OPTIMIZING ROOF FUNCTIONALITY IN COMMERCIAL BUILDINGS

Final Report

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Roof Consultants Institute Foundation (RCIF)

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1. INTRODUCTION

1.1 GOALS AND OBJECTIVES

The goals of this research are: 1) to increase awareness of the importance of maximizing and optimizing the use of roofs in commercial buildings, and 2) to offer a new paradigm for building practitioners to be able to systematically approach, design and develop roofs as a key platform to achieve NZEBs by 2025 and carbon-neutral buildings by 2030.

To achieve these goals, objectives were set to develop a compendium of strategies for optimizing roof functionality in commercial buildings in Phase-I (1st Year).

1.2 TASKS PERFORMED

The specific tasks performed were as follows:

✓ Reviewed the existing tools and programs that can help design and develop sustainable roofs for commercial buildings
✓ Examined codes, standards, and guides that inform minimum requirements and/or best practices for roof design
✓ Identified seven functional areas of roofs that should be systematically deliberated by building practitioners to best-utilize the potential of the roof
✓ Benchmarked the PNNL’s 16 cities, which represent the 16 climate zones in the US, to develop the climate-specific strategies for sustainable roof design
✓ Explored state-of-the-art technologies that can be applied to roofs to increase energy efficiency and renewable energy utilization along with other design considerations
✓ Developed a compendium of strategies to help maximize and optimize the functionality of roofs in commercial buildings
✓ Developed an online, interactive tool or RoofConsultant incorporating the compendium of strategies for the design of sustainable roofs in commercial buildings.
2. EXISTING TOOLS AND PROGRAMS

There are not many useful tools or programs that aid sustainable roof design. However, a few programs were found that provide designers and consultants with valuable information for their practices. Three programs (Climate Consultant, RoofNav, and RoofPoint) are introduced in the following subsections.

2.1 CLIMATE CONSULTANT

The Climate Consultant, developed by UCLA (Milne, 2007), is a more general tool that analyzes the climate conditions in specific locations. The purpose of this tool is to demonstrate with graphic images the attributes of climate conditions, including temperatures, humidity, wind velocity, sky cover, and solar radiation for every hour of the year in specific locations, and present some guideline and strategies for design decisions. The Climate Consultant helps designers generate energy efficient sustainable buildings for a chosen location. As a general tool, Climate Consultant is frequently utilized by architects and students for their design projects. It gives relevant information in terms of climate conditions. There is no specific information or strategies given for roof design; however, roof consultants can utilize this tool to preliminarily analyze the environmental and climate conditions of their projects.

2.2 ROOFNAV

RoofNav is a source of Factory Mutual (FM) Approved roofing assemblies and products. It is a tool for roofing professionals to put the roofing information from the approval guide and related installation recommendations from FM global property loss prevention data sheets. RoofNav presents roofing professionals step-by-step guidance on how to identify, configure and install different roofing assemblies and components that comply with the FM approval roofing-standard.

Some benefits of this tool are:

- Configuring and installing FM Approved roofs and roofing assemblies
- Determining hail, wind/uplift, and fire ratings specific to the projects
- Producing accurate installation guidelines
- Accessing the latest FM Approvals information and FM Global property loss prevention data sheets
- Identifying available substitute products that meet FM Approvals requirements
- Accessing the information via the internet real time

RoofNav is a useful tool that provides roofing practitioners with valuable and practical information for their projects.
2.3 ROOFPOINT

RoofPoint specifically designed for the performance evaluation of a roofing system. RoofPoint is a consensus-based green rating system developed by the Center for Environmental Innovation in Roofing. The National Roofing Contractors Association (NRCA) is one of the supporters of this tool. It provides a means for users to select nonresidential roof systems based on long-term energy and environmental benefits. It includes a calculator (using CO₂ calculator) to evaluate both new and replacement roof systems in terms of energy performance over the life cycle of the buildings. The primary function of the calculator is to measure the energy and environmental characteristics of roofing systems in commercial and institutional buildings and compare different roof system solutions in regard to energy and environmental impacts (Hoff, 2013). RoofPoint also utilizes existing technologies such as PVWatts, developed by the US National Renewable Energy Laboratory (NREL), which models and calculates the Photovoltaic (PV) energy production of grid-connected systems at locations around the world.

Similar to LEED of the USGBC, as a rating tool RoofPoint focuses on end results and practices. It provides a total of 23 sustainable strategies to obtain roof points, or “rates”. There are five functional areas that RoofPoint includes: energy management, materials management, water management, life-cycle management, and roofing innovation.

Currently, RoofPoint is one of the most systematic rating programs that can give roofing practitioners quantitative outcomes, which result in benchmarking for better practices in terms of energy efficiency and renewable energy systems application.

2.4 SUMMARY OF EXITING TOOLS

There are three programs available for roofing practitioners to use in their projects. Each of these has specific target areas of analysis. Climate Consultant is not a tool that deals with roof projects, but an analysis tool that targets general audiences to provide design strategies based on climate conditions. RoofNav is a large materials database that provides FM certified material options for roof practitioners. RoofPoint is a rating system that gives performance status of a roof compared to other roof projects in terms of energy efficiency and renewable energy generations.

A new tool, RoofConsultant, is introduced in this project. It focuses on design aspects that are different from the information the existing tools and programs provide. RoofConsultant focuses on providing specific options and sustainable measures for architects and other designers to consider during early phases of
designing. The following chapter discusses the methodology and contents of RoofConsultant.

