radiation will enter through a flat skylight in the summer than in the winter, just the opposite of what you want.

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

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

4. Optimally size overhang on south-facing glazing

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

b. To reduce winter heating load, place 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 sun's altitude, even at noon, is low.

c. Remember that it is very easy to put in enough glazing to provide a very high daylighting contribution. The key will be using the maximum while not negatively impacting 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 correct, optimum location. You do not want anymore radiation entering the space during peak cooling times than is necessary to deliver the footcandles necessary. If during peak cooling time the space has higher footcandle levels than is necessary, you will increase cooling loads.

d. 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 produced a "controlled" daylighting solution that maximizes winter gain and minimizes summer gain. Avoid east and west glazing.

5. Reduce installed lighting

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

1) consider how classroom usage changes from typical daytime conditions to nighttime uses
2) evaluate if there are different lighting requirements associated with different uses (e.g., during the day the desired light level is ***40*** footcandles in the classrooms but, at night, the necessary light level may drop to 40 footcandles, when parent-teacher meetings and other activities require less light)
3) determine the minimum daylighting contribution during school hours
4) determine if there was a minimum amount of daylight that can be counted on to reduce the installed lighting

b. Good daylighting design that provides two-thirds of the lighting needs during daytime hours will typically allow at least 10 footcandles of natural light to enter the space even on a very overcast day. The only exception is normally (depending upon what time classes start) 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, and considering the few hours that are impacted, lowering the footcandle level makes good sense. The result will be one-fifth less installed lighting.

c. If the space has the same nighttime function (for example a classroom that will have night classes) you will need to install the amount required to address the full footcandle demand.

d. Another good example of a space that cannot be reduced is a gymnasium. Since the gymnasium is used for the same function during the day and night, no reduction in installed light is possible.

6. Reducing cooling loads

a. In the warmer months, cooling loads can be reduced by providing just the right amount of daylighting in your school. Because the lights are out, the cooling load is lower. This is because the lumens per watt from daylighting is twice that of typical 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:

1) no more radiation is allowed to enter your building than is required to meet your footcandle objectives
2) properly sized overhangs limit the radiation to optimal amounts
3) the lights, with the use of photo sensors, are automatically dimmed (or stepped)

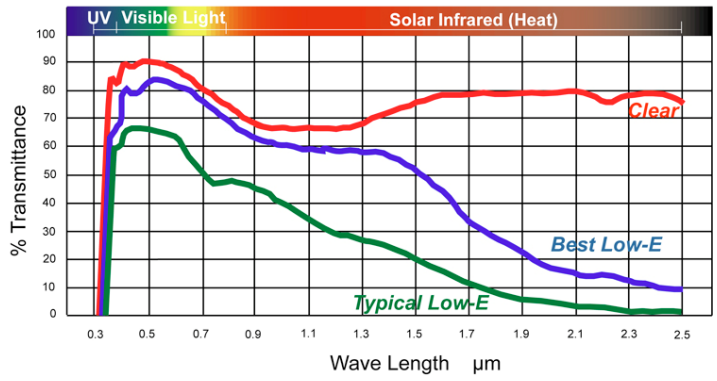
7. Passive solar can offset heat previously provided by lights

a. However, you also need to remember that, like in the summer, the lights are mostly off in the winter. This means that the heat that was typically being produced by the lights is gone, appearing to create a seemingly increased heating load. Not so. It is simply the result of the lights being off and not producing heat and the mechanical heating system having to address more of the load.

b. If the school is heated with a gas boiler, slightly more natural gas but much less electricity will be used. Typically, even with greatly increasing natural gas rates, this is a good tradeoff. If heating is to be accomplished with a heat pump, the tradeoff would likewise be smart since the heating efficiency of the heat pump is greater than that of electric lights.

c. 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 into a classroom. But, if that same monitor were facing south, the glazing area could be 15% to 20% less in size (resulting in lower first cost as well as conductive heat losses). When coupled with well-designed overhangs, the south-facing monitors could maximize winter solar gain. This strategy can do a lot to offset winter heating requirements. Remember that in Ohio, the school's heating demand was previously masked by the fact that the lights were doing a lot of the heating.

Solar Energy Transmittance



8. Select the right glazing

a. 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 addresses daylighting needs

b. 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.

c. 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 is seldom worth it from a life-cycle approach. However, wherever low, view glass windows are incorporated, low-E coatings should be used to improve comfort and save energy.

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

9. Consider reduced maintenance

a. 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 on the majority of the time. When comparing a typical non-daylit classroom to one daylit, the lamps in the non-daylit space will require lamp replacement three times more than in the daylit space.

C. 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 consumes more land area but maximizes your opportunities for roof monitors.

1. Account for shading from adjacent buildings and trees

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

2. Consider the reflectance from adjacent surfaces

a. Consider the reflectance of the materials in front of the glazing areas. The use of 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.

3. Utilize landscaping to benefit overall design

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

D. Select Well-Integrated Daylighting Strategies

Most designers who are considering implementing daylighting strategies for the first time are very concerned that their projects will go over budget and result in having to delete the daylighting strategy altogether. More often than not, this creates a negative consequence. In trying to think ahead to the process of "taking the daylighting out of the design," the designer never truly integrates the daylighting components into the overall design, thus hurting the budget that they are trying to protect.

1. Don't consider daylighting strategies as alternates

a. The most economical 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 inter-related aspects of the school's architecture, landscape, and engineering must be considered. If daylighting is fully integrated, many common architectural components can serve dual functions. White roofing material will reduce overall cooling loads while allowing desired radiation into a south-facing daylighting aperture, thereby reducing the glazing requirement. Mechanical cooling equipment can be further 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.

b. The opposite is true if the design is 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. Once the designer has 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.

c. 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 good 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.

2. Consider roof monitors and lightshelves

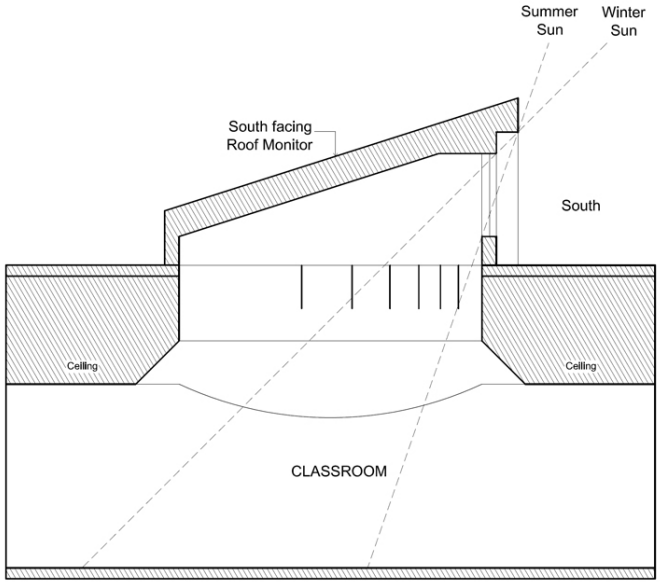
a. When considering the best daylighting strategies for a particular school, many factors will play a role in determining the best daylighting strategies to employ. However, from a typical school situation, you should place roof monitor and lightshelves at the top of that list to consider.

b. South-facing Roof Monitors - Roof monitors, incorporating vertical south glazing and properly sized overhangs and interior baffles, have an advantage in that they:

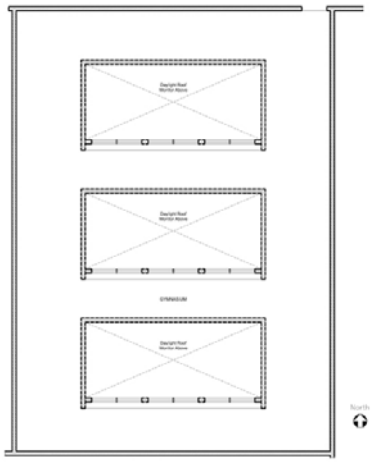
1) Create very uniform lighting throughout the space
2) Can be used to daylight spaces far from the perimeter of the building
3) Create passive heating benefits, allowing more radiation to enter the space in the colder months
4) Create a more diffuse, filtered lighting strategy; and eliminate contrast.

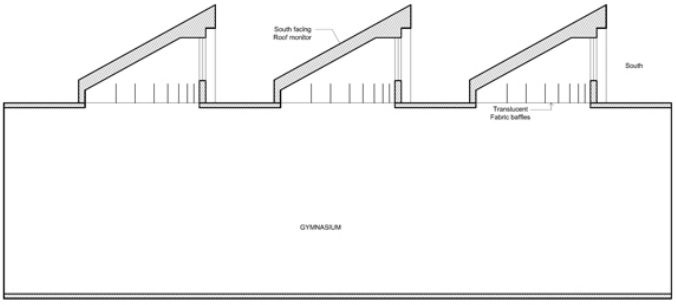
The big downside of roof monitors is that they can only be employed in single story designs

a) South-facing daylighting roof monitors

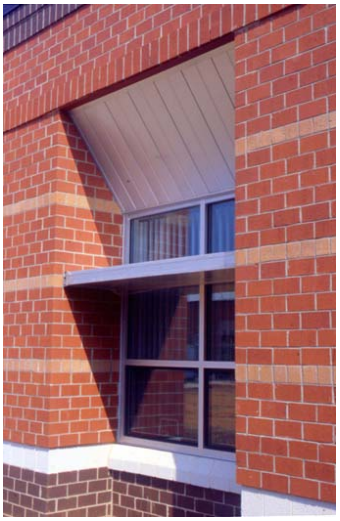


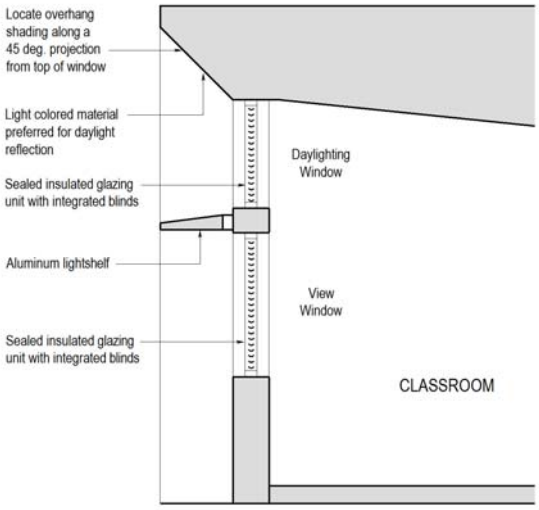
b) Classroom with south-facing roof monitor





c) Plan & Section of a Gymnasium with 3 south-facing daylighting roof monitors





d) South-facing lightshelf with blinds between the glass in the transom window

c. South-facing Lightshelves - From a light quality standpoint, lightshelves incorporated into south glazing strategies are typically the next best option in that they:
   1) Can be used in multi-story situations
   2) Can bounce sunlight to the back of most school classrooms
   3) Help shade lower view glass (located below the lightshelf)
   4) 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 at the back of rooms that are deeper than 20 feet and have ceilings that are 10 feet. Contrast between the brighter glazed wall and the opposite side of the room also must be addressed.

d. 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 15% to 20% more glazing to achieve the same annual daylighting contribution and they produce higher lighting levels in the summer than winter. North monitors are 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-facing monitor.

e. North-facing Transom Glazing - In north-side rooms, the use of high transom glazing can also be an effective strategy but requires more glazing. In spaces with both north and south exposures it may be logical to use a combination of south-facing lightshelves or roof monitors with the high, north glazing.

3. Provide proper glass-to-floor area ratios

a. Until detailed daylighting analysis is conducted, you can use basic rules-of-thumb (for Columbus, Ohio) that will help you in determining the right amount of daylighting glazing for particular systems. The percentages equal the glass-to-floor area ratio. The floor area in the classroom is equal to the primary area being daylit and excludes the area that is intentionally shaded at the teaching wall to allow for projector/TV monitor viewing.

	South-facing roof monitor	North-facing roof monitor	South-facing B-B-G, double	South-facing B-B-G, triple	High-North transom
900 sf Southside Classroom	9-10%	10-11%	11.5-12.5%	12-13%	--
900 sf Northside Classroom	9-10%	10-11%	--	--	11-12%
1,200 sf Southside Classroom	9-10%	10-11%	11-12%	11.5-12.5%	--
1,200 sf Northside Classroom	9-10%	10.5-11.5%	--	--	11-12%
600 sf Southside Resource	9-10%	10.5-11.5%	13-14%	13.5-14.5%	--
600 sf Northside Resource	9-10%	10.5-11.5%	--	--	13-14%
3,500 sf Gym/multipurpose	7.5-8.5%	--	--	--	--
16,000 sf High school Gym	9-10%	--	--	--	--
4,500 sf Ag-Tech Lab*	--	9-10%	--	--	--

*Ag-Tech lab assumed to not have a ceiling cavity

(continued on next page)

4. Factors for altering the glass-to-floor area ratio

a. If the following conditions exist, add or subtract the following percentage points from the ranges in the ratio of glass-to-floor area shown above. The percentages should be added or subtracted from the ratios pertaining to just the daylit space. For example, if an elementary gym's roof color in front of the south-facing roof monitor is a dark color instead of white, the glass area in the monitor should be increased from 8% glass-to-floor ratio to 9% glass-to-floor area.

	Classroom	Gymnasium
Color of Roof - In the case of a dark roof in front of a south-facing roof monitor	Add one-half of one percentage point to glass-to-floor area ratio	Add one percentage point to glass-to-floor ratio
Sloped Ceiling - In the case of a flat ceiling versus a sloped ceiling (sloped from a high above the daylighting window to back of room)	Add one-half of one percentage point to glass-to-floor are ratio	---
Ceiling Cavity - If the ceiling cavity is 10 feet versus 5 feet	Add three percentage points to glass-to-floor area ratio	---
Color of Interior Finishes - If the finish colors are darker than assumed (with a roof monitor)	Add one-half of one percentage point to glass-to-floor area ratio	---
If the finish colors are darker than assumed (with a side lit strategy)	Add one percentage point to glass-to-floor area ratio	---
If the finish colors are lighter than assumed (with a roof monitor)	Subtract one-half of one percentage point from glass-to-floor area ratio	---
If the finish colors are darker than assumed (with a side lit strategy)	Add one percentage point to glass-to-floor area ratio	---

	Light Colors	Assumed Colors	Darker Color
Walls	70%	60%	50%
Ceiling	85%	80%	70%
Floor	50%	35%	30%

Location in Ohio		
If in Cincinnati versus Columbus	Subtract one-half of one percentage point from glass-to-floor area ratio	Subtract one-half of one percentage point from glass-to-floor area ratio
If in Cleveland versus Columbus	Add one percentage point to glass-to-floor area ratio	Add one percentage point to glass-to-floor area ratio

E. Optimize the Most Appropriate Daylighting Strategies

1. 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. When optimizing your south-facing monitor strategy, consider the following:

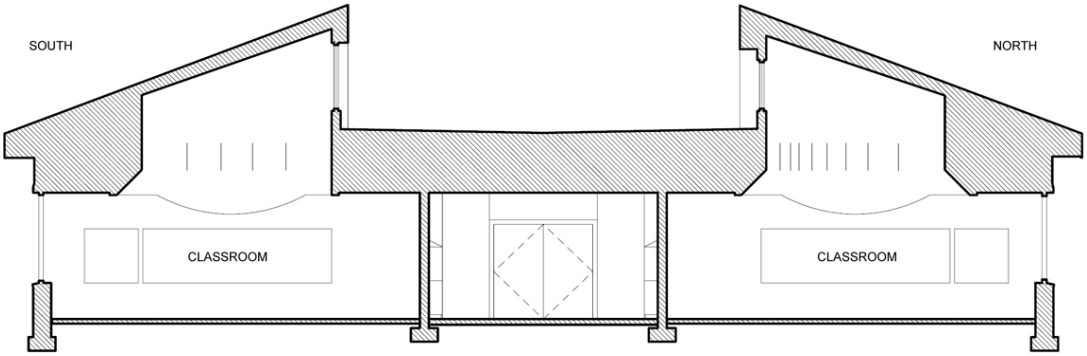
a. Minimize size by maximizing transmission

1) Minimize the size of the glazing by maximizing the transmission through the glass.

b. Consider the passive benefits

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

2) The glazing area, if south-facing, is typically 15% to 20% less than if north-facing. If you have 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.



c. Use light colored roofing in front of monitors to enhance radiation

1) 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. If installing a modified bituminous roof, use an Energy Star-rated, elastomeric coating with a reflectance of over 65%.

a) White roof in front of roof monitor windows reflects daylight deeper into the spaces.

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%

[1] Source: Berdahl 2000. "Cool Roofing Material Database"

2) When white roofing is placed directly in front of the south-facing roof monitors, the glazing area in the monitors is able to be reduced by 5% to 10% because of the additional reflected radiation entering the monitor. Add one-half of one percentage to glass-to-floor area ratio for classrooms and one percentage point to glass-to-floor area ratio for gymnasiums.

3) 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.

d. Use baffles to block direct beam radiation and diffuse light

1) In the roof monitor's light well assembly, 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 determined so that when standing inside the room looking out, you do not see the sky. This will ensure that no direct beam light gets in.

e. Specify fire-retardant, UV resistant baffles

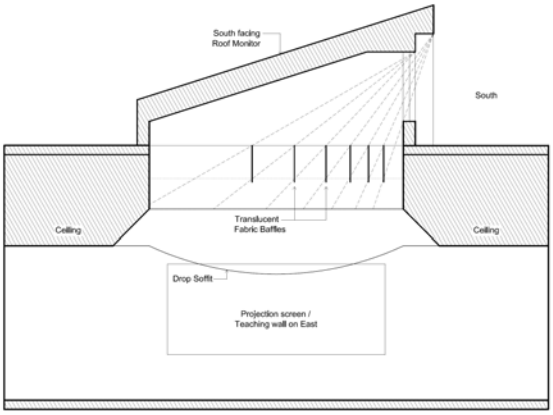
1) The baffles should be fire-retardant and UV resistant.

f. Use translucent baffles to help reduce contrast

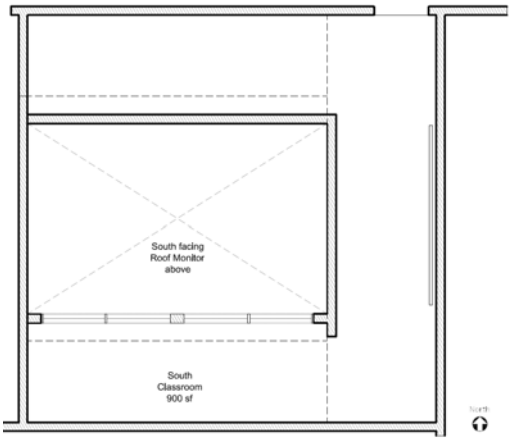
1) Light-colored translucent baffles not only reflect the sunlight into the space, but also help eliminate contrast from one side of the baffle to the other.

g. Minimize contrast at well-ceiling intersection

1) At the bottom of the light well, contrast is greatly lessened 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.



