

# Montana Daylight Design Manual



Integrated Design Lab, Bozeman  
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The Integrated Design Lab - Bozeman is funded by the Northwest Energy Efficiency Alliance. Our services include energy and lighting analysis for Montana architects and engineers who wish to become more aware of the environmental impacts of energy consumption.

As a member of the BetterBricks Lab Network, Montana State University's Integrated Design Lab- Bozeman is your Montana contact for energy and daylighting information, education and tools for assessing integrated design decisions, including daylighting and efficient electric lighting techniques.

We are available for consulting and training workshops.

Visit us on the web at [www.idlbozeman.com](http://www.idlbozeman.com)



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# OVERVIEW

The Integrated Design Lab—Bozeman has created this daylighting manual to assist designers throughout the design process. Daylighting design depends on the climate where the building is located. Montana's climate brings about unique challenges which affect the daylighting feasibility and implementation. This manual is created to provide the building design team techniques and tools to achieve high performance daylighting in commercial buildings in Montana.

The second portion of this guide describes how to effectively daylight a space in Montana through proper building orientation, well-designed openings and shading systems, and appropriate glazing. While we will be looking at an example located in Bozeman, Montana, this guide provides the required information to perform the daylighting analysis for many other Montana cities as well. This guide will take you step-by-step through the daylighting design process, showing you how to size and select your glazing and shading systems, while also accounting for your location in Montana.

While many of the specifications here relate directly to Montana's climate, the general information presented here would be useful to anyone designing for energy efficient daylighting, regardless of location. If you are in the southern hemisphere, please remember that instructions regarding the north and south façade will be reversed (in other words, in the southern hemisphere, treat your northern façade the way the southern façade is described in this guide; in the southern hemisphere your southern façade will behave like the northern façade described in this guide.)

This manual is broken down into five parts as outlined below and as shown on the colored margin tabs.

## FIVE PARTS

### 1. Why Daylight?

Addresses the benefits of daylight, including energy efficient benefits and health benefits. Each building typology has unique benefits, advantages, and disadvantages when considering daylight design. Specific building typologies are looked at throughout the first part; these include offices, schools, retail, and health care.

### 2. How to Daylight

The second part of this manual gives an introduction to daylighting design, approaches to take throughout the entire design process, and several different strategies. These different approaches and strategies depend heavily upon the climate or the site such as sky conditions, as well as the orientation of the windows. There are many variables throughout the building design and climate that change the way daylight enters and responds within the space. Three different types of lighting are explored throughout this part; side lighting, top lighting, and atria lighting.

### 3. Montana Daylight Design

Several specific approaches are described along with examples of each strategy. Throughout this section, the example is specific to Bozeman, Montana, but the concepts for the strategies can be applied in other climates.

### 4. Tools for Daylight

Several methods and approaches are available to the design team. The fourth part of this manual gives several techniques to achieve the correct amount of glazing, visible transmittance values, and calculation method to produce accurate results. Hand calculation methods and computer simulation methods are discussed.

### 5. Case Studies

Two successful day lit commercial buildings are discussed, addressing their energy efficient design strategies. These buildings are recognized as having a similar climate to that of Montana and achieving high levels of building performance.

## LEARNING OBJECTIVES

1. Why daylighting is the cornerstone of energy efficient design.
2. Provide techniques for meeting and verifying LEED daylight and view credits.
3. Demonstrate early design assistance tools for effective daylighting solutions.
4. Why is appropriate building orientation so important?
5. How do shading systems and efficient glazing work together to help daylight a building?
6. What are the benefits to using energy efficient glazing?
7. What do the acronyms and numbers all mean?
8. Present case studies that demonstrate the value of quality daylighting design.

## PART ONE—WHY DAYLIGHTING?

“In a world newly concerned about carbon emissions, global warming, and sustainable design, the planned use of natural light in non-residential buildings has become an important strategy to improve energy efficiency by minimizing lighting, heating, and cooling loads. The introduction of ...daylighting strategies and systems can considerably reduce a building’s electricity consumption and also significantly improve the quality of light in an indoor environment”

International Energy Agency Task 21

### ENERGY BENEFITS OF DAYLIGHT

Commercial buildings in the US consume approximately 32% of electricity. Of that total, 33% is used for electric lighting in the building. Electric lighting is a significant load that also affects cooling loads and electrical demand. The addition of daylight can significantly reduce this demand of electric lighting. Some cases, it can reduce it to zero, so that the building would only need electric lighting throughout the night and on darker days.

### DAYLIGHTING CAN PROVIDE A BETTERING LIGHTING ENVIRONMENT

In the article by Franta and Anstead, “Daylight...most closely matches the visual response that, through evolution, humans have come to compare with all other light,” it is shown that daylight provides a balanced spectrum of color. It is also shown that daylight provides the highest levels of light needed for biological functions.

### WE ARE AFFECTED BOTH PSYCHOLOGICALLY AND PHYSIOLOGICALLY BY DAYLIGHT

Daylight also affects the human body physically. Light is a nutrient for metabolic processes and increases the metabolic rate. Natural views produce positive responses and is shown to reduce stress, decrease anxiety, and improve mood.

### LIGHT AFFECTS OUR CIRCADIAN CYCLES

The human clock relies upon light. Both light and dark are necessary to synchronize our internal 24 hour clock. The pineal gland secretion of melatonin affects sleep, modifies mood, and mental agility. Melatonin also is produced in the absence of light; high levels lead to drowsiness while low levels produce alertness. In the workplace or during the daytime, natural light is more effective at creating these natural phenomena's.

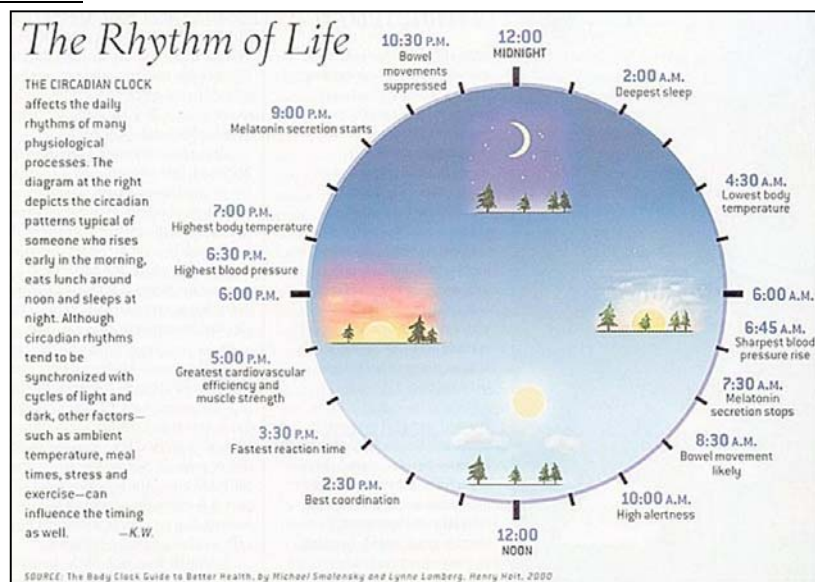


Image from The Body Clock Guide to Better Health, by Michael Smolensky and Lynne Lomberg, Henry Holt, 2000



## BENEFITS OF DAYLIGHT

### **Office**

With the addition of natural light in an office setting, benefits are seen in all sections of the business. The benefits for the employees include better health, reduced absenteeism, and increased productivity. Financial savings are seen with the addition of daylight as well. Daylighting is the preferred method by everyone in the building. In some European countries, workers cannot be further than 27 feet from a window. In general, a well day lit building may contribute to a more positive mood.

Most companies have found that the increased value of productivity outweighs the increased cost of technology. Many companies that have benefitted from reduced absenteeism of employees, also benefitted from a reduction in employee turnover (churn).

The health of the employees are improved overall. These benefits include decreased headaches, reduced SAD (Seasonal Affective Disorder), reduced stress and eyestrain when the workplace is properly day lit. Of workers polled, 96% preferred to work under natural lighting conditions. This was also seen by the amount of complaints within a workspace. Workers seated further away from windows complain more than those near windows. Even a central atrium that brings in natural light produces a positive attitude.

There are many success stories that can be seen and told. A few of those stories are highlighted in the following examples.

Lockheed Martin in Sunnyvale, CA increased productivity by 15% with the addition of daylight. They also benefitted from a 15% reduction in absenteeism of employees. They lastly found that a 2% increase in productivity was worth \$3 million saved per year.

Verifone company in Los Angeles increased productivity by more than 5% and had an absence reduction of 6.8 hours per person per year.

ING Bank reported a 15% reduction in absenteeism.

West Bend Mutual Insurance had a 16% increase in claims processing productivity when renovating their building. They also found that productivity gains were worth \$364,000 per year.

Reno, Nevada post office productivity increase by 6% with the addition of natural light into the building. Gains of over \$400,000 per year paid for the renovation in less than a year.

## Part One: Why Daylighting?

### Schools

Benefits from adding daylight areas into schools are seen in all sections, including administration, teachers, and student performance improvement. Financial benefits include reduced utility costs, dividends through lower energy costs and an enhanced learning environment. Some states, such as Connecticut have passed legislation to maximize natural light in schools to improve student performance. Student improvement is seen in attendance and health. Reduced fatigue factors are seen throughout all employees and students. Some school districts have also recorded savings due to reduced dental cavities of students.

"The positive effect of daylighting was distinct from all other attributes of windows." Hershong Mahone Group.

Success stories can be told throughout all of the US. A few of the stories are told below.

In North Carolina, at Durant Middle School, it was found that teachers feel better mentally and physically. Attendance rate is over 98% which is the best in their system. Faculty have the lowest health absences in their district. Student achievement scores were higher than peer schools.

Extensive study of student performance in second grade through fifth grade was conducted in Orange County, CA, Seattle, WA, and Fort Collins, CO. The results were as follows:

1. CA: 20% faster learning rate in math and 26% faster in reading.
2. WA: 9% higher math scores and 13% higher reading scores.
3. CO: 7% higher scores in reading and in math.



*Diffuse top lighting within University of Oregon Lillis Business School lecture halls create a better learning environment.*

### Retail

Benefits in the retail environment lead to increased sales and productivity. Enhanced store environments create more pleasant shopping and attract customers. Improved color rendering and light levels allow the customer to get a more accurate representation of the sale and leads to an increase in return customers. In the studied retail stores, customers were not aware of the daylighting feature. Customers also felt the stores were cleaner and more spacious and open. Elderly appreciated the brightness and light quality. Overall, customers responded with comments such as “nice feel” and “more comfortable.”

### Health Care

In the health care environment, daylight addition most prominently improves the health of the patients. Improved physiological and psychological state of both patients and staff were found. Reduced mental and physical strain of patients, doctors, and nurses were also indicated. The recovery time of patients were faster in day lit recovery areas.

It has been discovered that daylight and views have a psychotherapeutic quality. Light can improve health and help cure some ailments. Over 100 years ago, sunlight was found to cure rickets. Seasonally Affective Disorder (SAD) or Winter Depression has been known to be treated with light also. Sunlight on the skin aids in the production of Vitamin D.



*Diffuse top lighting throughout Walmart in Aurora, Colorado help reduce the need for electric lighting.*

## Part One: Why Daylighting?

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### BENEFITS OF DAYLIGHT THROUGH WINDOWS

Conclusions found through a study done by Boyce et al, Lighting Research Center are as follows:

- 1 Daylight is just another source of electromagnetic radiation.
- 2 Daylight is a stimulant to the human visual system and the circadian system.
- 3 Daylight and view are much desired.
- 4 Daylight has a high probability of maximizing visual performance.
- 5 Daylight can cause visual discomfort: glare, distraction, veiling reflections, and shadows.
- 6 If people have discomfort they will reduce or eliminate daylight.
- 7 Daylight can provide bright light during the day for entraining the circadian system.
- 8 There is no simple recipe of how or if lighting will produce a positive mood. Depends on individual preference and expectations.
- 9 Weak understanding of how mood influences productivity and what role daylighting plays.
- 10 Daylight has both positive and negative health effects. Outdoors daylight may cause tissue damage but also generate Vitamin D. View may reduce stress.
- 11 Window walls cost more to build and maintain but may be offset by reduced operating costs. Windows have a positive effect on rental values.
- 12 Daylighting a windowless retail space can have a positive effect on sales.

Suggested further research topics:

1. Reducing discomfort from windows to minimize behaviors that reduce daylight.
2. Quantify the financial return on windows: what are people willing to pay?
3. Explore circadian system impacts on task performance.
4. Test the Biophilia Hypothesis: Do we have an innate need to be in contact with nature?



*Idaho Central Credit Union maximized north and south exposure, creating an energy efficient and well day lit building.*

## DAYLIGHT AND HEALTH RESEARCH

### “LIGHT AND HEALTH: LIGHTS IMPACT ON HEALTH IS PLAYING A CENTRAL ROLE IN DESIGN.” DONOFF

#### Recent research findings:

1980—Light could suppress production of melatonin

2001—Different photoreceptors in the eye that govern and distinguish day vision and night vision

2002—Photosensitive ganglion cells in front of the retina work independently of visual system and have a significant impact on our endocrine system.

#### Areas of Investigation

Circadian cycle, sleep disorders, Seasonal Affective Disorder (SAD), eye strain, visual performance, tissue damage (eyes and skin—UV), Vitamin D deficiency, correlation between light and specific cancers.

#### Circadian Cycle Investigations

Electric lighting allows us to ignore day/night cycle but at what cost?

Long term problems of shift works.

What color and type of light is more effective in coordinating our circadian rhythms?

Design impacts for health care to provide more natural light into patient areas.

### “DAYLIGHT EXPOSURE AND OTHER PREDICTORS OF BURNOUT AMONG NURSES IN A UNIVERSITY HOSPITAL” ALIMOGLU AND DONMEZ

#### Findings:

1. Daylight exposure of at least three hours per day causes less stress and higher satisfaction at work.
2. Daylight exposure may be effective on job burnout.
3. Daylight exposure has curative effects on mood disorders like depression.
4. Lack of windows in the workplace has reported to be a contributing factor to work stress.

### “A TURNING POINT FOR SEASONAL AFFECTIVE DISORDER AND LIGHT THERAPY RESEARCH?” AVERY

#### Findings:

1. Bright light is superior to the placebo conditions in treating SAD.
2. Morning bright light therapy is effective in treating SAD.

### “SUNNY HOSPITAL ROOMS EXPEDITE RECOVERY FROM SEVERE AND REFRACTORY DEPRESSIONS” BEAUCHEMIN

#### Findings:

1. Bright light therapy is effective in treating SAD.
2. Average stay as a psychiatric inpatient: 19.5 days for a dull room, 16.9 days for a sunny room.

## Part One: Why Daylighting?

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### “DYING IN THE DARK: SUNSHINE, GENDER, AND OUTCOMES IN MYOCARDIAL INFARCTION” BEAUCHEMIN

#### Findings:

1. Patients stayed shorter times in sunny rooms: 2.3 days versus 3.3 days, most significant for women.
2. Mortality rate higher in dull rooms: 39 deaths/335 for a dull room, 21 deaths/293 for a sunny room.

### “DAYLIGHT, ARTIFICIAL LIGHT, AND PEOPLE IN AN OFFICE ENVIRONMENT, OVERVIEW OF VISUAL AND BIOLOGICAL RESPONSES”

BEGEMANN ET AL

#### Findings:

1. People prefer to follow a daylight cycle instead of a constant light level.
2. Preferred lighting levels are significantly higher than today's indoor lighting standards and correspond to levels where biological stimulation can occur.
3. Medical research has shown that a prolonged lack of “light vitamin” can cause health problems ranging from minor sleep and performance difficulties to major depressions.
4. Creative healthy luminous indoor environments may turn out to be a simple form of preventative medicine that provides a new challenge for the lighting community.

### “A SEASONAL PATTERN OF HOSPITAL MEDICATION ERRORS IN ALASKA”

BOOKER AND ROSEMAN

#### Findings:

1. 58% of all medication errors occurred during the first quarter of the year.
2. Medication errors were 1.95 times more likely in December than in September.

### “LIGHT DURING DARKNESS AND CANCER: RELATIONSHIPS IN CIRCADIAN PHOTORECEPTION AND TUMOR BIOLOGY”

JASSER, BLASK, AND BRAINARD

#### Findings:

1. Melatonin is a circadian marker.
2. Is higher risk of breast cancer in industrialized countries partly due to increased exposure to light at night?
3. Melatonin implicated as a potential mediator of this effect but it is not fully understood.

### “VIEW THROUGH A WINDOW MAY INFLUENCE RECOVERY FROM SURGERY”

ULRICH

#### Findings:

Patients with a view of nature versus a brick wall had:

1. Shorter postoperative hospital stays.
2. Fewer negative evaluative comments from nurses.
3. Took fewer moderate and strong analgesic doses.
4. Slighting lower scores for minor postoperative complications.



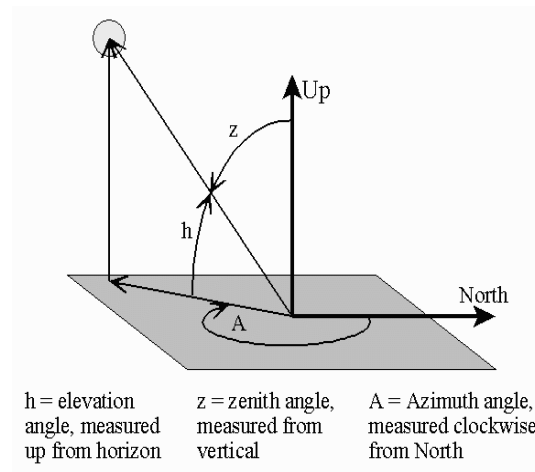
## PART TWO—HOW TO DAYLIGHT

**“I use light abundantly, as you may have suspected; light for me is the fundamental basis of architecture. I compose with light.”**

Le Corbusier

### THE BASICS OF DAYLIGHTING

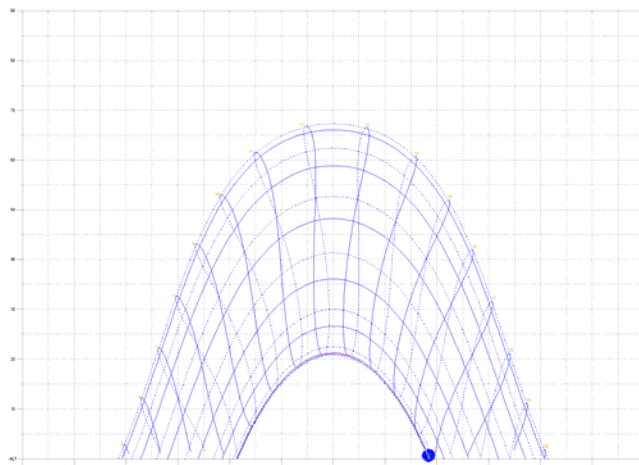
Daylighting design deals with the movement of the sun across the sky throughout the day and year. We define the location of the sun at a particular time and date by its altitude and azimuth angles. The altitude angle ( $h$ ) describes the height of the sun; it is defined as the angle between a line connecting the sun and a point on the ground and the ground plane. The azimuth angle ( $A$ ) describes the relationship of the sun to one of the cardinal directions (usually south, but sometimes north) and is the measured angle in plan between the sun and due south (or another specified direction). The diagram below illustrates these angles.



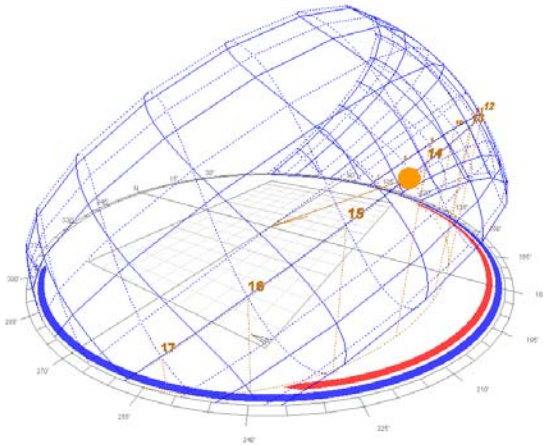
*Solar Angles*

Image from: <http://www.solsticeamateur.com/SolarGeneral.htm>

These altitude and azimuth angles for a specific latitude are often represented for an entire year in a sun angle chart such as this:



While these charts can be useful in determining the location at a specific time of year, it is rather challenging to intuit exactly what the sun is doing at a particular site throughout the year. Since daylighting is important year-round, it is wise to first have a sense of the movement of the sun throughout the year. Programs such as Autodesk Ecotect Analysis 2011 and Revit Architecture 2011 provide simple computer generations such as this “sun bubble.”



This type of 3D model helps you determine the range of daylight that the site will be exposed to throughout the year. This information begins to speak to the four façades and how each façade requires a different strategy of designing for daylight.

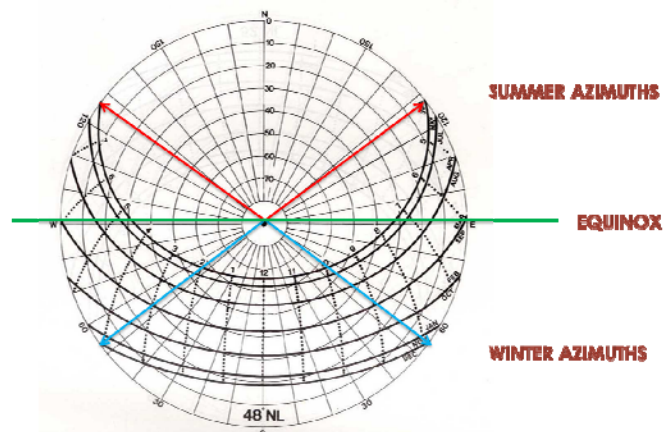
In the Northern Hemisphere, opening the south side of the building up to the sun is often best, as it is the easiest to control on this side of the building. The east and west facades pose difficult shading challenges that will be discussed later. The northern façade often requires no shading and provides an excellent source of

even daylight (reflected or diffused into the space), however, glazing must be minimized because you will not have the solar heat gain compensation, which is especially welcome in the winter in Montana. Which brings up another point. Deciding how much glazing you want becomes another issue, too much and you will have excessive glare, too little and you must use electric lighting. You can design for a good balance by investigating the amount of daylight you want to have in the room. To do this you must first understand a little about footcandles.

### GENERAL DAYLIGHTING DESIGN STEPS

Once this is known, you can move forward in daylighting design. The following list outlines a basic process that you will typically go through when designing for daylighting:

1. Determine the latitude and longitude of the site and based on this information, gather information about the sun at this location.
2. Begin to take into account that each façade is different.
3. Decide how much glazing you actually want. Too much or too little will both cause problems for daylighting performance.
4. Select shading systems based on the sun; these will be different for each façade.
5. Specify glazing with the appropriate properties; this may also be different for each façade.



*Solar Angle Graph*



HOW DAYLIGHTING IS MEASURED

Light is typically measured in footcandles. A footcandle unit (fc) can be thought of as the amount of light that actually falls on a given surface. On an overcast day, exterior surfaces can measure on average around 10,000 fc. Depending on the application, the interior target range of footcandles within a building is approximately 20 to 100 fc. The latest version of LEED (v3) now has a cap to the amount of footcandles that may enter a space. In order to receive the daylighting credits, you must make sure that there is not only enough daylight, but also not too much. With the use of high-performance glazing and sun shading devices, the target range (25-500 fc on Sept. 21 at 9am and 3pm) can be met with a reasonable amount of glazing distributed on all orientations.

The images below are graphic representations of the daylight distribution within a small 2,000 square-foot office located in Bozeman, Montana. Footcandle charts produced by AGI-32, a lighting analysis program, can help determine if the target illumination of 50fc to 100fc has been achieved. This is done by creating a 3 ft. x 3 ft. grid of measurement points on a work plane set at 2.5 ft. (30 in) above the floor level. The grid points indicate how many footcandles are sensed at those particular points. These kinds of analyses are typically done by lighting professionals or labs such as IDL-Bozeman, and are a good tool for an in-depth study of the interior daylighting and electric lighting of a particular project.