3. METHODOLOGY

This chapter includes the methodology and structure of RoofConsultant. It starts with comparing RoofConsultant to the RoofPoint program, which helps better understand the differences between the two programs that may otherwise appear similar to each other. Roof functions are categorized in seven different areas in RoofConsultant. Numerous sustainable strategies for individual functional areas are introduced. Significant boundary conditions and guidelines that should be considered are presented, such as climate conditions, codes, and standards. Additional issues are discussed at the end, including roof shapes, implementation costs, and psychological effects.

3.1 ROOFCONSULTANT VS. ROOFPOINT

Table 1 shows the differences between RoofConsultant and RoofPoint. The target area of RoofConsultant is the early design phase. Although it has a significant role in developing sustainable buildings and achieving Net Zero Energy Buildings (NZEBs), designers do not usually give much attention to the roof area during the design process. RoofConsultant aims to provide design strategies that help achieve the goals of energy efficiency and renewable energy generation strategies that result in sustainable building.

Table 1. Comparison of Programs between RoofConsultant and RoofPoint

<table>
<thead>
<tr>
<th>RoofConsultant</th>
<th>RoofPoint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool for early design decision making</td>
<td>Tool for rating (like USGBC’s LEED)</td>
</tr>
<tr>
<td>Focused on early design phases and education</td>
<td>Focused on end results (points or scores) and practices</td>
</tr>
<tr>
<td>Uses 7 functional categories</td>
<td>Uses 5 management categories</td>
</tr>
<tr>
<td>- Energy efficiency</td>
<td>- Energy management</td>
</tr>
<tr>
<td>- Energy generation (renewables)</td>
<td>- Materials management</td>
</tr>
<tr>
<td>- Daylighting</td>
<td>- Water management</td>
</tr>
<tr>
<td>- Equipment allocations</td>
<td>- Durability &amp; life cycle management</td>
</tr>
<tr>
<td>- Rain water collection</td>
<td>- Environmental innovation</td>
</tr>
<tr>
<td>- Water proofing</td>
<td>-</td>
</tr>
</tbody>
</table>

6
Recreation

| Provides comprehensive strategies to design sustainable roofs | Provides 23 strategies to obtain roof points or rates |

RoofConsultant also aids in increasing the designer’s awareness of the importance of best utilizing the roof area by providing information about potential energy savings for different scenarios.

As RoofConsultant focuses on the early design phases providing as much useful information as it can for designers, it includes seven comprehensive functional areas. The first three functional categories (energy efficiency, energy generation, and daylighting) deal with energy issues more closely than the other four categories (equipment allocation, rain water collection, water proofing, and recreation). Each of seven categories include multiple design strategies for the development of sustainable buildings; e.g., green roof, cool roof, and added insulations for the energy efficiency category.

Unlike RoofPoint, which is a benchmarking tool focusing on end results, RoofConsultant is an educational tool that focuses on the early design phases and helps designers make sustainable roof design decisions. RoofConsultant aims to be an information gateway for the design of sustainable roofs, which are energy efficient, thermally comfortable, environmentally friendly, and economically feasible. RoofConsultant is an interactive system, so that the user can try different design options for different scenarios with preliminary analysis information.

### 3.2 ROOFCONSULTANT: FRAMEWORK

There are a large number of parameters that affect the performance of roofs. Roof functions can also vary substantially depending on the area of interests. Developing a tool (RoofConsultant) is the ultimate goal of this research. The first phase of it was to develop a compendium of strategies that can be utilized for the design of sustainable roof systems.

The main framework of RoofConsultant was created based on three key conceptual areas: roof functions, boundaries, and realities of implementation. Figure 1 shows the idea of the three areas. The roof functions work with the boundary conditions. The boundary conditions affect the performance of the roof functions. Reality issues need to be considered carefully. As a result, RoofConsultant is organized into
three primary areas representing the most important principles for optimal roofing systems. Each of the three conceptual groups includes:

- **Roof Functions**: key design parameters or sustainable strategies that should be considered in the early design phases.
- **Boundaries**: specific code requirements and guidelines for particular climate conditions.
- **Reality**: overarching concerns that need to be thought out since there are always issues about aesthetics (roof shape), implementation costs, and/or psychological aspects within a built environment.

Figure 1. Three Conceptual Areas of RoofConsultant Framework

Figure 2 shows the framework of RoofConsultant, which is an expanded version of Figure 1. In Roof Functions, a total of seven sub-categories were identified: 1) Energy Efficiency, 2) Energy Generation (Renewables), 3) Daylighting, 4) Equipment Allocations, 5) Rainwater Collection, 6) Water Proofing, and 7) Recreation. The first three functional areas are clustered as a group indicating that they are closely related to the energy issues, such as energy efficiency, energy generation, and daylight utilization.

The other four functional areas are also clustered as a group that deals with important functions other than energy related issues. Equipment allocation is included as one of the roof functions. The roof areas in commercial buildings are frequently used to site HVAC systems such as Rooftop Air Handling Units (AHUs) and cooling towers. The rainwater collection function is included since water conservation becomes increasingly important. Water proofing a roof is of great concern in the roofing industry, so it included as one of the roof functions. Roofs
can also be used as recreational areas depending on the shape and program of the roof area.

These seven functional areas of roofs were investigated in detail to develop specific design strategies. Strategy details are presented in the following subsections.