2) Section through south-facing roof monitor monitor in a classroom



3) Plan showing daylight roof

h. Address the monitor design

1) To help reduce conductive gains and losses, the walls and ceiling of the roof monitor should be well insulated and incorporate appropriate infiltration and moisture ***retarders***.

2) 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.

3) Also consider the acoustic issues. If acoustical ceiling material is used, make sure that the reflectance as well as the acoustical properties are high. Often manufacturers will specify the paint color when describing the reflectance of an acoustical tile. Remember that you also need to account for the reduced reflectance due to the fissures and holes in the tile.

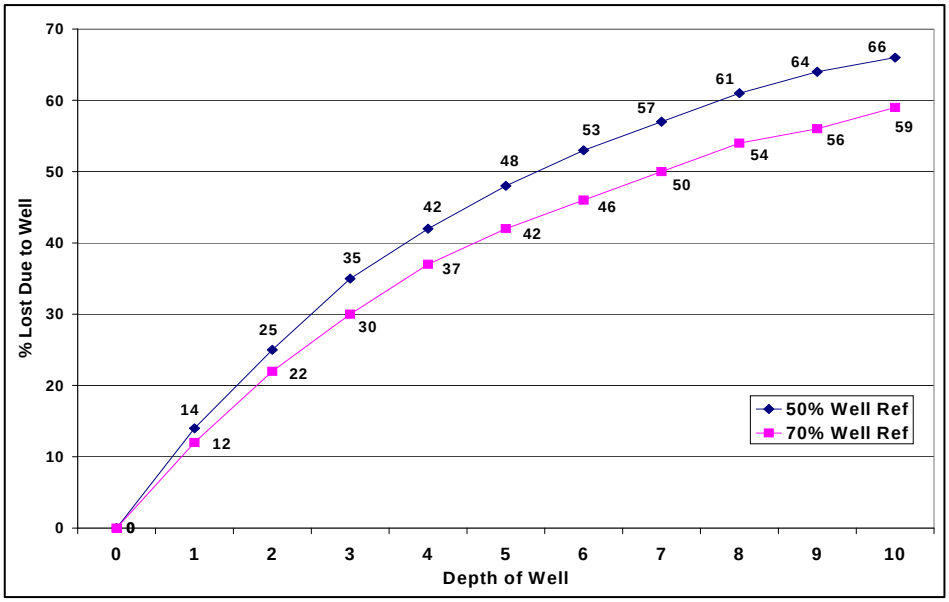
i. Let the heat stratify

1) One of the keys to achieving the desired cooling reductions is to rely on the stratification of heat within the monitor itself. 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.

j. Minimize the depth of the ceiling cavity

1) 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 sky well that has a 70% reflectance, the loss in effectiveness due to the well will be 50%.

2) To adjust your desired glass-to-floor area ratios from a ceiling cavity that is five feet deep to ten feet deep, add three percentage points to your glass-to-floor area ratio.



2. North-Facing Roof Monitors - North-facing monitors, while having a downside of being less energy efficient, can still provide good daylighting and a net energy benefit in particular types of spaces. In Ag-Tech labs, where baffles may be problematic from a cleaning standpoint, north-facing monitors may be a logical choice. When optimizing your north-facing monitors, consider the following:

a. Can dual-functionality serve as a mounting surface for a solar system

1) Because of the additional high costs associated with structural elements involved in supporting solar hot water systems or photovoltaic systems, 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.

Solar collectors mounted on north-facing roof monitors

b. Consider the elimination of baffles
   1) 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 these spaces.
   2) With north-facing monitors, baffles may be required in gymnasiums because this space is often utilized more during the summer.
   3) The baffles also can help from an acoustic standpoint. Other acoustical treatment may be required.
   4) The baffles, particularly in classrooms, help reduce the scale of the space, making the room not seem as tall.

3. Lightshelves on South Walls (Glass with internal, horizontal blinds)

Your choice of both interior and exterior lightshelves will be, for the most part, driven by the depth of the space. If the primary locations within classrooms (with 10 foot ceilings) that you are attempting to daylight are less than 20 feet from the south window, lightshelves can be effectively used. If the ceiling is higher (as in a multi-purpose room) or the ceiling is sloped, 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. When optimizing your lightshelf design, consider the following.

a. Recognize the limitations of side daylighting
   1) 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.
   2) From a normal window the illuminance levels will drop off considerably as you move away from the window. It would be common for a light level to be 120 footcandles at the window and 20 footcandles at a distance 8 feet back.

b. Bounces light deeper into space
   1) The lightshelf, made of a highly reflective material, will bounce the sunlight that strikes the top of the shelf's surface deeper into the building. The reflected sunlight will hit the ceiling and provide light for the room.
   2) Don't use lightshelves on northern exposures. They provide no benefit.

c. Shade lower view glass
   1) The exterior lightshelf also serves the vital role of shading the window below. With extended lightshelves covering lower view glass, it is possible to keep the lower view glass window treatments open more, particularly in the warmer months when the sun is higher in the sky.

d. Select durable but reflective lightshelf material
   1) Select durable materials for both interior and exterior lightshelves and, if reachable, design them to be capable of carrying the weight of a person.
   2) Specify aluminum exterior lightshelves as a good compromise between good reflectance, little or no maintenance, and cost.

e. Interior lightshelves

1) While the majority of the guidance in this document stresses the use of horizontal blinds-between-glass, the use of an extended interior lightshelf would allow you to implement a strategy with less glass area and better energy performance. The difficulty normally arises from the length the interior lightshelf has to be in order to block all the direct beam radiation.

2) Incorporate white painted gypsum board on top of interior lightshelves. However, aluminized acrylic sheets applied to the top of the interior shelf allows light to bounce further back into spaces and can improve performance in deeper rooms without top lighting.

3) A white or very light colored, translucent, interior lightshelf is better than a solid lightshelf because it will allow light to filter down directly under the lightshelf as well as reflect back into the space.

f. Interior, horizontal lightshelves are difficult to implement in schools

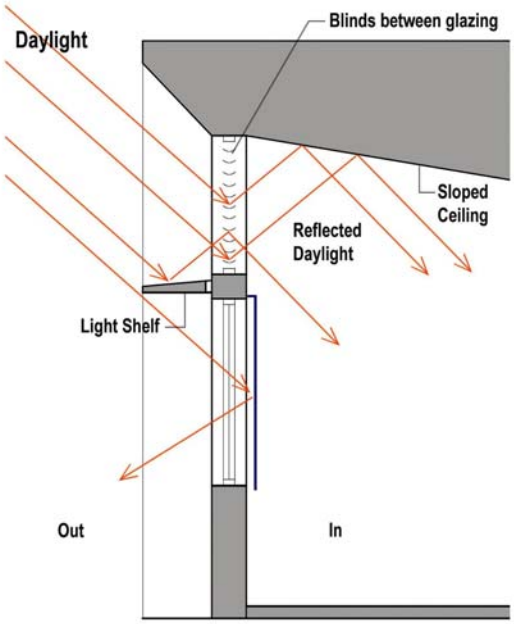
1) The use of an exterior lightshelf will shade much of the view glass below the shelf but it can not stop direct beam radiation from coming through the top section of glazing and into someone's face when the sun is low in the sky. One option is to incorporate an interior light shelf but this option often requires a significant depth to effectively block low altitude sunlight. They also can become problematic in schools if placed too low inside the classroom. A better option is to incorporate horizontal directional blinds that would intercept the direct beam light and either reflect it up to the ceiling or sideways to the walls.

g. Stop direct beam with vertical directional blinds

1) If the lightshelf area is narrow (in east-west direction) and located adjacent to the perpendicular walls (running north-south), vertical blinds can be employed to bounce the sunlight outward or towards the walls.

2) When installing vertical blinds make sure that one continuous blind is not installed that covers both the top lightshelf area and the view glass. This will clearly have 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. Install separate blinds for the glass above and below the lightshelf.

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



h. Use horizontal blinds-between-glass

1) If the lightshelf is more extensive and is incorporated across all or most of the southern exposure, as is typical of most daylighting strategies, the design will require that the light is bounced up to the ceiling and back, to reach deeper into the space.

2) For these horizontal blinds to be most effective they should have the blades either flat or curved upward. If curved, they perform better if they are turned the opposite way that they are normally installed and are curved upward to reflect the light up to the ceiling. (Note that they do work reasonably well if curved downward, just not as well) Additionally, because of potential dirt build-up and maintenance, they should be placed between the glazing panes.

3) When sizing the amount of glazing required, make sure to account for the loss in transmission due to the internal shades and the third pane of glass.

4) Most of the shades that are available today are operable and have the opportunity to be closed if desired. 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. By fixing the angle and not allowing the occupants to operate the blinds, there will less opportunity for the daylighting to be negated. The key is to look at the geometry of the blind in combination with the room – the width and spacing of the blinds, as well as the depth of the room. Understand that the blinds should be angled up so no direct beam radiation can hit any student sitting at their desks or working at a teaching station. But the blinds should be as horizontal as possible in order to bounce the light back into the space. The depth of the room is also a critical factor to consider. With the same angle of blind, direct sunlight may hit a student at the back of a deep room, while in a shallow space, the direct beam may simply hit high on the north wall. In a typical 900 square foot, square classroom, the angle should be approximately 35 degrees up from horizontal.

5) If the internal blinds do need to be operated for darkening purposes, it is desirable to have one setting that optimizes the gain while intercepting direct beam radiation and a second "closed" position.

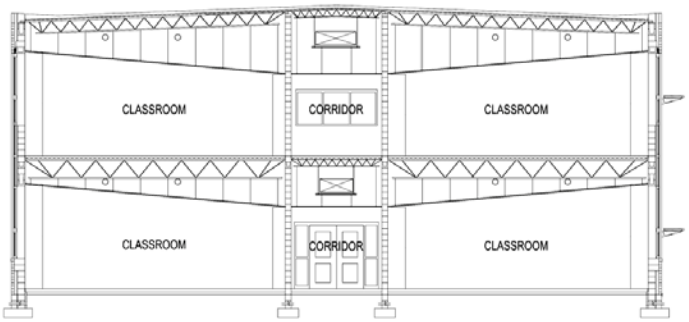
i. Elongate room to maximize glazing opportunity

1) The more elongated the classrooms and offices are in the east-west direction, the more opportunity there will be to achieve an adequate daylighting strategy that employs a lightshelf.

j. Slope ceiling from top of lightshelf glazing to back of room

1) To maximize the ability to bounce light deep into a space using a lightshelf and blinds-between glass, consider the advantages of sloping the ceiling from the top of the south-side lightshelf glazing down to the back of the room (north wall of space).

2) By sloping the ceiling from the outside wall 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 comparison can be made by looking at a classroom with a flat ten foot ceiling versus one that might be 11'-4" at the lightshelf and 9'-0"at the back of the classroom. By dropping the ceiling at the corridor wall, there is still adequate ceiling cavity for mechanical units and ductwork can run between the floor joists out to the perimeter.



k. Implement lightshelves to complement roof monitors
   1) Lightshelves on south-facing windows can be very effective in complementing the daylighting provided by the roof monitors. Windows placed on the south wall, one on each end of a classroom, could be used to better balance the daylighting within the space.

4. High Transom Glazing on North Walls - From a daylighting perspective, high, north transom glazing can provide a good daylighting option in spaces that are not too deep. Like north-facing roof monitors, they take 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.

High north clerestories provide daylighting to a media center

a. Don't use lightshelves
   1) Because of the lack of direct beam radiation on the north, lightshelves do not provide any benefit and should not be used.

b. Employ many of the same optimization strategies as with south lightshelves
   1) Place the glazing high in the room with the head of the glazing at the ceiling.
   2) Utilize sloped ceilings to enhance performance.
   3) It is even more important to elongate rooms in an east-west direction so that there is more exposed wall area in which to place the glazing.
   4) 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 do not block any more light than possible.
   5) As with glazing in lightshelves, do not use low-E glass in the high, designated daylighting apertures. It will reduce visible light transmission and require more glazing.

c. Utilize lower glass areas as a last resort

1) Establishing ceiling height can be difficult when implementing a daylighting strategy in a classroom wing that faces both north and south. On the south side you can use lightshelves that generally require less glazing than high, north transom apertures. 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, as a last resort, consider some of the lower view glass as an integral part of your north side daylighting strategy. Because the 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 can be considered. The big drawback is that the window area could still be used as a display board, blocking the light.

2) Assuming that lower, north view glass is considered in your daylighting strategy, it would be advisable, because of comfort, to utilize low-E glass in this case, sacrificing the 10% to 30% reduction in visible light benefit.

5. General Recommendations for All Daylighting Options

a. Minimize contrast

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

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

3) If you do use lightshelves, consider using blinds-between-the glass so that you are not looking directly at the window.

b. Select light colors for interior finishes

1) The colors of the ceiling, walls, floor, and furniture have major impacts 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 your:

a) sky well
b) ceiling
c) wall
d) furniture
e) floor

2) All have an impact. The darker these surfaces, the more glazing will be required to achieve the same net effect. In a typical 900 square foot classroom with a roof monitor strategy, the difference between the lighter and darker finish colors is one percentage point in glass-to-floor area ratios. In a typical 900 square foot classroom with a side lit strategy, the difference between the lighter and darker finish colors is two percentage points in glass-to-floor area ratios.

	900 sf classroom w/lightshelf and B-B-G	900 sf classroom w/south-facing roof monitor
Light Colors Wall reflectance = 70 Ceiling reflectance = 85 Floor reflectance = 50	10.5% g-t-f	8.5% g-t-f
Mid-Range Colors Wall reflectance = 60 Ceiling reflectance = 80 Floor reflectance = 35	11.5% g-t-f	9.0% g-t-f
Darker Colors Wall reflectance = 50 Ceiling reflectance = 70 Floor reflectance = 30	12.5% g-t-f	9.5% g-t-f

c. Select highly reflective ceiling tile
   1) Consider a ceiling tile or surface that has a high reflectivity. Make sure that you account for any fissures or holes within acoustical tiles and how this will impact the amount of light absorbed. Don't assume that the color of a tile alone dictates reflectance.
   2) When selecting a tile, question the product manufacturers regarding the listed reflectance. Most will list the reflectance as if it were the paint color reflectance.

d. Use continuous dimming controls
   1) To enhance the economic benefits and provide for smoother transition between varying light conditions, dimmable lighting controls should be used in most cases. Stepped strategies should be used if continuous dimming strategies are not utilized. In a typical classroom, a continuous dimming strategy will be in a range of 20% to 25% better than a 2 stepped strategy and 5% to 10% better than a 4 stepped strategy.
   2) Depending upon the daylighting strategy employed, photosensor controls should be used to dim specific, logical groupings of lights.
   3) Implement a lighting fixture layout and control wiring plan that complements the daylighting strategy.
   4) 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 that will occur close to the window and back further from the window, having this individual control by bank will help balance out the space.
   5) In a space that has a roof monitor, you may prefer to install a photosensor that controls all the perimeter lights and a second that controls all the lights within the monitor well.

6) In gymnasiums, ganged fluorescent fixtures coupled with dimmable ballasts are a great way of eliminating the problems typically associated with the long re-strike times associated with using metal halide fixtures.

7) With certain products it may be advantageous to employ a control strategy that dims to 20% and then cuts off. There is currently not much data available from manufacturers on the effects of low-level dimming on lamp life.

e. Compatibility between lamps, ballasts and controls

1) Absolutely insure that there is compatibility between your lamps, continuous dimming ballast, and controller. Your controller should kick in at full light/power and then dim down to the appropriate level. If it is not controlled in this manner, it is likely that you will experience premature lamp failure.

f. Locate your photosensors correctly

1) Mount the photosensors in a location that closely simulates the light level at the work plane (desk height). You can also locate the sensor in a place that is brighter or darker than the work plane but the amount of light should, during the course of a day, modulate at a relatively constant amount above or below the level at the work plane. In this later case, simply set the controller accordingly to account for the amount of the constant variation.

2) Provide a means and convenient location to override daylighting controls in spaces that are intentionally darkened to use projectors. In the examples provided for Ohio school classrooms, the dropped soffit area at the teaching wall should have its own lighting controls, separate from the rest of the classroom.

g. Select compatible light fixtures

1) First consider the use of indirect lighting fixtures. They more closely match the quality of daylighting by producing more uniformly distributed light with less glare than individual lay-in light fixtures.

h. Consider the space layout and need to darken the teaching wall

1) When designing 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 versus a lightshelf.

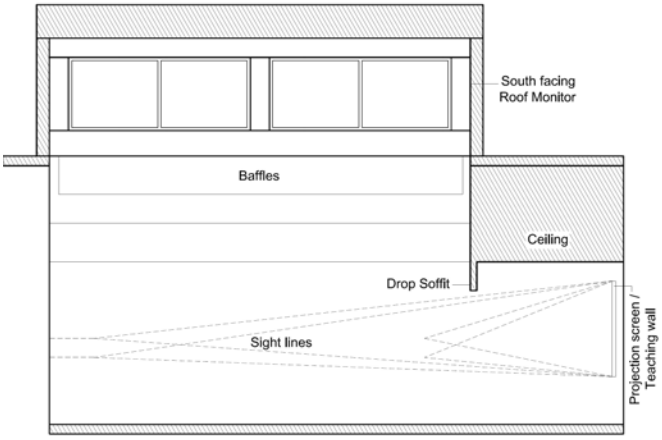
2) The teaching wall will have key teaching aids that have unique lighting requirements. The teaching wall is normally the location for the projection screen, white board, and TV monitor. Implement strategies in the teaching wall area where both the electrical lighting and daylighting can be controlled. Allow the majority of the classroom to remain well daylit while creating a lighting condition at the teaching wall that is, under normal daylit conditions, approximately 20 footcandles or less. To be effective, this design strategy will necessitate a separate light switching circuit that controls the lights at this specific area versus the remaining part of the classroom. If this space is normally at 20 footcandles it means that if the projection screen or TV monitor are not being utilized, the lights should be able to dim up (or be switched on) to reach at least the 50 footcandles desired for good viewing of the white board. Place the switch convenient to the teaching wall. This grouping of lights may also fall over the teacher's desk and enable the teacher to use the space at night while not turning on all the lights in the classroom.