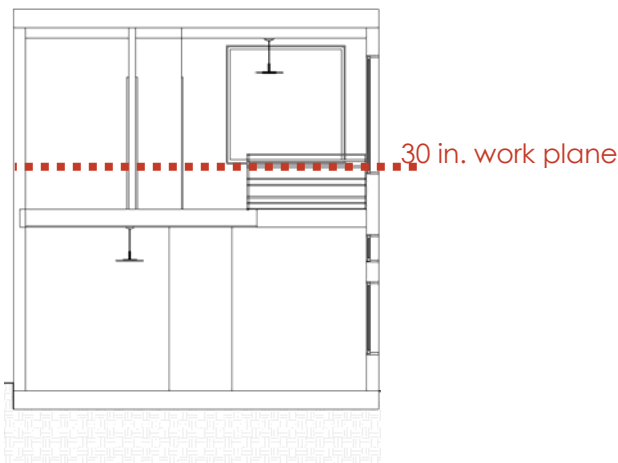


Image created in Revit 2008

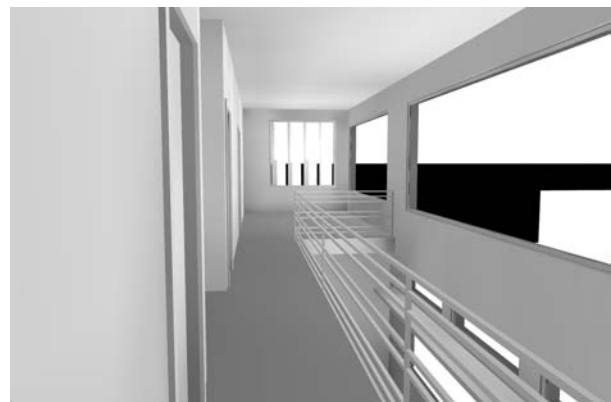
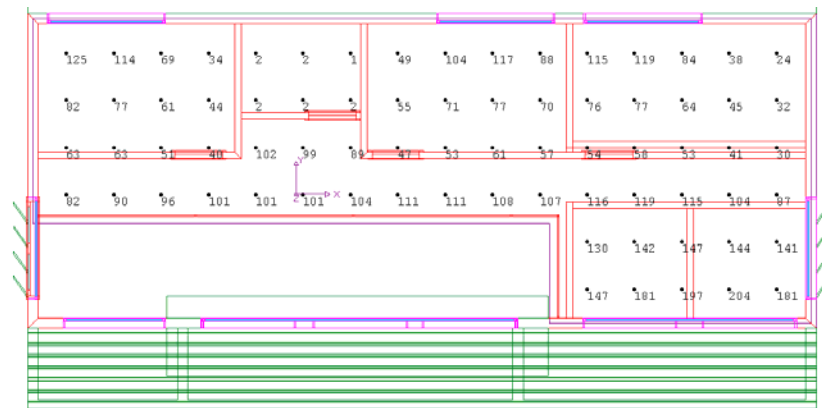


Image created in AGI-32 (47 average footcandles)



(Chart produced by AGI-32)

Second Floor Footcandle Chart

## Part Two: How To Daylight

### SOURCES OF DAYLIGHT

**Daylight**—Diffuse light from the sky dome, modeled as an area light source

**Sunlight**—Direct beam sunlight, modeled as a point light source

**Reflected light**—Man-made or natural surfaces that reflect daylight

### SKY CONDITIONS

#### Overcast sky

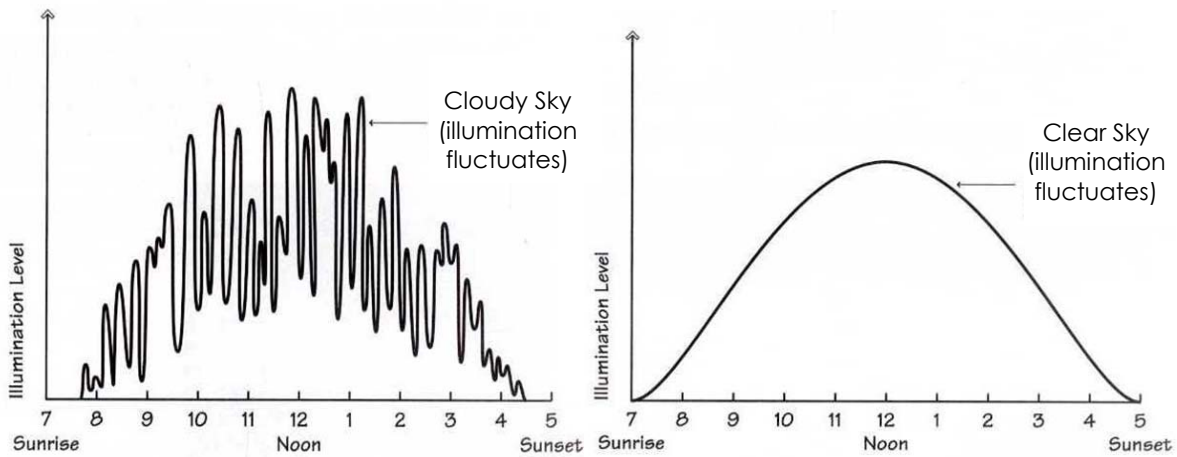
1. Sun is obscured
2. Diffuse daylight
3. Three times brighter at zenith than horizon
4. Sky is brightness element in scene
5. Illumination can exceed 2500 fc.

#### Partly Cloudy Sky

1. Thin clouds are extremely bright
2. Fluctuating intensity
3. Changing distribution
4. Variable color temperature
5. Difficult to simulate or model

#### Clear Sky

1. Sun is the bright source
2. Point source causing distinct shadows
3. Illumination can exceed 10,000 fc
4. Intensity depends on: air mass thickness, latitude, solar altitude, and atmosphere.



*Solar Illuminance Charts for Cloudy Sky and Clear Sky*

Images from [Daylighting](#), by R.G. Hopkins et al. and [Applied Solar Energy](#) by A. B. Meinel and M. P. Meinel

MONTANA LIGHT

**General Conditions:** In general: high altitude, low atmospheric turbidity, low humidity, low smog or haze, intense sunlight, deep blue skies. The northwest corner has more overcast sky conditions.

See appendix for detailed cities of Montana and their specific sky conditions.

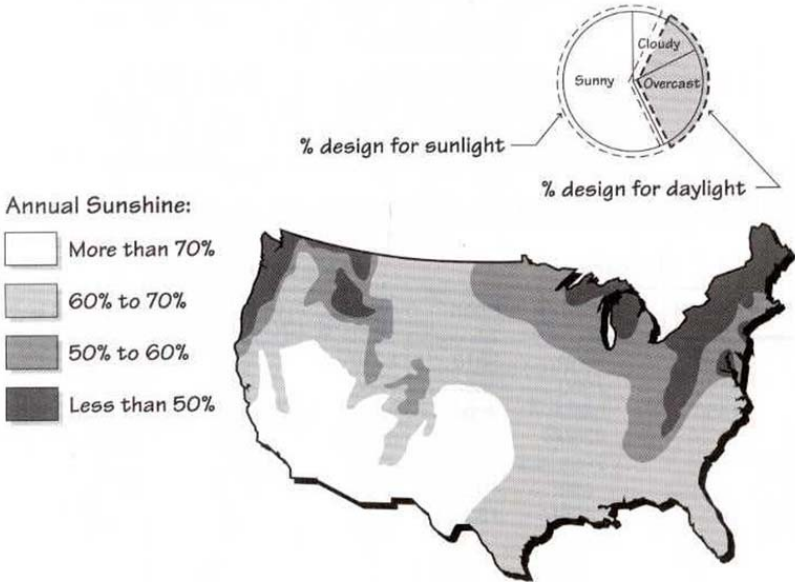
DETERMINING YOUR DOMINATE SKY CONDITION

**Sunny or sunny with some Cloudy**

Optimize for SUNLIGHT provide glare control, point source lighting

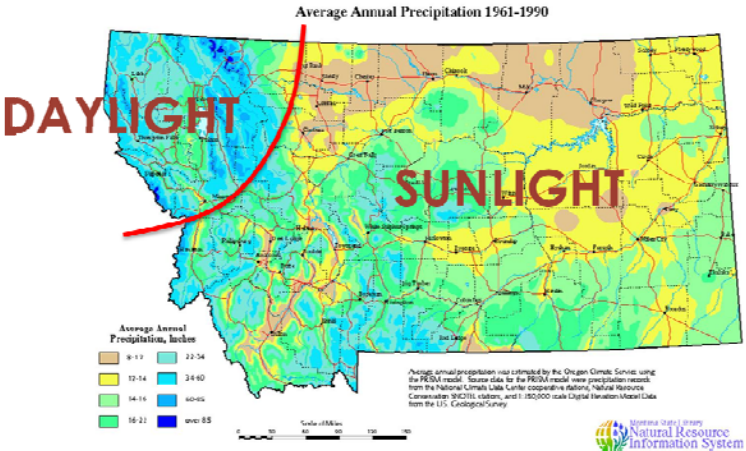
**Overcast or overcast with cloudy**

Optimize for DAYLIGHT, area source lighting.



*United States Annual Sunshine Chart*

Image from Sun Lighting as Form Giver for Architecture, by W. M. C. Lam



*Montana Precipitation Data*

Image from Montana State Library Natural Resource Information System

How to Daylight

### SUNLIGHT

#### **Approach**

The best approach is to use sunlight indirectly. This helps reduce light intensity and mediates the potential for glare or extreme heat gain. Apply proper amount of sunlight, using sunlight efficiently, and redirect the light to provide balanced illumination.

#### **Strategies**

Sun lighting done well is energy efficient, while also aesthetically pleasing. Sun lighting done poorly experiences excessive heat loss and gain, poor light distribution, and can be extremely glaring.

General design goals are to provide appropriate illumination and provide visual delight.

1. Shade—Prevent glare and heat gain.
  - North/South openings: illuminate horizontal surfaces
  - East/West openings: illuminate vertical surfaces
2. Redirect—Direct the light where needed, create proper distribution. It is best to spread light over large area for balanced brightness. This also reduces the contrast between windows and surrounding surfaces.
3. Control—Provide the right amount of light at the right time. Do not over light the space. Over lighting the space causes too high of light levels and is detrimental to health effects and stress levels.
4. Efficiency—Shape interior to use the light, using high reflectance surfaces. Also design to reduce the total sun light amount needed.
5. Integrate—Coordinate with the architecture to provide for views or other essential characteristics. Integration with the architecture and other systems can be the key to making the space pleasant and energy efficient.

### DAYLIGHT

#### **Approach**

The approach to use with daylight design is to remember that the sky is the light source.

#### **Strategies**

1. Maximize sky view—Maximize solid angle of sky seen from task
  - Side lighting depth = 2.5 times window head height
2. Shade for glare—Shade to prevent glare, direct view of sky can be glaring.
3. Do not block daylight—For daylighting do not use light shelves or overhangs that block task view of the sky. These elements benefit for skylight design with direct sunlight hitting the surface.
4. Locate high openings—Higher opening means deeper daylight penetration.
5. Shape space—Use high reflectance finishes and provide high ceilings at windows. This allows for the light to diffuse into the space and create a pleasant space.

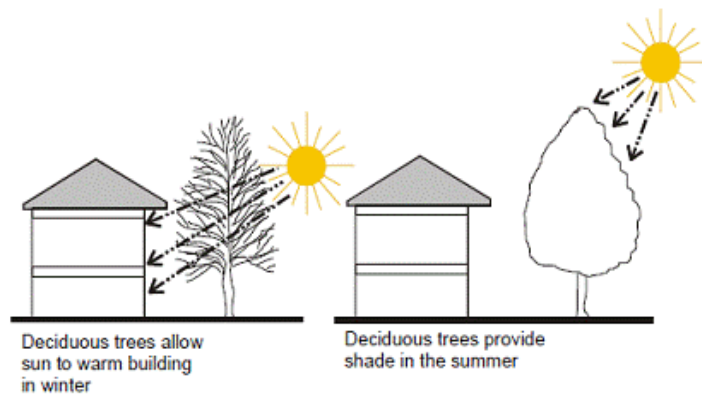
### PROGRAMMING FOR DAYLIGHT

The preliminary steps are often the most important when integrating daylight design into the building. For each space ask the following questions:

1. **How important is daylight?** If daylight is important to the space, consider putting this space against an exterior wall that has daylight potential (preferably north or south exterior wall location) or on the top most floor for top lighting potential.
2. **How important is view?** If view is important for the space, consider putting this space on an exterior wall depending on the best view out.
3. **When is the space occupied?** If the space is only occupied during the afternoon hours, western orientation is not beneficial, while eastern would be better suited.
4. **How important is direct sun and glare control?** If the task that is done within the space is sensitive to direct sun and glare control, the best orientation would be on the north. A northern orientation allows it to receive no direct sun or glare.
5. **What is the appropriate solar orientation?** Within this question, consider any topography and building shading to orient the tasks the best.
6. **What is the best strategy for providing daylight?** After deciding the basic orientations for the spaces and glazing, refer to this guide to aid in discovering the best strategy for providing the best daylight for each space.

### PLANNING FOR SOLAR ACCESS

1. **Topography**—Land forms and vegetation can aid in providing shading in the summer months while allowing the sun to penetrate in the winter months.
2. **Building Shading**—Obstruction and reflection from surrounding buildings can cause direct glare even on the north elevation, possibly leading to discomfort and heat gain for the occupants.
3. **Solar envelopes**—Zoning to preserve solar access with setbacks from the street and surrounding building.



*Effective Use of Vegetation for Shading*

Image from Daylighting Guide for Canadian Commercial Buildings, Public Works and Government

## Part Two: How To Daylight

### BUILDING ORIENTATION

**Long axis North-South**—This building orientation receives a large amount of morning and afternoon exposure. It also receives more light and solar in summer, making it difficult to shade direct sunlight. Top lighting is the best strategy for this orientation.

**Long axis East-West**—This building orientation receives greater exposure to south sunlight. Throughout winter, it has greater solar on south, while summer has greater solar on roof. Top lighting and side lighting is best suited for this orientation. South façade is easily shaded to protect and utilize the daylight potential.

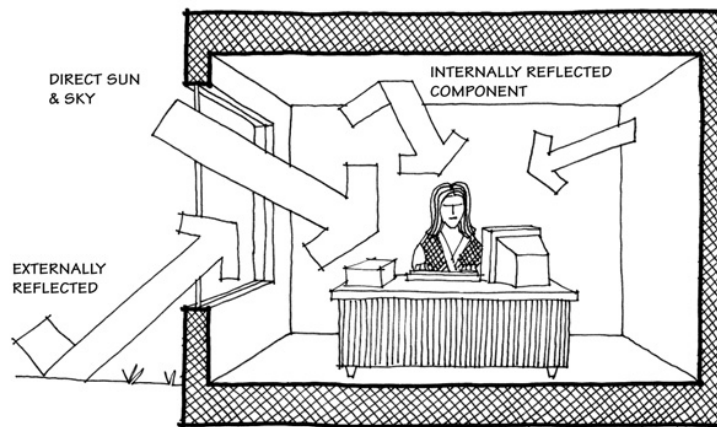
### BUILDING SHAPE

In general, narrow forms are the best to maximize daylight zones, due to the close proximity to the exterior facades. Deep floor plates are difficult to daylight, except for the top floor.

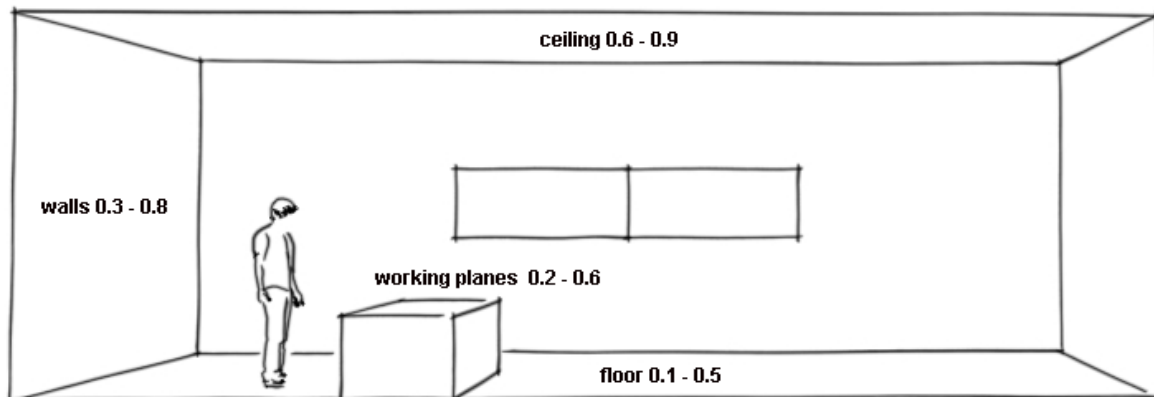
### ROOM VARIABLES

**Room Proportions**—Higher ceiling heights allow for more even distribution of top lighting and side lighting, but often limited by other concerns.

**Room Reflectance**—Ceiling reflectance values are the most important light reflecting surface. In small rooms, side walls become more important.



*Sources of Daylight Contribution*



*Typical Interior Reflectance Values*

Image from Daylighting Guide for Fort Carson, Directorate of Public Works



### Forms for Admitting Daylight

There are three distinct ways of admitting daylight into a space: side, top, and atria lighting.

### SIDE LIGHTING

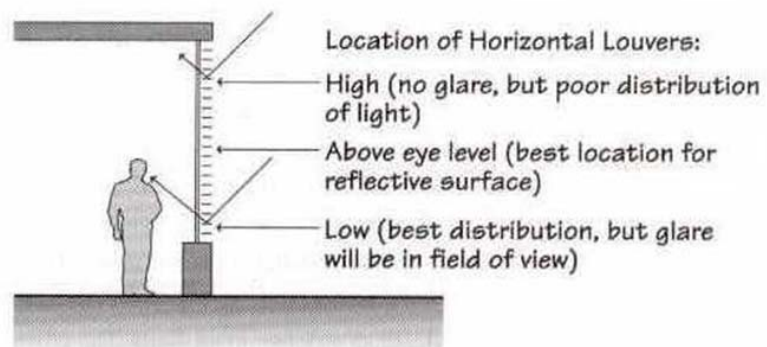
#### Room Reflectance

The ceiling is the most important light reflecting surface. A higher reflectance value on the ceiling allows more light to be reflected towards the back of the room, creating a brighter appearance overall. The reflected surface should be unobstructed and “seen” by the tasks. The reflectance should be as high as possible but not highly articulated. Too high of a reflectance can cause harsh reflectance, creating unwanted glare for the occupants.

#### Exterior Windows

In a vertical section:

1. **Upper section:** Best for overcast conditions. High sun and glare potential, need to properly baffle to protect against the high sun and glare potential.
2. **Middle Section:** Best for view orientation. Avoid reflected glare problems by shading devices, depending on the orientation of the window.
3. **Lower Section:** Optimal for reflected sunlight, but can be a source of reflected glare.



*Vertical building section showing best placement of glazing and shading products.*

Image from [Architectural Lighting](#), by M. David Egan and Victor Olgyay

#### Windows near interior walls

The interior walls nearest the windows are the walls that receives and redistributes light, therefore should have a high reflectance value. A higher reflectance will help minimize shadows and reduce glare and contrast of the window (bright surface) and wall (darker surface). This is a good option for low angle (horizontal) sun light penetration.

#### Horizontal Shading Devices

Shading design for horizontal shading devices are based on the solar altitude angles. These devices are most effective on southern elevation. They have good seasonal sunlight control.

#### Vertical Shading Devices

For vertical shading device design, it is based on solar azimuth angles. The effectiveness changes diurnally. These shading devices provide low angle sun control, suited for east and west elevations. Due to the vertical nature of the shading devices, they might block views out of the windows. To mitigate blocked views and to have continuous sun control, adjustable shading devices are available.

#### Eggcrate Shading Devices

Eggcrate shading devices combine horizontal and vertical shading. These are best for orientations that receive both southern and eastern/western sun light.

## Part Two: How To Daylight

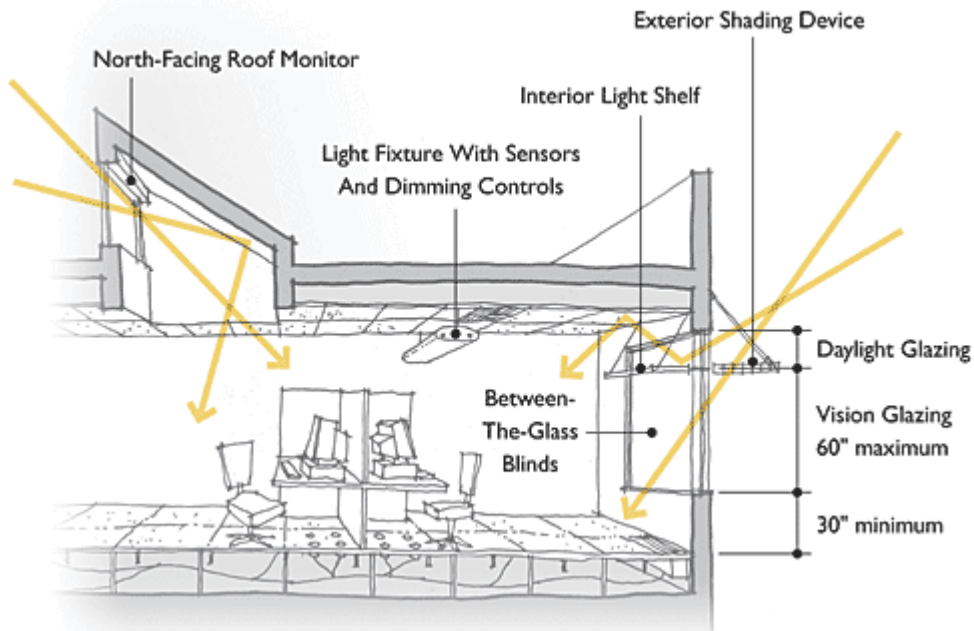
### GLARE AND THERMAL CONTROL STRATEGIES

Listed from Exterior to Interior:

1. Automated exterior shading system
2. Fixed exterior shading system
3. Exterior fabric awning
4. High performance glazing
5. Operable window
6. Automatic interior shading system—Double skin facade
7. Manual interior shading system

### HVAC COOLING LOAD REDUCTION

For maximum benefit to the HVAC load, provide shading outside the building. This prevents the sunlight and heat gain from coming into the building.



*Many design strategies can be used to maximize*

Image from LEED-NC Reference Guide. © 2005 U.S. Green Building Council

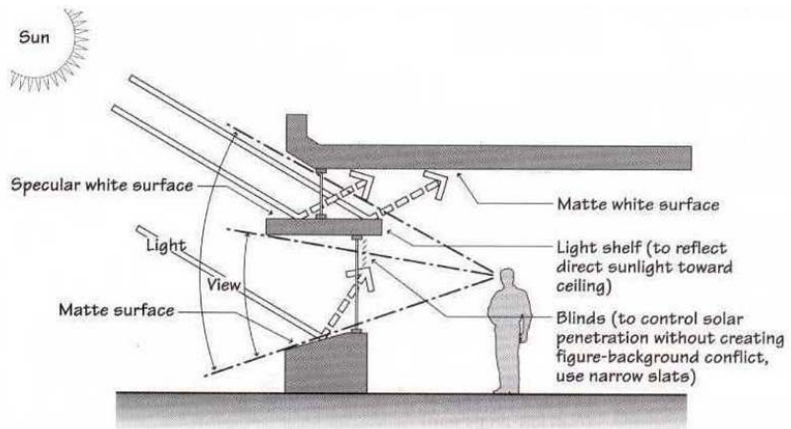


**SUNLIGHT REDIRECTING**

Redirecting devices apply to direct sunlight conditions. They are not appropriate for overcast conditions as they block the view of the sky. The two types are light shelves and sun catchers.

**Light Shelves**

Light shelves are a type of horizontal shading and redirecting device. They are most effect on the southern elevation. Due to their nature, they reduce illumination near the window while pushing lighting deeper into the space. The depth is determined by shading needs and geometry of the space and window. Typically, they are located at a height of 7 feet above the finished floor. Above the light shelf is used of daylight of the space, while the lower portion of the window (below the light shelf) is used for views. Many shelves are perforated metal. Going to a level of a metal grate is not beneficial as a light shelf, as it is more like a shading device.

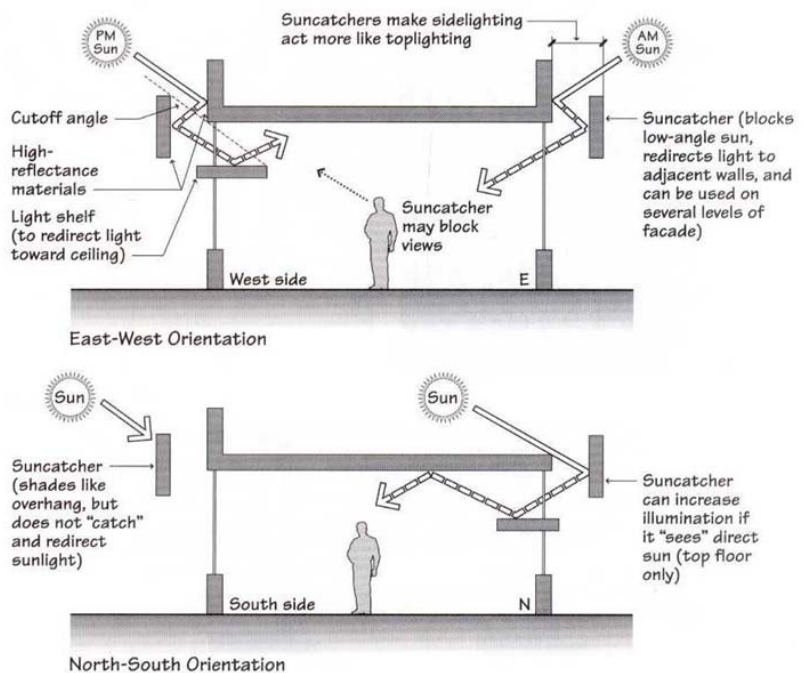


*Vertical building section showing reflected light off light shelf while maintaining view window at lower heights.*

Image from *Architectural Lighting*, by M. David Egan and Victor Olgay

**Sun Catchers**

Sun catchers are vertical sun light redirecting device parallel to the façade. The best utilization of these devices are for low angle sun light on the east and west elevation. Many be effective on the top floor of the northern elevation.