Figure 2. Framework of RoofConsultant

These strategies can or cannot work properly depending on certain environments and climate conditions. Figure 3 shows how the three conceptual areas (Functions, Boundaries, and Reality) are related and connected with other groups of parameters. Design strategies need to be filtered through the boundaries and reality issues. In other words, each strategy in the left column is related to other parameters in the right column.

In the U.S., there are eight climate zones defined in the International Energy Conservation Code (IECC). To represent all climate zones in the U.S., USDOE’s Pacific Northwest National Laboratory (PNNL) identified sixteen cities. The sixteen cities and their locations were used in this study to specifically develop design
strategies that work suitably for individual climate locations. The existing codes, standards, and guidelines were inspected to find information relevant to the projects and measures that deal with roof systems.

There are also existing programs that can be benchmarked to help determine design parameters. The aforementioned existing programs, such as RoofPoint, RoofNav, and Climate Consultant, include valuable information to apply to RoofConsultant. Especially, the RoofPoint program provides 23 strategies, some of which were referenced in the RoofConsultant database.

After functions and boundaries have been determined there are other important aspects to consider in the design process, such as aesthetics (i.e., roof shapes), implementation costs, and potential psychological effects. This is one of the three structural areas in the RoofConsultant framework. The following sections discuss more details of individual strategies in each category.
3.3 ROOFCONSULTANT: MAIN FUNCTIONS OF ROOF

As discussed earlier, there are seven functional areas identified for roofs. Each of these roof functions includes specific design strategies. The specific technologies of the strategies are explained in this section.

3.3.1 ENERGY EFFICIENCY

In buildings, energy efficiency can be achieved by several different means. There are typically three areas of concern: energy loads, air handling systems, and thermal power plant. The building’s energy loads are mainly determined in the early phases of design; Some typical parameters include the building’s geometry, insulation materials, window to wall ratio, glazing, and orientation, which governs the energy loads of a building and is constant until the end of the building’s life. HVAC systems and plants also have substantial effects on energy efficiency; however, their effects are less than those of energy loads.

Figure 4. Energy Efficiency Strategies and Relationship with Other Conditions
The independent parameter most affecting a building’s energy load and consumption is the current weather conditions. To maintain a comfortable built environment, some type of energy should be consistently provided to indoor spaces as a form of heating and/or cooling. Heat transfer issues (heat loss and heat gain – i.e., conduction, convention, and radiation) always exist within the building fabric.

Of all building surfaces, the roof is the area that is mostly sensitive to heat transfers due its exposure to the outdoor environment. For this project, several energy efficiency strategies were examined and classified into three groups: green roof, cool roof, and high-performance roof materials. Figure 4 shows how these three strategic areas of achieving energy efficiency are inspected with respect to boundary conditions and reality issues.

3.3.1.1 GREEN ROOF (VEGETATION)

Green roofs provide additional insulation value by reducing the amount of solar radiation reaching the roof structure beneath it. The key properties of green roofs are direct shading, evaporative cooling, and photosynthesis, which leads to a lower surface temperature and reduced heat transfer through the roof (Saiz, 2006).

Most environmental benefits of green roofs are categorized in three main sections: storm-water management, energy conservation and urban habitat provision. These include aesthetic appeal, water retention, improved urban air quality as a result of producing more oxygen and less carbon dioxide, reduction of the urban heat-island effect, protecting the underlying roof membrane and the longevity of the roof, fire resistance, and increased insulation for energy savings and noise mitigation. Despite high installation costs, green roofs are more economical due to the extension of roof life and energy savings (Costleton, 2010; Saiz, 2006; Saadatian, 2013; Oberndorfer, 2007).

Green roofs are an ecosystem that can be integrated with other ecological systems, such as solar thermal and photovoltaic applications, to minimize waste products and maximize energy capture. It is also called an “eco-roof”. Green roofs improve the insulation properties of buildings due to the additional mass and low stiffness that induces damping effects. Despite the multiple environmental advantages of green roofs, its maintenance is an
important issue that directly affects the life-time analysis of the system. In the realm of water management issue, the green roof decreases run-off water and reduces the load on water treatment facilities; however some green roofs increase water consumption because they require irrigation (Oberndorfer, 2007; Wark, 2003).

There are two types of green roof systems:

- **Extensive** green roof construction: This system is known as low profile or performance system and has a substrate. It contains an insulation surface, a water proofing membrane, a layer of growing medium, and a vegetation surface. It is designed for maximum thermal performance and minimum weight load while requiring minimal plantings (Wark, 2003; Oberndorfer, 2007).

- **Intensive** green roof system: A deeper substrate layer to allow for deeper rooting plants like shrubs. This type is known as high profile or a roof garden and contains a variety of plant types. Because of the increase weight load, intensive green roofs require specific structural improvement. Intensive roofs have a considerable affect on air quality and act as an urban carbon sink (Spala, 2008; Wark, 2003; Oberndorfer, 2007).

The extensive green roof construction is of our interest in this research.

**Energy performance of green roofs:** Green roofs have diverse performance in various seasons. In summer, they have more efficiency in part because it provides shading and protection from solar radiation, filtering polluted air and reduce the heat island effect. During winter, a green roof system’s effect is relatively insignificant and may result in increase energy consumption if improperly designed. Choosing appropriate materials is the key for durability, energy efficiency, and environmental effects of a green roof (Oberndorfer, 2007; Spala, 2008).