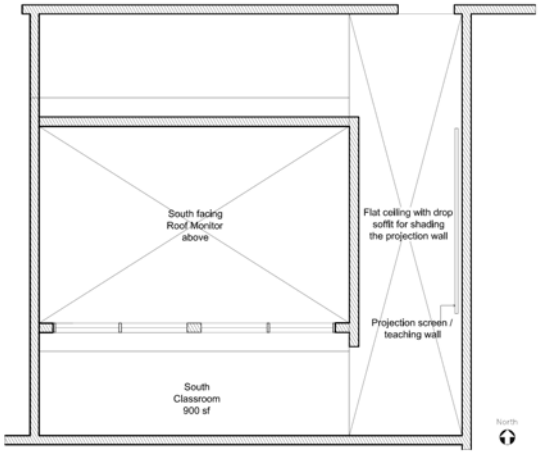
3) Ideally, the teaching wall (in south-side classrooms with either lightshelves or roof monitors) will be on the east wall within the classroom. This placement is preferred because the projection screen area, as well as TV monitors, will need to be placed in a location where the light level is low enough for viewing. By placing it on the east wall in a daylit space the sunlight will be less intense on this surface. Only during the late afternoon will the sun have a chance of more directly reflecting on to this surface.

4) The second best position for the teaching wall in a south-side classroom (with a lightshelf) would be the north classroom wall. This is because the light level drops off as it goes deeper into the space from the south glazing. However, (even with the below explained architectural element to shade the projection screen) it is possible, at certain limited times, to have 40 footcandles of light on the screen area. If you incorporate a teaching wall on the north classroom wall and have a south-facing lightshelf strategy, make sure that your projector and screen are capable of overcoming this level of light. See the recommendations below.

5) If you have a classroom with a high, north glazing section as your daylighting strategy, the teaching wall is still best placed on the east or north wall.

6) At the same time it is good to intentionally darken the teaching wall during video viewing, it is best to maintain the desired 50 footcandle level within the rest of the classroom. To accomplish this objective, the enclosed classroom examples indicate a dropped, flat ceiling area for the 8 feet area in front of the teaching wall. It additionally indicates a vertical shading element coming down from the ceiling that helps block the reflected sunlight from bouncing onto the projection screen. This element also visually hides the projector and can serve as a mounting surface for the projector.





7) Students normally 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 facing the outside windows.

8) A good location for computer stations in daylit spaces with lightshelves or high, north glass would be on the exterior wall, in locations where there isn't any low view glass. With roof monitors there isn't a likely problem from the roof monitor since it diffuses the light and creates a more uniform lighting condition. However, it may still be best to locate the computers on the outside wall (in sections of the wall where there isn't any view glass) that contains view glass. By placing the computers on this wall they will not receive glare from any low, view glass windows.

i. Select projectors and screens appropriate for daylit spaces

1) Select video projectors that are designed to be used in spaces with high ambient light levels.

2) Digital projectors should be 3,000 to 3,500 lumens or better and have a contrast ratio of 1000 to 1 or better. Many newer projectors have control modes that allow the user to adjust for daylit or bright ambient conditions.

3) In order to ceiling mount the projector as close to the screen as possible, specify types with keystone correction and lens shift capabilities. Some allow the projector to me mounted closer than 8 feet, allowing the dropped area in the classroom (over the teaching wall) to be reduced to 6 feet.

4) Look for projectors that have a low standby power mode.

5) Projection screens should be designed for high-contrast and have a high "gain" factor of 1.5 or above.

6) The screen characteristics should be appropriate for the "viewing angle." If you draw a straight line from the projector to the center of the screen, the screen type selected should consider the angle between that straight line and the closest viewer to either the far left or right (the student in the front row of desks the furthest from the projector).

6. Typical Daylit Spaces

a. The attached daylighting designs have been provided for designers of schools in Ohio. Several typical spaces, common to most school projects have been included. The following chart represents a summary of the results of simulations developed with the daylighting computer simulation model Daysim. The chart provides recommended amounts of glass for each application. The amounts are expressed in "glass-to-floor" area ratios. These results are specific to the conditions analyzed and described in the attached details. Variations from these amounts can be achieved by applying the various rules-of-thumb included within this text.

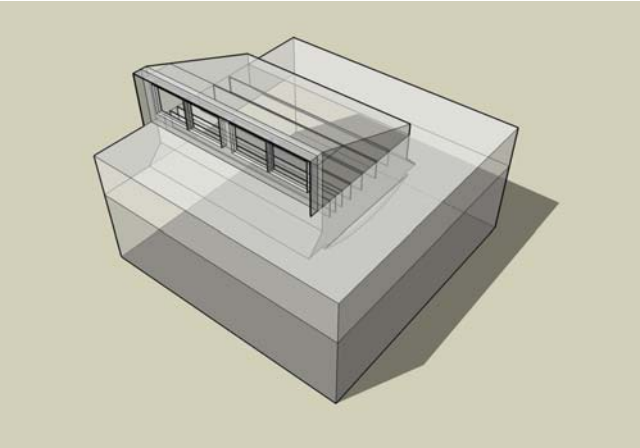
b. These glass-to-floor (GTF) ratios are expressed as a percentage of the total area of the space and also as a percentage of just the daylit space, excluding the space by the teaching wall that is intentionally being darkened.

Note: * indicates the spaces where the analysis of the north-facing roof monitor strategy predicts that the peak cooling reduction energy savings and overall energy savings will not be as significant as the south-facing roof monitor options. They still represent positive energy solutions (particularly from a lighting reduction standpoint) but, because the south-facing monitor has passive heating benefits in the winter and reduced heat/light in the warmer months, the south-facing options are better and should be considered first.

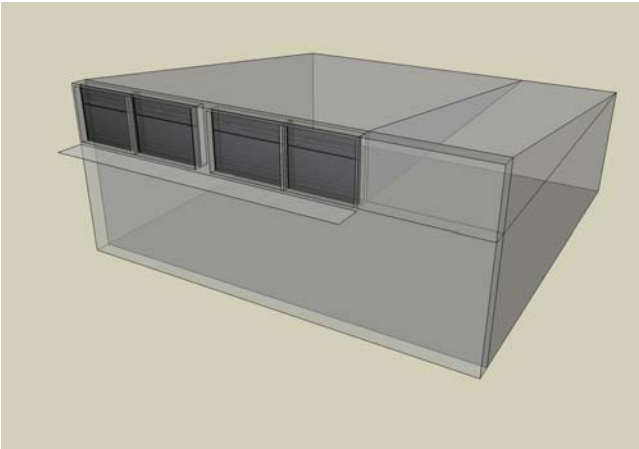
Space	Orientation	Daylighting Strategy	Glazing Type	G-T-F of Total Area	G-T-F of Daylit Area
900 sf clrm	S or N	South-facing roof monitor	***clear, sealed insulation unit***	6.5% - 7.5%	9.0% - 10.0%
900 sf clrm	S side	South-facing lightshelf	***clear, sealed insulation unit***	8.5% - 9.5%	11.5% - 12.5%
900 sf clrm	S side	South-facing lightshelf	***clear, sealed insulation unit***	9.0% - 10.0%	12.0% - 13.0%
900 sf clrm	N or S	North-facing roof monitor*	***clear, sealed insulation unit***	7.5% - 8.5%	10.0% - 11.0%
900 sf clrm	N side	High, north glass	***clear, sealed insulation unit***	8.0% - 9.0%	11.0% - 12.0%
1200 sf lab/cr	S or N	South-facing roof monitor	***clear, sealed insulation unit***	6.5% - 7.5%	9.0% - 10.0%
1200 sf lab/cr	S side	South-facing lightshelf	***clear, sealed insulation unit***	8.5% - 9.5%	11.0% - 12.0%
1200 sf lab/cr	S side	South-facing lightshelf	***clear, sealed insulation unit***	9.0% - 10.0%	11.5% - 12.5%
1200 sf lab/cr	N or S	North-facing roof monitor*	***clear, sealed insulation unit***	7.5% - 8.5%	10.5% - 11.5%
1200 sf lab/cr	N side	High, north glass	***clear, sealed insulation unit***	8.0% - 9.0%	11.0% - 12.0%
600 sf resource	S or N	South-facing roof monitor	***clear, sealed insulation unit***	6.5% - 7.5%	9.0% - 10.0%
600 sf resource	S side	South-facing lightshelf	***clear, sealed insulation unit***	9.0% - 10.0%	13.0% - 14.0%
600 sf resource	S side	South-facing lightshelf	***clear, sealed insulation unit***	9.5% - 10.5%	13.5% - 14.5%

Space	Orientation	Daylighting Strategy	Glazing Type	G-T-F of Total Area	G-T-F of Daylit Area
600 sf resource	N or S	North-facing roof monitor*	***clear, sealed insulation unit***	7.5% - 8.5%	10.5% - 11.5%
600 sf resource	N side	High, north glass	***clear, sealed insulation unit***	9.0% - 10.0%	13.0% - 14.0%
3500 sf gym	S or N	South-facing roof monitor	***clear, sealed insulation unit***	7.5% - 8.5%	7.5% - 8.5%
3500 sf gym	S and N	South-facing lightshelf High, north glass	***clear, sealed insulation unit***	8.0% - 9.0% 50/50	8.0% - 9.0% 50/50
3500 sf gym	S and N	South-facing lightshelf High, north glass	***clear, sealed insulation unit***	8.5% - 9.5% 50/50	8.5% - 9.5% 50/50
16000 sf gym	S or N	8 S-facing roof monitors	***clear, sealed insulation unit***	9.0% - 10.0%	9.0% - 10.0%
16000 sf gym	S and N	4 S-facing roof monitors South-facing lightshelf High, north glass	***clear, sealed insulation unit***	11.0% - 13.0% 40/30/30	11.0% -13.0% 40/30/30
16000 sf gym	S and N	4 S-facing roof monitors South-facing lightshelf High, north glass	***clear, sealed insulation unit***	11.5% - 13.5% 40/30/30	11.5% -13.5% 40/30/30
4500 sf high bay	S and N	High, south-facing glass High, north glass	***clear, sealed insulation unit***	11.5% - 12.5% 40/60	11.5%-12.5% 40/60
4500 sf high bay	N side	High, north glass	***clear, sealed insulation unit***	10.0% - 11.0%	10.0%-11.0%
4500 sf high bay	N or S	3 N-facing roof monitors	***clear, sealed insulation unit***	9.0% - 10.0%	9.0%-10.0%

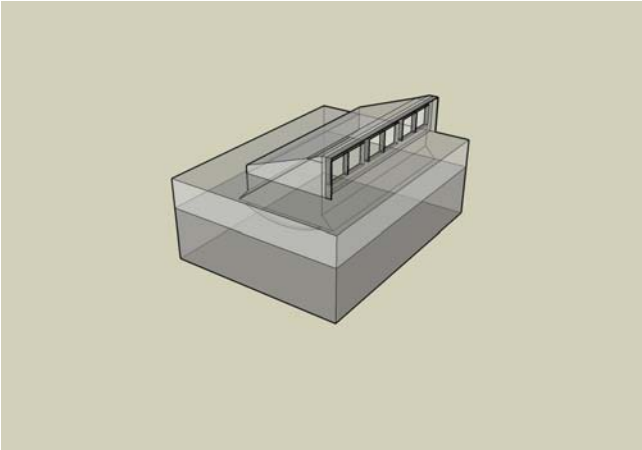
d. Examples of typical daylit spaces:



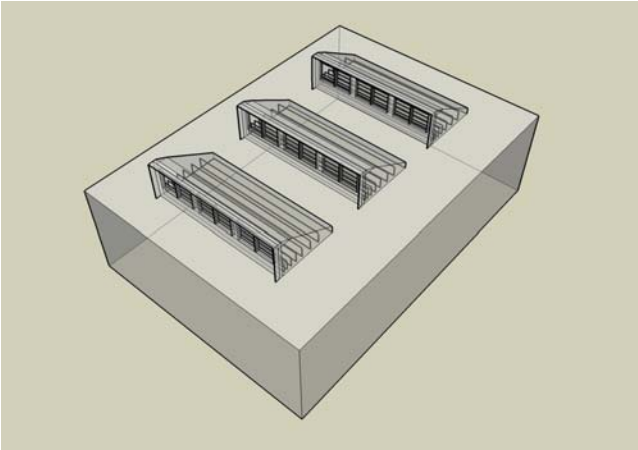
900 sf classroom with south facing monitor



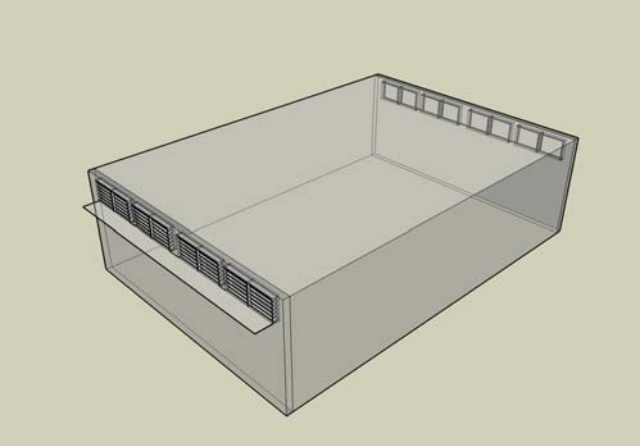
900 sf south classroom with blinds between the glass



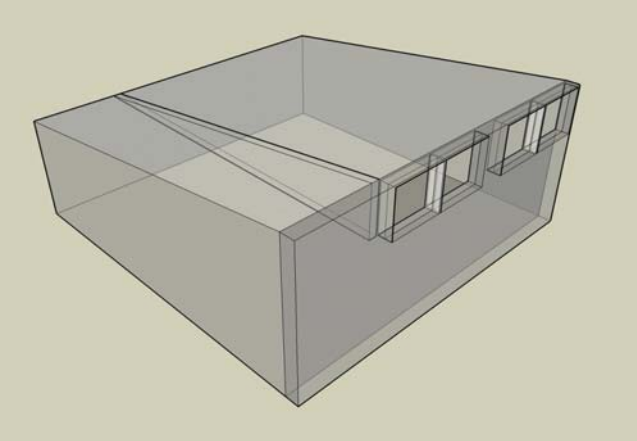
1200 sf classroom/lab with north facing monitor



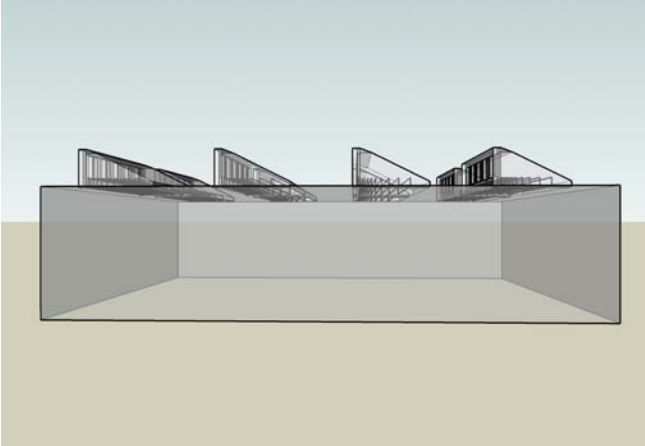
3500 sf elementary gymnasium with south facing monitors

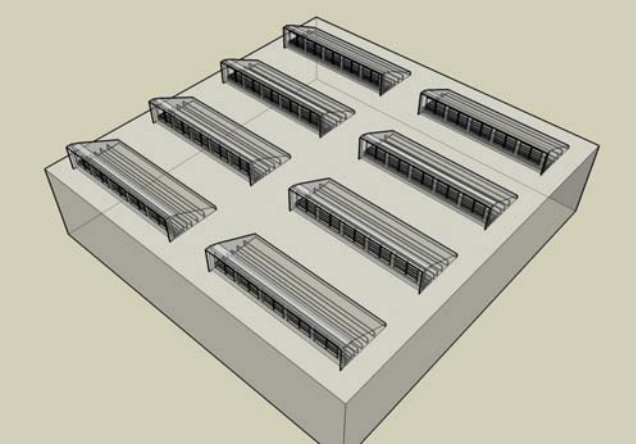


4500 sf high-bay space with south & north clerestories



600 sf north resource room with clerestory





16000 sf high school gymnasium with south facing monitors

e. Keep in mind that these glass-to-floor area ratios are based upon specific assumptions and, in order to maximize potential energy savings, more detailed analysis is recommended. In every project you should consider the unique conditions including:
   1) Characteristics of the space -Size, proportions, colors, etc.
   2) Location -These recommendations are based upon Columbus. We have provided rules-of-thumb to vary these amounts for Cincinnati and Cleveland. Other locations with greatly different conditions than Columbus, Cincinnati or Cleveland should be simulated.
   3) Time of use - This analysis was based upon the school operational times:
      a) Classrooms 8am – 5pm
      b) Gymnasiums 7am – 6pm
   4) Orientation - These recommendations are based upon the building facing true south. If the building varies by more than 15 degrees from true south it is advisable to conduct more detailed analysis.
   5) Depth of ceiling cavity - These recommendations for classrooms were based upon a ceiling cavity depth of 5 feet. Rules-of-thumb are included for variations to 10 feet. The gymnasiums and high-bay spaces are assumed to not have any ceiling cavity.