*Vertical building sections showing reflected light off sun catchers on different building orientations.*

Image from *Architectural Lighting*, by M. David Egan and Victor Olgay

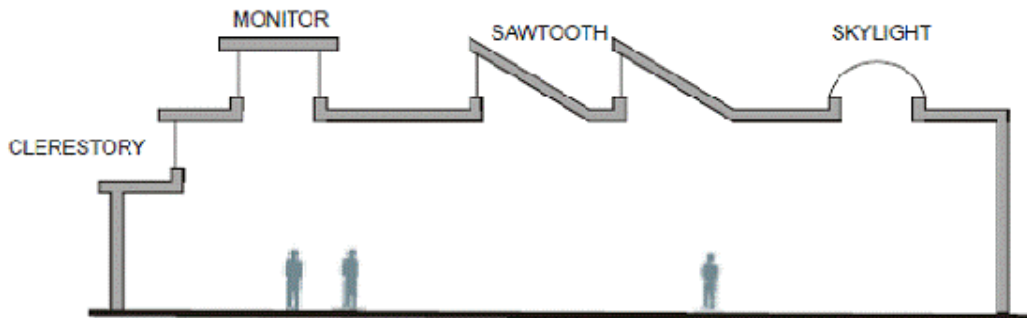
## Part Two: How To Daylight

### TOP LIGHTING

Top lighting has had a long history in Architecture. It provides a view of sunlit surfaces. Top lighting provides more light per unit area of opening than side lighting and has less glare potential if properly screened. The orientation of the top lighting devices can be set independently of the building.

#### Design Options

1. Clerestory
2. Monitor
3. Saw tooth
4. Skylight



*Different Top Lighting Design Options*

Image from Daylighting Guide for Canadian Commercial Buildings, Public Works and Government

#### Shape

The shape, reflectance, and proportions of the top lighting devices are critical. Higher ceilings provide better light distribution. Too high of a ceiling will not provide the most light to the task work plane, but will still make the room appear brighter overall. Sunlight should be used indirectly. Use walls or deep wells for light receiving surfaces. Deep splayed light wells improve light distribution, reduce contrast, and increase apparent size of source.

#### Tilt

The tilt of the top lighting device should match seasonal lighting needs. Horizontal skylights maximize light and heat at high solar altitude angles, making them the most beneficial in overcast sky conditions. Clerestories work best for low sun angles and sunlight (not for overcast sky conditions). Clerestories work best facing South with clear sky conditions.

#### Bearing

Clerestories and monitors act as windows and are highly dependent on bearing or azimuth orientation.

### ATRIA LIGHTING

Atria lighting combines top lighting and side lighting characteristics. Usually atria lighting is done in a central space, such as an atria, courtyard, light well, light court. This method of lighting allows multiple levels to be illuminated and creates a strong architectural feature. These devices may be thermally isolated or connected to adjacent spaces.

#### **Types**

1. Atria as “holes” to create thinner floor plates
2. Atria as “winter garden” for tempered space

#### **Shape**

1. Atrium—Visual relief and interest of an outdoor space.
2. Litrium—Optimized to provide natural light to adjacent spaces, usually wider at top floors.

#### **Openings**

1. Horizontal Skylight—This type is good for overcast skies. With overcast skies, the skylight wouldn't receive excessive summer heat gain, like it would with clear sky conditions. Another option is to have a movable roof.
2. Slanted or Clerestory—This option balances lighting with thermal gains in a temperate climate.
3. Atria—This provides a second filter which can modify the light.
4. Light at perimeter may be diffused or redirected with sun catchers or light shelves.

#### **Light Wells**

Light wells allow light to be brought deep into the interior. Large, wide wells will produce more illumination. Higher reflectance values or mirrored wall finishes within the light well will result in less light loss.

### INTEGRATION WITH ELECTRIC LIGHTING

#### **Strategies**

To integrate the daylight design with electric lighting, it is best to design the electric lighting level to balance what is provided by the outdoor illumination levels. Doing so will result in even illumination throughout the day. As outdoor illumination levels decrease, the electric lighting can compensate.

1. Side lighting—This includes wall washing, using direct illumination as the illumination source.
2. Top lighting—This allows direct lighting to reach the task work plane.

#### **Top Ten Common Control Failures**

1. Inappropriate or unexpected transitions.
2. Emergency Fixtures always ON.
3. Cultural resistance.
4. What the photocell sees is not representative of the space.
5. No specification of reference location for calibration.
6. No specified light levels.
7. Not commissioned or properly done.
8. Commissioning not in anyone's scope.
9. Insufficient relays or power loss in long runs.
10. Inappropriate zoning that does not relate to daylight patterns.

### DAYLIGHT CHECKLIST

1. Determine availability of natural light and the dominant sky condition.
2. Identify visual program needs.
3. Choose the appropriate strategy.
4. Use design strategy effectively.
5. Check and test design
6. Integrate with electric lighting system

## GLAZING TERMS

**Glass:** Only the glass portion of a window unit.

**Glazing:** The window or door assemblies that includes all parts of the window unit.

**Insulated Glass Unit (IGU):** The assembly of a minimum of two pieces of glass separated by a spacer. More layers of glass allow for greater U-values.

**U-Value:** The measurement of the conductive transfer of heat through a *single material*, measured in BTU/hr-sq.ft.-F°. Each aspect of the assembly has a U-Value that contributes to a combined U-Value (known as a U-Factor). **The U-Value should be 0.35 or less for Montana's climate.** A standard single-pane window has a U-Value of 1.13 BTU/hr. Lower numbers indicate better insulation values.

**U-Factor:** The measurement of the transfer of heat through an *assembly of materials*. Many manufactures interchange U-Value and U-Factor. Both U-Value and U-Factor refer to the quantity of heat transferred through materials.

**R-Value:** The resistance to heat flow. It can be calculated by taking the reciprocal of the U-Value. Higher numbers indicate better insulation. This term is not typically used to represent heat transfer through window units.

**Solar Heat Gain Coefficient (SHGC):** The fraction of solar radiation admitted through a window. An SHGC of 1.00 indicates that 100% of the solar heat striking the glazing will enter the space. The higher the value, the more solar heat will enter the space.

**Shading Coefficient (SC):** The number defining the solar control aspect of glazing. This value only refers to the glass in the assembly and has recently been replaced by SHGC.

**Visible Light Transmittance (VT):** The percentage of available visible daylight entering through a window or glazing system. Clear glazing has a VT of 90%; that means that 90% of the available visible light is entering the space.

**Visible Reflectance:** The value that indicates to what degree the glazing appears like a mirror from both inside and out. High reflectance equates to low VT and all the interior disadvantages that may be associated with that characteristic.

**Low-emittance coating (Low-E glass):** A coating on glazing that is comprised of microscopically thin, virtually invisible, metal or metallic oxide layers deposited on a window or skylight glazing surface primarily to reduce the U-factor. Low-E glass is a standard choice for climate zones like Montana.

## Part Two: How To Daylight

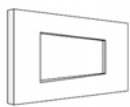
### UNDERSTANDING GLAZING PROPERTIES

Insulating units constructed of equal glass thicknesses and 1/2" (12.7mm) airspace

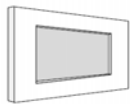
Product	Nominal Glass Thickness		Visible Light <sup>2</sup>			U-Factor <sup>5</sup>					Solar Heat Gain Coefficient <sup>7</sup>	Shading Coefficient <sup>8</sup>
			Transmittance <sup>3</sup> %	Reflectance <sup>4</sup> %		U.S. Summer		U.S. Winter		European <sup>6</sup>		
	in.	mm		Outside	Inside	Air	Argon	Air	Argon	Air		

Pilkington Uncoated Float Glass Outer Lite and Energy Advantage™ Low-E Glass Inner Lite (#3 Surface)

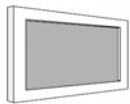
Optifloat Clear	3/32	2.5	76	18	17	0.33	0.28	0.34	0.29	1.9	1.6	0.73	0.84
	1/8	3	75	18	17	0.33	0.28	0.33	0.29	1.9	1.6	0.71	0.82
EverGreen High-Performance Tint	1/4	6	54	11	14	0.33	0.28	0.33	0.29	1.8	1.5	0.35	0.40



High VLT 88%



Mid VLT 53%



Low VLT 38%

#### VLT

The first step in choosing glazing is to pick a manufacturer. In this example, we will be using charts showing glass properties for Pilkington window products. Looking at the table above, focus on the Transmittance percentage (in yellow); the clear glazing has a visible light transmittance value of 76%, meaning that 24% of the daylight is not entering the space. Typically lower VLT glazing is best for glare-sensitive conditions with large window areas. However, you must take into consideration the average of overcast days to sunny days, as lower VLT glazing in cloudy climates may create 'gloomy' conditions, causing the electric lights to be used more frequently. Ultimately you want to base your decision on the size of your windows and the dominant sky condition.

#### U-Value / U-Factor

The U-factor and U-value are basically the same value. Many glazing manufacturers interchange these two terms. The difference is that the U-value is the insulating value of the glazing measured through the glass, whereas the u-factor is the insulating value of the whole glazing unit. Both U-value and U-factor are measured in BTU/hr-sq.ft.-F°. The chart above shows U-factors for U.S. Summer, U.S. Winter and European, and then again broken down by air filled and argon filled. Montana glazing should have a U.S. Winter U-value of 0.35 BTU/hr-sq.ft.-F° or less for all orientations in Montana. Depending on the project, choose either air- or argon-filled glazing. Argon has a lower conductance than air so the U-values for argon-filled are lower.

#### SHGC / SC

The Solar Heat Gain Coefficient represents the proportion of heat produced by the sun that will enter through the glass of a window unit. The higher the number, the more solar heat will enter the building. Look for low values when choosing glazing for the north, east, and west orientations in Montana, and choose a high number for the south orientation if passive heating strategies are to be incorporated into the design. The Shading Coefficient is basically the same as SHGC; SC represents the solar aspects of only the glass in an assembly. Many manufacturers will either show both or just SHGC. Either way you still want to choose a low value for all orientations except where solar gain is desirable.



## PART THREE—DAYLIGHTING DESIGN IN MONTANA

**“In our time, light has turned into a mere quantitative matter and the window has lost its significance as a mediator between two worlds, between enclosed and open, interiority and exteriority, private and public, shadow and light. Having lost its ontological meaning, the window has turned into a mere absence of wall.”**

Pallasmaa, J.

To design appropriately for daylighting, we must have a clear understanding of how the sun relates to different locations within a time zone. Although time is marked as being the same within one time zone, the way that the sun moves across that time zone — for instance, the time of sunrise and sunset, the point of “high noon,” etc. — change as one progresses from one side of the time zone to the other. A quick explanation of how the world is divided into time zones will make this clear.

Looking at the Arctic Circle, we can see that the earth can be divided into several different “pie wedges.” These pie wedges begin to describe what is meant by longitude — the lines that define the east-west location of a place. These lines are what are used to separate time zones. Since there are 360 degrees in a circle and the earth takes 24 hours (give or take) to complete one rotation, it has been assumed that this 360-degree circle can be divided into 24 hours. Dividing the 360 degrees evenly between 24 hours, gives 15 degrees for each hour. Therefore, the size of each time zone is approximately 15 degrees wide (give or take, depending also on political boundaries, etc.). The degrees of longitude (°) have also been divided into minutes (′) and seconds (″) to further help define the precise east-west location on the planet, relative to 0° longitude which has been placed at the Greenwich Meridian in England.



## Part Three: Daylighting Design

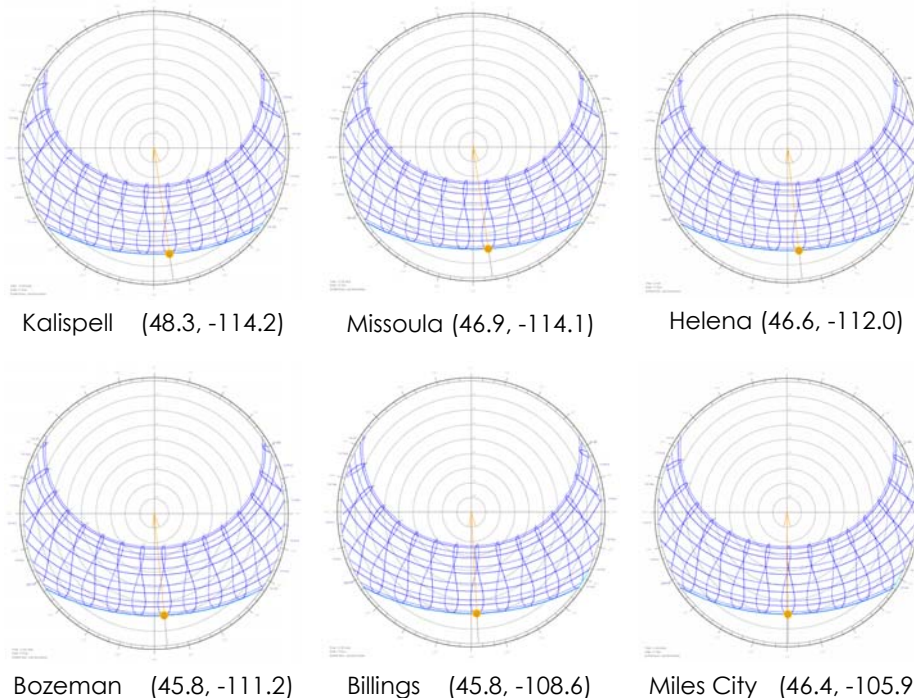
While this may sound like a clean mathematical solution to define east-west location, we know that the sun does not rise and set at the same exact time for all 15 degrees within one time zone. The sun is constantly in motion, so it makes sense that it would rise a little earlier on the eastern side of a time zone than on the western side. (Conversely, the sun sets a little earlier on the eastern side of the time zone and a little later on the western side. You have probably been more aware of this evening "twilight" in certain cities and the absence of it in others.) Understanding the degrees-minutes-seconds system of longitude, the changes in solar time throughout a time zone can be represented this way:

- 15° of longitude = 1 hour (a time zone)
- 1° of longitude = 4 minutes
- 1' (minute) of longitude = 4 seconds
- 1" (second) of longitude = 0.066(repeating) seconds

Armed with this knowledge, let's look at the state of Montana and how this information will affect designing for daylight through the state.

The state of Montana spans from 104° 2' W to 116° 3' W longitude. This means that the difference in true solar time from one side of the state to the other is about 48 minutes 4 seconds. That is a large difference in the actual time the sun rises and sets from one side of the state to the other!

What this means for designers in Montana is that the sun does not behave the same way in every city throughout the state. On the contrary, some cities will experience more sun in the morning, but as you move progressively west throughout the state, you will find that there is more and more afternoon sun because the sun is actually rising and setting later in the day (according to the time zone time). Below is a series of six solar angle charts for different cities in Montana with December 21st solar noon highlighted. Take note of how solar noon shifts between each city.





Once you have a clear idea of what the sun is doing at the site, you can design for daylighting by answering some simple questions:

- How big do my glazing openings need to be on each wall? (What is my window-wall ratio (WWR)?)
- Based on size and placement, what is the appropriate shading strategy for each façade?
- Considering the size of my openings and my shading strategies, what are the appropriate glazing properties?

The next several pages will show you how to answer these questions when designing for efficient daylighting in Montana.

### HOW TO SIZE GLAZING OPENINGS

When sizing windows, it is important to calculate the Window Wall Ratio or WWR. A quick way to do this is to divide the net glazing area by the gross exterior wall area. Net glazing is defined as the window area minus the mullions and framing (approximately equal to about 80% of the rough opening). Exterior wall area is measured from the bottom of the finished floor to the ceiling (not including parapets).

$$\frac{\text{Net Glazing Area}}{\text{Gross Exterior Wall Area}} = \text{WWR}$$

Note: WWR should be  $\leq 40\%$  on all orientations.

Another way to calculate the WWR is to take a known percentage of window area and multiply that by your exterior wall area. For example, if you know that you want 30% of the wall to be glazing, multiply 30% by your exterior wall area.

$$\text{Window \%} \times \text{Gross Exterior Wall Area} = \text{WWR}$$

Armed with this information, you can then begin to place openings throughout your facades. This will be important as we seek to answer the second question about shading.

## Part Three: Daylighting Design

### CHOOSING AN APPROPRIATE SHADING SYSTEM

The following describes how to design shading for specific building elevations.

External attached shading is the most common way to block direct sunlight at specific times of the day. Shading should not be an afterthought. It should be considered as component of the design. There are many ways to design a building to shade itself. For example, windows can be set deep into a deep wall section, balconies or arcades could provide shade, or elements of the skin can be extended to create a distinct façade.

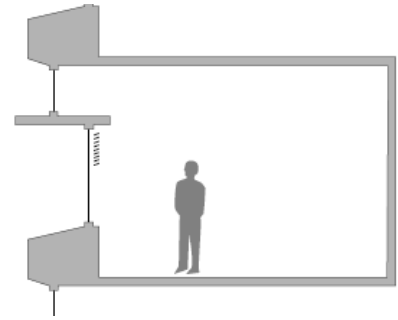


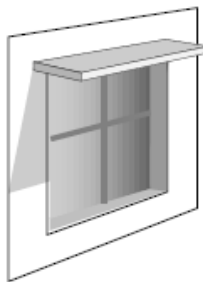
Image from [Tips for Daylighting with Windows](#), by Lawrence Berkeley Laboratory

### SHADING EXAMPLES

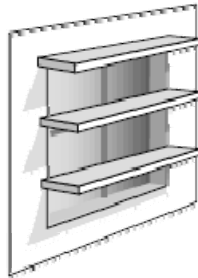
The images to the right show various types of exterior shading devices that are widely available. The main types include horizontal louvers and vertical fins. These exterior systems are typically more effective at blocking solar heat. Since they do not allow the heat from the sun to enter the building.

The next few pages show how to design exterior louvers and fins.

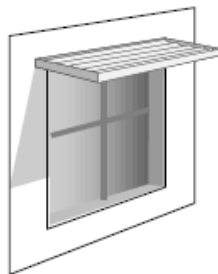
#### South Shading



*Typical Horizontal Louver*

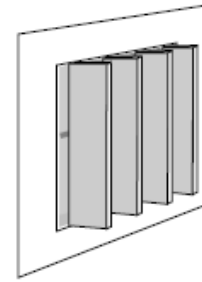


*Stacked Horizontal Louver*

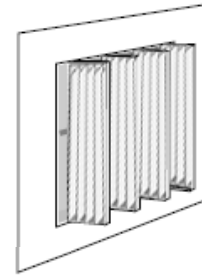


*Slatted Horizontal Louver*

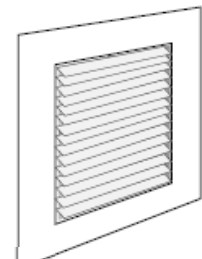
#### East / West Shading



*Typical Vertical Fins*



*Slatted Vertical Fins*



*Horizontal Blinds*

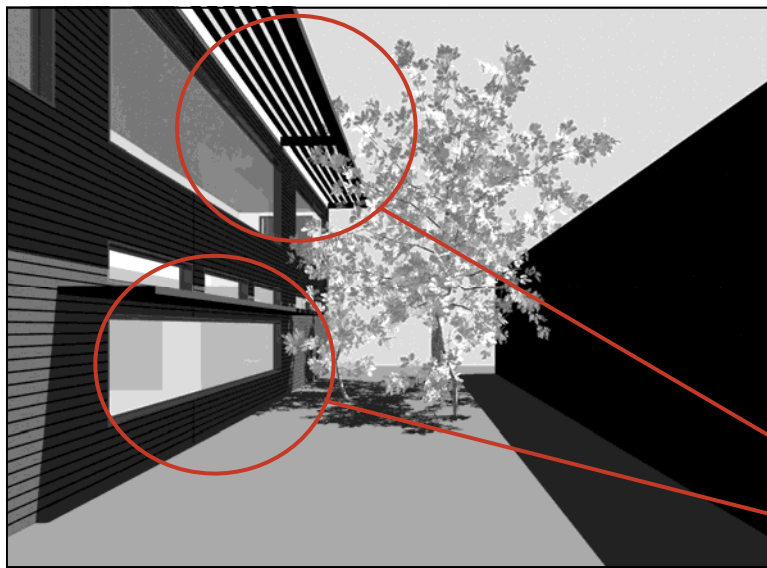
Images from [Tips for Daylighting with Windows](#), by Lawrence Berkeley Laboratory

HOW TO SIZE SHADING SYSTEMS

**Sizing South Overhangs**

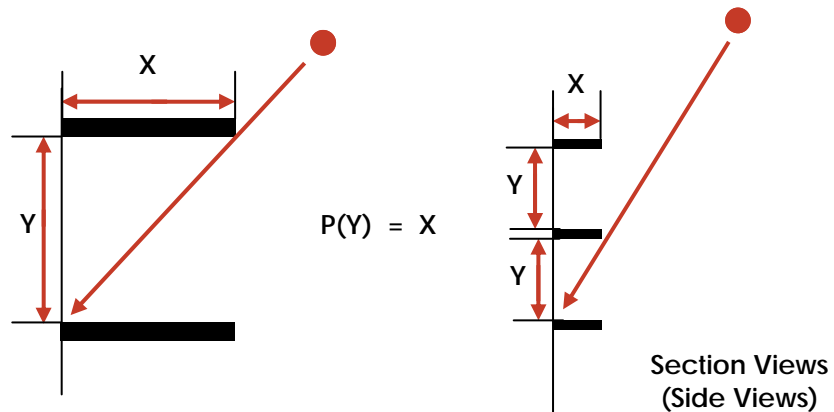
Sizing shading is easy. For this example we will be using a simple office building created in Revit Architecture 2008. This is a two-story building with the latitude and longitude of Bozeman, Montana. To size horizontal shading follow these simple steps:

1. Choose your location and the time of year most critical to shade from the chart, refer to charts on pages in the Appendix.
2. Multiply distance Y by variable P and the result is X.



*South Façade 12 Noon*

Y	P	X
10'	0.40	4'
7'	0.40	2.8'



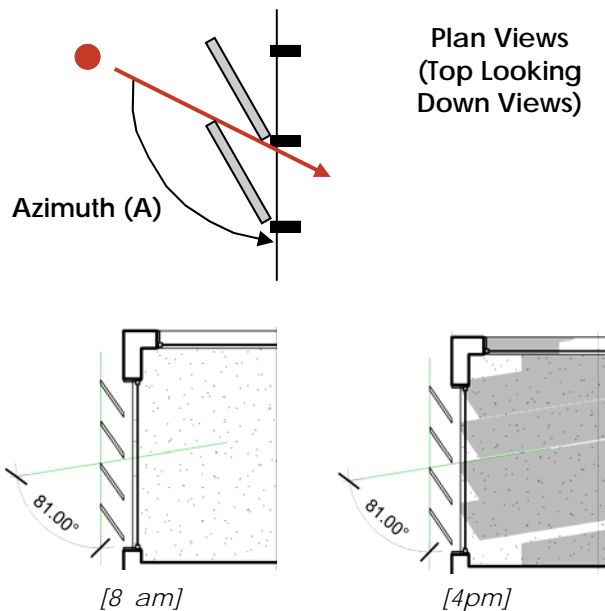
## Part Three: Daylighting Design

### Sizing East/West Vertical Fins

Horizontal louvers are not typically used for east or west facing glazing. Instead, use vertical fins to regulate sun penetration on these façades. It is best to minimize window area on the east and west façades because the sun is harder to control in these orientations. However, designing vertical fins is also simple. Just follow these steps:

1. Determine your azimuth angle for your location, refer to the charts in the Appendix. Use the morning angle for use with the east façade and the afternoon angle for the western façade.
2. The angle determines the fin length, spacing and slant angle.

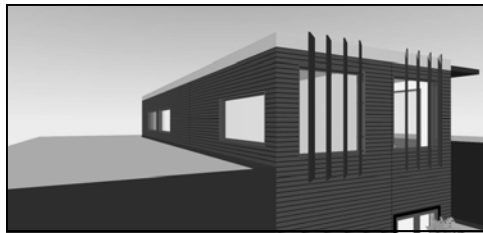
For the example below, the azimuth angle corresponding to Bozeman for June 21st,  $81^\circ$ , was used.



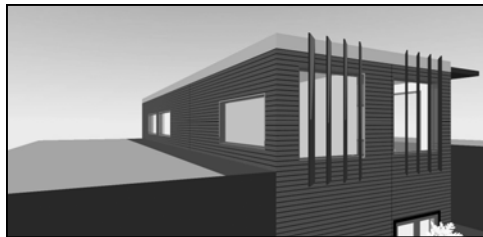
Western façade at 4 PM

**NORTH FAÇADE DESIGN**

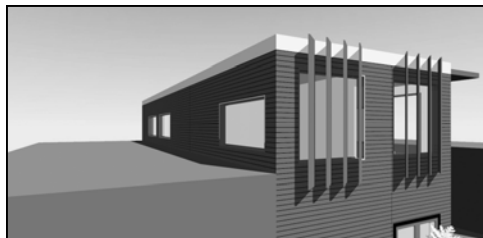
North glazing provides high-quality, consistent daylight with minimal solar heat gains. Heat loss can be a problem during the winter season and can also contribute to individual comfort problems. North-facing windows are an excellent option to evenly distribute daylight without the need for additional shading devices, but beware of the additional heat loss during the winter months. Follow these guidelines for north facing glazing:



9 AM—Bozeman, MT



12 Noon—Bozeman, MT



3 PM—Bozeman, MT

**Glazing properties: (What to look for on a glazing properties chart)**

*Refer back to the example on page 28:*

- Use a Solar Heat Gain Coefficient of approximately 0.46 for northern façades. A high SHGC is not needed because northern façades do not receive large amounts of direct sunlight, and therefore do not create opportunities for passive solar heating.
- Choose a U-value of approximately 0.35 or less. Low U-values allow for the least amount of atmospheric heat to transfer through the glazing assembly.
- The northern façade of a building will receive a large amount of daylight so the window area should be reasonable. Too much can contribute to heat loss; too little and the daylight is not being utilized efficiently. The WWR (window to wall ratio) should be 40% or less.