Solar radiation is absorbed by plants via biological functions such as photosynthesis, respiration, transpiration and evaporation. The remaining solar radiation is converted to thermal load, which passes through the building roof. Dropping thermal fluctuations in the external layer of the roof and enhancing the thermal capacity of the
roof reduces thermal losses and decreases energy consumption. (Niachou, 2001). Green roofs can be installed on both flat and pitched roofs with an angle between 0° and 45°.

3.3.1.2 COOL ROOF (COLORS OR ALBEDO)

A cool roof is a roof that stays cool from minimizing solar absorption and thermal emissions. The lower temperature of cool roofs leads to reduced heat transfer into interior spaces and a resulting reduction in the cooling load of the building. Cool roofs also lower peak energy demand by 10%-30% by reducing heat gain through the roof. In the times of the day when the outdoor temperature is lower than the inside temperature, using heavily insulated roofs prevent heat flow out of the space (Akbari et al, 1999). The efficiency of a cool roof depends on building construction, building operation, and climate conditions. In cold climates, applying a cool roof may have negative consequences, increasing the annual heating load. Lower temperatures lead to accumulation of moisture in roofing systems. So, the energy efficiency of cool roofs and associated moisture behavior should be analyzed in cool climate conditions. Generally, the energy cost savings for climates with a long cooling season and a short heating season are much larger than those with a long heating season. In hot climates the amount of roof insulation required can be reduced by increasing roof reflectivity. For instance, by raising the level of roof reflectivity from 20% to 60%, we can reduce the roof insulation by half and expect annual energy consumption to remain the same. (Akbari et al, 1999; Levinson, 2010; Moghaddaszadeh, 2012).

The advantages of cool roofs are:

- Reduction in building heat gain
- Decreased summer cooling loads ranging 10-40% on average, depending on building characteristics, function and climate conditions
- Reducing the size of AC equipment required due to the reduction of peak cooling electricity demand
- Increasing the life expectancy of the roof system while reducing maintenance expenses
- Mitigating the heat island effect by 1-2° C
Reducing air pollution and CO\textsubscript{2} emissions

Applying cool roof technology is a common strategy in the U.S. There are some organizations that provide useful information and guides such as U.S. EPA and the U.S. Cool Roof Rating Council. The USGBC’s LEED program promotes this technology. There are also standards in the energy code related to cool roofs.

In Europe, the European Cool Roof Council (ECRC) was founded to provide relevant information about cool roof technology and its development for practitioners such as industry, research institutes, marketing and manufacturing, contractors, consultants, and end users. The ECRC’s website (http://coolroofs-eu-crc.eu/) presents a technical glossary, publications, and resources about technical, market and policy aspects, and a database about cool roofing materials (Seynnefa, 2012).

Substituting a cool roof for a non-cool roof decreases electricity demand due to cooling loads and cooling equipment capacity requirements, while slightly increaseing heating energy consumption. A simple way to measure the efficiency of cool roof is by calculating the ratio of annual heating load increase to annual cooling load decrease (Levinson, 2010; Akbari, 2011).

**Properties of cool roof materials:** A roof surface with cool material that has high solar reflectance (SR) and high infrared emittance will have lower temperature rather than the same roof with lower SR and e-values. Due to the lower surface temperature, less heat is transferred from the relatively cooler exterior surface in to the indoor spaces, and cooling loads and peak energy demand for cooling interior spaces is decreased (Santamouris, 2011). The definitions of solar reflectance and emittance are:

- **Solar reflectance (SR):** The ability of the product to reflect solar radiation and energy away from the roof ranging, from 0 to 1 (0-100%).
- **Emittance:** A roof’s ability to radiate absorbed heat. It represents how well a surface releases energy away relative to a black surface, ranging from 0 to 1.

Recently, with the development of new materials and techniques, which present advanced thermal characteristics with enlarged
thermal capacities and dynamic optical properties, new, cooler materials are being generated. These are categorized in four phases including:

- Highly reflective and emissive light colored materials
- Cool colored materials with increased near-infrared radiation
- Phase change materials
- Dynamic cool materials

New technologies exist for advanced construction methods for cool roofs. Fractal roofs, which simulate strategies used by trees, are new roof design strategies that consist of many Sierpinski tetrahedron units and block 100% sunlight from a particular direction. The roof does not provide complete shading and has some open spots to allow air to flow, creating a healing, luminous environment. This type of roof is very effective for reducing surface temperatures without resulting in high heat radiation (Sakai, 2012).

Using a smart vapor retarder or self-drying roof is an appropriate technology for reducing the risk of moisture accumulation in a roofing system. Other new roofing system technologies include smart vented roofs and self-drying roofs, which reduce the risk of mold growth (Moghaddaszadeh, 2012).

Some of the important issues related to highly reflective surfaces in general:

- People walking on highly reflective surfaces would experience unpleasant glare in addition to direct sunlight.
- Solar radiation reflected off light-colored pavements can increase the temperature in nearby buildings.
- Although reflective roofs decrease temperatures in the buildings they enclose and mitigate the “urban heat island effect,” they may actually increase global temperature.
- Cool roof can increase heating costs in winter months.
- In some climates where there are more heating days than cooling days, cool roofs may not be effective in terms of energy efficiency.

A roof can qualify as cool when it meets two requirements. The first is by meeting or exceeding both the minimum solar reflectance and thermal emittance values. The other is to meet or exceed the
minimum Solar Reflectance Index (SRI) requirement, which lets roofs have a low thermal emittance and a high solar reflectance. Table 2 shows the minimum cool roof requirements.