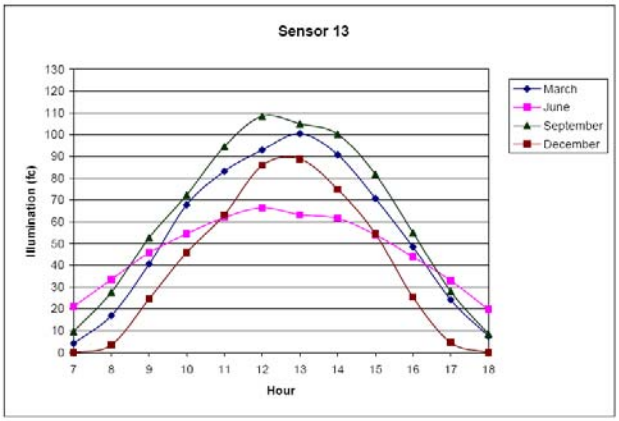
F. Accurately Simulate Daylighting Performance

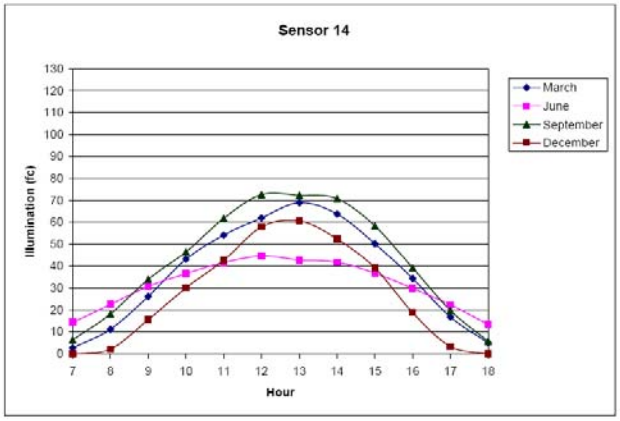
1. Daylighting Analysis

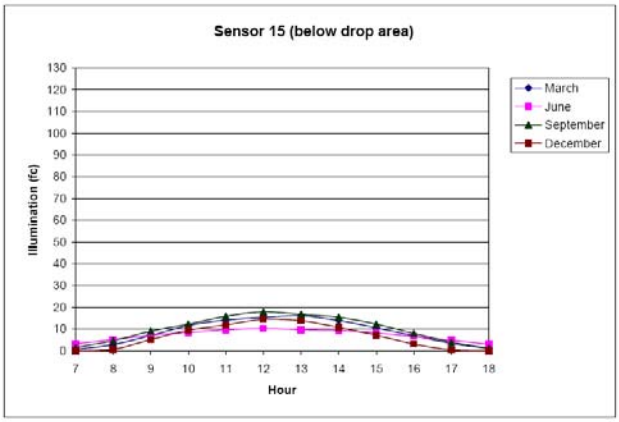
a. To determine the optimum daylighting and glazing strategy for each application, the designer should conduct detailed daylighting computer simulations that compare options. The program variables should allow you to input different locations (TMY data for various cities) as well as component configurations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

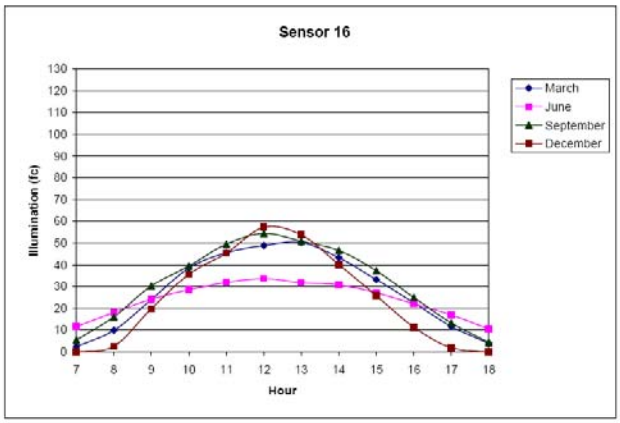
b. Simplistically, the goal in conducting this evaluation should be to establish the optimum amount of glazing, regardless of the strategy, that does not ultimately produce overheating and best creates a uniform light distribution. This is most easily done early in schematic design, by looking carefully at the peak cooling months to see 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, change the interior reflectances, alter the depth of the ceiling cavity, or change the overall strategy.

c. Analyze your daylighting strategies by conducting computer simulations of each key representative space. You should analyze numerous points within each space for hourly, monthly, yearly contributions. It is important to understand the range of 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.









d. 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 with south-facing strategies it is very difficult to achieve the desired footcandle level more than 75% of the time without overheating.

e. Once this is completed, the hourly data (by month) for each representative space should be input into the 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 dynamic model of how the school performs and most accurately accounts for the typical cooling load reduction of 10% - 20%.

f. The following daylighting simulation tools are commonly utilized:

	Program	Originator
1)	Daysim	National Research Council, Canada
2)	Daylite	Solarsoft
3)	Lumen Micro	Lighting Technology, Inc.
4)	Radiance	USDOE/University of California
5)	Superlite	University of Michigan

2. DOE-2 Whole-Building Energy Analysis

a. 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 programs available are based upon 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.

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

1) eQUEST www. DOE2.com/equest
2) ENERGY PLUS 2.0 www.eere.energy.gov/buildings/energyplus
3) VISUAL DOE 4.0 www.archenergy.com/products/visualdoe
4) POWER-DOE (2.2) www.DOE2.com

3. Build physical models

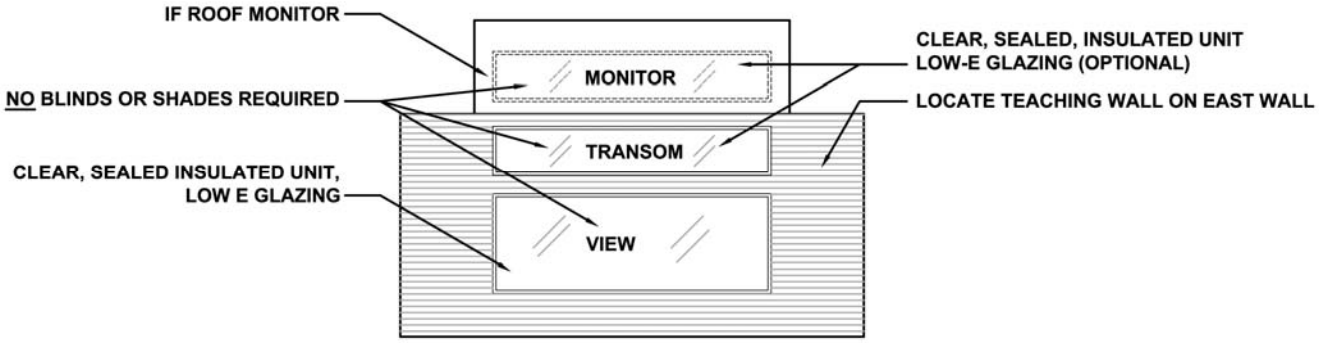
a. Another excellent method of better understanding how spaces within your school will perform is by building and measuring scaled models of particular spaces. There is not a computer model that has been developed that can simulate performance as well as an actual scaled model.

Physical model to study daylighting

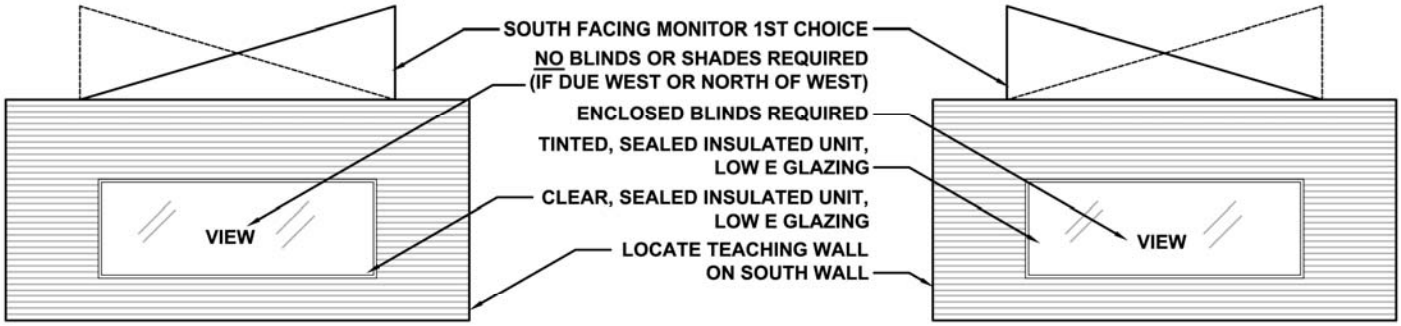
G. Verify and modify your design process

1. After your daylit school 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.

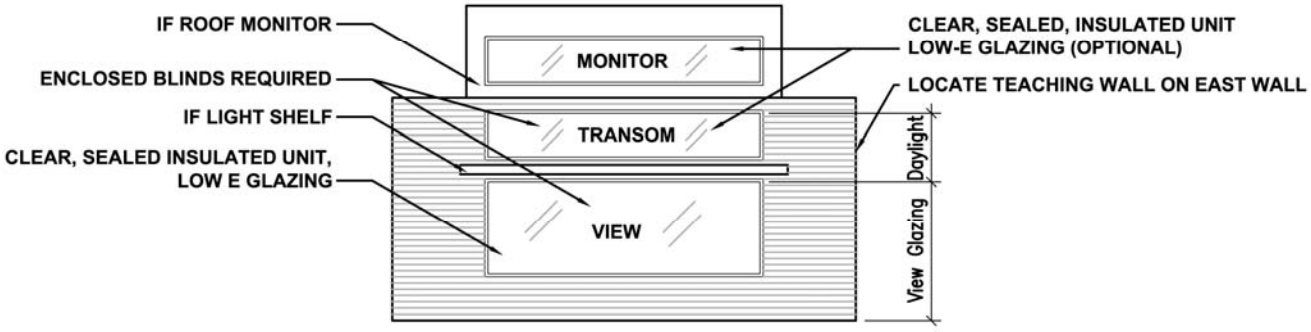
2. Part of your post-occupancy analysis should also be an evaluation of how well the human factors were addressed. Every project offers you a new opportunity to improve your next design.



NORTH



WEST EAST



SOUTH CLASSROOM

ENERGY EFFICIENT PLUG LOADS

A. Equipment Provided by Building Contractor

1. Commercial Food Service Equipment

a. Food service equipment shall not exceed energy consumption for each type of equipment as follows:

1) Dishwashers, idle energy rate
   a) Under counter, high temperature: 0.90 kW
   b) Under counter, low temperature: 0.5 kW
   c) Stationary Single Tank Door, high temperature:1.0 kW
   d) Stationary Single Tank Door, low temperature: 0.6 kW
   e) Single Tank Conveyor, high temperature: 2.0 kW
   f) Single Tank Conveyor, low temperature: 1.6 kW
   g) Multiple Tank Conveyor, high temperature: 2.6 kW
   h) Multiple Tank Conveyor, low temperature: 2.0 kW

2) Fryers
   a) Open, deep-fat gas
      .1 Heavy load cooking efficiency shall be minimum 50% and idle energy rate shall not exceed 9,000 btu/hr (2,635 W)
   b) Open, deep-fat electric
      .1 Heavy load cooking efficiency shall be minimum 80% and idle energy rate shall not exceed 1,000 watts

3) Hot Food Holding Cabinets
   a) Maximum Idle Energy Rate = 40 watts/ft^3

4) Steam Cookers
   a) 3-, 4-, 5-, and 6-pan capacity, including countertop models, wall-mounted models and floor-models mounted
      .1 3-pan electric: 50% cooking energy efficiency and 400 W idle rate
      .2 4-pan electric: 50% cooking energy efficiency and 530 W idle rate
      .3 5-pan electric: 50% cooking energy efficiency and 670 W idle rate
      .4 6-pan electric: 50% cooking energy efficiency and 800 W idle rate
      .5 3-pan gas: 38% cooking energy efficiency and 6,250 btu/hr idle rate (1,830 W)
      .6 4-pan gas: 38% cooking energy efficiency and 8,350 btu/hr idle rate (2,445 W)
      .7 5-pan gas: 38% cooking energy efficiency and 10,400 btu/hr idle rate (3,046 W)
      .8 6-pan gas: 38% cooking energy efficiency and 12,500 btu/hr idle rate (3,661 W)
   b) Cooking Energy Efficiency is based on heavy load (potato) cooking capacity.

c) Idle Energy Rate: The rate of appliance energy consumption while it is maintaining or holding at stabilized operating condition or temperature

5) Braising pan
   a) Specify insulated wall units.
   b) When in operation, keep lid closed to maximum extend practical.

6) Combi-oven
   a) Reduce use of the 'combination' function to maximum extent practical to reduce energy and water consumption.

b. Do not exceed the most recent version of commercial food service equipment performance specifications published by the US EPA 'Energy Star' Program. See www.energystar.gov for the most recent commercial food service equipment performance specifications.

c. See www.energystar.gov for an updated list of ENERGY STAR Qualified Models Submitted to the EPA.

2. Reach-In or Pass-Through Cabinets, Roll-In or Roll-Through Cabinets

a. Maximum Daily Energy Consumption in kWh shall not exceed the following formulae for each type of cabinet where V = total volume (ft3) and AV = Adjusted Volume = [1.63 x freezer volume (ft3)] + refrigerator volume (ft3)]:

1) Reach-in cabinets, pass-through cabinets, and roll-in or roll-through cabinets that are refrigerators
   a) Solid door: (0.10V + 2.04) kWh
   b) Transparent door: (0.12V + 3.34) kWh

2) Reach-in cabinets, pass-through cabinets, and roll-in or roll-through cabinets that are freezers (except ice cream freezers)
   a) Solid door: (0.40V + 1.38) kWh
   b) Transparent door: (0.75V + 4.10) kWh

3) Reach-in cabinets, pass-through cabinets, and roll-in or roll-through cabinets that are freezers that are ice cream freezers
   a) Solid door: (0.39V + 0.82) kWh
   b) Transparent door: (0.88V + 0.33) kWh

4) Reach-in cabinets that are refrigerator-freezers and that have an adjusted volume (AV) of 5.19 ft3 or greater
   a) Solid door: (0.27AV – 0.71) kWh

5) Reach-in cabinets that are refrigerator-freezers and that have an adjusted volume (AV) of less than 5.19 ft3
   a) Solid or transparent door: 0.70 kWh

3. Kitchen Ventilation Hood

a. Group appliances according to effluent production and associated ventilation requirements. Specify different ventilation rates for hoods or hood sections over the different duty classification of appliances. Where practical, place heavy-duty appliances in the center of a hood section, rather than at the end.

b. Provide UL Listed proximity type hoods.

c. Provide hood construction details (such as interior angles and flanges along the edge) or high-velocity jets to promote capture and containment at lower exhaust rates.

d. Provide side and/or back panels on canopy hoods to increase effectiveness and reduce heat gain.

e. Maximize transfer air/minimize direct makeup air. Integrate the kitchen ventilation with the building HVAC system (i.e., use dining room outdoor air as makeup air for the hood). Kitchen equipment designer and the mechanical engineer shall coordinate their designs.

f. Minimize the velocity (fpm) of the makeup air as it is introduced near the hood by minimizing the volume (cfm) of makeup air through any single distribution system, by maximizing the area of the diffusers through which the makeup air is supplied, or by distributing through multiple pathways.

g. Do not use short-circuit hoods. Use caution with air-curtain designs.

h. Avoid four-way or slot ceiling diffusers in the kitchen, especially near hoods.

i. Diversify makeup air pathways using a combination of backwall supply, perforated perimeter supply, face supply, displacement diffusers, etc.

j. Minimize makeup air velocity near the hood; it should be less than 75 fpm.

k. Consider variable or two-speed exhaust fan control for operations with a high diversity of appliances or with a set schedule of use.

l. Provide air balance schedule in design drawings to avoid over- or under-supply of MUA.

m. Require building air balancing and system commissioning as part of the construction requirements.

n. Discourage use of fans by kitchen staff for cooling near hoods as they can negatively impact the performance of the hood.

4. Ice Machines

a. Maximum Daily Energy Consumption in kWh for automatic commercial ice-makers shall not exceed the following formulae for each type of ice maker where H = harvest rate in pounds if ice per 24 hours:

1) Water-cooled Ice-Making Head
   a) Harvest Rate up to 500 lbs = (7.80-.0055H) kWh/100 lbs.
   b) Harvest Rate from 500 to 1,436 lbs.=(5.58-.0011H) kWh/100 lbs.
   c) Harvest Rate greater than 1,436 = 4.0 kWh/100 lbs.
2) Air-cooled Ice-Making Head
   a) Harvest Rate up to 450 lbs = (10.26-.0086H) kWh/100 lbs.
   b) Harvest Rate over 450 lbs. = (6.89-.0011H) kWh/100 lbs.
3) Air-cooled Remote Condensing (but not remote compressor)
   a) Harvest rate up to 1,000 lbs = (8.85 - .0038H) kWh/100 lbs.
   b) Harvest rate over 1,000 lbs. = 5.10 kWh/100 lbs.
4) Air-cooled Remote Condensing and remote compressor
   a) Harvest rate up to 934 lbs. = (8.85 - .0038H) kWh/100 lbs.
   b) Harvest rate over 934 lbs. = 5.03 kWh/100 lbs.
5) Water-cooled, self-contained
   a) Harvest rate up to 200 lbs. = (11.40 - .0190H) kWh/100 lbs.
   b) Harvest rate over 200 lbs. = 7.60 kWh/100 lbs.
6) Air-cooled, self-contained
   a) Harvest rate up to 175 lbs. = (18.0 - .0469H) kWh/100 lbs.
   b) Harvest rate over 175 lbs. = 9.80 kWh/100 lbs.

b. Do not exceed the most recent version of automatic commercial ice machine performance specifications published by the US EPA 'Energy Star' Program. See www.energystar.gov for the most recent commercial ice-maker performance specifications.

c. See www.energystar.gov for an updated list of ENERGY STAR Qualified Models Submitted to the EPA.

5. Walk-in Refrigerators / Freezers

a. Assembly
1) Wall, ceiling, and door insulation shall be minimum R-28 for refrigerators and minimum R-34 for freezers.
2) Floor insulation shall be minimum R-28.
3) Use CFC free insulation.
4) Doors shall be provided with automatic closer and shall be no wider than 3'-9" and no higher than 6'-11", that shall be closed to within one inch of full closure.
5) Install dew point sensors and controls for anti-condensate heater.
6) Install strip curtains or plastic swinging doors in doorway.

b. Lighting
1) Use light sources with an efficacy of 45 lumens per watt or more, including ballast losses.
2) Install low-temperature occupancy sensors or timed switches to control lighting.
3) Consider use of LED light bulb.

c. Refrigeration System
   1) Condenser fan motors of under one-horse power shall be electronically commutated motors (ECM), permanent split capacitor-type motors or polyphase motors of ½ horsepower or more. Single-phase evaporate fan electronically commuted motors shall be used for fan motors of one horse power and less than 460 volts.
   2) Install evaporator fan controls to reduce fan use.
   3) Install insulation on bare suction lines.
   4) Locate remote condensers under shade from direct sunlight while allowing air flow into and around.
   5) Consider use of refrigerant heat-recovery systems to pre-heat water for hot water used in a kitchen.
   6) Consider use of adsorption refrigeration system with solar thermal panel as a heat source.

d. Do not exceed the most recent version of performance specifications for walk-in freezers and coolers developed by the California Energy Commission. See www.energy.ca.gov for the most recent version of the CEC performance specifications.