**Shading devices**

- The northern façade does not require shading due to its low exposure to direct sunlight.
- The images to the left show the north and west façade throughout the day.
- There is no direct sunlight at any point in the day.
- In early and late summer days, however, some direct sunlight will hit a north façade.

## Part Three: Daylighting Design

### SOUTH FAÇADE DESIGN

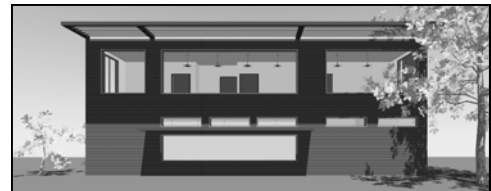
Southern glazing provides an excellent source of natural daylight and is also a good source of solar heat gain in the winter months. Careful consideration of the south façade design and some knowledge of the appropriate shading devices will save time and money over the life of the building. Follow these design tips for south facing glazing:

#### **Glazing properties: (What to look for on a glazing properties chart)**

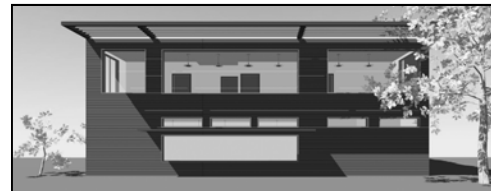
- Maximize window area to 40% of the exterior wall area on the southern façade; this is a prime opportunity to utilize the passive heating potential of the sun.
- Use glazing with a higher SHGC; if designed in conjunction with proper shading, this will allow for more solar heat to enter the space in the winter months and in turn lower heating bills.
- Again, use a U-Value of 0.35 or less to ensure that the glazing areas are insulated to reduce unwanted heat loss. Consider insulated shutters to help reduce night heat loss.



*9 AM—Bozeman, MT*



*12 Noon—Bozeman, MT*



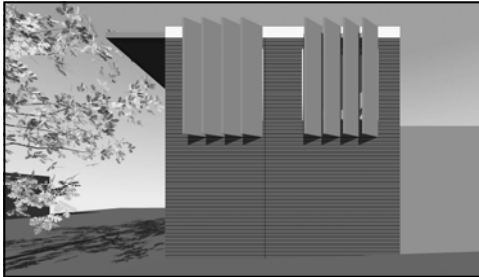
*3 PM—Bozeman, MT*

#### **Shading devices**

- Shading the southern façade is fairly easy. The best solution is to incorporate shading elements in the design of the exterior skin. For example, deep inset windows will create built-in shading.
- Use horizontal shades when adding shading devices to an existing building. Some examples are:
  - Awnings
  - Overhangs / Louvered overhangs
  - Recessed windows
- If the budget for the building is small, give shading priority to the south and west windows.

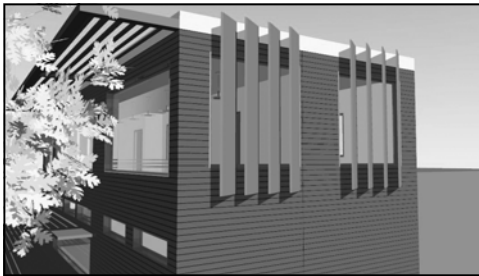
### EAST FAÇADE DESIGN

Precautions should be taken when designing the east façade. Unless it is absolutely necessary to design large view windows, it is good practice to keep glazing to a minimum on east-facing walls. Follow these guidelines for east façade glazing:



#### **Glazing properties: (What to look for on a glazing properties chart)**

- Use a SHGC of 0.35 or lower to prevent solar heat gain from direct sunlight penetration.
- Use a U-Value of 0.35 or lower to prevent conductive heat gain or loss.



#### **Shading devices**

- East glazing is difficult to shade but various steps can be taken:
  - Use vertical louvers set at an angle that blocks the morning sun. (See page 11.)
  - Utilize the buildings skin as a shading element by designing the façade to shade itself.
  - Use interior shades to block morning glare.

## Part Three: Daylighting Design

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### WEST FAÇADE DESIGN

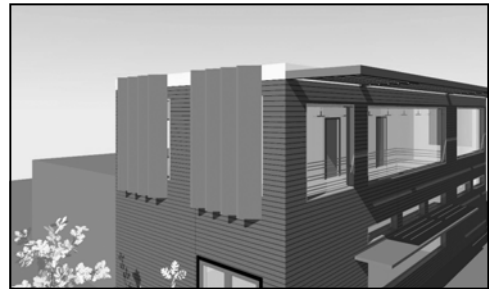
Western glazing is often popular in Montana because of picturesque mountain views. However, west glazing should be greatly minimized in Montana due to excessive solar heat gain and intense glare issues, especially with lower altitude sun angles throughout the year in the late afternoon and evening. If west glazing must be incorporated into a design, it should be kept to a minimum and the following should be observed:

#### **Glazing properties: (What to look for on a glazing properties chart)**

- Use a SHGC of 0.35 or lower to prevent solar heat gain from direct sunlight penetration.
- Use a U-Value of 0.35 or lower to prevent conductive heat gain or loss.

#### **Shading devices**

- West glazing is difficult to shade but various steps can be taken:
  - Use vertical louvers set at an angle that blocks the afternoon sun.
  - Utilize the buildings skin as a shading element by designing the façade to shade itself.
  - Take precautions when designing the glazing area; use view windows sparingly to prevent large amounts of direct afternoon sun and glare.
  - Interior shades can also be used to block direct afternoon sun.





## PART FOUR—TOOLS FOR DAYLIGHTING

“A room is not a room without natural light. Natural light gives the time of day and the mood of the seasons to enter.”

-Louis Kahn

### Targets

LEED 2009 New Construction—Indoor Environmental Quality  
Credit 8.1 Daylight (1 point) and Credit 8.2 Views (1 point)

### CREDIT 8.1 DAYLIGHT

This credit requires the building to achieve daylighting in 75% of the regularly occupied spaces.

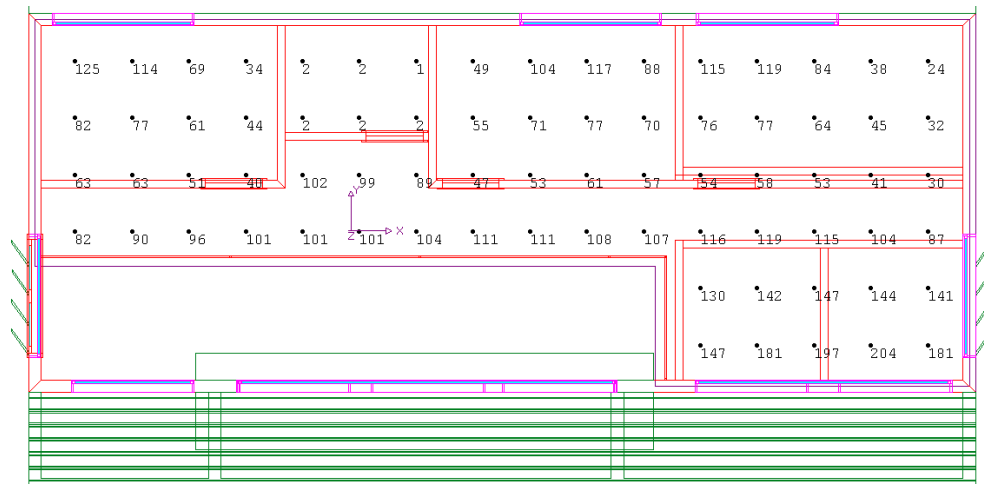
Four options to demonstrate performance

1. Simulation
2. Prescription
3. Measurement
4. Combination of 1, 2, and 3



### Option 1—Simulation

This method requires the building to provide a minimum of 25 fc and a maximum of 5000 fc in 75% of the regularly occupied spaces. Use clear sky conditions on September 21 at 9 am and 3 pm (equinox). View preserving automated shades for glare control may demonstrate compliance for the 25 fc level.



(Chart produced by AGI-32)

Second Floor Footcandle Chart

## Part Four: Tools for Daylighting

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### Option 2—Prescriptive

This method consists of requirements of a combination of side lighting and/or top lighting to achieve a total daylighting zone that is provided for 75% of regularly occupied spaces.

#### 1. Side lighting:

VLT X WFR = 0.15 to 0.18

VLT: visible light transmittance

WFR: window to floor area ratio

#### 2. Top lighting:

Daylight zone under skylight—outline of the opening beneath skylight plus the lesser of: 70% of ceiling height OR half distance to edge of nearest skylight **OR** distance to any permanent opaque partition farther than 70% of distance between top of partition and ceiling.

Achieve skylight roof coverage of 3% to 6% with a minimum of 0.5 VLT

Distance between skylight not more than 1.4 times ceiling height

Skylight diffusers must have a measured haze value greater than 90% as tested by ASTM D1003

### Option 3—Measurement

Indoor light measurement: minimum of 25 fc in 75% of regularly occupied spaces. Measurement is to be taken on 10 foot grid. Only area associated with portions of room meeting minimum illumination may be counted.

### Option 4—Combination

May use a combination of any of the above three methods to achieve the credit.

### CREDIT 8.2 VIEWS

This credit is aimed at providing occupants with a connection to the outdoors. The building must achieve direct line of sight to outdoors via vision glazing between 30" and 90" above finished floor in 90% of all regularly occupied areas to receive the credit.

1. In plan view: area within sight lines drawn from perimeter vision glazing. May be drawn through interior glazing.
2. In section view: direct sight line can be drawn from area to perimeter vision glazing. May be drawn through interior glazing.

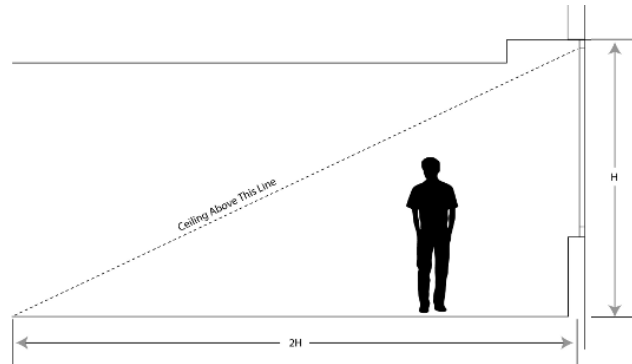


*Providing views for the occupants allows a connection to the outdoors.*

**HEIGHT RULE OF THUMB**

These rules of thumb are useful during preliminary daylighting design.

1. **2.5H guideline**—Assumes clear glazing, overcast skies, no obstructions and window area about half of the exterior wall area. Daylight penetration within the room will be 2.5 the height of the glazing.
2. **15/30 guideline**—After the 2.5H guideline, the next 15 feet is partially day lit, needs electric light supplement. Beyond 30 feet, very little daylight is available.



*2.5H Guideline Diagram*  
Image from ACI Glass Products, LLC.

**DAYLIGHT FACTOR RULE OF THUMB**

**Daylight Factor Guidelines**

$$DF = (\text{interior horizontal illumination} / \text{exterior horizontal illumination}) \times 100\%$$

**Daylight Factor Recommendations**

Ordinary visual tasks	1.5 to 2.5
Moderately difficult tasks	2.5 to 4.0
Difficult prolonged tasks	4.0 to 8.0
Minimum for circulation	0.5

**Side Lighting Daylight Factor Guidelines**

- DF average = 0.2 (window area/floor area)
- DF minimum = 0.1 (window area/floor area)

**Top Lighting Daylight Factor Guidelines**

Three conditions:

- |                                   |   |
|-----------------------------------|---|
| 1. Vertical monitor or clerestory | DF average = 0.2 (glazing area/floor area)  |
| 2. North facing saw tooth         | DF average = 0.33 (glazing area/floor area) |
| 3. Horizontal skylights           | DF average = 0.35 (glazing area/floor area) |

**Top Lighting Daylight Factor Guideline Example**

Room 100 feet by 100 feet

Assume target of DF = 2% or 0.02

Vertical monitor

$$0.02 = 0.2(\text{Glazing area}/10,000)$$

$$\text{Glazed area} = (0.02 \times 1000)/0.2$$

$$\text{Glazed area} = 1,000 \text{ sq. feet or } 10\% \text{ of roof}$$

North facing saw tooth

$$0.02 = 0.33(\text{Glazing area}/10,000)$$

$$\text{Glazed area} = (0.02 \times 1000)/0.33$$

$$\text{Glazed area} = 606 \text{ sq. feet or } 6.06\% \text{ of roof}$$

Horizontal Skylights

$$0.02 = 0.35(\text{Glazing area}/10,000)$$

$$\text{Glazed area} = (0.02 \times 1000)/0.35$$

$$\text{Glazed area} = 571 \text{ sq. feet or } 5.71\% \text{ of roof}$$

## Part Four: Tools for Daylighting

### Horizontal Skylight Spacing

Large widely spaced skylights will produce uneven illumination. Will need more but smaller skylights to maintain even illumination.

Use  $\text{Max } S/MH = 1.4$  as a guideline.

Example: If MH (ceiling height) = 12 feet.

Then maximum spacing would be  $1.4 \times 12 \text{ feet} = 16.8 \text{ feet}$

### EFFECTIVE APERTURE

The effective aperture is achieving the right balance between the amount of glazing and glare potential. The more glazing you provide, the lower the visual transmittance should be to keep within visual comfort ranges.

### Effective Aperture Guideline

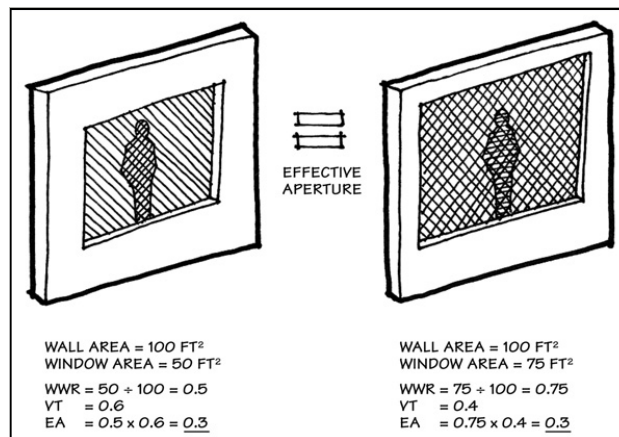
$$EF = WWR \times VT$$

WWR = window wall ration: net window area to gross exterior wall area

VT = visual transmittance

Target: EF of about 0.18

Effective Aperture Examples		
Assuming $WWR \times VT = 0.18$		
Then	WWR = 0.2	VT = 0.9
	WWR = 0.5	VT = 0.36
	WWR = 0.8	VT = 0.225



*Effective Aperture Example*

Image from Daylighting Guide for Fort Carson, Directorate of Public Works

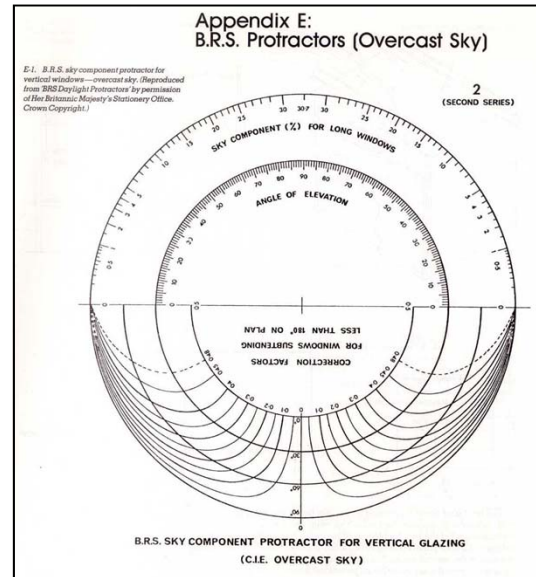
CALCULATION TOOLS

LUMEN METHOD HAND CALCULATION

This method is similar to electric lighting calculations that use coefficients of utilization (CU). For full description and methodology please refer to IES "Recommended Practice of Daylighting." Most designers are using computer simulations today.

PROTRACTORS AND PATTERNS

1. BRS Daylight Protractors
2. Skylight Worksheets
3. Daylight Pattern Examples—"Patterns to Daylight Schools for People and Sustainability" by the LRC



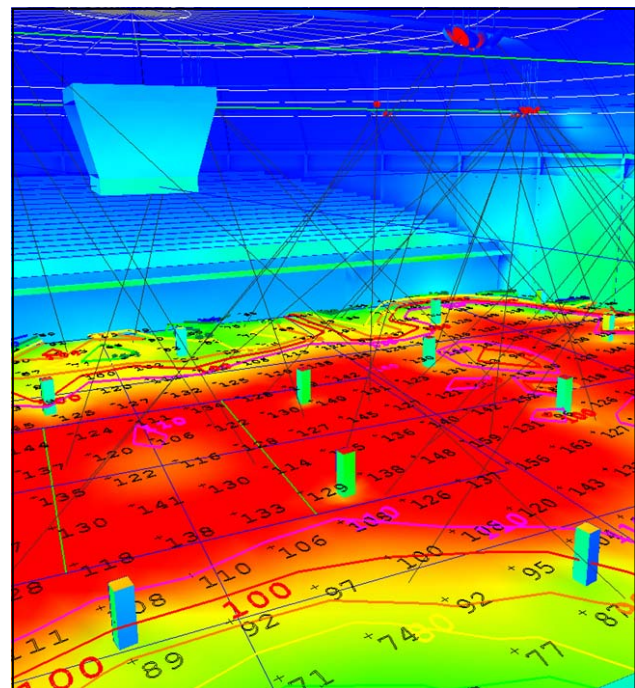
COMPUTER SIMULATIONS

**Programs Available**

There are many computer simulation programs available, such as Radiance, Superlite, DOE2, and many others. Commercial programs include AGi32 and Lumen Designer. The programs are similar in their processing methods.

**Computer programs should allow**

1. Daylight and electric lighting calculations.
2. Illumination, luminance, and daylight factor calculations.
3. Perform both radiosity and ray tracing calculations.
4. Electric lighting using standard IES file format photometrics.



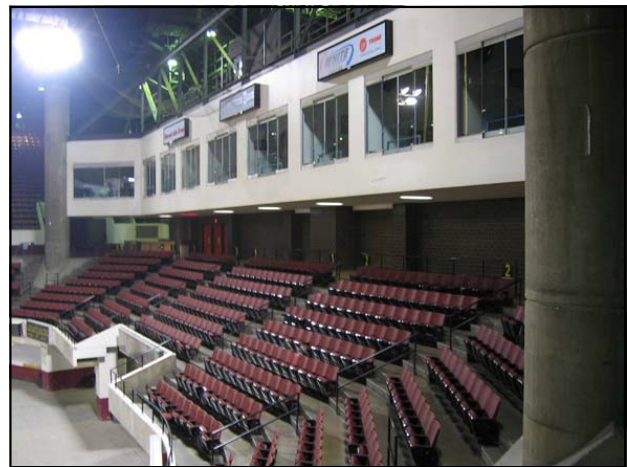
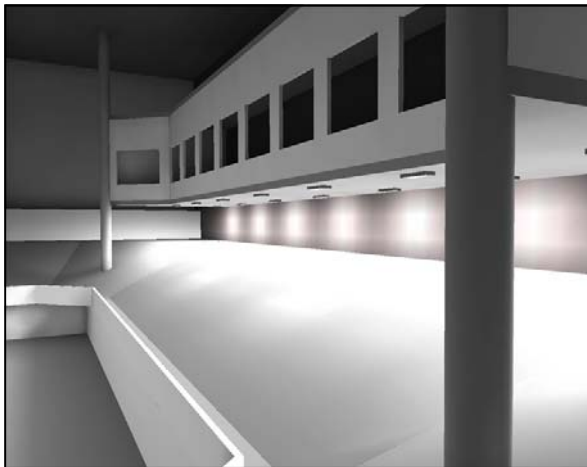
Computer simulated AGi 32 footcandle chart and pseudo color image showing illumination levels.



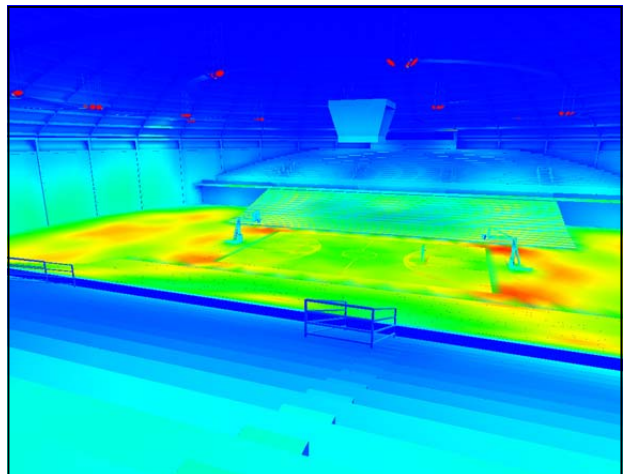
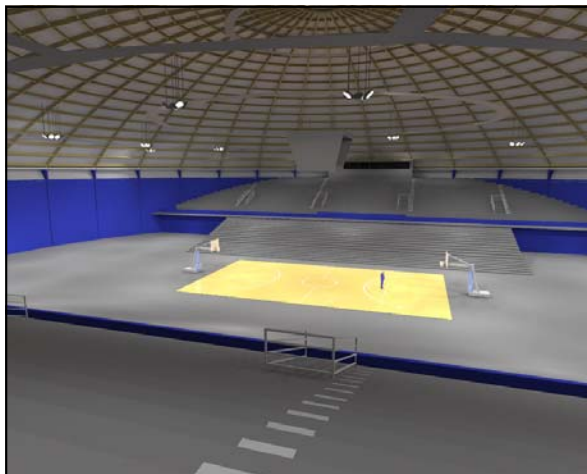
## Part Four: Tools for Daylighting

### Basic Processing Steps

1. Define 3D geometry with surfaces: can be imported or created with the program.
2. Define surface characteristics: single or double sided, interior or exterior, reflectance or color, finish (flat or glossy), openings (glazed or open).
3. Define and place light sources  
Daylight: define location (latitude and longitude), sky condition, orientation, date and time.  
Electric lighting: select actual luminaire, use manufacturer IES files.
4. Define calculation grids: on any surface or defined plane  
Calculation types: illumination, luminance, daylight factor



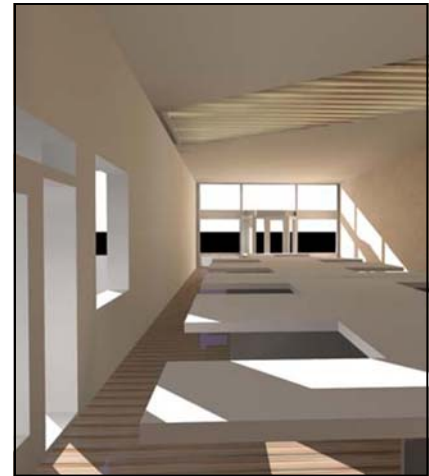
Computer simulated AGI 32 model (right) with actual space (left) showing similarities.



Computer simulated AGI 32 model ray traced image and pseudo colored image showing illumination levels. This indicates visual "hot spots" within the space.

**Calculation Processes**

1. Radiosity—This process assumes all surfaces are perfectly diffuse. It then applies a mesh to all surfaces. The process continues to distribute light energy from all sources that contribute to a mesh intersection and interpolates illumination between calculation mesh points. Within radiosity solutions all surfaces appear as matte finish (diffuse). A benefit for this type of process is that it is fairly fast and can be viewed from any viewpoint.
2. Ray Tracing—For added realism, ray tracing adds surface effects such as glossiness. Ray tracing depends on a specific viewpoint and can take a long time to process. The process starts by taking a line of sight from the viewer to a point on a surface. Surface characteristics determine what happens: how much is reflected, scattered, or absorbed. Process repeats a set number of times (bounces).



*Computer simulated AGI 32 model ray traced image.*

PHYSICAL MODELS

Best reference is "Building Daylighting Models" by the Integrated Design Lab—Puget Sound, Joel Loveland, University of Washington

**Benefits of physical models**

The benefits are that there are no scaling issues, can use at any stage of design, can address other issues, and we are familiar with the techniques.

**Sky Conditions**

1. Artificial Sky: replicates overcast sky luminance distribution. This allows for a controlled environment for comparative testing. We have an artificial sky simulator in Bozeman within the Integrated Design Lab.
2. Outdoor Testing: least expensive but unpredictable. This method can be done anywhere with a sun peg diagram.