**Table 2. Minimum Cool Roof Requirements by California Energy Commission**

(Urban and Roth, 2010)

<table>
<thead>
<tr>
<th>Roof Type</th>
<th>Solar Reflectance (3-year aged)</th>
<th>Thermal Emittance (New or aged)</th>
<th>OR Solar Reflectance Index (SRI) 3 Year aged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Sloped</td>
<td>0.55</td>
<td>0.75</td>
<td>64</td>
</tr>
<tr>
<td>Steep Sloped</td>
<td>0.20</td>
<td>0.75</td>
<td>16</td>
</tr>
</tbody>
</table>

The cool roof requirements depend on the slope of the roof. Low sloped roofs have a pitch of 9.5° angle or less, while steep sloped roofs have more slope than 9.5°.

Although white materials are considered very good solar reflectors, colored roofing materials can also be made to reflect more sunlight. More than half of the sunlight reaching the earth is invisible to human eye and can heat a roof. A cool, dark color reflects more sunlight than a similar conventional roof, but less than light-colored surface (Urban & Roth, 2010).

### 3.3.1.3 ROOF MATERIALS

**Roof Insulation and R-Values:** Since heat transfer through roof is significant, the thermal insulation of a roof is a critical factor to decrease incoming heat flux. The proper use of thermal insulation leads to both reducing annual energy costs and the size of air-conditioning systems required to keep an interior environment comfortable. Thermal insulation can also increase the time of thermal comfort independent of mechanical air-conditioning. The amount of energy savings resulting from thermal insulation differs based on building type, climate conditions, and the type of insulation material used (Al-Homoud, 2005).

Thermal insulation is a material or a combination of materials related to the rate of heat flow by conduction, convection, and radiation. It retards heat flow into or out-of a building due to its high thermal...
resistance. Insulation and infiltration control is important for reducing heating and cooling loads in buildings (Spivak, 2013).

The term “R-value” expresses a material’s resistance to heat transfer. Thermal resistance is a material’s resistance to heat flow through conduction, convection and radiation, and depends on specific characteristics of a material, including conductivity, thickness and density (expressed in hr-ft\(^2\)-F/Btu (Al-Homoud, 2005).

Calculating the U-factor of the roof depends on the direction of heat flow in both summer and winter due to the resistances of indoor air films and plane air spaces, which would be influenced by heat flow direction (ASHRAE handbook fundamentals, 2009).

A summary of benefits of using thermal insulation:

- Reduced dependence on mechanical/electrical systems
- Reduced energy consumption
- Reduced emittance of pollutants
- Customer satisfaction and ethical good; making energy available to others, decreased costs, fewer interruptions of energy services, extension of the life of finite energy resources
- Thermally comfortable buildings; thermal insulation extends the periods of indoor thermal comfort especially in between seasons
- Reduced noise pollution
- Increased building structural integrity – minimum temperature fluctuations help preserve the integrity of building structures and contents
- Vapor condensation prevention
- Increased fire protection (Al-Homoud, 2005).

The different types of thermal insulations are categorized in the following components:

- Inorganic Materials:
  - Fibrous materials such as glass, rock, and slag wool
  - Cellular materials such as calcium silicate, bonded perlite, vermiculite, and ceramic products
- Organic Materials:
  - Fibrous materials such as cellulose, cotton, wood, pulp, cane, or synthetic fibers
- Cellular materials such as cork, foamed rubber, polystyrene, polyethylene, polyurethane, polyisocyanurate and other polymers
  - Metallic or metallized reflective membranes. These must face an air-filled, gas-filled, or evacuated space to be effective.

Insulating materials also can be produced in different forms

- Mineral fiber blankets: batts and rolls (fiberglass and rock wool)
- Loose fill that can be blown-in (fiberglass, rock wool), poured-in, or mixed with concrete (cellulose, perlite, vermiculite).
- Rigid boards (Polystyrene, polyurethane, polyisocyanurate, and fiberglass)
- Foamed or sprayed in-place (polyurethane and polyisocyanurate)
- Boards or blocks (perlite and vermiculite)
- Insulated concrete blocks
- Insulated formed concrete
- Reflective materials (aluminum foil, ceramic coatings) (Al-Homoud, 2005)

**Thermal Mass:** Thermal mass can reduce the maximum indoor temperature in buildings in summer, when heavy roofs delay heat transfer from the exterior to interior spaces (Shaviv, 2001). The heat is stored in a thermal mass, reducing peak cooling loads (Balaras, 1996).

The capability to conserve energy during the winter is another benefit, since energy can be stored in the roof from one sunny day to the next cloudy one (Shaviv, 2001). In winter, the solar gain is stored during the day and then slowly released into the indoor environment throughout the night. This prevents discomfort condition due to high solar radiation during the day, and the stored heat is radiated into the room in late evening hours when it is most required (Balaras, 1996).

Parameters affecting the performance of thermal mass are:

- Material thermal properties and performance, including proper density, high thermal capacity, and high thermal conductivity value
- Thermal mass location and distribution: Thermal mass must be distributed around the building appropriately depending on the orientation of surfaces at desirable times. Since roofs are exposed to high solar radiation during the day, they require appropriate insulation.
- Insulation
- Ventilation: Ventilated air increases convective heat loss from mass surfaces during the night.
- Occupancy patterns: Determine the peak cooling load and the extent of utilizing the building HVAC system (Balaras, 1996).