B. Equipment Provided by School District – Independent of Building Contractor

1. Desktops, Integrated Computers, and Desktop-Derived Servers

a. For the purposes of determining Idle state levels, Desktops, Integrated Computers and Desktop-Derived Servers shall be categorized as follows:
   1) Category A
      a) All desktop computers that do not meet the definition of either Category B or Category C.
   2) Category B
      a) Multi-core processor(s) or greater than 1 discrete processor
      b) Minimum of 1 gigabyte of system memory.
   3) Category C
      a) Multi-core processor(s) or greater than 1 discrete processor
      b) A GPU with greater than 128 megabytes of dedicated, non-shared memory.
      c) In Addition to the requirements above, models qualifying under Category C must be configured with a minimum of 2 of the following 3 characteristics:
         .1 Minimum of 2 gigabytes of system memory;
         .2 TV tuner and/or video capture capability with high definition support; and/or
         .3 Minimum of 2 hard disk drives.

b. Desktops, Integrated Computers and Desktop-Derived Servers shall have power consumption no greater than as follows:
   1) Standby (Off Mode): 2.0 W
   2) Sleep Mode: 4.0 W
   3) Idle State:
      a) Category A: 50.0 W
      b) Category B: 65.0 W
      c) Category C: 95.0 W
         .1 Desktop-derived servers are exempt from the Sleep level.

c. Do not exceed the most recent version of computer hardware classification and performance specifications developed for or published by US EPA 'Energy Star' Program. See www.energystar.gov for the most recent hardware classification and performance specifications.

d. See www.energystar.gov for an updated list of ENERGY STAR Qualified Models Submitted to the EPA.

e. Do not enable the 'screen saver' function. Set power options to turn off monitor and PC units at shortest practical interval that will not impinge on classroom instruction activity.

f. Unplug each computer from the wall, UPS or surge protector at the end of each day to reduce phantom loads.

g. Do not locate any computer or monitor near a thermostat. Coordinate location of teacher equipment with the architect and mechanical engineer during design.

2. Computer Monitors

a. Power consumption, in the three operational modes, shall not exceed:
   1) 'On' Mode:
      a) Monitors less than 1 megapixel shall not exceed 23 times the number of megapixels (Y= 23X)
      b) Monitors greater than 1 megapixel shall not exceed 28 times the number of megapixels (Y=28X)
         .1 Where Y is expressed in watts and rounded up to the nearest whole number and X is the number of megapixels in decimal form
   2) 'Sleep' Mode: 2 watts
   3) Off Mode: 1 watt.

b. Do not exceed the most recent version of computer hardware classification and performance specifications developed for or published by US EPA 'Energy Star' Program. See www.energystar.gov for the most recent hardware classification and performance specifications.

c. See www.energystar.gov for an updated list of ENERGY STAR Qualified Models Submitted to the EPA.

d. Turn monitor off when not being actively used by student or staff.

e. Unplug each monitor from the wall, UPS or surge protector at the end of each day to reduce phantom loads.

f. Do not locate any computer or monitor near a thermostat. Coordinate location of teacher equipment with the architect and mechanical engineer during design.

3. Notebook and Tablet Computers

a. For the purposes of determining idle state levels, notebooks and tablets shall be categorized as follows**:**
   1) Category A
      a) All notebook computers that do not meet the definition of Category B.
   2) Category B
      a) A GPU with a minimum of 128 megabytes of dedicated, non-shared memory.

b. Notebooks and tablets shall have power consumption no greater than as follows:
   1) Standby (Off Mode): 1.0 W
   2) Sleep Mode: 1.7 W
   3) Idle State
      a) Category A: 14.0 W
      b) Category B: 22.0 W

c. Do not exceed the most recent version of computer hardware classification and performance specifications developed for or published by US EPA 'Energy Star' Program. See www.energystar.gov for the most recent hardware classification and performance specifications.

d. See www.energystar.gov for a complete list of ENERGY STAR Qualified Models Submitted to the EPA.

4. Television and Video Replay Equipment

a. Power consumption for televisions and television monitors, component television units, TV/VCR combination units and TV/DVD, VCR/DVD, and TV/VCR/DVD combination units shall not exceed 1 watt in 'standby mode'.

b. Power consumption for VCR, DVD and audio units shall not exceed 1 watt in 'standby mode'.

c. Do not exceed the most recent version of television and video replay equipment performance specifications developed for or published by US EPA 'Energy Star' Program. See www.energystar.gov for the most recent television and video replay equipment performance specifications.

d. See www.energystar.gov for a complete list of ENERGY STAR Qualified Models Submitted to the EPA.

5. Vending Machines

a. Provide vending machines consuming no more ennergy, on a daily basis, than:
   1) Y = 0.45 [8.66 + (0.009 x C)] where
      a) Y = 24 hr energy consumption (kWh/day) after the machine has stabilized
      b) C = vendible capacity
         .1 Vendible capacity is the maximum number of 12 ounce cans dispensed from one full loading of the vending machine without further reload operations when used as recommended by the manufacturer.

b. Provide a vending unit that meets, at aminimum, one of the following Low Power Modes:
   1) Lighting low power state:
      a) Unit with hard-wired controls or software capable of automatically placing the machine into a low-power lighting mode, meaning a state where the lighting system is automatically turned off for an extended period of time, then return to normal operating conditions at the conclusion of the low-power lighting mode.
   2) Refrigeration low power state:
      a) Unit equipped with hard-wired controls or software capable of automatically placing the machine into a low-power refrigeration mode, meaning a state where the average beverage temperature is allowed to rise above 40° F. for an extended period of time, then return to normal operating conditions at the conclusion of the low-power refrigeration mode.
   3) Whole machine low power state:
      a) Unit equipped with hard-wired controls or software capable of automatically placing the machine into a low-power lighting mode, meaning a state where the lights are off and the refrigeration operates in its low power state for an extended period of time, then return to normal operating conditions at the conclusion of the low-power lighting mode.
   4) Low-Power State – On-Site Adjustment:
      a) Unit equipped with hard-wired controls or software capable of on-site adjustments to the various low-power modes by the vending machine operator or machine owner.

c. Provide the following refrigerant type:
   1) None ozone depleting

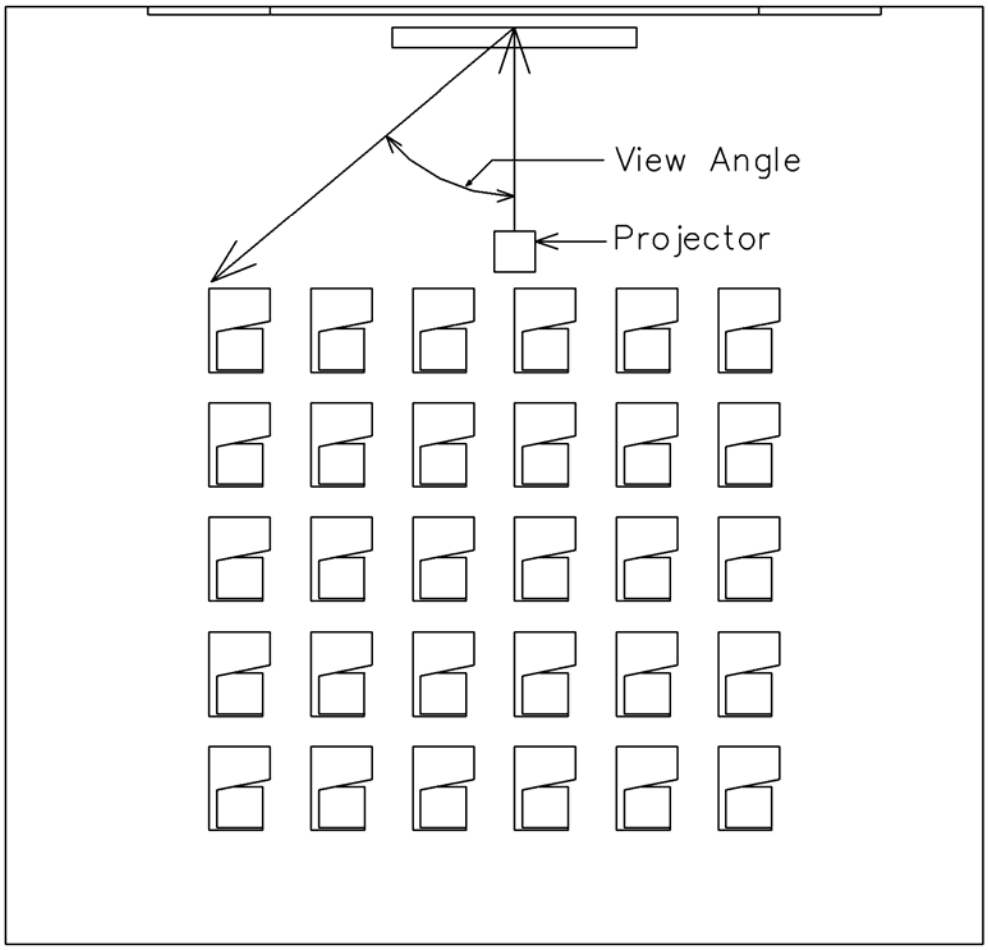
d. Provide the following insulation type:
   1) None ozone depleting

e. Provide the following illumination type:
   1) T8 fluorescent lamp with electronic ballast

f. Do not exceed the most recent version of performance specifications for vending machines developed by the California Energy Commission. See www.energy.ca.gov for the most recent version of the CEC performance specifications.

6. Screens in Daylit Spaces

a. Provide projection screens for daylit rooms with a viewing surface peak gain higher than 1.5 at the appropriate view angle.
   1) Gain is a relative measure of a screen's reflectivity
   2) View angle is the angle one views the screen as the angle deviates from a perpendicular view of the screen.



7. Digital Video Projector

a. Video projection systems shall include DLP or LCD video projection systems for connection to, but not limited to, computers, DVDs and VCRs and digital document cameras.
   1) DLP refers to digital light processing projectors.
   2) LCD refers to liquid crystal display projectors.

b. Video projection systems for daylit classroom spaces shall be minimum 3,000 lumens.
   1) Lumens are a measure of the light produced by a projector bulb. A high lumen output is vital in a daylit classroom environment.

c. Video projection systems for daylit classroom spaces shall provide a high contrast ratio of a minimum of 1,000:1.
   1) Contrast ratio is a figure that compares the ratio between the brightest white and the darkest black a projector produces. A higher contrast ratio delivers a better image quality for videos and natural pictures with details in the darkest of scenes.
   2) A high contrast ratio is vital in a daylit classroom environment. In a bright room, a picture with a higher contrast ratio looks clearer than a picture with a lower contrast ratio at equal brightness levels.

d. Video projection systems shall be equipped with an energy efficient, low power standby mode or an "Eco-Mode" feature.

e. Provide keystone correction function.
   1) Keystone is the effect that produces a keystone shaped image on the screen from any angle the projector lens deviates from horizontal. The keystone correction function is a digital control that brings the image back to square.

f. Provide lens shift correction function.
   1) Lens shift is the effect that produces a keystone shaped image distortion as the projector lens angles deviates from 90 degrees to the screen. The lens shift correction function is a digital control that brings the image shape back to square.

g. Unplug each component of the projection system from the wall, UPS or surge protector at the end of each day to reduce phantom loads.

INTRODUCTION

Although the available amount of fresh water remains relatively constant, our population is growing. It already takes a lot of energy to deliver clean water, and as potable water demand increases it will take even more. Water treatment and delivery use 7-8% of the country's energy. At the same time, our fossil and nuclear energy production methods use large quantities of water. So, by conserving potable treated water, we are saving valuable water and energy.

There are localized concerns about water resources previously considered dependable. Over the past couple of decades, many aquifers have become increasingly polluted from nitrogen, pesticides and toxic chemicals. Sixty percent of the wells sampled in agricultural areas of the United States in the 1990s contained pesticides. With many polluted aquifers, the use of non-treated aquifer water is being questioned. Periods of low rainfall across the country have caused communities to question both their preparation for these occurrences and the consequences of their inability to respond to drought conditions. Along with current population growth, city municipal systems for both potable water supply and storm water treatment are being strained. The solution to these problems is two-fold: reduce water use, and reuse water by installing a **Rainwater Collection System**.

A typical school plumbing system uses city- or well-supplied potable water to satisfy all user demand, and separately sends all site water runoff to an off-site storm water management system. In this case, the school is unnecessarily paying for drinking water at non-potable applications and is unable to easily respond to rising utility prices or periods of drought.

By employing a **Rainwater Collection System**, a school building will take advantage of on-site water sources (rainwater and mechanical condensate) to fulfill non-potable water demands (toilet flushing and site irrigation). In this case, the school is reducing potable water consumption and utility bills, preparing for low-rainfall periods when potable water is in short supply, minimizing load on storm water systems, and providing a valuable educational resource.

IMPORTANCE OF RAINWATER COLLECTION

The minimum annual water consumption needed to sustain life, including food production, is 7,500 gallons per year per person. In the United States, the average consumption is 1,370 gallons per day per person, or 500,000 gallons per year. This must drastically change. Water conservation in the United States must become routine and rainwater harvesting must become commonplace. By being accountable of where our water resources are coming from, what we demand of them, and where they go after use, we can make responsible water consumption feasible for everyone.

A. SYSTEM DESCRIPTION

The concept and value of rainwater collection is simple to understand, however the actual system design is a sequence of several processes and can be complex. The differences in equipment manufacturers, system sizing, and site locations will cause changes to the system model, but the basic water flow diagram will remain the same. Notice the several filtering steps at the roof, in the ground, and in the Equipment Room. Also important is that all systems and pumps are connected and activated by an overall System Controller (described later in this document).

1. Rainwater falls in the designated Roof Catchment Area, sloped towards a filtered gutter and downspout system that leads to the cistern tank.

2. Along the pipe to the cistern tank, the rainwater is filtered through the Storm Drain Trap Pit. This serves to slow the flow rate of the collected water, and to separate heavy sediment and contaminant from water.

3. The water is contained outside in the Cistern Tank, until it is needed for use. The water is drawn from the cistern tank into the building with a submersible pump located in the cistern water. If there is too much rainwater, then the underground tanks overflow to the storm system or a constructed wetland.

4. Once inside the Rainwater Collection Equipment Room, the water is sent through a set of Dual Bag Filters to remove finer suspended particulates and contaminants.

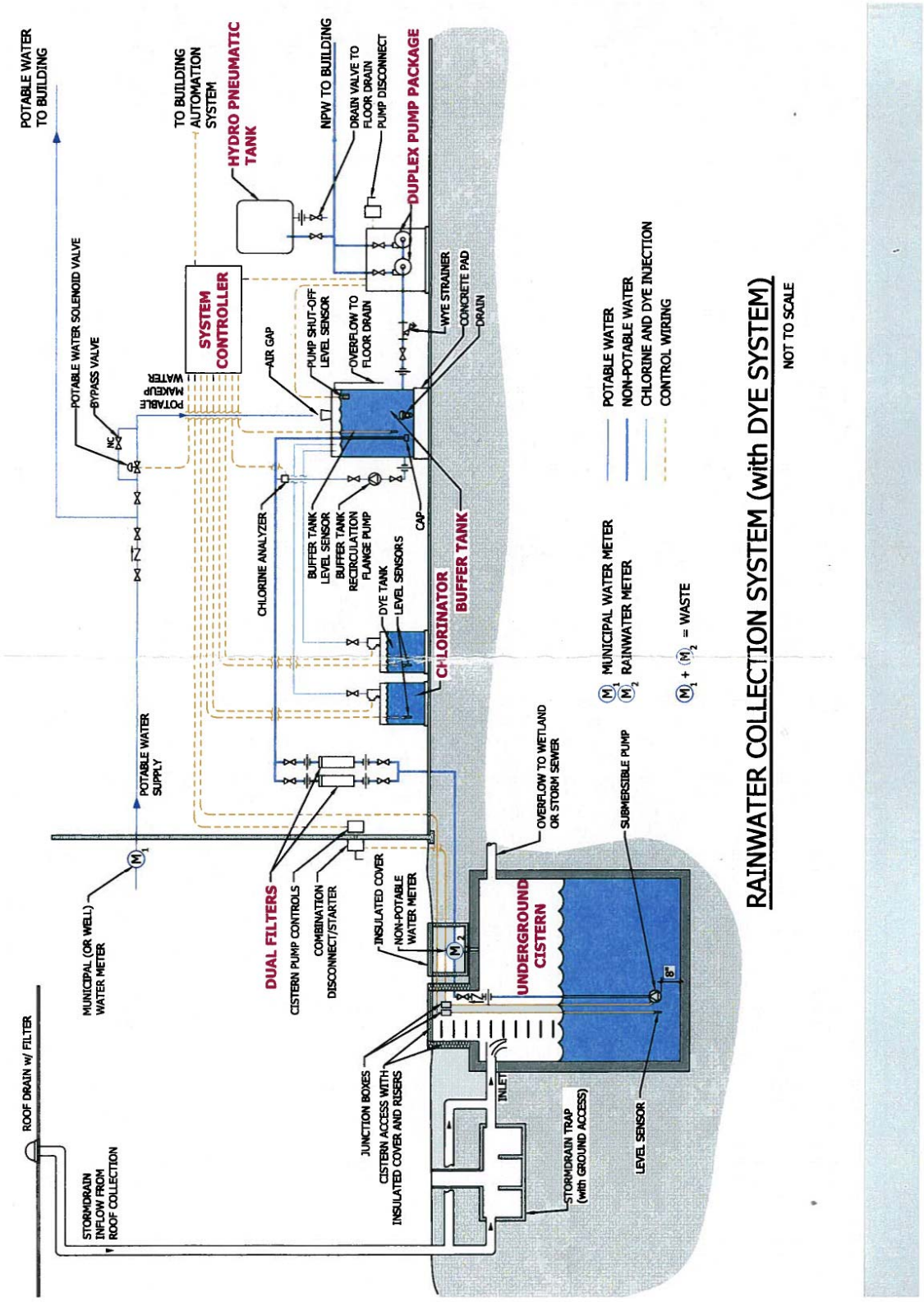
5. The water then is placed in the Buffer tank, where it is treated with chlorine and dye (if necessary) and becomes non-potable water. In response to user demand, the water is drawn from the buffer tank by a set of Dual Booster Pumps.