*Physical model built for daylighting studies.*

*Artificial sky simulator testing a physical model for daylighting potential. University of Washington, Integrated Design Lab*



Tools for Daylighting



## Part Four: Tools for Daylighting

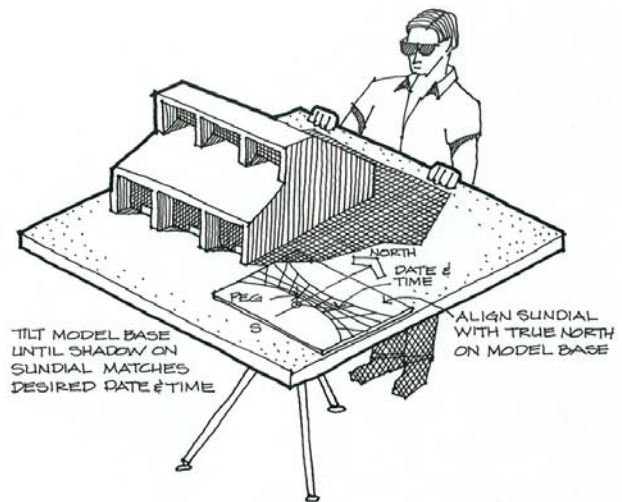
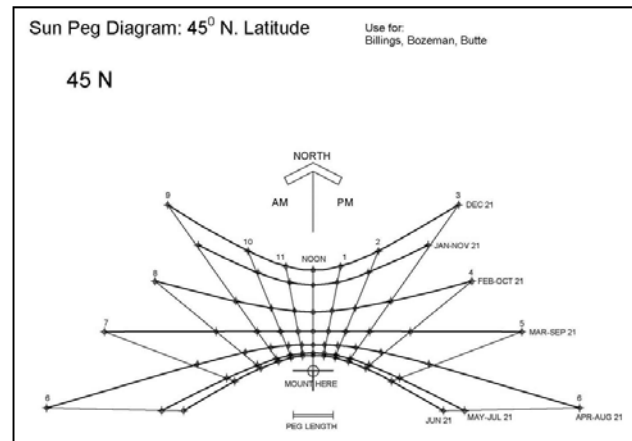
### Outdoor Model Testing

For the best results:

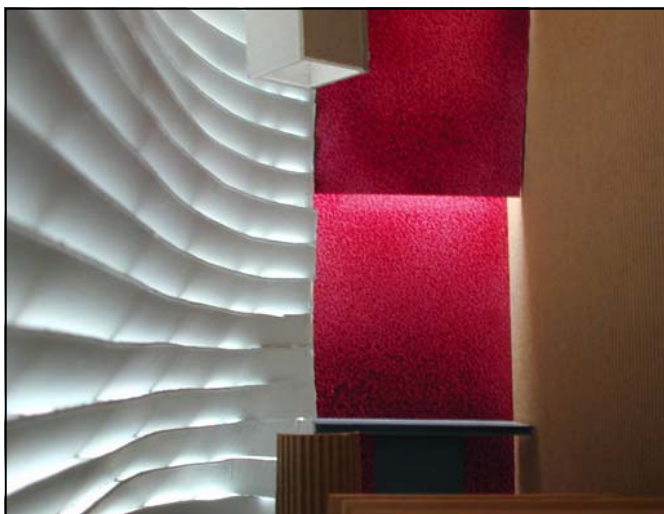
1. Avoid partly cloudy days.
2. Use clear midday or uniform cloudy skies.
3. Take measurements inside and outside on horizontal surface.
4. Use sun peg diagram to replicate sunlight angles. For Montana cities, sun peg diagrams can be found on the Integrated Design Lab Website, [www.idlbozeman.com](http://www.idlbozeman.com)

### Modeling Tips

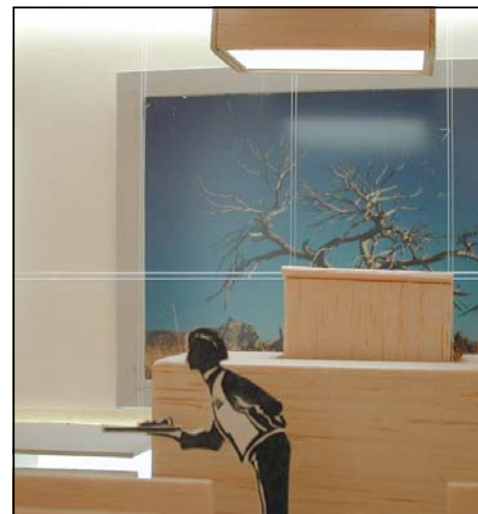
1. Use a convenient scale. During the early stages, it is recommended to use a scale of 1/16" or 1/8" which is adequate for massing, solar access and obstruction studies. A larger scale, such as a 1" scale to full scale mock-ups are used for refined analysis, photographic analysis, and measurements.
2. Materials: The reflectance and color of the actual materials need to be modeled as accurately as possible. Transparency is important to differentiate from opacity. Any color of Foam Core is translucent, so if the model is built from this it should be covered in paper. All intersections should be carefully inspected to be completely covered, as not to allow any light leaks within the model.



*Sun Peg Diagram example and directions on use.*



*Student Physical Model*



*Student Physical Model*

## PART FIVE—CASE STUDIES

### MOUNT ANGEL LIBRARY AND CLASSROOMS

#### **Overview**

Building Owner: Mount Angel Abbey

Size: 21,600 square feet

Location: St. Benedict, Oregon

Utilities: Portland General Electric, Northwest Natural

Completion Date: Fall 2006; Retrofits and repairs summer 2008

Practice changes: Exceptional integrated design process, construction and testing of a prototype high-performance classroom

Technologies: Passive heating, cooling and ventilation; daylighting; small radiant heating systems; heat recovery ventilators

Architect: SRG Partnership, inc.

Electrical Engineer: James Graham and Associates (now part of Interface Engineering)

Lighting Engineer: Jim Benya

Mechanical Engineers: Solarc Architecture & Engineering, Inc.

Building Energy Design: Energy Studies in Building Laboratory, University of Oregon

Mount Angel Abbey's new Annunciation Center for Theological Studies is the last addition to the Benedictine teaching, retreat and worship center in Mount Angel, Oregon. The Annunciation Center includes 25 faculty and administrative offices, six classrooms, and a board room in the 21,600 square foot building. Many of the spaces are designed to be used year round, excluding the classrooms which are primarily used September through May.

Starting with a study, funded by Better Bricks, SRG reviewed the results and models. Then with the help of ESBL, they built a prototype to test and refine their design. Some design innovations were a large central skylight with special integrated shading and light diffusion devices, as well as natural ventilation optimization. The design team and owners challenged the design to use no mechanical cooling and provide 95% of the annual lighting demand through daylighting. The result of their goals, the building achieved 62% more energy efficient than Oregon Energy Code required at the time.



*Mount Angle Library and Classrooms*  
Image from BetterBricks at [www.betterbricks.com](http://www.betterbricks.com)

### Daylight Strategies

The design team challenged themselves to provide evenly distributed daylight in all rooms during 95% of normal occupancy hours without glare. They aimed for a minimum-maximum range of 20-40 footcandles at a daylight factor of four percent.

To achieve this, each classroom was equipped with a large central skylight. With the addition of louvers that automatically rotate to control daylight levels, the results created a well day lit learning environment. Triangular extruded aluminum reflector tubes were arranged in concentric layers of diminishing density from the center outward. This helped reduce the light at the center, while pushing the light to the exterior walls. Sun shades and light shelves were added to all the south facing office and classroom windows, mitigating glare and moderating the solar heat gain. To control sunlight, all exterior windows are equipped with roll down shades.

To compliment the daylighting strategies, high efficiency electric lights with dimming ballasts and occupancy sensors were installed. SRG specified T-5 High Output (HO) lighting to be adjacent to the classroom reflectors. For the marker boards and offices, T-8 HO are being used; and compact fluorescents in the corridors.

### Energy and Financial

Total Project Cost: \$6.2 million (\$288 per square foot); according to SRG partnership, construction costs “likely are in a similar range to some of the nicer private institutions.”

Incremental Cost: \$174,000

Annual Energy Savings: Based on the energy study; the building is 62 percent more energy efficient than Oregon Energy Code. Actual savings achieved in 2008: 120,635 kWh of electricity and 5,106 therms of natural gas.

Energy Trust of Oregon Incentives: energy-efficient building shell with wall and roof insulation and glazing: \$3,029; high-performance integrated lighting, and passive heating and cooling: \$12,494; boiler: \$625.

Total incentives: \$16,148



*Mount Angle classrooms with central skylight and triangular louver system.*

Image from BetterBricks at [www.betterbricks.com](http://www.betterbricks.com)



*Mount Angle classrooms with external shading devices with interior light shelves.*

Image from BetterBricks at [www.betterbricks.com](http://www.betterbricks.com)



## LILLIS BUSINESS COMPLEX

### Overview

Size: 196,500 square feet

Location: Eugene, Oregon

Completion Date: October 2003

Practice changes: Exceptional integrated design process

Technologies: Passive heating, cooling and ventilation; daylighting

Architect: SRG Partnership, inc.

Mechanical Engineer: Balzhiser and Hubbard

Lighting Design: Benva Lighting Design

Contractor: Lease Crutcher Lewis

PV: Solar Design Associates and New Path Renewables

Energy Efficiency Consultants: Energy Studies in Buildings Laboratory, University of Oregon; Hatten/Johnson Associates/Solarc Architecture and Engineers; Eugene Water & Electric Board

Commissioning Agent: Solarc Architecture and Engineers

In need of a replacement, the University of Oregon's Lundquist College of Business created a new energy efficient classroom complex. The site has a high profile along with it, located along an axis between the historic entrance to the college and the main library. The university and Lundquist College had the desire and goal to make this the greenest building possible. The specific goal for this project was to make it at least 40% more efficient than what was required at the time from the Oregon Energy Code. The designers also set the goal to follow a process that resulted in a solution that would encompass performance of LEED (the USGBC program). Early in the process, the construction manager and general contractor were brought into help with the development of the design. To accomplish the goals, the design team developed several strategies that involved daylighting, solar control, natural ventilation, electricity generation with the use of photovoltaic arrays, expanding thermal comfort rang with the addition of ceiling fans, ventilation of thermal mass, and wiring half of all the plug load receptacles and lighting circuits in faculty offices on occupancy sensors. Throughout the design process, many scale models were built to test the feasibility along with a full scale test room to study daylighting and control strategies.



*University of Oregon Lillis Business Complex*

Image from BetterBricks at [www.betterbricks.com](http://www.betterbricks.com)

## Part Five: Case Studies

### Daylight Strategies

Electronic control systems were installed to apply when the building is in cooling mode, computers close shades or skylight louvers automatically in unoccupied rooms. The computer opens the shade and louvers for necessary daylight when people enter the room and turn on the light switch. If the shades are completely open, the electronic controls will turn on additional electric lighting to reach the target illuminance level.

Light shelves were applied on the south facing windows for shade protection and reduction in cooling loads. They also work to reflect light deeper into the building, achieving a more uniform daylight contribution. The light shelves were installed with external overhang shades too. The walls and ceilings were painted with a light finish, allowing for higher reflectance.

### Climate

Heating Degree Days: 4546 base 65°F [2529 base 18.3°C]

Cooling Degree Days: 247 base 65°F [137 base 18.3°C]

Solar Radiation: Jan 368 Btu/ft<sup>2</sup>/day [1.16 kWh/m<sup>2</sup>/day] Jun 1975 Btu/ft<sup>2</sup>/day [6.23 kWh/m<sup>2</sup>/day]

Annual Precipitation: 52 in. [1321 mm]

### Energy and Financial

Total Project Costs: \$29.8 million for construction; \$40 million total project

Incremental Cost: \$748,453 (excluding PVs, which were privately funded)

Annual Energy Savings: \$52,514 (The new facility is 41% more efficient than the ASHRAE 90.1 energy standard, and 37% more efficient than Oregon's energy code. The building will save an estimated 682,000 kWh of electricity per year, 119 kW of monthly peak demand, 1,060 pounds of steam, plus 97100 kWh/year at the campus chiller plant.)

Incentives: \$372,138 (excluding PVs)

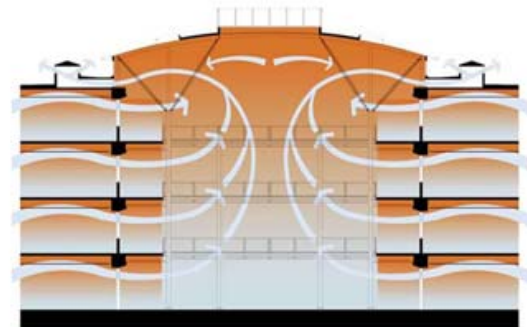
Eugene Water and Electric Board: \$201,961

Business Energy Tax Credit from Oregon Department of Energy: \$170,177 (estimate)



*Lillis Business Complex with external shading devices and interior light shelves.*

Image from BetterBricks at [www.betterbricks.com](http://www.betterbricks.com)



*The atrium couples with operable windows to create a natural ventilation system.*

Image from BetterBricks at [www.betterbricks.com](http://www.betterbricks.com)

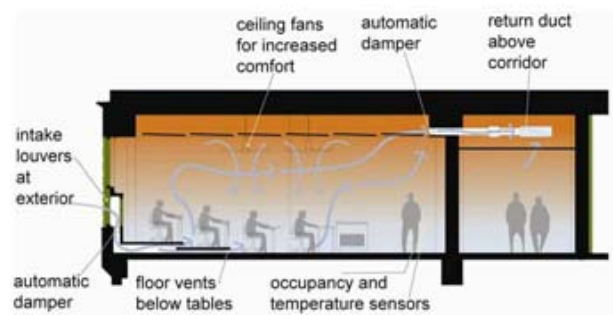


Image from BetterBricks at [www.betterbricks.com](http://www.betterbricks.com)



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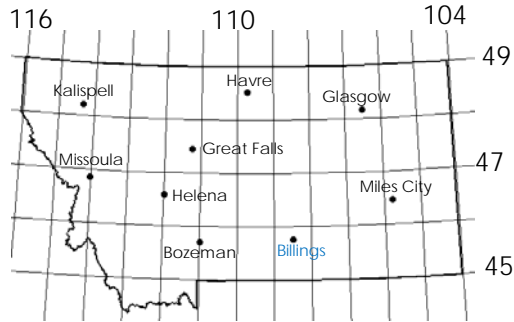


INTRODUCTION

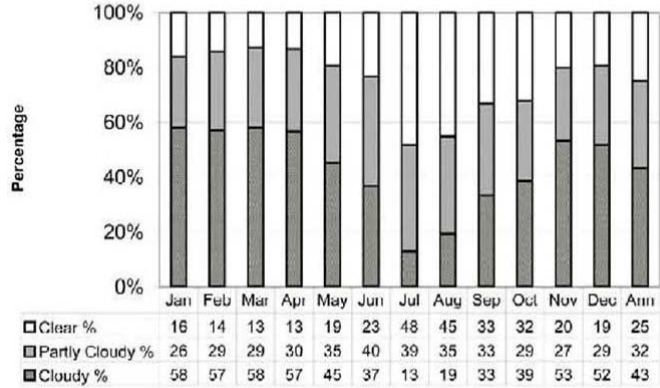
This appendix supplies resources mentioned in the text, including Montana solar charts and data, sun peg diagrams for various Montana cities, glossary of terms, and bibliography. These tools are explained in the manual text.

**BILLINGS, MONTANA**

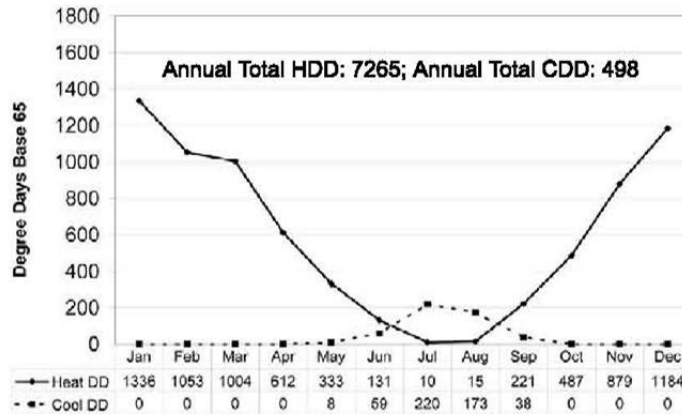
Latitude: 45.77 North  
 Longitude: 108.5 West  
 Elevation: 3567'



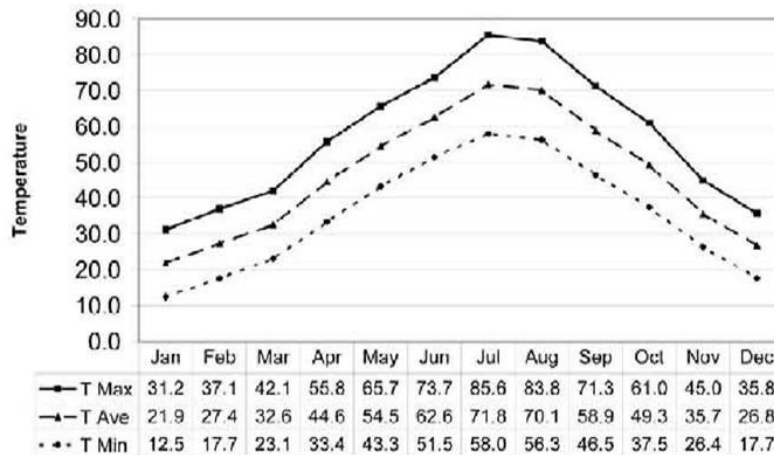
**Billings Sky Condition**



**Billings Degree Days**

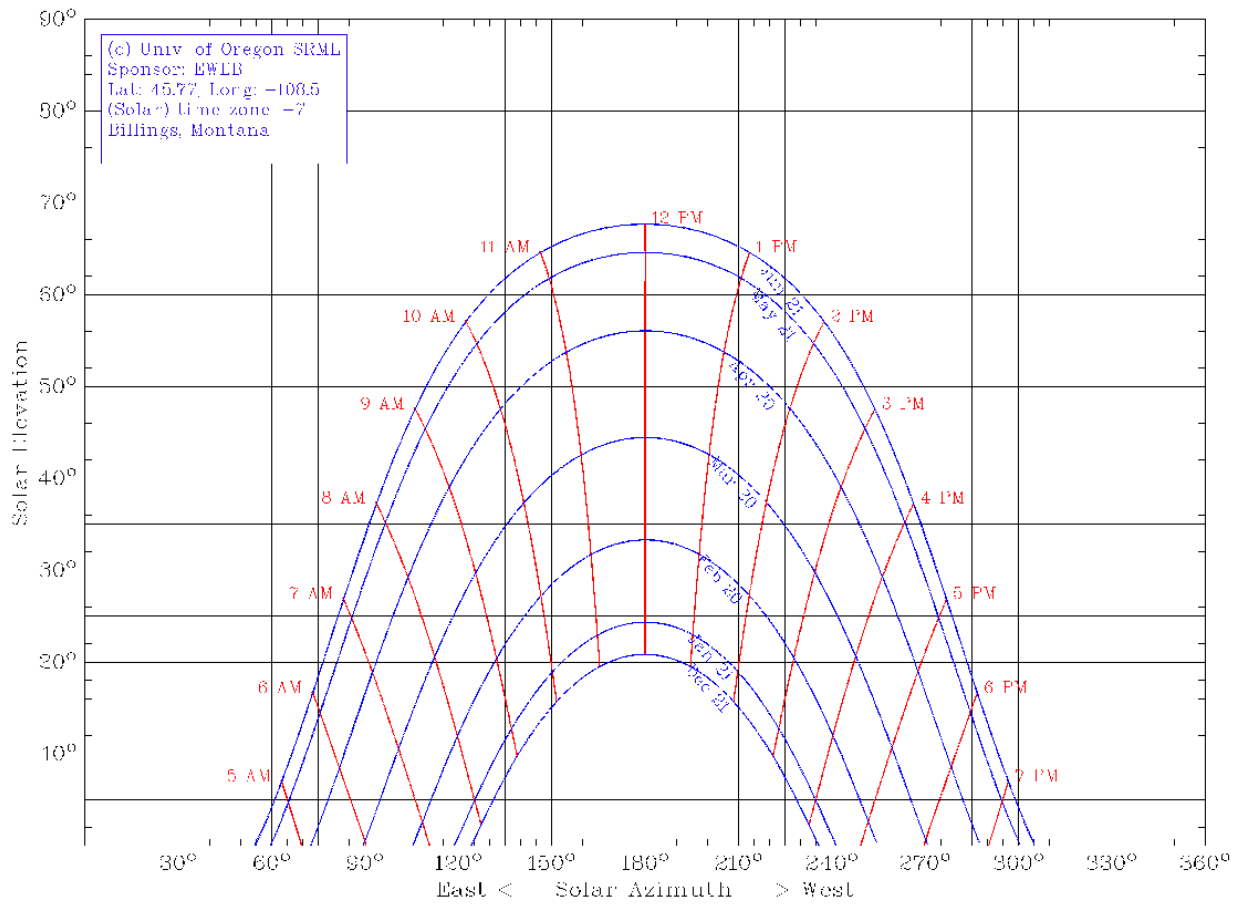
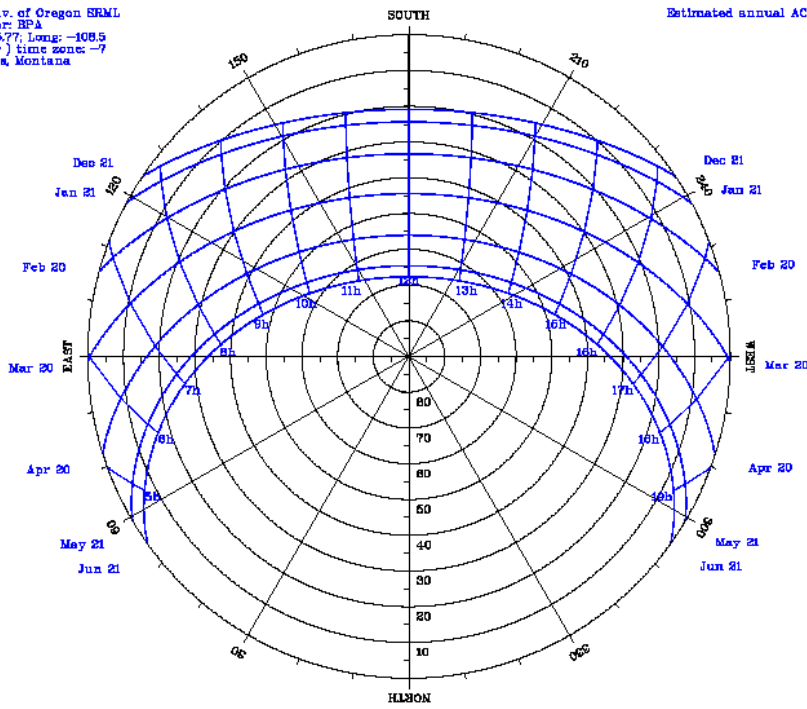


**Billings Temperatures**



(c) Univ. of Oregon SRML  
 Sponsor: BPA  
 Lat: 45.77; Long: -108.5  
 (Solar) time zone: -7  
 Billings, Montana

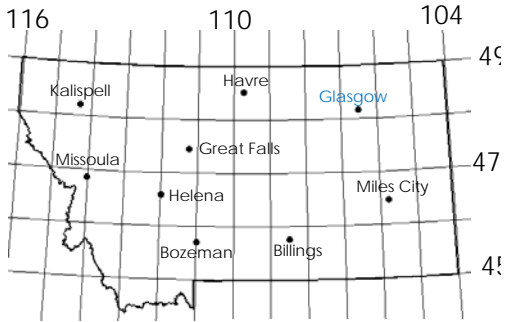
Estimated annual AC output:



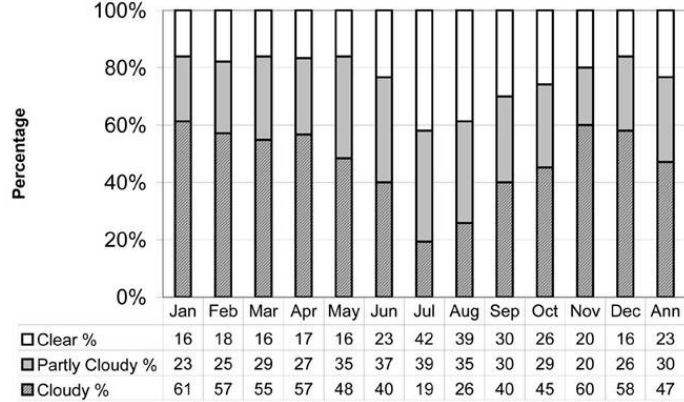
APPENDIX

# GLASGOW, MONTANA

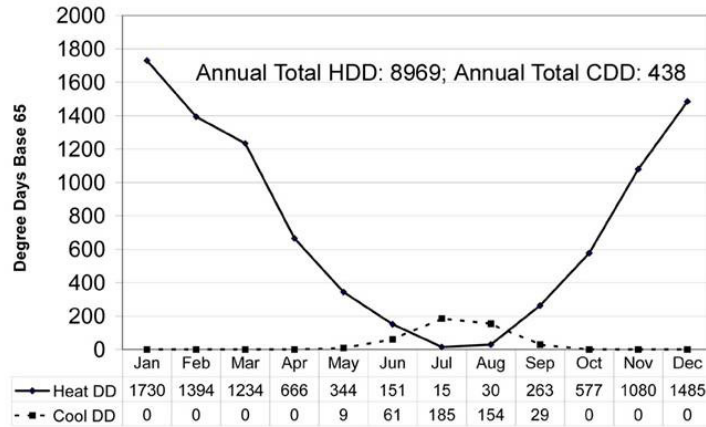
Latitude: 48.22 North  
 Longitude: 106.62 West  
 Elevation: 2284'