Massing of the building is influenced by climate conditions and temperature variation. Insulation is a proper strategy in climates with extreme seasonal variations and small daily variations, but thermal mass is an appropriate strategy in hot, dry climates with large diurnal ranges. The key important strategies about thermal mass effects are summarized as follows:

- Thermal masses reduce the heat gain of structures due to delaying the entry of heat into the building.
- Internal thermal masses store excess heat, both from the sun and from the internal loads of the building, and release it when interiors are cooler.
- Material thermal mass is characterized by its time lag, which is the length of time from when the outdoor temperature reaches its peak until the indoor temperature reaches its peak.
- The time lag required for each wall orientation and roof varies because the peak heat gain occurs at various times.
- The roof requires a long time lag because it receives sunlight most of the day. However, since it is both expensive and impractical to place a heavy mass on the roof, additional insulation is usually recommended for roofs.
- Thermal mass time lags postpone heat gains. Colors, on the other hand, significantly reduce heat gain.
- Insulation is more critical than thermal mass in humid climates with high summer temperatures and high humidity with small daily variations (Al-Homoud, 2005).

**Roof Layers:** The three primary roof types determined by ASHRAE Standard 90.1 are:
1. Insulation Entirely above Deck: a roof that has insulation installed above (outside of) the roof structure and should be continuous to decrease the potential for convection loss or thermal bridging through the edges. If the inverted roof system is applied, at least one layer of insulation should be installed above the membrane and maximum of one layer should be located below the membrane (ASHRAE 90.1-2010; ASHRAE AEDG 50%, 2011).

2. Metal Building: a metal building roof system constructed with a metal surface that has insulation compressed between structural members. It has no ventilation cavity and contains two configurations: metal roofing in direct contact with steel framing, and metal roofing which is separated from steel framing.

3. Attic and Other: Any roof insulation that is entirely below (inside of) the roof structure, with roof insulation both above and below the roof structure, falls into this category. Insulation is laid between roof joists. For ventilated attic spaces, the insulation is placed at the ceiling line, while insulation is placed at the roofline for unventilated attic space. When an inverted roof system is used with removable ceiling tiles, the best place for the installation of roof insulation is at the roofline (ASHRAE 90.1-2010; ASHRAE AEDG 50%, 2011).

According to the NRCA report, roof construction is categorized in two main parts: Low Slope Roofing, with a slope less than or equal to 3:12 or 14°, and Steep Slope Roofing, with a slope exceeding 3:12 or 14°.

**Low sloped roofing:** There are five primary categories for low slope roof membrane:

- Built-up roof (BUR) membranes
- Metal panel roof systems for low-slope applications
- Polymer-modified bitumen sheet membranes
- Single-ply membranes
  - Thermoplastic membranes (e.g., PVC, TPO)
  - Thermoset membranes (e.g., EPDM)
- Spray polyurethane foam-based (SPF) roof systems

Most low-slope roof membranes have three main components:
- **Weatherproofing layer(s):** The weatherproofing component is the most important element because it keeps water from entering a roof assembly.
- **Reinforcement:** Reinforcement adds strength, puncture resistance, and dimensional stability to a membrane.
- **Surfacing:** Surfacing is the component that protects the weatherproofing and reinforcement from sunlight and weather. Some surfacing provides other benefits such as increased fire resistance, improved traffic and hail resistance, and increased solar reflectivity.

**Steep-slope roofing:** There are six generic classifications of steep slope roof coverings:

- Asphalt shingles
- Clay and concrete tiles
- Metal roof systems for steep-slope applications
- Slate
- Wood shakes and shingles
- Synthetic products

Steep-slope roof assemblies typically consist of three primary parts:

- **Roof deck:** A roof deck is the structural substrate and usually is a wood-based material such as plywood or oriented strand board (OSB).
- **Underlayment:** Underlayment provides temporary protection until a roof covering is installed, and provides a secondary weatherproofing barrier. Sometimes underlayment is referred to as "felt" or "paper."
- **Roof covering:** The roof covering is the external water shedding material (NRCA, 2013).

### 3.3.2 ENERGY GENERATION

Renewable energy technologies produce sustainable, clean energy from sources such as the sun, wind, plants, and water. Renewable energy technologies have the potential to strengthen energy security, improve the quality of the environment, and contribute to a strong energy economy. According to the Energy Information
Administration (EIA), in 2007, renewable sources of energy accounted for about 7% of total energy consumption and 9.4% of total electricity generation in the United States.

For the RoofConsultant tool, three renewable energy generation technologies were considered: solar energy systems, wind energy systems, and biomass energy systems. As shown in Figure 5, these three energy generation strategies were examined for roof applications, with consideration of boundary conditions and reality checks.

3.3.2.1 SOLAR PV SYSTEMS

Solar photovoltaic (PV) energy systems generate pollution-free electricity and can easily be installed as grid-connected PV applications on roofs as well as on the walls of commercial buildings (Zahedi, 2006). The PV energy system is one of the most promising renewable energy technologies. In order to fulfil the potential of these technologies, two requirements should be met: 1) PV energy generation should have acceptable cost and performance, and 2) the net energy yield for PV systems should be more than zero – that is, energy output during the life time of the system should
be more than energy input including manufacturing of components, installation, maintenance and decommissioning (Alsma, 2000).