6. The last process before occupant use is by a Hydro-Pneumatic Tank to pressurize the system.

7. The non-potable water now flows to the toilets, urinals, and the irrigation system. No non-potable water is ever used for potable fixtures, despite any water quality testing.

There are design variations that may be applicable for Ohio projects. These include supplementing rainwater collection with mechanical condensate, adding a dye system to identify non-potable water, and using rainwater collection for irrigation purposes. Using these options will be determined by building needs, available water sources, and regulatory guidelines.

Please see the following page for a rainwater schematic diagram.


POTABLE WATER TO BUILDING
TO BUILDING AUTOMATION SYSTEM
HYDRO PNEUMATIC TANK
NPW TO BUILDING
DRAIN VALVE TO FLOOR DRAIN
PUMP DISCONNECT
DUPLEX PUMP PACKAGE
POTABLE WATER SOLENOID VALVE
BYPASS VALVE
SYSTEM CONTROLLER
POTABLE MAKEUP WATER
AIR GAP
PUMP SHUT-OFF LEVEL SENSOR
OVERFLOW TO FLOOR DRAIN
WYE STRAINER
CONCRETE PAD DRAIN
CHLORINE ANALYZER
BUFFER TANK LEVEL SENSOR
BUFFER TANK RECIRCULATION FLANGE PUMP
CAP
BUFFER TANK
DYE TANK LEVEL SENSORS
CHLORINATOR
POTABLE WATER
NON-POTABLE WATER
CHLORINE AND DYE INJECTION CONTROL WIRING
MUNICIPAL WATER METER
RAINWATER METER
= WASTE
NOT TO SCALE
RAINWATER COLLECTION SYSTEM (with DYE SYSTEM)
POTABLE WATER SUPPLY
OVERFLOW TO WETLAND OR STORM SEWER
SUBMERSIBLE PUMP
MUNICIPAL (OR WELL) WATER METER
DUAL FILTERS
CISTERN PUMP CONTROLS
COMBINATION DISCONNECT/STARTER
INSULATED COVER
NON-POTABLE WATER METER
UNDERGROUND CISTERN
8"
ROOF DRAIN w/ FILTER
JUNCTION BOXES
CISTERN ACCESS WITH INSULATED COVER AND RISERS
INLET
STORMDRAIN TRAP (with GROUND ACCESS)
LEVEL SENSOR
STORMDRAIN INFLOW FROM ROOF COLLECTION

B. SYSTEM COMPONENTS

1. Catchment Area

   a. Do not collect runoff from parking or groundwater, direct through bioswales to a constructed wetland instead.

   b. Only consider roof area collection, ideally with a smooth finish that does not collect dirt and debris. Single-ply and metal roofs are recommended; asphalt shingles require additional filtering because of the granular coating. The collected rainwater is initially filtered for large debris at the roof drain or top of downspout.

   c. The catchment area size depends on local rainfall trends, amount and scope of water demand, and roof size.

2. Storm Drain Trap Pit

   a. The Trap Pit is typically a pre-manufactured unit from a manufacturer of storm water management products. The size and type is determined by the purity of incoming water, the type of solids or oils being filtered, and the flow rate of incoming water.

   b. Maintenance involves accessing the separate filtration chambers and vacuuming all deposited sediment. There should be ground access at all filters within the unit to facilitate this cleaning.

   c. Sizing of the sediment trap is specific to the manufacturer. Factors to be considered in selection of the sediment trap include:

      1) Fluid velocity through the sediment trap to ensure solids do not remain suspended.
      2) Collection of hydrocarbons.
      3) If internal by-pass is employed ensure that the design of the sediment trap retains solids and hydrocarbons.
      4) Flow through the trap can typically be estimated based on a rain event of 1” per hour and the project roof area of the building.

3. Cistern Tank and Pumps

   a. Make sure all accesses and openings to and from the Cistern are fully screened to prevent animal access.

   b. From a construction cost standpoint, the choice of storage tank is a major driver. Underground tanks, unless buried too deeply, tend to be less expensive (even considering the high cost associated with excavation). It is hard to beat the cost of a prefabricated, structurally engineered septic tank. For safety purposes during construction, the grade at the access hole typically will need to be cut back at a 45º angle from the bottom, sloping upward.

c. One good option is using multiple, pre-cast concrete tanks that are buried and tied together with the individual tanks ranging in size from 10,000 gallons to 25,000 gallons. The weight of the concrete helps in areas where the water table is high and buoyancy issues come into play. Also, each tank section should have it's own manhole access.

d. Typically, the size of the storage tank(s) is driven by the normal frequency of rainfall, the amount of rainfall during a typical storm event, and the demand. A one-inch rainfall will produce .62 gallons of water / sf collection area. Assuming ten-percent evaporative losses, this will result in .55 gallons / sf. When sizing the tank, consider recent trends as well as long-term historic rainfall data. Also, remember that the size of the tank and the usable water amount are different. This is typically from 8" above the bottom of the tank to the invert elevation of the overflow pipe.

e. Location: When locating the tank(s), keep in mind the extent of the necessary excavation. Place the tanks as close as possible to the demand location. Do not place them too closely to the building foundation. When placing multiple tanks, allow enough space between the tanks so that the connecting piping can be adequately sealed from the outside as well as inside the tanks.

f. The Cistern pump is responsible for transferring rainwater from the cistern tank to the buffer tank, through the primary filtration system. The pump is typically a submersible pump at the bottom of the tank; consider maintenance access of ease of removing pump system when locating pump and maintenance access.

4. Dual Filters

a. Dual filters are the first processing step. They should be located at an easily accessible height with sufficient clearance for periodic maintenance and filter changing.

b. Removing the fine particulate and suspended solids will also ensure a higher-efficiency system. Bag filters are recommended and must be periodically changed.

c. The redundancy of the filters allows for routine maintenance without affecting the use of the entire system. Place valves above and below each filter, so each can be isolated from the system during maintenance.

5. Water Treatment

a. Although the collected rainwater may already meet quality requirements, it is necessary to integrate a water treatment system. This will ensure consistent water quality independent of the water source and storage periods. There are two primary methods for water treatment:

1) Chlorine – The chlorination system supplies a continuous disinfection of the buffer tank, and consists of a chlorine storage tank and a pump to send chlorine into the buffer tank. On the buffer tank, there is a recirculation pump, which monitors the chlorine level of buffer tank water and activates the chlorine injection rate.

2) Blue-Water Dye – The water dye does not affect the quality of the water, but serves to clearly identify non-potable water from potable water. This may not be required by local code officials. The system consists of a dye tank and a pump to send dye into buffer tank. The dye should be water- and vegetable- based, and not contain any element that will disrupt the piping or wastewater systems.

6. Buffer Tank and Pump

a. The buffer tank serves as the location of both water treatment and the storage of non-potable water for occupant use. This is also where make-up water, when necessary, is introduced to the system.

b. Upon demand, the water is pumped from the underground tanks into the smaller, inside buffer tank that is sized to handle the short-term demand. This is the on-demand supply for occupant use. If there is insufficient rainwater, municipal- or well-makeup water will be added into the top of the buffer tank.

c. The water treatment is maintained via a recirculating pump and chlorine analyzer attached to the buffer tank. This pump can be placed on a timer so that it does not run continuously, but on a cycle adequate to access chlorine levels.

7. Booster Pumps

a. The dual booster pumps respond to water demand, and draw non-potable water from the buffer tank to toilet, urinal, and irrigation fixtures.

b. Each pump is sized to individually accommodate peak user demand. Both pumps can be isolated, to allow maintenance without system interruption.

c. When irrigation demand is present (and greater than building demand), pumps shall be selected to operate in parallel to provide peak irrigation demand.

8. Hydro-pneumatic Tank

a. The hydro-pneumatic tank prepares the non-potable water for occupant use by supplying the appropriate pressure for water conveyance and fixture operation.

b. The air in the tank is compressed by non-potable water entering the tank. As the pressure in the tank increases, the pressure in the water distribution system also increases, since it is fed from the tank.

9. Rainwater Equipment Room

   a. The rainwater equipment room is typically located inside the school building, near the cistern tank. This minimizes pipe lengths and prevents the need to run supply pipes under the building. The room should have an exterior door, with sufficient opening for equipment maintenance and replacement. A hose bib and floor drain are recommended for maintenance. The floor drain should be sized and located appropriately to accommodate Buffer tank, chlorine tank, and dye tank overflow.

C. SAMPLE SEQUENCE OF OPERATION

1. When the buffer tank setpoint is reached, the cistern pump shall be de-energized. If the cistern tank water level is below setpoint (field adjustable), then the cistern pump shall not be energized and the potable water solenoid valve shall be energized. When the cistern tank water level reaches setpoint, the potable water solenoid valve shall be de-energized and the cistern pump shall be energized. If the cistern pump receives a start signal and the current switch does not detect current, then an alarm shall be generated.

2. A rise in buffer tank water level above setpoint (field adjustable), due to malfunction of the solenoid valve or cistern pump, shall generate an alarm and de-energize the system.

3. The buffer tank recirculating pump shall run every twelve hours (field adjustable) for ten minutes (field adjustable). Chlorine levels shall be monitored during this ten-minute run time and if levels are below setpoint (field adjustable), then the pump shall continue to run until setpoint is reached. When setpoint is reached, the pump shall be de-energized. If the buffer tank recirculation pump receives a start signal and the current switch does not detect current, then an alarm shall be generated.

4. The hydro-pneumatic tank shall maintain system pressure between a high limit (field adjustable) and low limit (field adjustable) setpoint. When the low limit setpoint is exceeded, the booster pump package shall be energized. The booster pump shall continue to operate until the high limit setpoint is reached. When the high limit setpoint is reached, the booster pump shall be de-energized. The pumps shall operate in a lead-lag sequence. If the booster pump receives a start signal and the current switch does not detect current, then an alarm shall be generated.

   (As an alternate to the above booster pump sequence, when there exists a demand for irrigation, the pumps shall typically operate in parallel to meet such demand. When there is no longer a demand for irrigation, the pumps shall index back to standard lead-lag sequence of operation.)

5. Observations

   a. Monitor the chlorine tank level constantly and generate a low-level alarm when minimum setpoint (field adjustable) is exceeded.

   b. Monitor the dye tank level constantly and generate a low-level alarm when minimum setpoint (field adjustable) is exceeded.

   c. Meter water flow from the cistern constantly.

d. Meter water flow from the municipality constantly.

e. Meter water from to the irrigation system constantly.

f. Flow rates from the cistern, municipality and irrigation shall be used to determine the quantity of wastewater.

6. At a minimum, the following items should be incorporated into the sequence of operation.

a. Setpoint shall be determined based on project specific requirements.

b. All pumps shall generate an alarm upon failure.

c. Buffer tank level shall be monitored and control strategies implemented to keep tank from flooding.

d. Monitor chlorine tank levels and generate an alarm when minimum setpoint is exceeded.

e. Monitor cistern, municipal, and irrigation demand to estimate quantity of wastewater.

D. SYSTEM POINTS LIST

Point Description	Hardware					Software		
	Output		Input			Alarms		
	Digital		Digital		Analog	Status	High	Low
	Open/Close	Start/Stop	Current Switch	Fault	Level/Flow	Failure	Limit	Limit
Cistern Pump		X	X			X		
ORP Controller					X			
Buffer Tank Level					X		X	X
Booster Pump		X	X			X		
Chlorine Tank Level					X			X
Water Filter Detla P							X	
Buffer Tank Recirculation Pump		X	X			X		
Water Meter for Cistern					X			
Water Meter for Re-flush					X			
Water Meter for Irrigation					X			

E. SYSTEM DESIGN TIPS

1. To help reduce the cost impacts of the rainwater system, think of how the tank can serve dual functions.

   a. The cistern can retain enough reserve water for fire protection.

   b. The top of the tank is used as a basketball court.

   c. It is possible to use the main rainwater storage tank for recovering and storing condensate from cooling equipment, further enhancing the value and water savings.

F. IMPACT OF PLUMBING FIXTURES

1. Decreasing the non-potable water demand of the building can reduce the size of both the rainwater collection area and cistern size. Because we assume a constant rate for student facility use, the opportunity for decreasing demand is found in fixture type.
2. Conventional fixtures use 1.6 gallons per flush for toilets and 1 gallon per flush for urinals. There are currently many manufacturers of low-flow fixtures, with efficiencies down to .8 gallons per flush for toilet and .5 gallons per flush for urinals.
3. Refer to the EPA resource **WaterSense** for a listing of recommended high-efficiency fixtures. www.epa.gov/watersense

G. BUILDING INSPECTION TIPS

1. Eliminate any chance that the rainwater can contaminate the municipal water line. To ensure that the rainwater cannot contaminate the potable line, provide an air gap between the makeup municipal or well water line and the buffer tank. The air gap is failsafe.
2. How can the city bill the owner for non-municipal water? Most municipalities bill by water supplied, not waste out. They assume equal waste. The answer is to install multiple flow meters. Measure both the municipal water and rainwater. In some cases, also measure the water that is going to irrigation and not into the sanitary sewer lines.
3. Building codes, almost everywhere, only mention gray water. *Rainwater is not gray water*. It does not come from sinks and drinking fountains and is not subject to the potential disease problems that are present with gray water. With a gray water system, excess water must be directed to the sanitary sewer, not the wetland or storm system. If the local building inspector incorrectly classifies the rainwater system as a gray water system, the costs for enhanced treatment and piping greatly impact the overall cost-to-benefit.

H. ADDITIONAL RAINWATER COLLECTION FACTS, BENEFITS, AND ISSUES

1. Relationship of water and energy: By conserving potable water, we are decreasing energy used for water treatment, conveyance, and infrastructure construction.

2. Municipal Service Fees: In many areas, there are storm water fees and nitrogen fees, both associated with the amount of water that is leaving the site. Rainwater harvesting acts like a retention pond, holding up to 2 in. of rainfall and reducing or eliminating the

need for outside retention strategies. With a rainwater harvesting system, a typical middle school site can avoid paying as much as $50,000 for a retention pond.

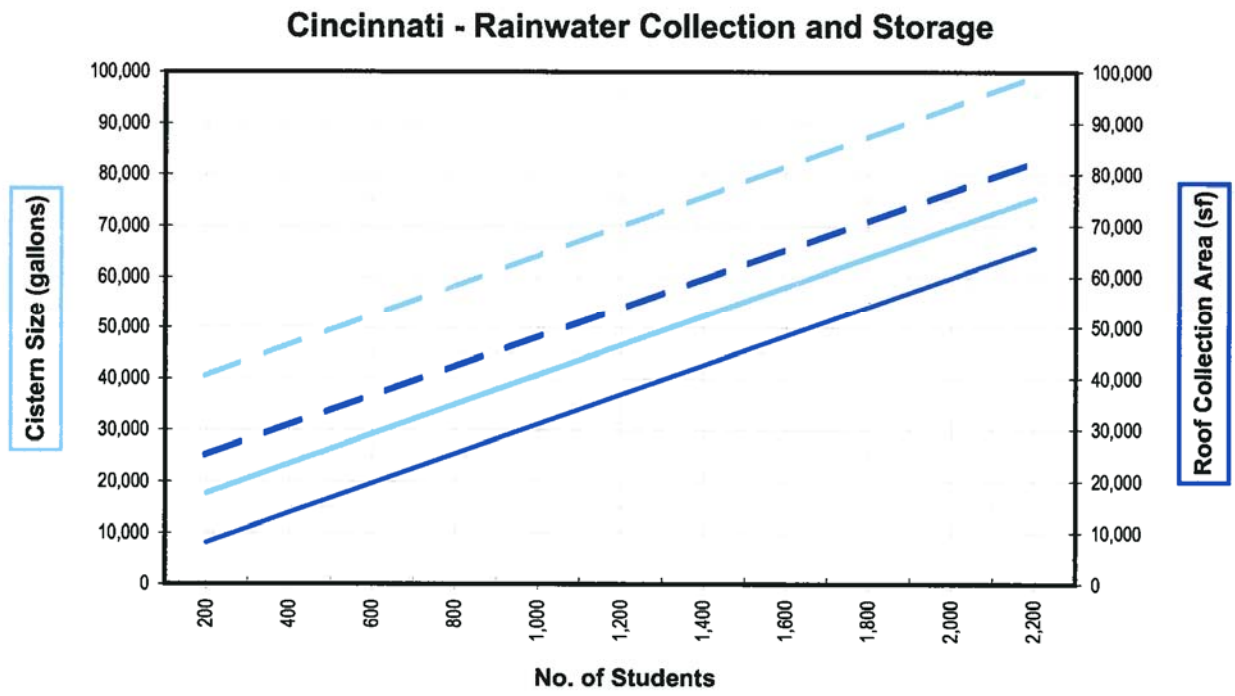
3. Still effective during drought: Because of the storage capacities of the cistern tank, the benefits of rainwater collection will be available during drought conditions. Case studies have indicated that rainwater systems can still provide more than 60% of demand during periods of low rainfall. This savings provides a more dependable water supply to the owner, and greatly reduces demand on the limited potable water availability.