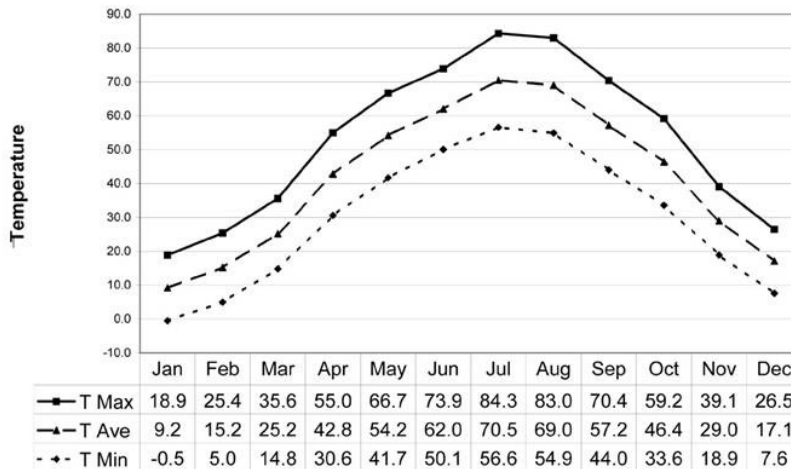
Glasgow Sky Condition



Glasgow Degree Days

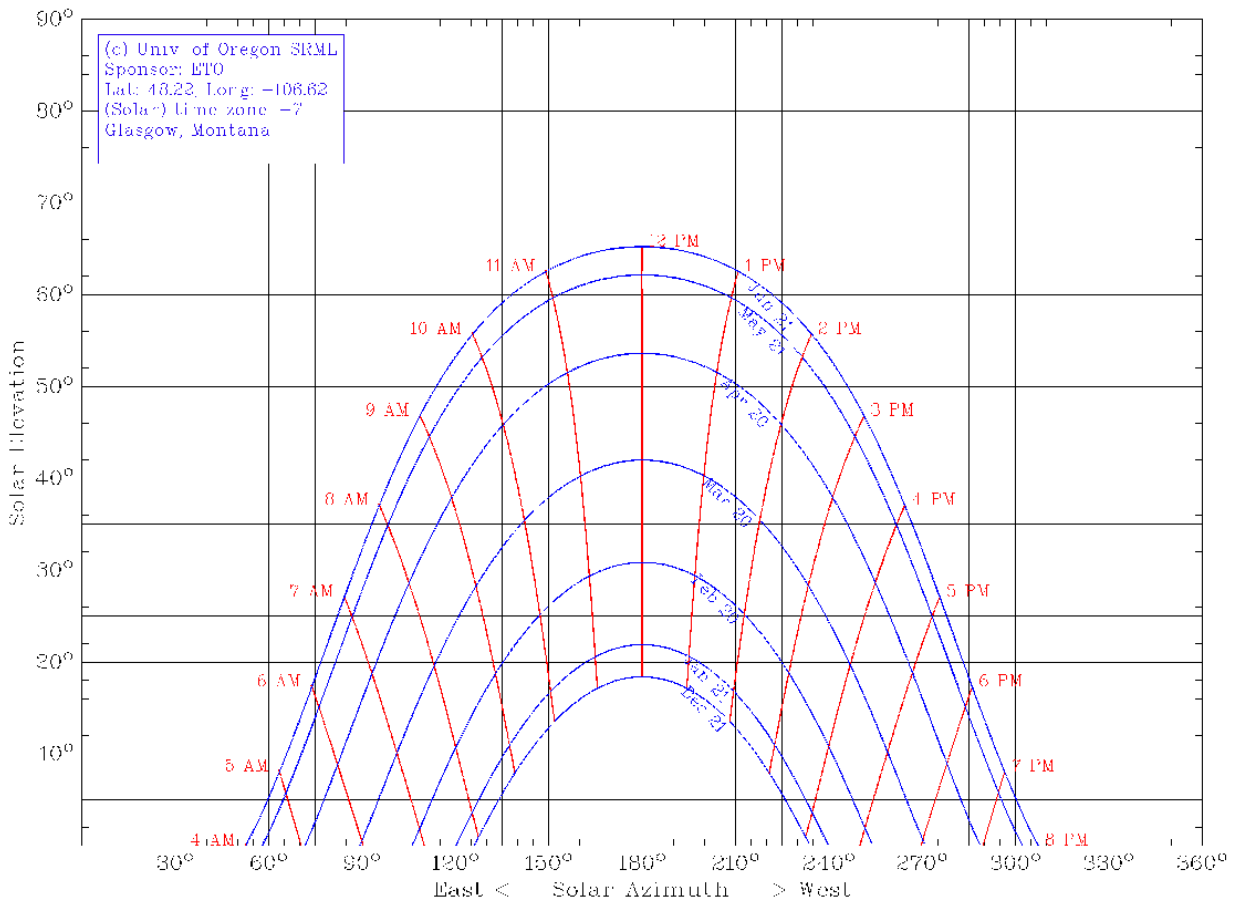
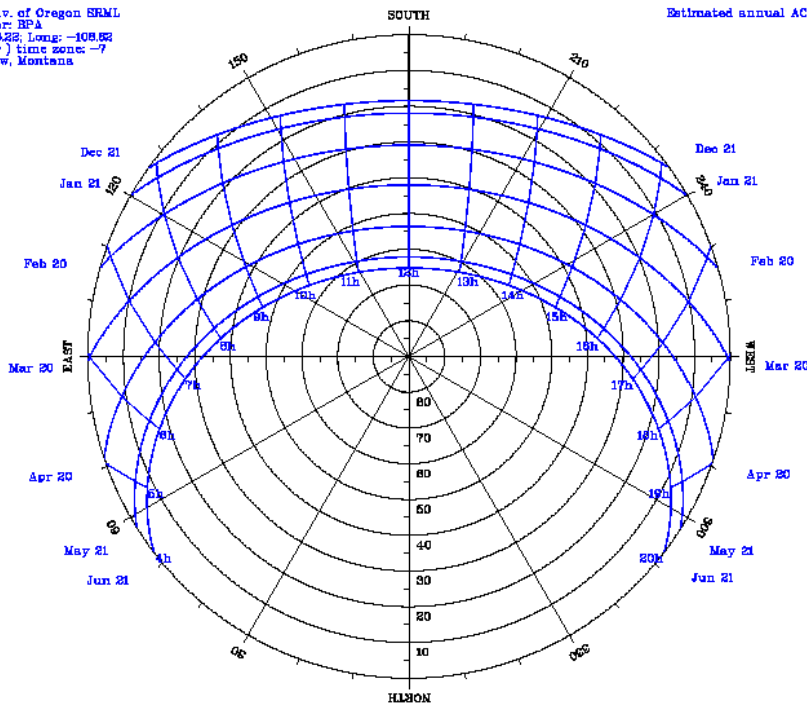


Glasgow Temperatures



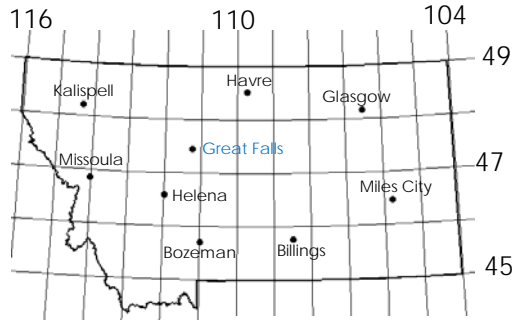
(c) Univ. of Oregon SRML  
 Sponsor: BPA  
 Lat: 48.23, Long: -106.62  
 (Solar) time zone: -7  
 Glasgow, Montana

Estimated annual AC output:

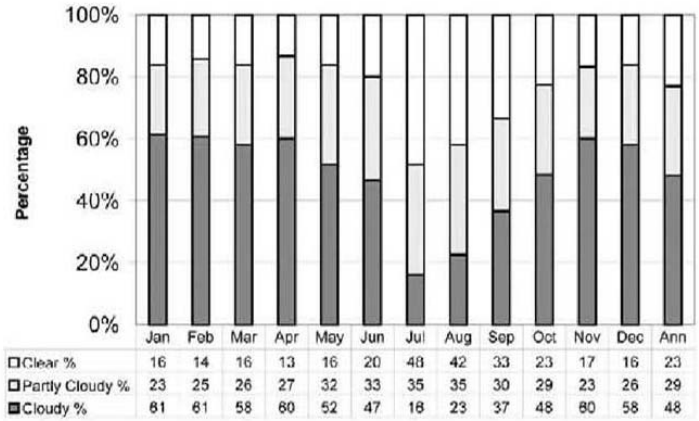


## GREAT FALLS, MONTANA

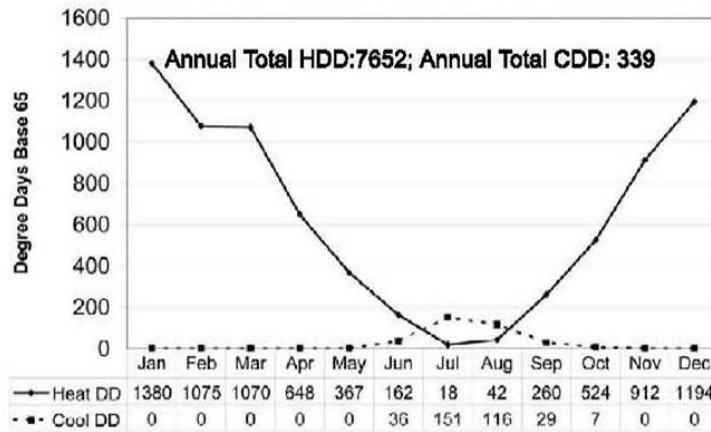
Latitude: 47.48 North  
 Longitude: 111.37 West  
 Elevation: 3663'



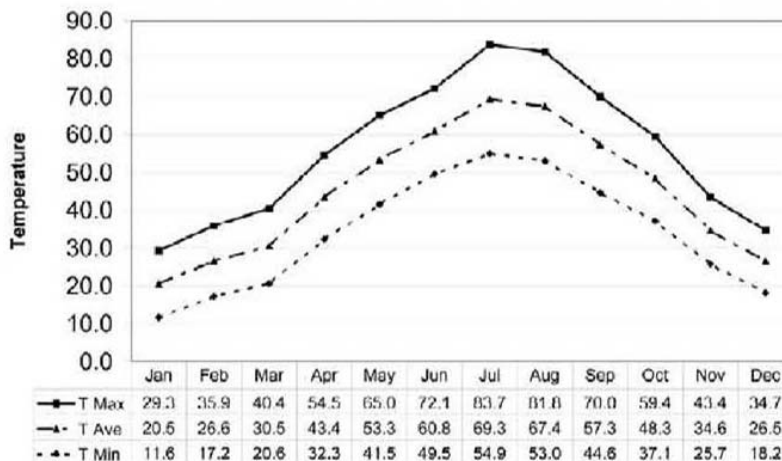
### Great Falls Sky Condition



### Great Falls Degree Days

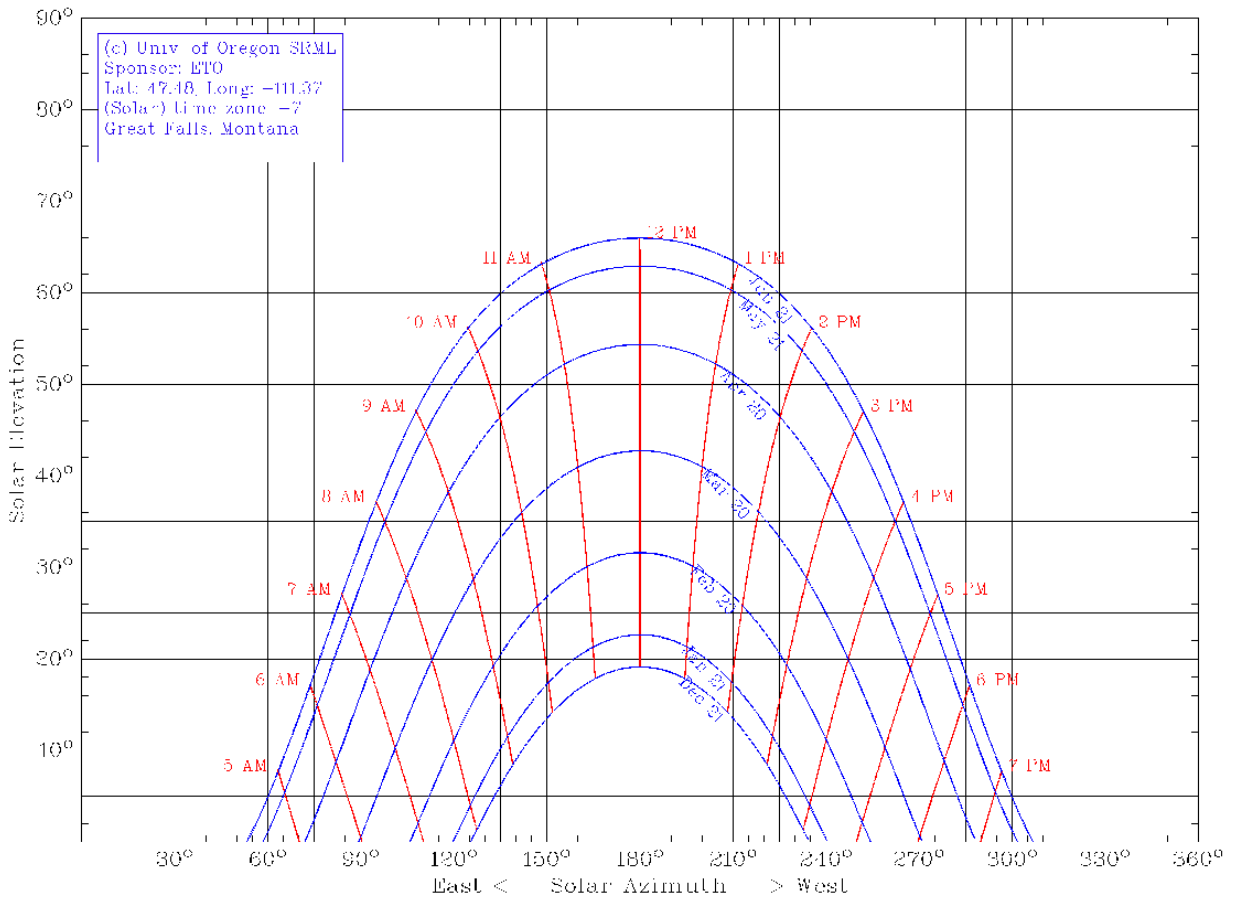
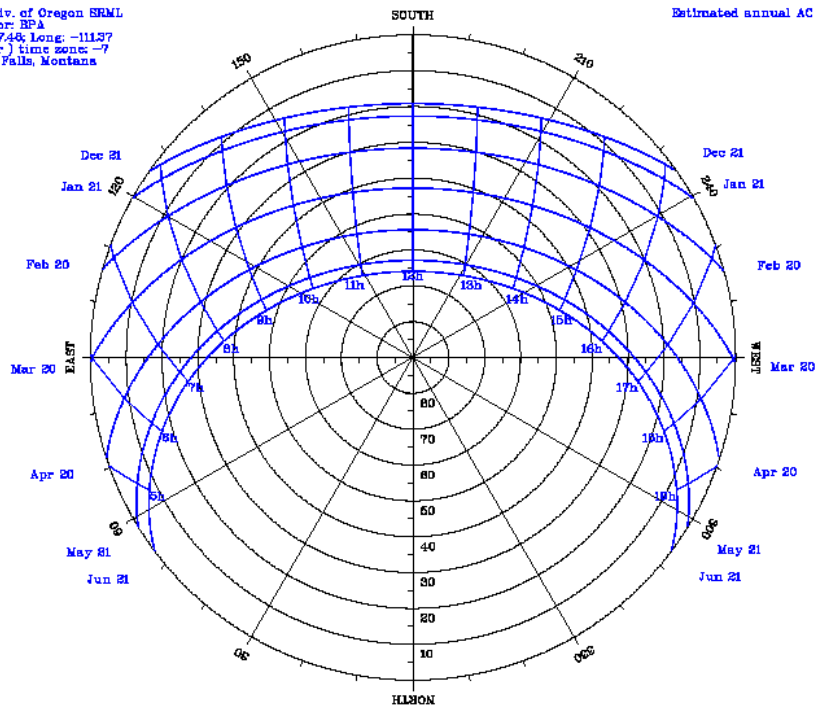


### Great Falls Temperatures



(c) Univ. of Oregon SRML  
 Sponsor: BPA  
 Lat: 47.48; Long: -111.37  
 (Solar) time zone: -7  
 Great Falls, Montana

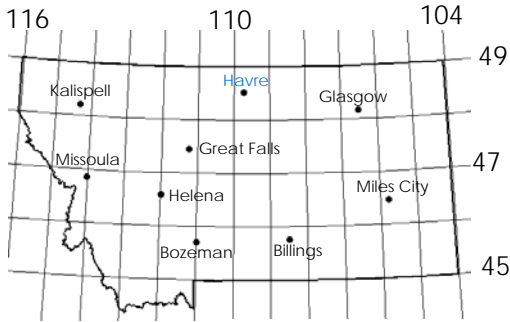
Estimated annual AC output:



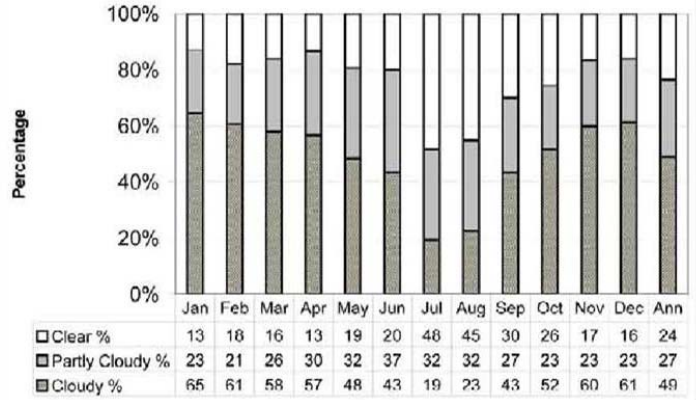


## HAVRE, MONTANA

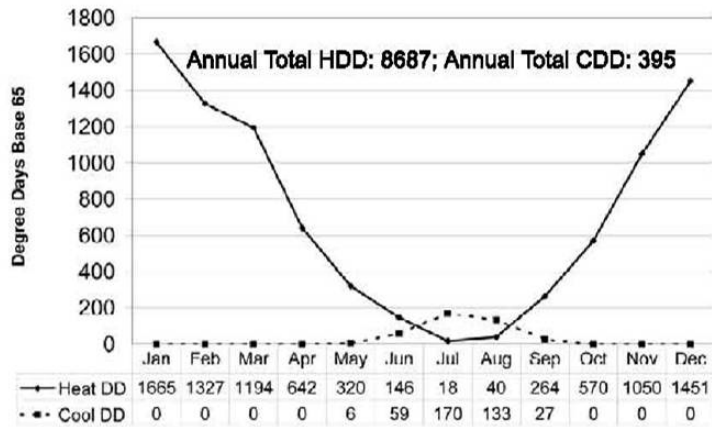
Latitude: 48.55 North  
 Longitude: 109.77 West  
 Elevation: 2584'



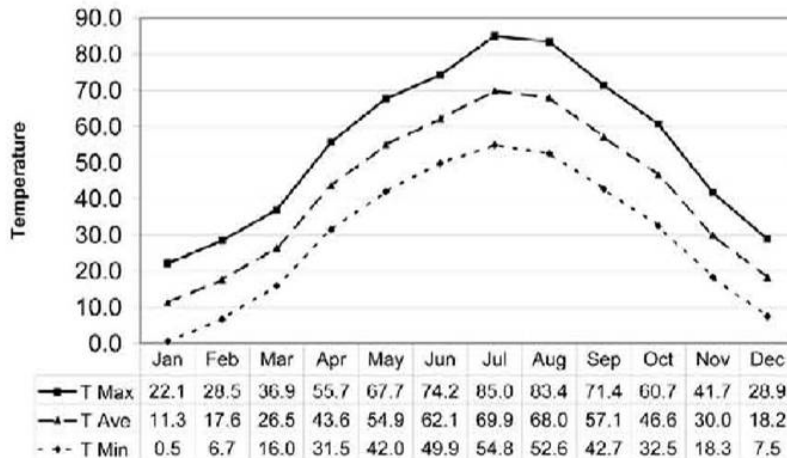
Havre Sky Condition



Havre Degree Days

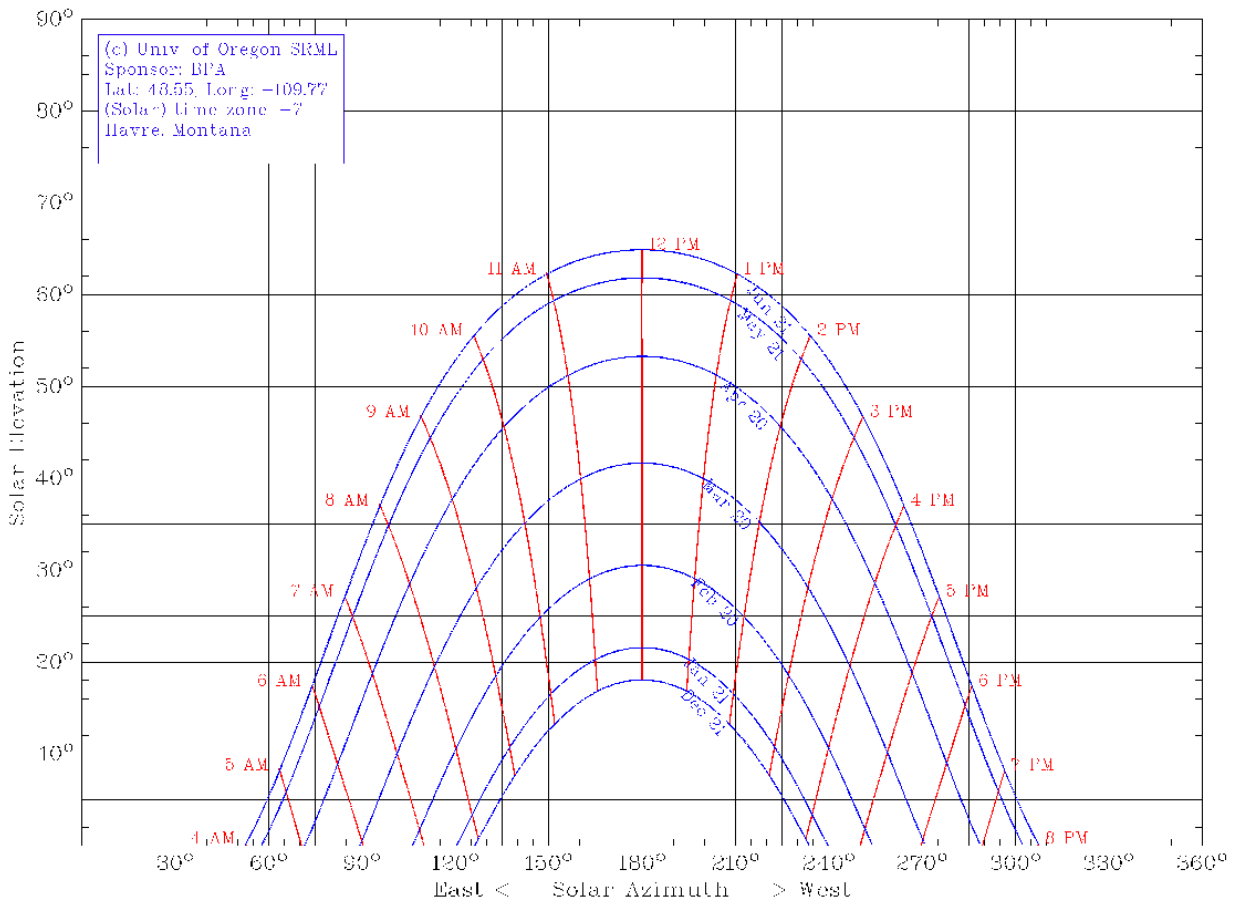
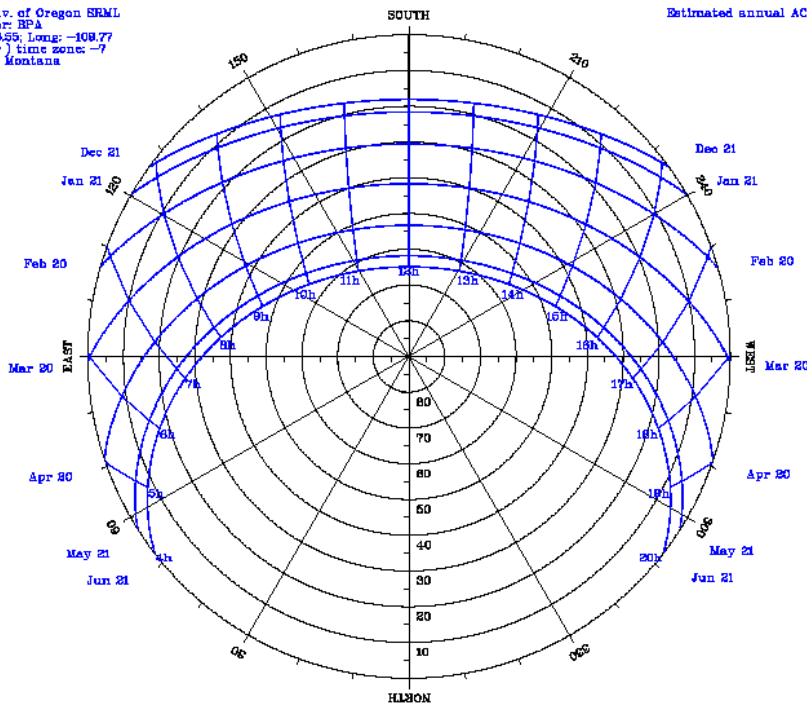