PV energy results from the direct conversion of sunlight into electricity without any heat engine interference. Photovoltaic systems consist of multiple components such as cells, mechanical and electrical connections, mounting and a means for modifying the electrical output. Solar cells consist of light absorbing materials in cell structures that capture photons and generate electricity through the photovoltaic effect. The following is a list of solar cell technologies:

- Silicon technology, including Amorphous silicon (with cell efficiency of 8-10%), and Crystalline silicon (with cell efficiency around 14-19%)
- Hybrid photovoltaic cells
- Thin-film technologies
- Organic and polymer cells
- Cadmium tellutide (Cdte) and cadmium sulphide (Cds) (Parida, 2011)

PV cell efficiency decreases with increasing temperature, especially in silicon cells. So, to decrease the temperature and increase efficiency, the back side of the PV modules can be ventilated. For effective cooling of roof-mounted PV systems, cool outdoor air should be provided through an opening close to the roof or provided in an air channel behind the PV cells (Gan, 2004).

Buildings’ roofs within urban areas have always been interesting locations for PV system installation, especially with the development of new technologies such as building integrated photovoltaic thermal (BIPV-T) systems. Photovoltaic properties in this system are incorporated into building materials such as roofing, siding and glass, and offer beneficial cost and appearance aspects. However, an efficient method for finding and evaluating suitable roofs for the optimal placement of PV systems remains a problem of crucial importance (Lukač, N. et al, 2012; Parida, 2011).

Some benefits of using PV system are as follows.

- Provides green, renewable power by exploiting solar energy
- Constitutes a reliable, industrially matured, green technology for the exploitation of solar energy
- Unlike wind turbines, Photovoltaic (PV) panels operate autonomously without any noise
- Unlike other renewable energy technologies, PV systems require minimum operating or maintenance costs
- PVs can be ideal for "off-the-grid" power generation in remote locations
• PVs are a renewable energy technology that can assist in balancing and smoothing-out the energy load curve and facilitating an increased penetration of renewable energy technologies within the power mix.

PV systems can be installed on rooftops – including collectors integrated with roof membrane – ground mounted, or as the top of a covered paring system. The system can be installed fixed– or tracing–mounted (ASHRAE AEDG 50%, 2011).

**Difficulties and barriers:** The use of photovoltaic systems is complicated due to the seasonal nature of solar radiation. PV systems have the potential to supply energy in excess of demand during the summer but less than demand during the winter. On the other hand, the time of the peak demand in summer for air conditioning is related to the time of the peak solar radiation. With appropriate policy, we can optimize the specific features of PV systems. The first policy is saving energy use in times when power demand does not match PV-power generation. The second strategy is combining PV with other energy technologies. The third policy is power. The final policy requires the location of the PV to be prioritized for distribution (Wiginton, 2010).

Despite consistently shattering growth projections and plunging prices, today’s solar panels, are still too expensive and fragile to replace asphalt shingles and the other materials that cover roofs. Some disadvantages of solar PV systems are:

• Placing large amount of PV panels on the roof is not desirable by architects
• PV panels require maintenance
• PV systems should always be used on the south façade, so, in the case of wall mounted BIPV they limit the area available for south-facing windows.
• PV system’s initial cost is high and may be financially unreasonable for regular clients.
• PVs should be renewed every 20-30 years.
• Water heating offers a shorter payback period and a higher return on investment than photovoltaic.

### 3.3.2.2 SOLAR THERMAL SYSTEMS

Solar energy can be directly used to heat spaces. There are two ways for utilizing solar heat: passive methods and active methods. The passive method uses design elements to take advantage of sunlight. The active
methods use solar collectors to heat water or air. Which strategy is used depends on the climate. Either may be inefficient in cold weather, or may result in increased cooling loads in hot climates. Strategies to minimize unwanted heat gain during summer time should be provided.

**Solar-Thermal System Energy Savings:** Solar collectors can be placed anywhere on a facility with access to direct sunlight. Estimates demonstrate that tapping the United States’ full potential for solar water heating could save 578 billion cubic feet of natural gas per year – 2.5% of national consumption – and 35 billion kWh of electricity per year, just under 1% of U.S. consumption.

Solar-thermal systems can also prevent emissions of 52 million metric tons of carbon dioxide annually, which is equal to 13 coal-fired power plants or 9.9 million cars emission (Control, 2012).

Simple solar-thermal systems are most efficient when producing heat at low temperatures. Some general suggestions for solar domestic hot water heating systems are:

- It is typically not economical to design solar-thermal systems to satisfy the full annual SWH load. Systems are typically most economical if they furnish 50%–80% of the annual load.
- Properly sized systems will meet the full load on the best solar day of the year.
- Approximately 1–2 gallons of storage should be provided per square foot of collector.
- In general, 1 ft² of collector heats about 1 gal/day of service water at 44° latitude.
- Glazed flat-plate systems often cost in the range of $100 to $150/ft² of collector.
- Collectors do not have to face due south; they receive 94% of the maximum annual solar energy if they are 45° east or west of due south.
- The optimal collector tilt for service water applications is approximately equal to the latitude where the building is located; however, variations of ±20° only reduce the total energy collected about 5%. This is one reason that many collector installations are flat to a pitched roof instead of being supported on stands.
- The optimal collector tilt for heating systems (rather than domestic water heating) is approximately the latitude of the building plus 15° (ASHRAE AEDG 50%, 2011).
Rooftop solar thermal systems are calculated based on the total collector area and assuming it produces 100,000 BTU per square foot annually for hot water production (RoofPoint, 2012).