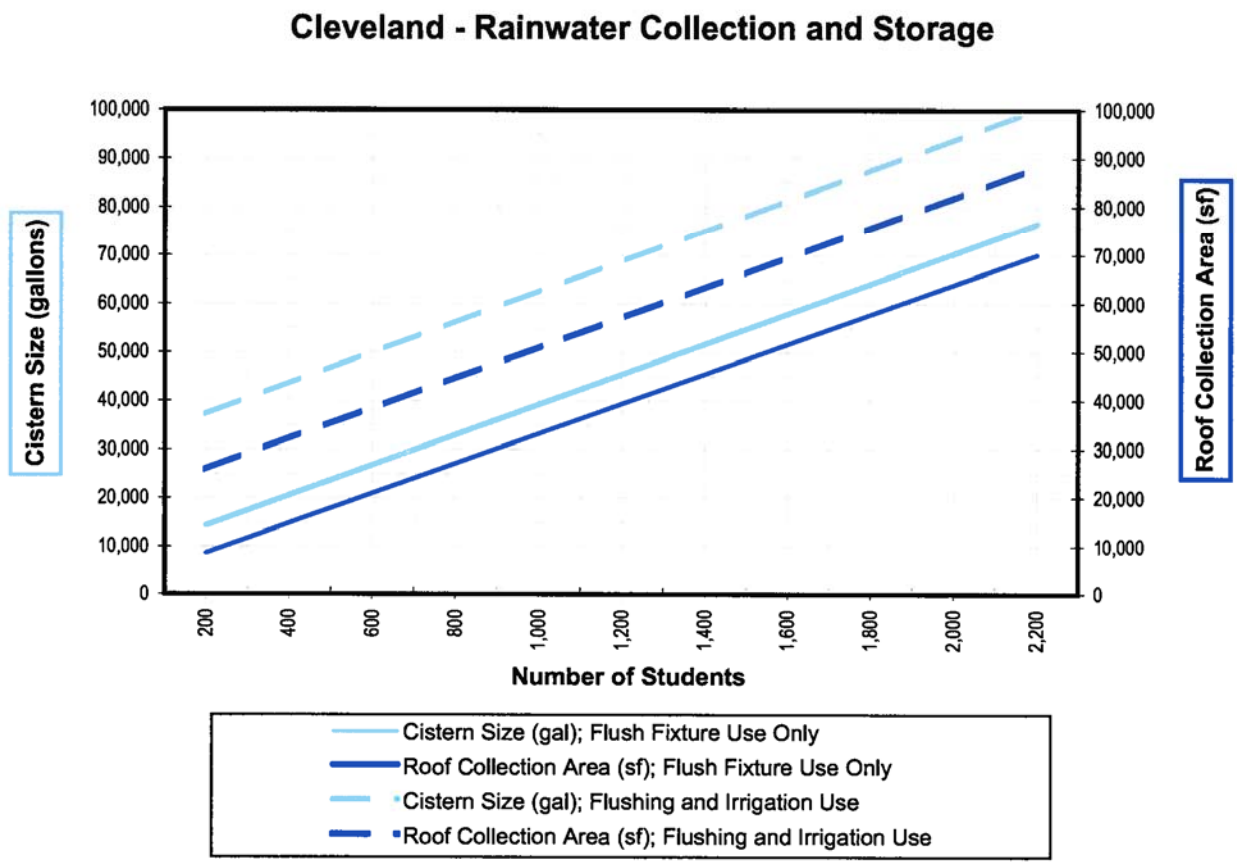
4. Requires Less Chlorine: Municipal systems typically use 4 parts per million of chlorine. Rainwater systems used for non-potable needs can be chlorinated to just 0.25 parts per million to eliminate algae formation, according to the U.S. Air Force. The simplest chlorination strategy ties the chlorinator to the pump that pulls rainwater from the underground cisterns at a known flow rate. Although algae growth is not a big concern with underground tank systems, it is for above ground storage tanks, which have a greater chance of exposure to sunlight. Chlorination to the recommended 0.25 parts per million safeguards the tank.

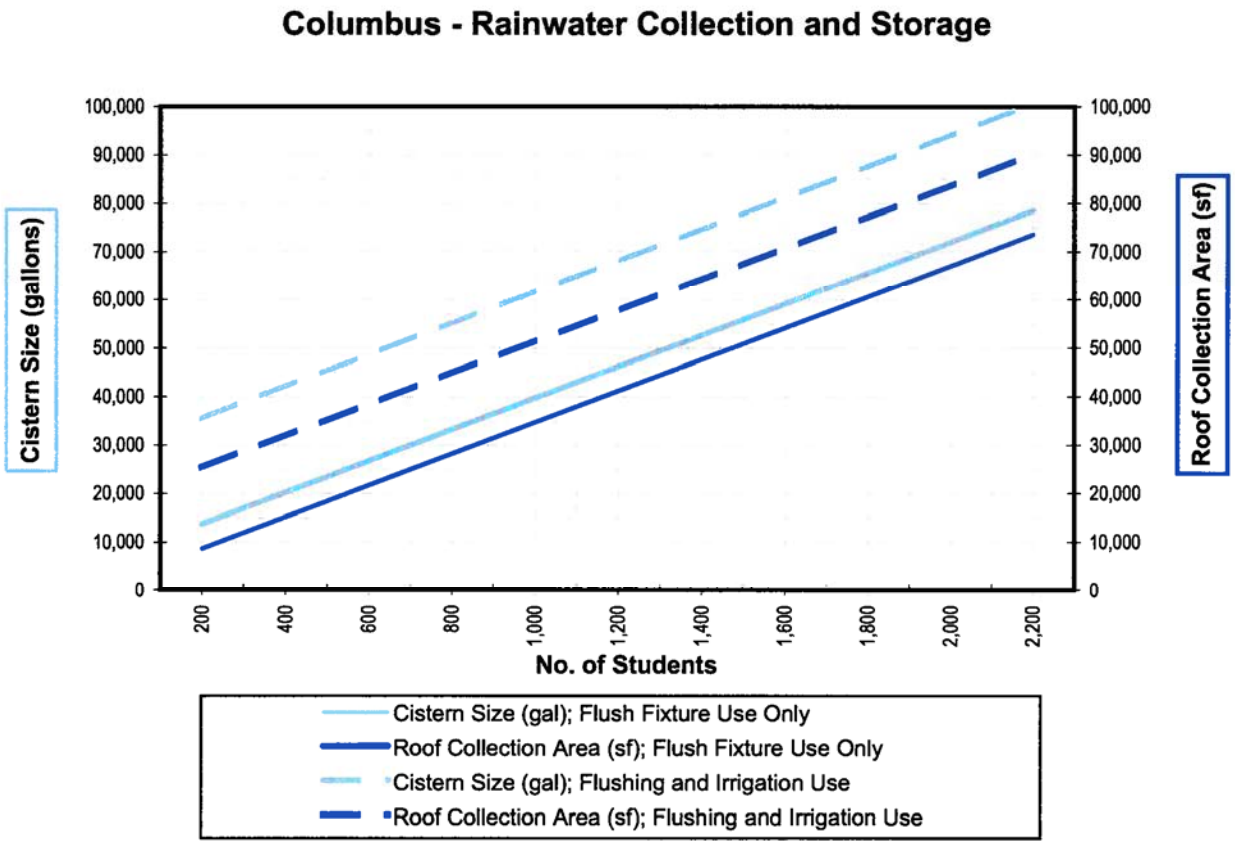
5. Lowers Nitrogen Flow Off Site Into Local Streams: One pound of nitrogen is reduced for every 7,000 to 10,000 ft^2 of roof area used for rainwater harvesting. However, a commonly used first flush strategy that allows the rain falling on the roof to be diverted to a storm drainage system reduces much of this benefit. Used to reduce filter maintenance, this strategy dumps the debris as well as the nitrogen. To reduce nitrogen flow, use better filters and allow all rainwater to flow into the storage tank.

6. Rural locations: By using rainwater collection for non-potable, irrigation, and fire-fighting purposes, the school demands less of the local well resource. This ensures a longer and more dependable period of well use, and benefits neighbors utilizing the same aquifer. Also if the school uses well water and treats wastewater on site, there are savings from not needing to connect to far-away municipal services.

(see graphs on following pages)


Cincinnati - Rainwater Collection and Storage
Cistern Size (gallons)
Roof Collection Area (sf)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
No. of Students


Cleveland - Rainwater Collection and Storage
Cistern Size (gallons)
Roof Collection Area (sf)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
Number of Students
Cistern Size (gal); Flush Fixture Use Only
Roof Collection Area (sf); Flush Fixture Use Only
Cistern Size (gal); Flushing and Irrigation Use
Roof Collection Area (sf); Flushing and Irrigation Use


Columbus - Rainwater Collection and Storage
Cistern Size (gallons)
Roof Collection Area (sf)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
No. of Students
Cistern Size (gal); Flush Fixture Use Only
Roof Collection Area (sf); Flush Fixture Use Only
Cistern Size (gal); Flushing and Irrigation Use
Roof Collection Area (sf); Flushing and Irrigation Use

A. ROOF SPACE AND SHADING REQUIREMENTS

The Designer shall designate areas on the roof plan that are suitable for future solar photovoltaic installations where the roof area remains free of shade from 9:00 a.m. to 5:00 p.m. solar time every day. No obstructions shall exist on the roof within the designated solar area. Obstructions to the south, east, or west of the designated solar area shall be limited in height to avoid shading the area. To the extent possible, any equipment, pipes, conduit, and vent stacks should be located north of the designated solar areas.

Select tree species and planting locations so that the mature trees will not shade roof areas that are suitable for solar installation.

B. STRUCTURAL REQUIRMENTS

New roof structures should be designed to anticipate a future additional dead load in areas suitable for solar photovoltaic installation. The Designer shall seek direction from the School District on design parameters for future photovoltaic installation. In the absence of specific direction, the Designer may assume that the photovoltaic panels are mounted parallel to the roof slope.

C. ELECTRICAL SYSTEM ACCESS

Provide an adequately sized chase from the main electrical room, electrical service closets, and the mechanical room to the roof if the building is multi-story. Locate the electrical room on an exterior wall (north side preferred) or plan for shading an adjacent exterior electrical equipment pad. Indicate on the site plan a 10’ by 10’ area reserved for a future outdoor pad for electrical equipment adjacent to the electrical equipment room.

Optional: Reserve 6 linear feet of wall space adjacent to the main electrical panel for future installation of inverters.

D. BUILDING MASSING AND ORIENTATION

If new building massing is dominantly rectangular, it is preferred to orient the long axis to the east-west cardinal points.

E. WAIVER

The provisions for solar readiness may be waived by the Commission when the building is shaded, or will be shaded, or when other conditions exist that make use of the roof area for solar energy production impractical. Requests for waiver shall be submitted to the variance committee.

OHIO - SOLAR DOMESTIC HOT WATER MATRIX

	Number Students	Hot Water Demand	Design Load	Solar Fraction	Gallons Storage	Number Collectors	Areas Collectors	Solar Production	kWh
		Gallons/day	Gallons/day				8'-0" x 4'-0" Sq. Ft.		
Cleveland									
Elementary	**400**	219	190	48%	120	3	96	18 Mbtu	5,870
Middle	**600**	328	285	49%	240	5	160	25.1 Mbtu	8,170
High 1000	**1000**	547	475	45%	240	8	256	41.6 Mbtu	13,557
High 2000	**2000**	1094	950	43%	480	15	480	80.0 Mbtu	26,052
Columbus									
Elementary	**400**	219	190	50%	120	3	96	18.3 Mbtu	5,969
Middle	**600**	328	285	51%	240	5	160	25.7 Mbtu	8,363
High 1000	**1000**	547	475	46%	240	8	256	42.3 Mbtu	13,790
High 2000	**2000**	1094	950	44%	480	15	480	81.4 Mbtu	26,504
Cincinnati									
Elementary	**400**	219	190	51%	120	3	96	17.9 Mbtu	5,816
Middle	**600**	328	285	51%	240	5	160	25.0 Mbtu	8,152
High 1000	**1000**	547	475	47%	240	8	256	41.0 Mbtu	13,363
High 2000	**2000**	1094	950	45%	480	15	480	78.9 Mbtu	25,701

Collector @ 40 degree tilt

Modeled 12 months & 5 days/week
Elementary June 70%, July 50%, Aug 80%
Middle June 70%, July 50%, Aug 80
High School year round

A. INDIRECT DRAIN-BACK OPTION 1

1. System Description

Drain-back systems offer freeze protection and high-limit protection because the collectors empty by gravity when the system pump in not operating. Since these differentially controlled systems often use distilled water as the heat transfer fluid, they offer improved heat transfer to the potable water. (This is because water has better heat transfer capabilities than other heat transfer liquids such as glycols or hydrocarbons.)

In some hard freezing climates, a mixture of 30% propylene glycol may be used or required to ensure freeze protection in the event of controller failure or the piping not draining completely.

When installed correctly, Drain-Back System Option 1 provides a fail-safe method for protecting the collectors and piping from freeze damage and the system from overheating. Each time the differentially controlled solar pump shuts off, all fluid in the slightly tilted collector array and pipes drains into an insulated storage tank located in the building's interior. The heat exchanger is incorporated in the solar storage tank at a level below the lowest anticipated level of the fluid when the collector array is filled and operating.

Drain-Back Option 1 has a large (80-200) gallon tank that serves as the solar storage tank and the drain back reservoir. Most solar collectors have a capacity of approximately 1 to 1.5 gallons each. Therefore, the storage tank/reservoir must be sized based on the number of collectors and the volume of fluid in the total length of the solar loop.

The solar loop and storage tank is closed to the atmosphere and has a measured volume of fluid and measured volume of air. This system does not require air vents or vacuum breakers. The air in these systems should not be added to or released.

The air is transferred to the storage tank when the solar pump is running and the heat transfer fluid fills the collectors. The fluid level in the storage tank never drops below the level of the water side heat exchanger located inside the tank. When the solar pump shuts off, the air in the reservoir is forced up and into the top of the collectors by the water draining back into the reservoir from the bottom of the collectors.

The cold water supply is routed through the heat exchanger in the solar storage tank and pre-heats make up water prior to entering the conventional water heater. Therefore any available heat in the storage tank is transferred to the water heater.

a. The solar pump must be sized correctly to overcome gravity and friction losses.
b. Since the system is not pressurized, expansion tanks and check valves in the collector loop are not required.
c. Collectors and pipe drains must be installed to allow proper and unimpeded drainage back to the drain back storage tank/reservoir (minimum ¼ inch per foot).

2. Sequence of Operation

There are two methods of operating the pumps on a Drain-Back system: a dedicated Temperature Differential Controller or a Building Automated Control System.

a. Temperature Difference Control
When the temperature difference between the sensor on the solar collector (T1) and the sensor in the storage tank (T2) exceeds the set point or Delta-T temperature difference setting (typically 25 degrees), the relay in the controller will activate the collector pump, fill the collectors and transfers the heat to the drain-back reservoir/solar storage tank. When the collector tank temperature (T2) indicates a 4°F differential setting, the controller will turn off the circulation pumps and allow the heat transfer fluid to drain back into the reservoir/solar tank.

b. Building Automated Control System

1) The operating protocols for the Building Automated Control System will include:

a) Solar Pump On: Solar pump turns on when the temperature difference between the sensor on the solar collector (T1) and the sensor in the solar storage tank (T2) exceeds the set point or Delta-T temperature difference setting (typically 25 degrees).

b) Solar Pump Off: Solar pump turns off when the temperature difference decreases and falls below 4°F.

c) Solar Storage Tank High Limit: When the temperature (T2) in the storage tank exceeds the HI-LIMIT dialed setting (typically 140-160 degrees), the solar pump relay will be turned off without delay regardless of the status of the temperature difference that exists between the solar storage tank and the solar collectors. When the storage tank temperature falls 4°F below the setting in the HI-LIMIT, the controller will then resume normal operation.

d) Solar Minimum Operating Temperature: The circulation pumps will be deactivated anytime the solar collector sensor (T1) is below 50°F. Normal control operation will not resume until the collector temperature returns to 70°F or above.

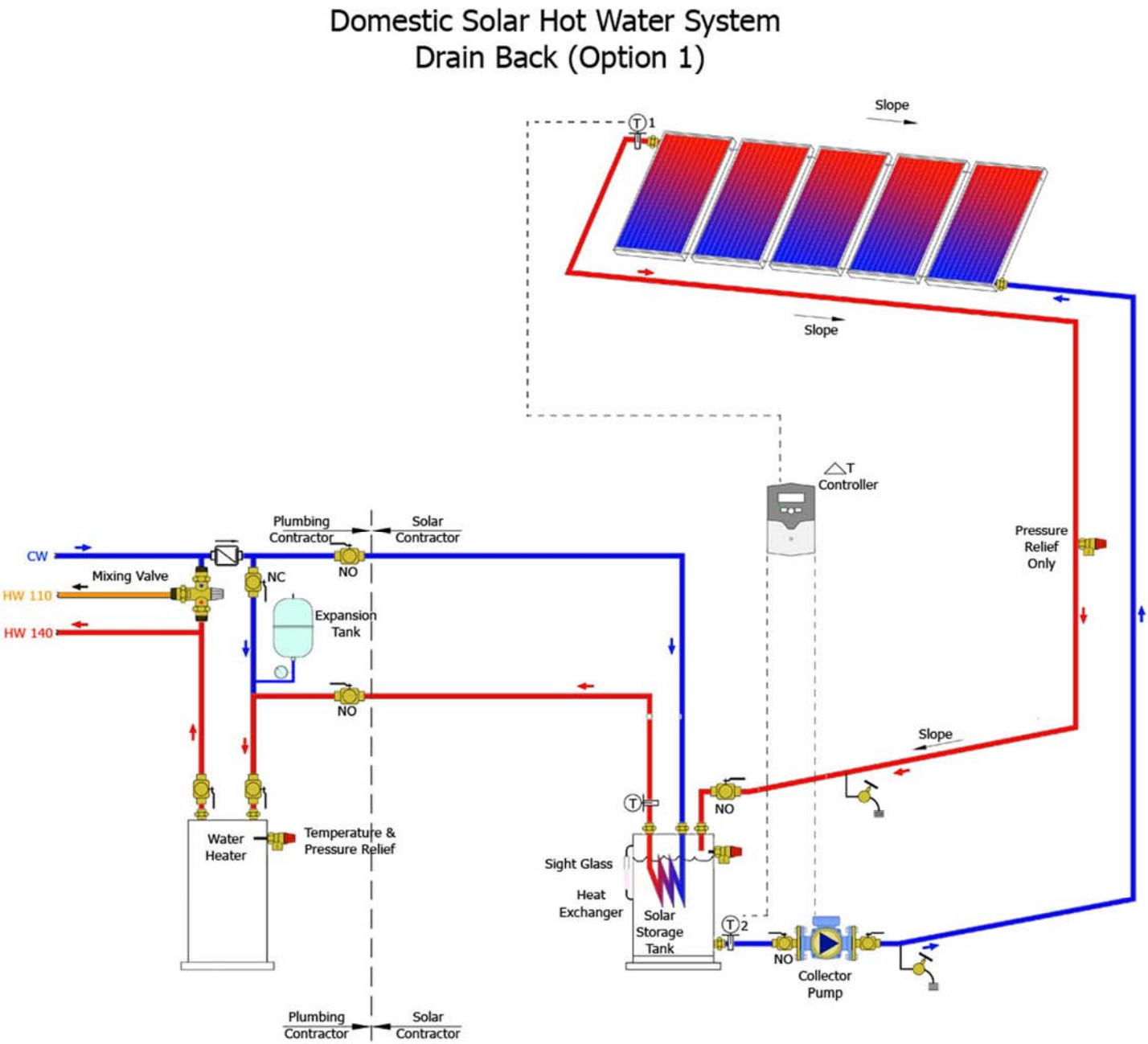
2) High Limit Control
When the temperature in the storage tank exceeds the HI-LIMIT dialed setting (typically 140-160 degrees), the solar pump relay will be turned off without delay regardless of the status of the temperature difference that exists between the solar storage tank and the solar collectors. When the storage tank temperature is lowered to 4°F below the setting in the HI-LIMIT, the controller will then resume normal operation.