Havre Temperatures



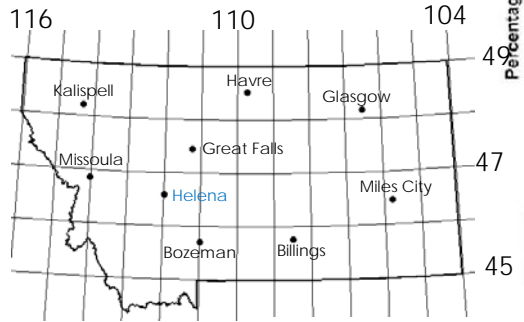
(c) Univ. of Oregon SRML  
 Sponsor: BPA  
 Lat: 48.55; Long: -109.77  
 (Solar) time zone: -7  
 Havre, Montana

Estimated annual AC output:

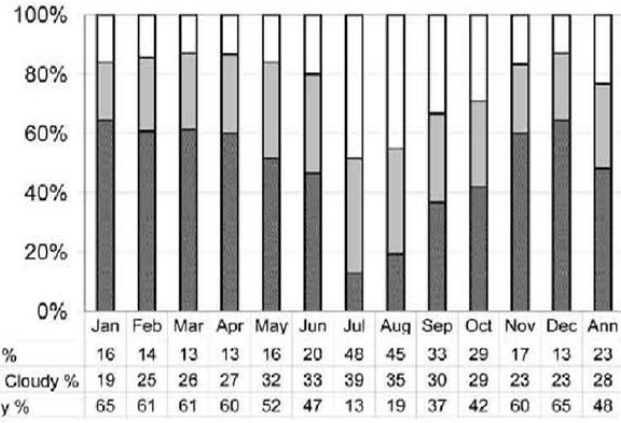


# HELENA, MONTANA

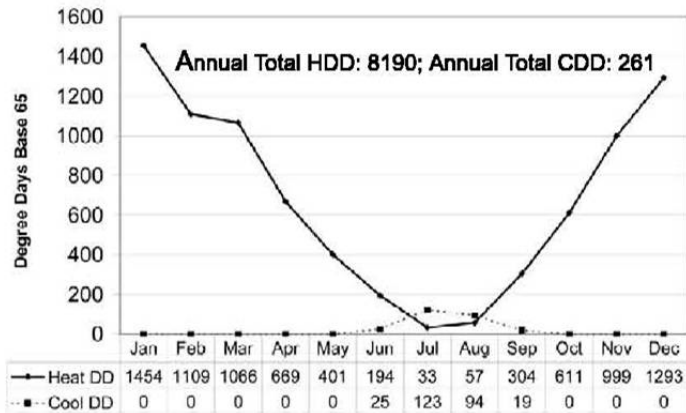
Latitude: 46.60 North  
 Longitude: 112.0 West  
 Elevation: 3828'



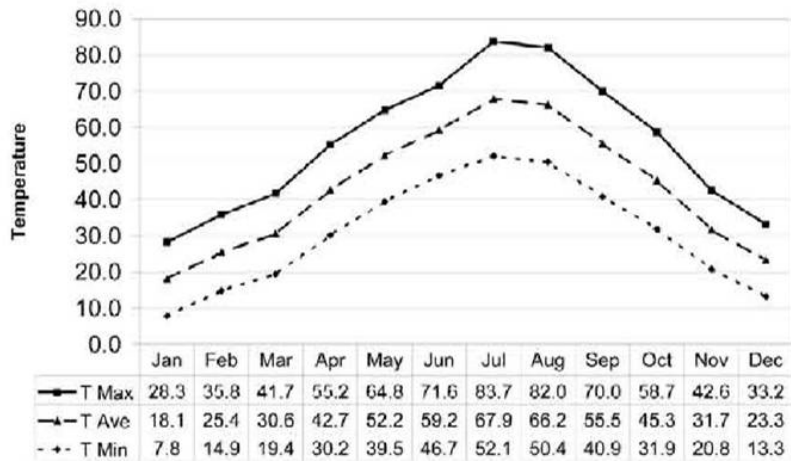
## Helena Sky Condition



## Helena Degree Days

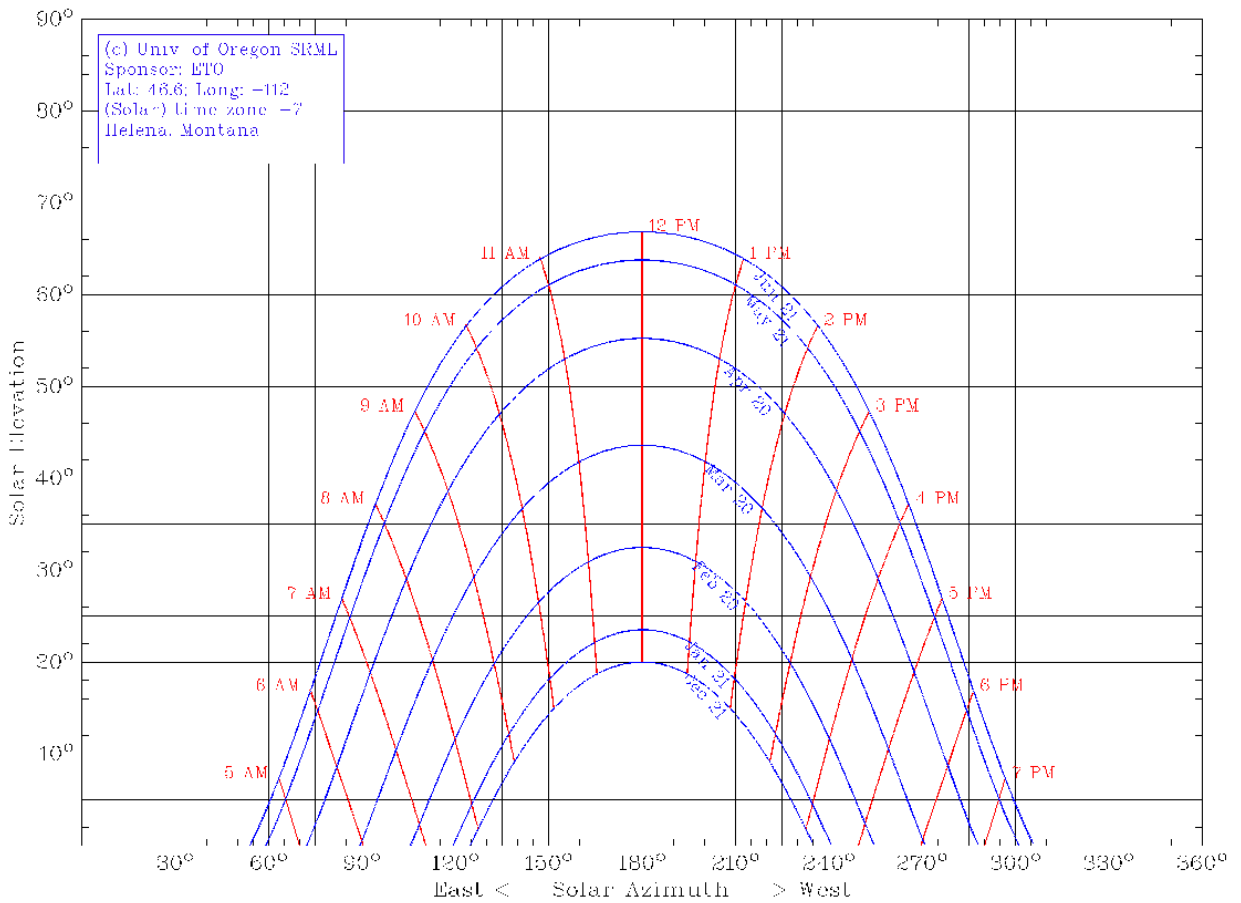
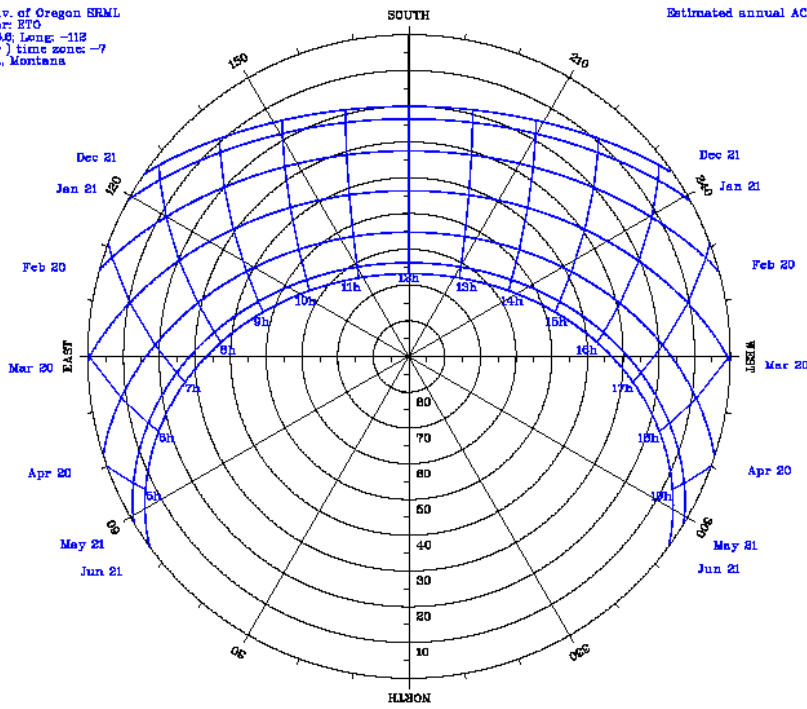


## Helena Temperatures



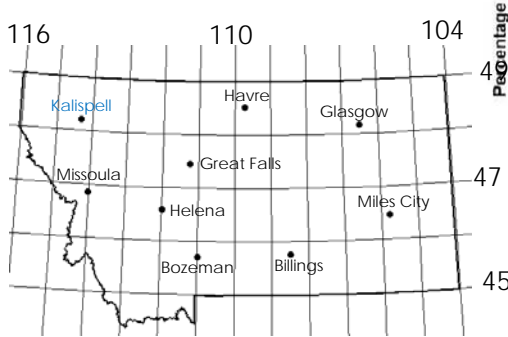
(c) Univ. of Oregon SRML  
 Sponsor: ETO  
 Lat: 46.6; Long: -112  
 (Solar) time zone: -7  
 Helena, Montana

Estimated annual AC output:

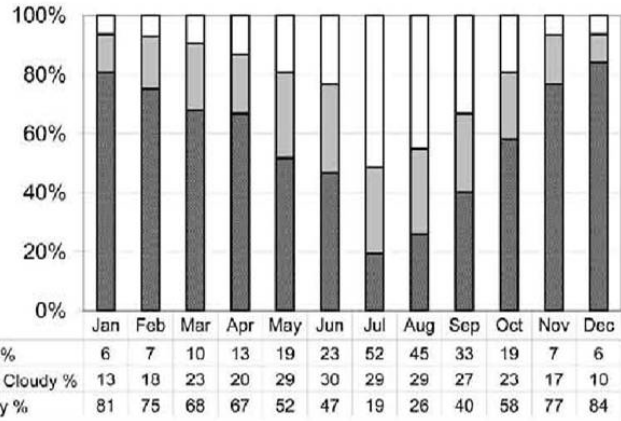


### KALISPELL, MONTANA

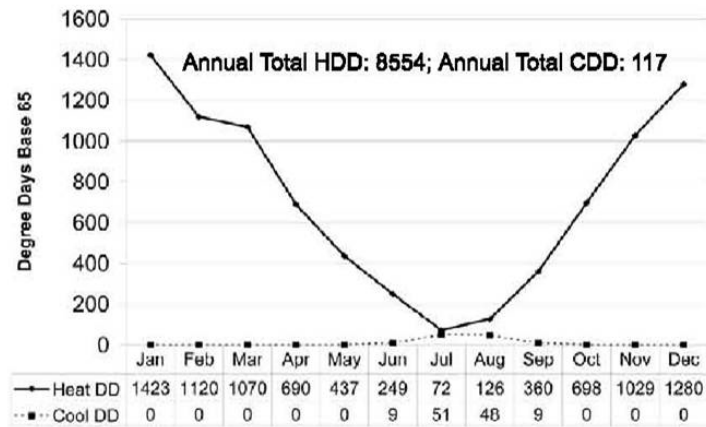
Latitude: 48.30 North  
 Longitude: 114.27 West  
 Elevation: 2965'



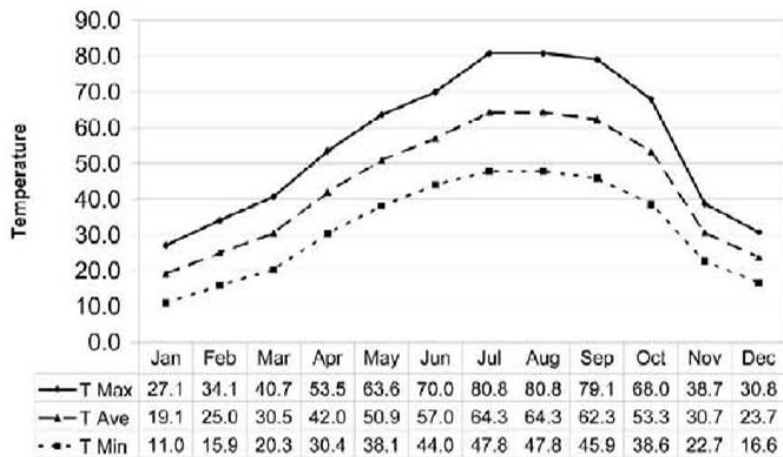
### Kalispell Sky Condition



### Kalispell Degree Days

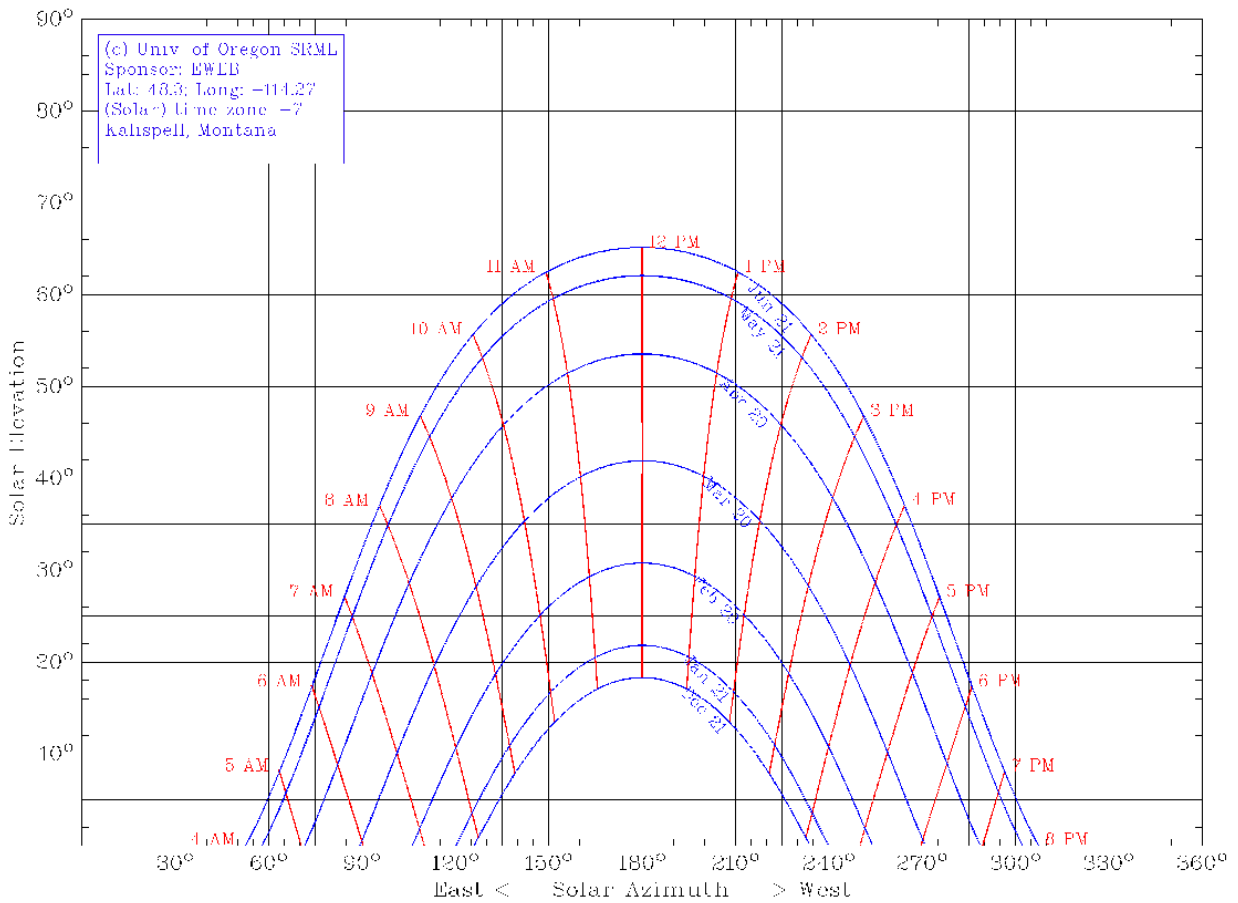
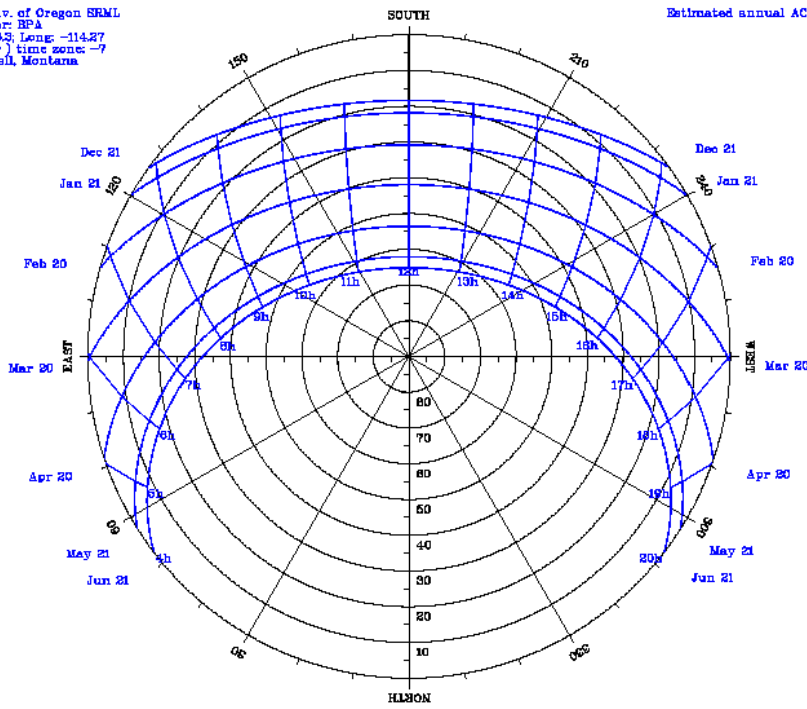


### Kalispell Temperatures



(c) Univ. of Oregon SRML  
 Sponsor: BPA  
 Lat: 48.3; Long: -114.27  
 (Solar) time zone: -7  
 Kalispell, Montana

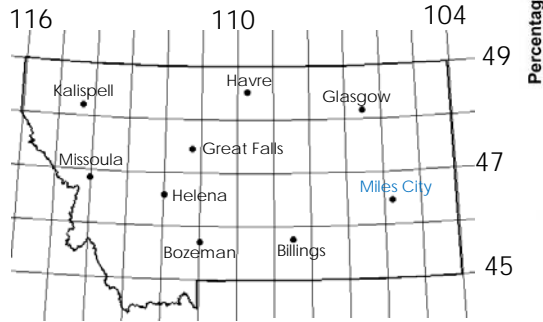
Estimated annual AC output:



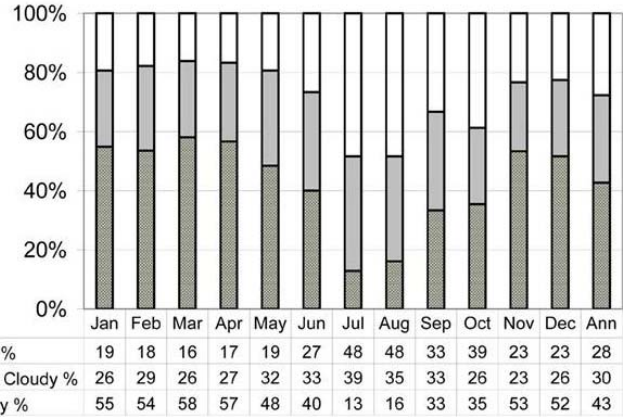


### MILES CITY, MONTANA

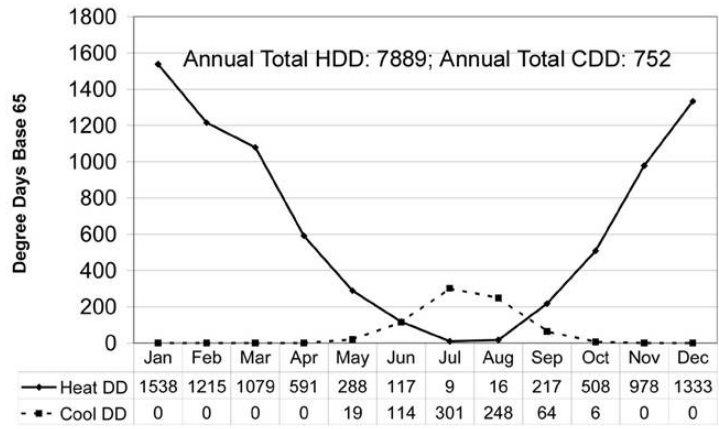
Latitude: 46.41 North  
 Longitude: 105.83 West  
 Elevation: 2629'