3) Low Temperature Shut Down Override
This feature may be available to prevent the system from operating at low outdoor temperatures. If this feature is enabled, normal operation will stop when the collector temperature falls below 50°F. The solar pump relay will then be turned off. Normal control operation will not resume until the collector (T1) temperature returns to 70°F or above.

3. Sensors

Modern solar controllers use Resistance Temperature Devices (RTD) or Industrial 400°F (204°C) rated 10K IMC thermistors that have +/- 1°F accuracy. When installed, they will not exceed one degree of additional error for cable distances up to 1,000 feet of 18ga; 700 feet of 20ga, or 500 feet of 22ga.

Please see the following page for a schematic diagram.


Domestic Solar Hot Water System
Drain Back (Option 1)
Slope
T 1
Slope
T
Controller
Pressure
Relief
Only
Plumbing
Contractor
Solar
Contractor
CW
Mixing Valve
HW 110
HW 140
NC
NO
Expansion
Tank
NO
Slope
NO
Water
Heater
Temperature &
Pressure Relief
Sight Glass
Heat
Exchanger
Solar
Storage
Tank
T 2
NO
Collector
Pump
Plumbing
Contractor
Solar
Contractor

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A. INDIRECT DRAIN-BACK OPTION 2

1. System Description

Drain-back systems offer freeze protection and high-limit protection because the collectors empty by gravity when the system pump in not operating. Since these differentially controlled systems often use distilled water as the heat transfer fluid, they offer improved heat transfer to the potable water. (This is because water has better heat transfer capabilities than other heat transfer liquids such as glycols or hydrocarbons.)

In some hard freezing climates, a mixture of 30% propylene glycol may be used or required to ensure freeze protection in the event of controller failure or the piping not draining completely.

When installed correctly, Drain-Back System Option 2 provides a fail-safe method for protecting the collectors and piping from freeze damage and the system from overheating. Each time the differentially controlled solar pump shuts off, all fluid in the slightly tilted collector array and pipes drains into an insulated reservoir tank located in the building's interior. The heat exchanger is in the inside at the bottom of this drain-back reservoir tank.

Drain-Back Option 2 has a reservoir on the solar loop and is sized to hold the total volume of heat transfer fluid in the collector array and exposed piping. The reservoirs are available in sizes from 8 gallons to 30 gallons and are designed to hold the fluid of 3 to 15 collectors (based upon the example school systems provided) plus the volume of fluid in total length of the solar loop. Most solar collectors have a fluid capacity of approximately 1 to 1.5 gallons per collector.

The solar loop is closed to the atmosphere and has a measured volume of fluid and measured volume of air. This system does not require air vents or vacuum breakers. The air in these systems should not be added to or released.

The air is transferred to the reservoir tank when the pump is running and the heat transfer fluid fills the collectors. The pump is never without water since the pump is located below the lowest water level when fully drained. When the pump shuts off, the air in the reservoir is forced up and into the top of the collectors by the water draining back into the reservoir from the bottom of the collectors.

a. The solar pump must be sized correctly to overcome gravity and friction losses.

b. Since the system is not pressurized, expansion tanks and check valves in the collector loop are not required.

c. Collectors and pipe drains <u>must</u> be installed to allow proper and unimpeded drainage back to the drain back reservoir (minimum ¼ inch per foot).

2. Sequence of Operation

There are two methods of operating the pumps on a Drain-Back system: a dedicated Temperature Differential Controller or a Building Automated Control System.

a. Temperature Difference Control

When the temperature difference between the sensor on the solar collector (T1) and the sensor in the storage tank (T2) exceeds the set point or Delta-T temperature difference setting (typically 25 degrees), the relay in the controller will activate the collector pump and the water pump. The two pumps operating simultaneously will fill the solar collector and transfer the heat to the reservoir and circulate the cold water from the solar storage tank or water heater through the heat exchanger to transfer the collector heat to the water heating system. When the collector tank temperature (T2) indicates a 4°F differential setting, the controller will turn off the circulation pumps and allow the heat transfer fluid to drain back into the reservoir.

b. Building Automated Control System

1) The operating protocols for the Building Automated Control System will include:

a) Solar Pump On: Solar pump turns on when the temperature difference between the sensor on the solar collector (T1) and the sensor in the solar storage tank (T2) exceeds the set point or Delta-T temperature difference setting (typically 25 degrees).

b) Solar Pump Off: Solar pump turns off when the temperature difference decreases and falls below 4°F.

c) Solar Storage Tank High Limit: When the temperature (T2) in the storage tank exceeds the HI-LIMIT dialed setting (typically 140-160 degrees), the solar pump relay will be turned off without delay regardless of the status of the temperature difference that exists between the solar storage tank and the solar collectors. When the storage tank temperature falls 4°F below the setting in the HI-LIMIT, the controller will then resume normal operation.

d) Solar Minimum Operating Temperature: The circulation pumps will be deactivated anytime the solar collector sensor (T1) is below 50°F. Normal control operation will not resume until the collector temperature returns to 70°F or above.

2) High Limit Control

When the temperature in the storage tank exceeds the HI-LIMIT dialed setting (typically 140-160 degrees), the solar pump relay will be turned off without delay regardless of the status of the temperature difference that exists between the solar storage tank and the solar collectors. When the storage tank temperature is lowered to 4°F below the setting in the HI-LIMIT, the controller will then resume normal operation.

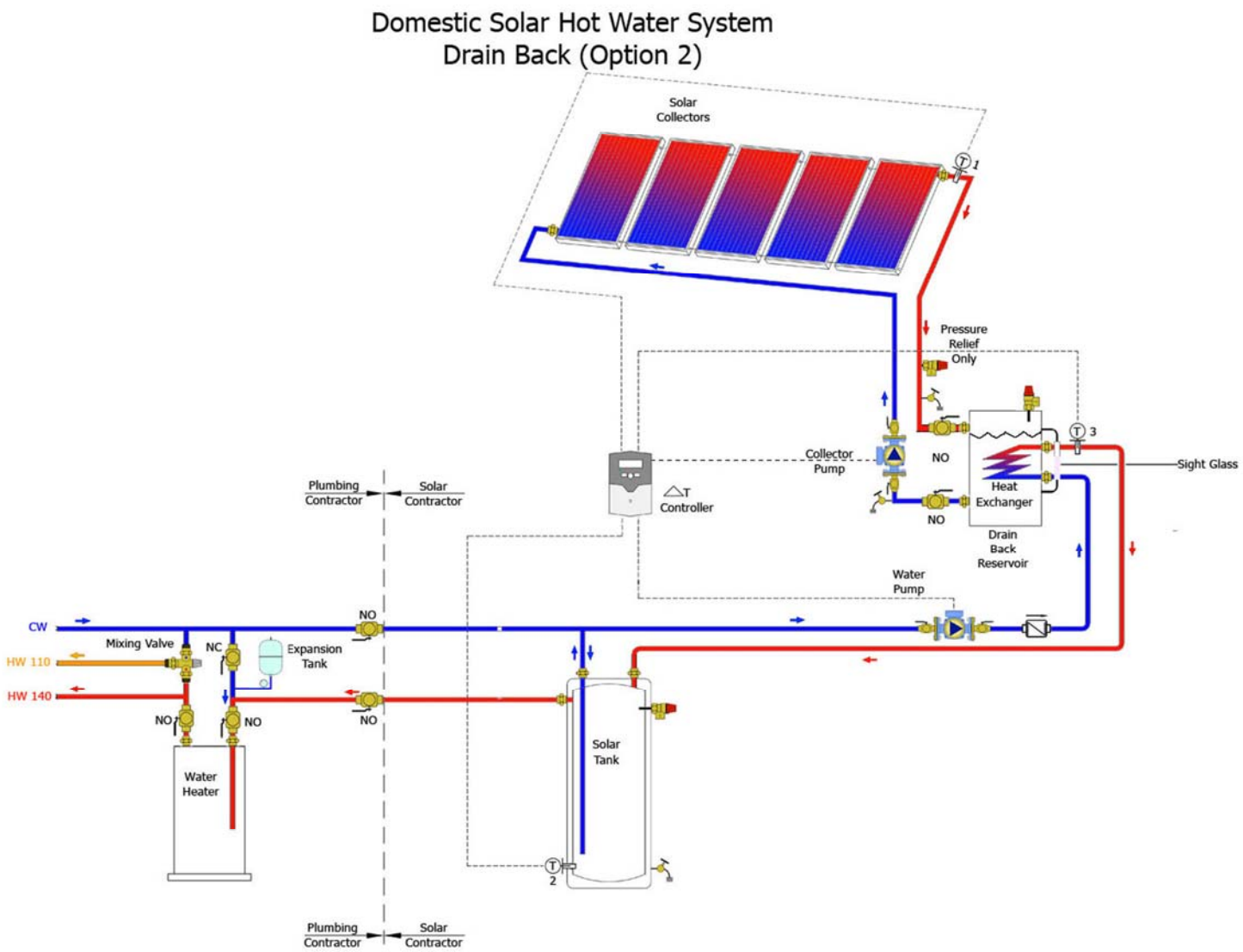
3) Low Temperature Shut Down Override

This feature may be available to prevent the system from operating at low outdoor temperatures. If this feature is enabled, normal operation will stop when the collector temperature falls below 50°F. The solar pump relay will then be turned off. Normal control operation will not resume until the collector (T1) temperature returns to 70°F or above.

3. Sensors

Modern solar controllers use Resistance Temperature Devices (RTD) or Industrial 400°F (204°C) rated 10K IMC thermistors that have +/- 1°F accuracy. When installed, they will not exceed one degree of additional error for cable distances up to 1,000 feet of 18ga; 700 feet of 20ga, or 500 feet of 22ga.

Please see the following page for a schematic diagram.


Domestic Solar Hot Water System
Drain Back (Option 2)
Solar Collectors
Pressure Relief Only
Collector Pump
NO
Heat Exchanger
Sight Glass
Drain Back Reservoir
Water Pump
ΔT Controller
Plumbing Contractor
Solar Contractor
CW
HW 110
HW 140
Mixing Valve
NC
Expansion Tank
NO
Water Heater
Solar Tank

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A. INDIRECT PRESSURIZED GLYCOL

1. System Description

A pressurized glycol solar hot water system is a closed loop solar water heating system that uses an antifreeze heat transfer fluid. The use of a propylene glycol fluid mixture in the solar loop prevents the fluid from freezing and damaging the solar collectors or the exterior piping in the winter. This system is recommended to be used in extreme weather areas or facilities that have a balanced daily or annual load. Caution should be taken when applying an indirect pressurized glycol system where over heating or collector stagnation could be a problem.

As in most solar hot water systems the indirect pressurized glycol system preheats service hot water through a heat exchanger(s) located at the solar storage tank(s). The glycol heat transfer solution is circulated through the solar collectors and returns to the heat exchangers in the solar storage tank with a higher heat content. This higher heat content is then transferred through the heat exchangers to the water in the solar storage tank increasing the water temperature.

Options for preventing overheating may include over sizing the storage system, installing a larger expansion tank or incorporating a heat dump from the storage tank or on the solar loop with the use of a hydronic coil to atmosphere.

2. Sequence of Operation

There are two methods of operating the pumps on a Pressurized Glycol System: a dedicated Temperature Differential Controller or a Building Automated Control System.

a. Temperature Difference Control
When the temperature difference between the sensor on the solar collector (T1) and the sensor in the storage tank (T2) exceeds the set point or Delta-T temperature difference setting (typically 25 degrees), the relay in the controller will activate the solar collector pump and circulate the heat transfer fluid through the collector array transferring the energy to the heat exchanger inside the storage tank.

If an external heat exchanger is used on the system the relay in the controller will activate the collector pump and the pump to the heat exchanger.

When the collector tank temperature (T2) indicates a 4˚ F differential setting, the controller will turn off the solar pump. In this case the heat transfer fluid remains in the collector loop.

b. Building Automated Control System
1) The operating protocols for the Building Automated Control System will include:
a) Solar Pump On: Solar pump turns <u>on</u> when the temperature difference between the sensor on the solar collector (T1) and the sensor in the solar storage tank (T2) exceeds the set point or Delta-T temperature difference setting (typically 25 degrees).
b) Solar Pump Off: Solar pump turns <u>off</u> when the temperature difference decreases and falls below 4°F.

c) Solar Storage Tank High Limit: When the temperature (T2) in the storage tank exceeds the HI-LIMIT dialed setting (typically 140-160 degrees), the solar pump relay will be turned off without delay regardless of the status of the temperature difference that exists between the solar storage tank and the solar collectors. When the storage tank temperature falls 4°F below the setting in the HI-LIMIT, the controller will then resume normal operation.

d) Solar Minimum Operating Temperature: The circulation pumps will be deactivated anytime the solar collector sensor (T1) is below 50°F. Normal control operation will not resume until the collector temperature returns to 70°F or above.

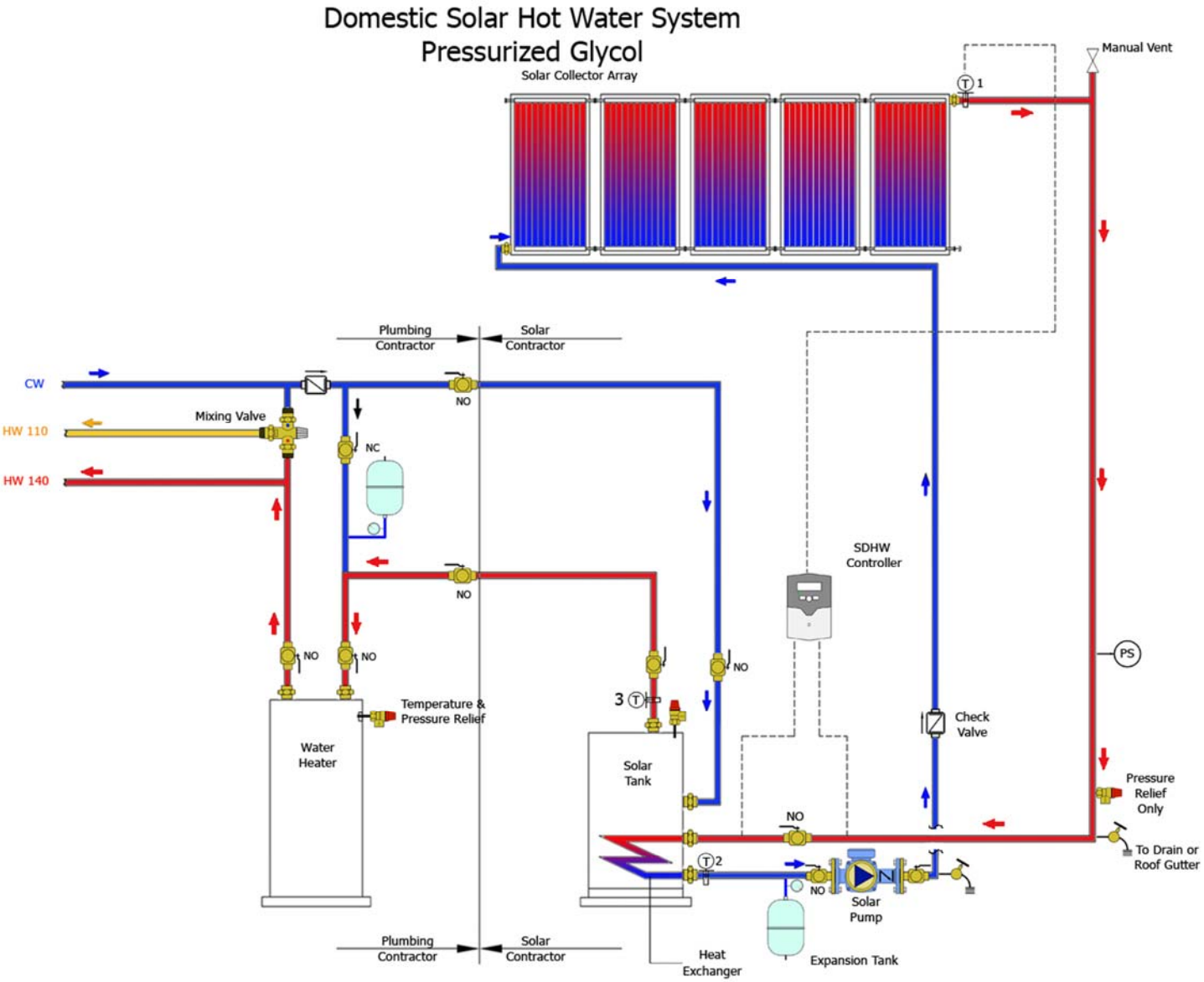
2) High Limit Control
When the temperature in the storage tank exceeds the HI-LIMIT dialed setting (typically 140-160 degrees), the solar pump relay will be turned off without delay regardless of the status of the temperature difference that exists between the solar storage tank and the solar collectors. When the storage tank temperature is lowered to 4°F below the setting in the HI-LIMIT, the controller will then resume normal operation.

3) Low Temperature Shut Down Override
This feature may be available to prevent the system from operating at low outdoor temperatures. If this feature is enabled, normal operation will stop when the collector temperature falls below 50°F. The solar pump relay will then be turned off. Normal control operation will not resume until the collector (T1) temperature returns to 70°F or above.

3. Sensors

Modern solar controllers use Resistance Temperature Devices (RTD) or Industrial 400°F (204°C) rated 10K IMC thermistors that have +/- 1°F accuracy. When installed, they will not exceed one degree of additional error for cable distances up to 1,000 feet of 18ga; 700 feet of 20ga, or 500 feet of 22ga.

Please see the following page for a schematic diagram.


Domestic Solar Hot Water System
Pressurized Glycol
Solar Collector Array
Manual Vent
1
Plumbing Contractor
Solar Contractor
CW
HW 110
HW 140
Mixing Valve
NO
NC
SDHW Controller
PS
Check Valve
Temperature & Pressure Relief
Water Heater
3
Solar Tank
Pressure Relief Only
To Drain or Roof Gutter
2
Solar Pump
Heat Exchanger
Expansion Tank

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