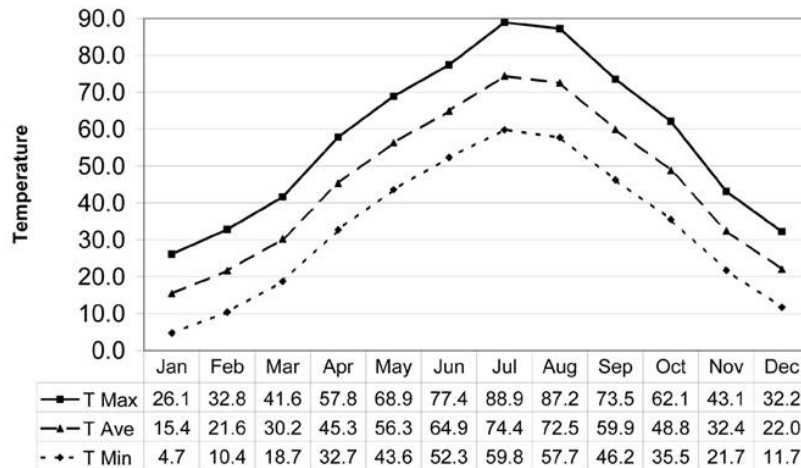
### Miles City Sky Condition



### Miles City Degree Days



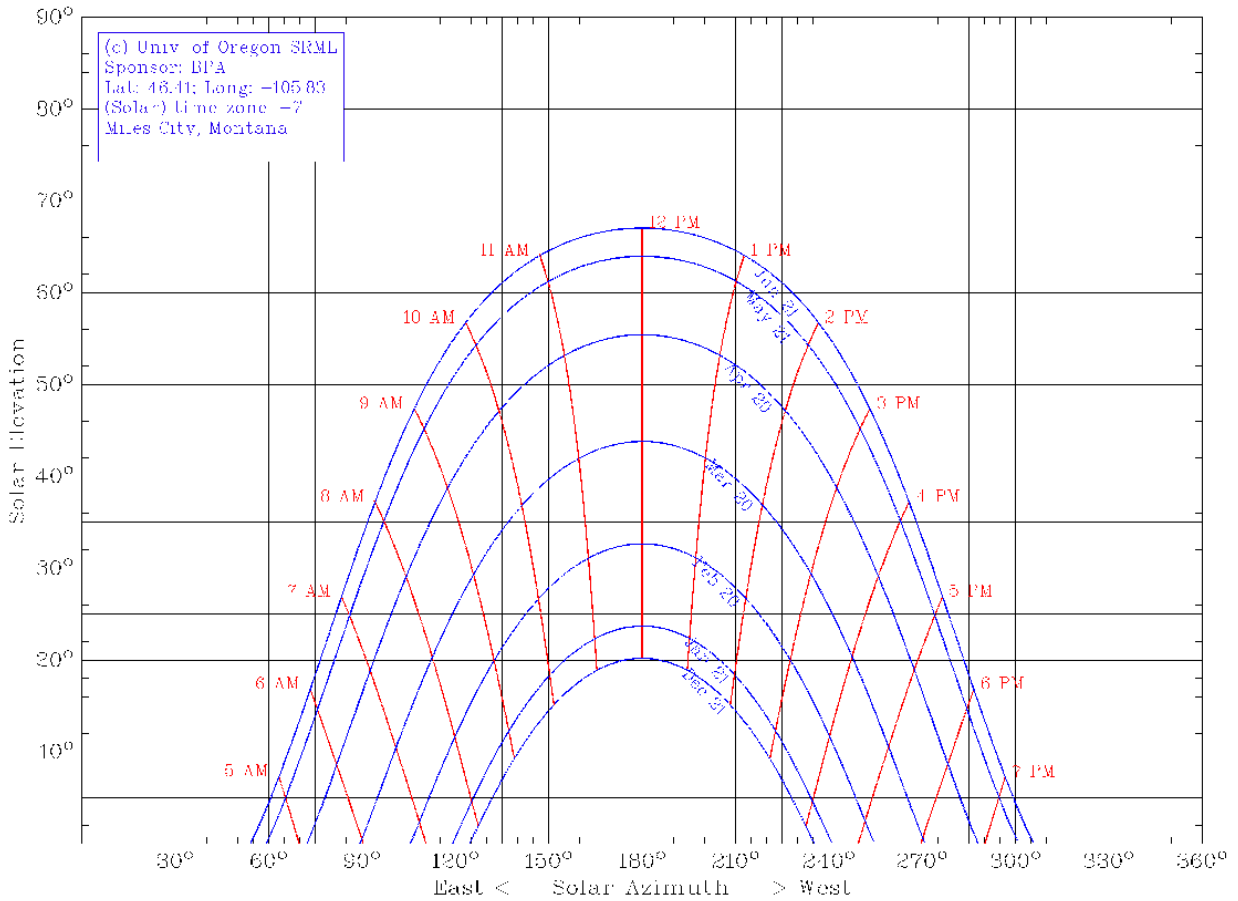
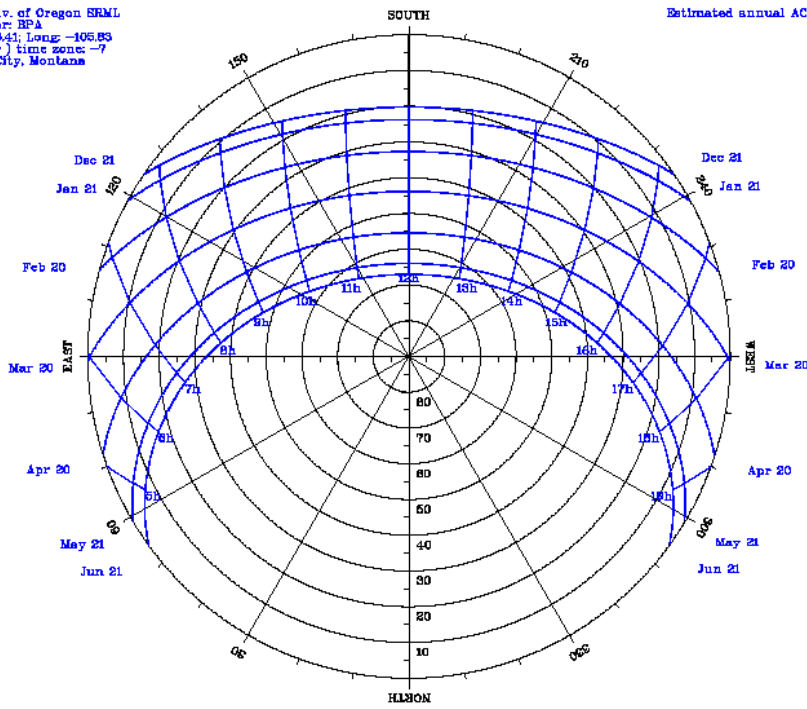
### Miles City Temperatures





(c) Univ. of Oregon SRML  
 Sponsor: BPA  
 Lat: 46.41; Long: -105.83  
 (Solar) time zone: -7  
 Miles City, Montana

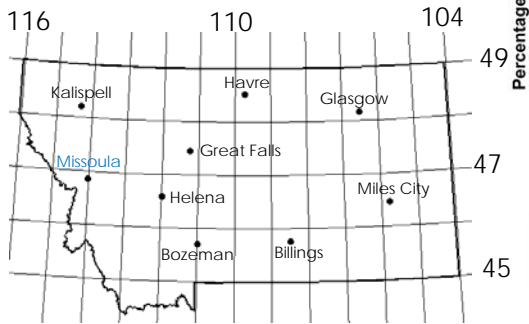
Estimated annual AC output:



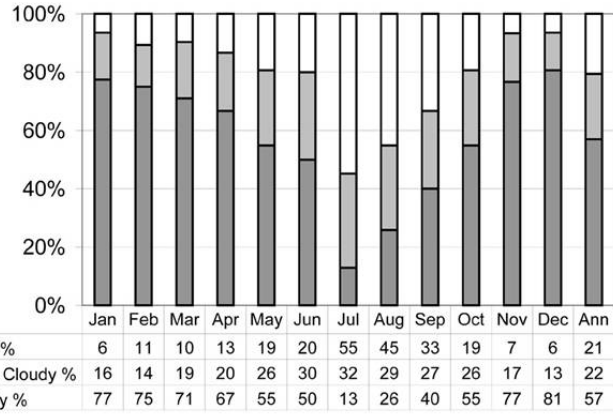
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## MISSOULA, MONTANA

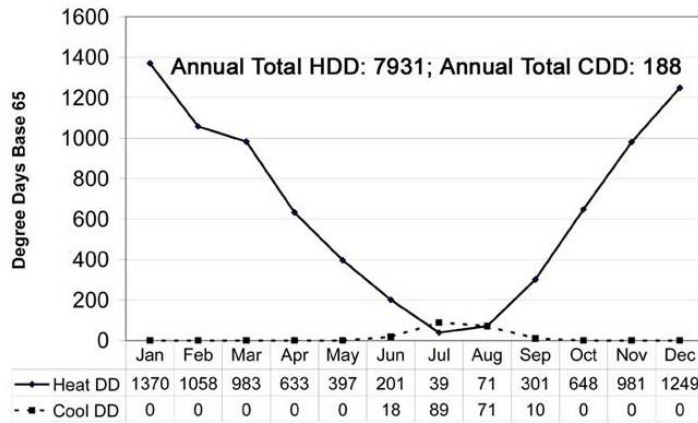
Latitude: 46.92 North  
 Longitude: 114.10 West  
 Elevation: 3197'



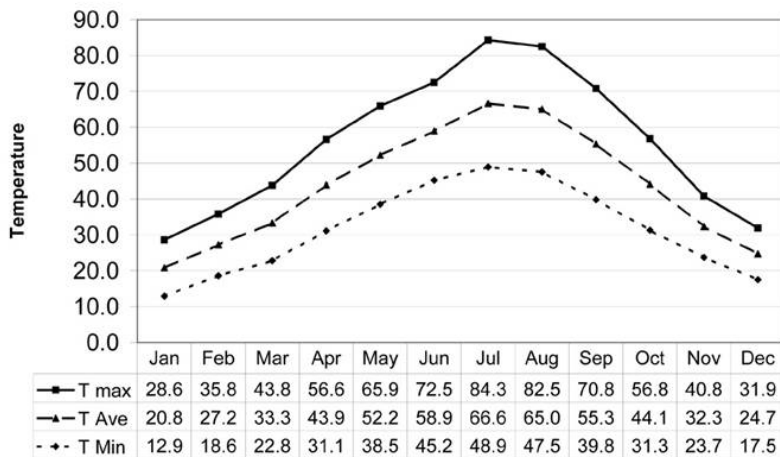
### Missoula Sky Condition



### Missoula Degree Days

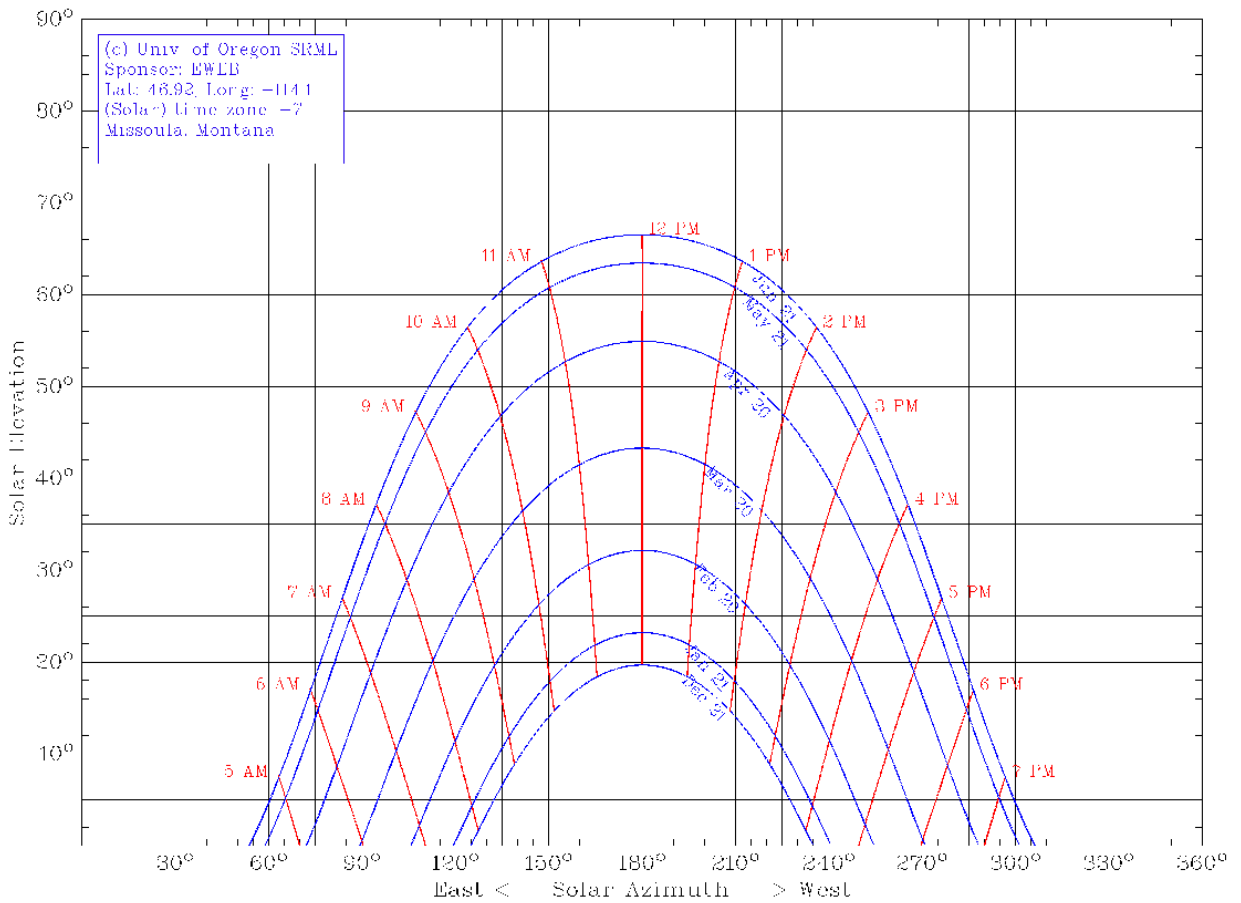
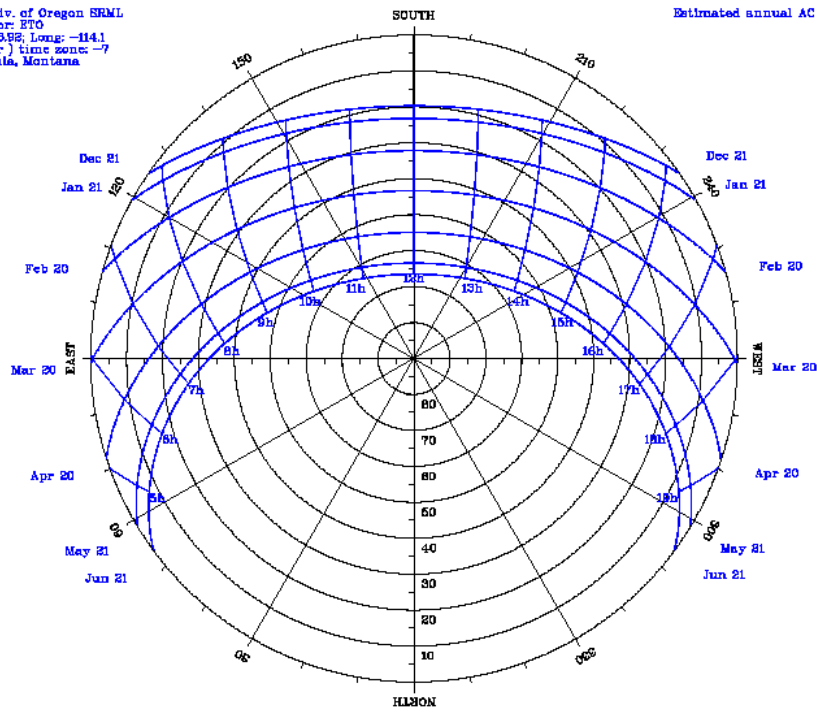


### Missoula Temperatures



(c) Univ. of Oregon SRML  
 Sponsor: ETO  
 Lat: 46.92; Long: -114.1  
 (Solar) time zone: -7  
 Missoula, Montana

Estimated annual AC output:



APPENDIX

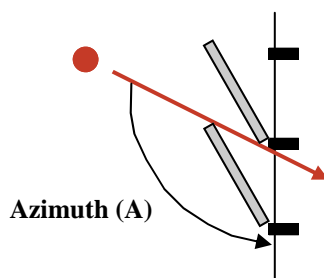
## Azimuth Angles

### FOR EAST GLAZING FINS: Solar Azimuth Angles at 8am (degrees measured from South)

City	Jan 21	Feb 21	Mar 21	Apr 21	May 21	Jun 21	Jul 21	Aug 21	Sep 21	Oct 21	Nov 21	Dec 21
Billings	59	66	72	79	85	89	88	80	70	60	55	55
Bozeman	61	68	74	81	87	91	90	82	72	63	57	57
Glasgow	58	64	69	76	82	86	85	77	67	58	53	53
Great Falls	61	68	73	80	86	90	89	82	71	62	57	57
Havre	60	66	72	78	84	88	87	80	70	61	56	56
Helena	62	68	74	81	87	91	90	82	72	63	57	57
Kalispell	63	70	75	82	88	92	90	83	73	65	59	59
Miles City	57	64	69	76	83	87	85	78	67	58	53	53
Missoula	63	70	76	82	89	93	91	84	74	65	59	59

### FOR WEST GLAZING FINS: Solar Azimuth Angles at 4pm (degrees measured from South)

City	Jan 21	Feb 21	Mar 21	Apr 21	May 21	Jun 21	Jul 21	Aug 21	Sep 21	Oct 21	Nov 21	Dec 21
Billings	50	55	63	73	81	83	80	73	67	61	55	50
Bozeman	48	52	61	71	79	81	77	71	65	59	53	52
Glasgow	51	56	64	74	81	83	79	73	68	62	56	48
Great Falls	47	52	60	70	77	80	76	70	64	58	53	48
Havre	49	53	61	71	78	80	76	70	65	59	54	49
Helena	47	52	60	70	78	80	76	70	64	58	52	48
Kalispell	45	49	57	67	74	76	73	67	61	56	50	46
Miles City	52	57	65	75	83	85	81	75	69	63	57	52
Missoula	45	50	58	68	76	78	74	68	62	56	51	46



VALUES OF P at 8am

City	Jan 21	Feb 21	Mar 21	Apr 21	May 21	Jun 21	Jul 21	Aug 21	Sep 21	Oct 21	Nov 21	Dec 21
Billings	36.6	3.2	1.0	0.4	0.1	0.0	0.1	0.3	1.0	2.2	6.7	164.7
Bozeman	-34.5	3.8	1.1	0.4	0.1	0.0	0.0	0.3	0.9	2.4	9.2	-24.2
Glasgow	43.6	3.3	1.1	0.5	0.2	0.1	0.1	0.4	1.0	2.4	7.4	-341.6
Great Falls	-16.2	4.4	1.1	0.4	0.1	0.0	0.0	0.3	1.0	2.7	13.6	-13.6
Havre	-21.9	4.1	1.2	0.4	0.2	0.0	0.1	0.4	1.1	2.6	11.9	-16.1
Helena	-16.0	4.3	1.1	0.4	0.1	0.0	0.0	0.3	1.0	2.6	12.3	-14.1
Kalispell	-6.7	6.6	1.2	0.3	0.1	-0.1	0.0	0.3	1.0	3.1	98.4	-6.8
Miles City	14.7	2.8	1.1	0.4	0.2	0.1	0.1	0.4	1.0	2.2	5.8	24.7
Missoula	-8.3	5.7	1.1	0.3	0.0	-0.1	0.0	0.3	1.0	2.8	26.8	-8.5

VALUES OF P at 12pm

City	Jan 21	Feb 21	Mar 21	Apr 21	May 21	Jun 21	Jul 21	Aug 21	Sep 21	Oct 21	Nov 21	Dec 21
Billings	2.3	1.5	1.0	0.7	0.5	0.4	0.5	0.7	1.0	1.5	2.2	1.2
Bozeman	2.3	1.5	1.0	0.7	0.5	0.4	0.5	0.7	1.0	1.5	2.2	2.7
Glasgow	2.5	1.7	1.1	0.7	0.5	0.5	0.5	0.7	1.1	1.6	2.5	3.0
Great Falls	2.5	1.6	1.1	0.7	0.5	0.4	0.5	0.7	1.1	1.6	2.4	2.9
Havre	2.6	1.7	1.1	0.8	0.5	0.5	0.5	0.7	1.1	1.7	2.5	3.1
Helena	2.4	1.6	1.1	0.7	0.5	0.4	0.5	0.7	1.0	1.5	2.3	2.8
Kalispell	2.6	1.7	1.1	0.7	0.5	0.5	0.5	0.7	1.1	1.7	2.5	3.1
Miles City	2.3	1.6	1.1	0.7	0.5	0.4	0.5	0.7	1.0	1.5	2.3	2.7
Missoula	2.4	1.6	1.1	0.7	0.5	0.4	0.4	0.7	1.0	1.6	2.3	2.8

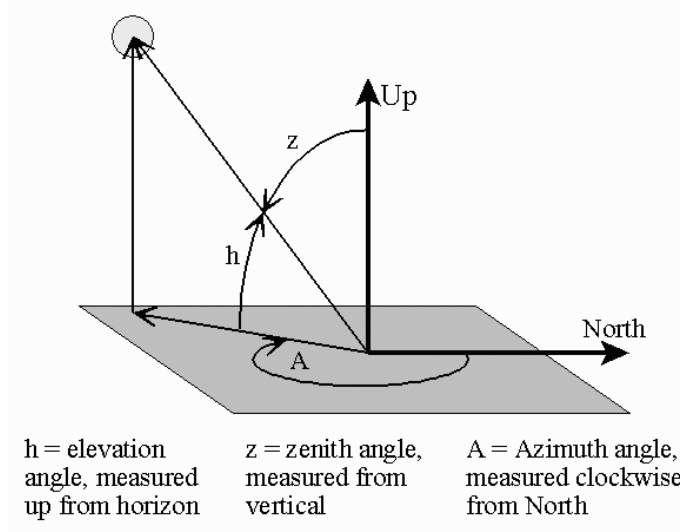
VALUES OF P at 4pm

City	Jan 21	Feb 21	Mar 21	Apr 21	May 21	Jun 21	Jul 21	Aug 21	Sep 21	Oct 21	Nov 21	Dec 21
Billings	4.6	2.0	1.0	0.5	0.2	0.1	0.2	0.5	1.0	2.3	6.7	10.1
Bozeman	4.1	1.9	1.0	0.5	0.2	0.2	0.3	0.5	1.0	2.1	5.4	7.6
Glasgow	6.5	2.4	1.1	0.5	0.2	0.2	0.2	0.5	1.0	2.7	13.3	32.2
Great Falls	4.6	2.1	1.1	0.5	0.3	0.2	0.3	0.5	1.0	2.3	6.3	9.5
Havre	5.5	2.2	1.1	0.5	0.3	0.2	0.3	0.5	1.1	2.5	8.4	14.9
Helena	4.2	2.0	1.1	0.5	0.3	0.2	0.3	0.5	1.0	2.2	5.6	7.8
Kalispell	4.4	2.1	1.1	0.6	0.3	0.3	0.3	0.6	1.1	2.2	5.7	8.3
Miles City	5.7	2.2	1.1	0.5	0.2	0.1	0.2	0.4	1.0	2.5	10.4	19.5
Missoula	4.0	2.0	1.1	0.6	0.3	0.2	0.3	0.5	1.0	2.1	5.0	6.9

GLOSSARY

**Altitude (angle  $h$  in *Solar Angles image*):** The vertical angular distance of a point in the sky (usually the sun) above the horizon; also known as Elevation. Altitude is measured positively from the horizon ( $0^\circ$ ) to the zenith, the point in the sky directly overhead ( $90^\circ$ ).

**Azimuth (angle  $A$  in *Solar Angles image*):** The horizontal angular distance between a vertical plane containing a point in the sky (usually the sun) and true north. In other words, the angle of the sun from south as seen in plan view.



*Solar Angles*

Image from: <http://www.solsticeamateur.com/SolarGeneral.htm>

**Footcandle (fc):** A common unit of illuminance used in the U.S. A well day lit space has an average of 50 to 100 footcandles.

**Glass:** Only the glass portion of a window unit.

**Glazing:** The window or door assemblies that includes all parts of the window unit.

**Insulated Glass Unit (IGU):** The assembly of a minimum of two pieces of glass separated by a spacer. More layers of glass allow for greater U-values.

**Light Shelf:** A horizontal element positioned above eye level to reflect daylight onto the ceiling.

**Louver:** A series of baffles used to shield a light source from view at certain angles, or to absorb some light. Louvers are most common on east and west windows as a daylight controls. Vertical louvers are also known as Fins.

**Low-emittance coating (Low-E glass):** A coating on glazing that is comprised of microscopically thin, virtually invisible, metal or metallic oxide layers deposited on a window or skylight glazing surface primarily to reduce the U-factor. Low-E glass is a standard choice for climate zones like Montana.

**R-Value:** The resistance to heat flow. It can be calculated by taking the reciprocal of the U-Value. Higher numbers indicate better insulation. This term is not typically used to represent heat transfer through window units.

**Shading Coefficient (SC):** The number defining the solar control aspect of glazing. This value only refers to the glass in the assembly and has recently been replaced by SHGC.

**Solar Heat Gain Coefficient (SHGC):** The fraction of solar radiation admitted through a window. An SHGC of 1.00 indicates that 100% of the solar heat striking the glazing will enter the space. The higher the value, the more solar heat will enter the space.

**U-Factor:** The measurement of the transfer of heat through an assembly of materials. Many manufacturers interchange U-Value and U-Factor. Both U-Value and U-Factor refer to the quantity of heat transferred through materials.

**U-Value:** The measurement of the transfer of heat through a single material, measured in BTU/hr-sq.ft.-F°. Each aspect of the assembly has a U-Value that contributes to a combined U-Value (known as a U-Factor). **The U-Value should be 0.35 or less for Montana's climate.** A standard single-pane window has a U-Value of 1.13 BTU/hr. Lower numbers indicate better insulation values.

**Visible Light Transmittance (VT):** The percentage of available daylight entering through a window or glazing system. Clear glazing has a VT of 90%; that means that 90% of the available light is entering the space.

**Visible Reflectance:** The value that indicates to what degree the glazing appears like a mirror from both inside and out. High reflectance equates to low VT and all the interior disadvantages that may be associated with that characteristic.

**Window to Wall Ratio (WWR):** The ratio (percentage) of glazing area to the exterior wall area.  
$$\text{window area} \div \text{exterior wall area} = \text{WWR}$$

**Work plane:** The plane at which work is performed, usually horizontal and at desk height (30") from the floor. The work plane is typically the height at which the average footcandle measurement is taken.

**Zenith Angle (angle  $z$  in *Solar Angles* image):** The direction pointing directly above a particular location, measured from the vertical.



## REFERENCES

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- Carmody, J. (2004). *Window Systems for High-Performance Buildings*. New York: W.W. Norton & Co.
- Dykers, C. *Time Between Light and Dark*. The Daylight Site. Retrieved 2011 from, <http://thedaylightsite.com/showarticle.asp?tp=6&id=65&catid=17&hl=time%20between%20light%20and%20dark>
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