**Challenges:** Recent developments in solar thermal systems have improved reliability and made them more practical for future design. Using evacuated tube collectors can meet the large heating demands with increased suitability and cost-effective potentials. However, some important challenges that should be considered for thermal systems are:

- Polymer durability is the key technical challenges for solar thermal system.
- System performance factors include:
  - Overheating protection
  - Heat exchanger sizing and placement
- Building code issues:
  - Use of plastics, e.g., flammability
  - Structural concerns, e.g., roof weight, wind loading
- The high initial cost of a solar thermal system (Zipp, 2013).

### 3.3.2.3 WIND TURBINE SYSTEMS

Wind energy is another renewable energy that can be adopted via roofing systems to help decrease reliance on fossil fuels. New technologies lead to increased annual energy output and decreased turbine weight and the noise they emit.

The terms “wind energy” and “wind power” describe the process by which wind is used to generate mechanical power or electricity. Application of wind power is an important role as a national energy resource due to it being a mature technology, it having a good infrastructure already in place, and its relative cost competitiveness. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water). A generator can convert this mechanical power into electricity (Herbert, 2007).

Modern wind turbines fall into two basic groups:

- The horizontal-axis variety
- The vertical-axis design

Rooftop turbines can be applied in conjunction with other micro generation options. The amount of electricity produced depends on:
Available wind resources (speed)
Area being swept by the blades

Small changes in each of these could lead to considerable difference in electricity generation. Calculating energy generation mostly depends on the mean annual wind speed. The amount of wind flow at roof level is affected by position, shape and size of the roof. The other important factor to be considered in estimating wind flow is the effect of neighboring buildings in all directions (Mithraratne, 2009).

Rooftops are elevated above ground, where it’s windier; electricity is generated right where it’s needed, and wind energy can make a strong visual statement. Important parameters affecting the wind turbine efficiency include location, roof shape, wind direction, building height, and surrounding urban conditions. Careful positioning of a wind turbine for a particular roof shape can maximize the energy harvest. For all roof cases, wind turbines should be positioned at a height equal to or more than 1.3 times the height of the building (Abohela, 2013).

Difficulties and barriers: Wind turbine technology is limited by roof-top implementation:

- Rooftop installations, even the best of them, are too small to be cost-effective.
- Air-flow is too turbulent to be effectively harvested by both vertical-axis or horizontal-axis turbines.
- Even if vibration and noise concerns are successfully addressed, truly integrated installations large enough to generate significant power are too hard to permit and insure in North America to become a serious option.
- Cost-effective wind turbines are too big for the structure of buildings.
- Turbines are more costly to maintain than other systems.
- Turbine vibrations and noise affect buildings and building occupants.
- Obtaining actual measured performance data is difficult.

Wind turbines need to be placed at sufficient distance from the nearest building to reduce turbulence and noise, and control safety. The organization between the owner, design team, and site planner is imperative to find the optimal wind turbine placement relative to other facilities on the site (ASHRAE AEDG 50%, 2011).
3.3.3 DAYLIGHTING

By properly designing rooftop apertures, an adequate amount of daylight can enter a building to offset energy consumed from non-renewable sources. Lighting is both a major energy end-use and a major contributor to internal loads, increasing cooling loads and reducing heating loads. Appropriate design should meet the lighting functional criteria of the space while minimizing energy consumption. Effective control of solar radiation is important for energy-efficient design due to the high level of internal heat generation present in most commercial buildings. Figure 6 shows the structure of RoofPoint regarding the daylighting function of roofs. Three daylighting strategies were examined: skylights, roof monitors & saw tooth roofs, and light pipes.

Figure 6. Daylighting Strategies Applicable on Roof and Relationships with Boundaries and Reality Issues.

Skylights: Skylights are one of the most common top-lighting systems. They provide horizontal or slanted openings on the roof to admit the daylight to indoor spaces. Skylights are covered with transparent materials such as glass or plastic. Skylights are found widely in residential and non-residential buildings due to their psychological and physiological effects, and their energy savings potential. Skylight shape, fenestration glazing type, and surface area are major design parameters to consider.
when thinking about the tradeoffs between daylighting and associated solar heat gains, and to achieve better amenities and significant energy savings. The mechanical (HVAC) and lighting systems should be programmed to respond to the variability of the outdoor conditions. Daylighting optimization is also sensitive to climate conditions (Johnson, 1984; Shi, 2012).

In a properly designed daylighting system – such as reduced negative effects of curbs, and glazing materials with high VT and lower SHGC – the advantages of reduced electric lighting can overcome the disadvantages of increased conductive heat loss with increased solar heat gains through the glazing material.

Increased window areas and transmittance will increase total energy consumption due to larger cooling loads. Controlling solar heat gains is one of the vital daylighting strategies in order to provide net energy benefits. The energy codes require the skylight areas to be between 3% (IECC) and 5% (ASHRAE 90.1-2004).

The effective aperture dimension for a skylight can be obtained by the formula below (IECC, 2012):

\[
\text{Skylight Effective Aperture} = \frac{0.85 \times \text{Skylight Area} \times \text{Skylight VT} \times \text{WF}}{\text{Daylight Zone Under Skylight}}
\]

Where: VT: area weighted average Visual Transmittance of skylights
WF: area weighted average Well Factor, where WF is 0.9 if light well depth is less than 2 feet, or 0.7 if light well depth is 2 feet or greater.

Skylight curbs need to be insulated to the level of the roof with insulation entirely above deck or R-5.0, whichever is less. The skylight needs to have a glazing material or diffuser with a measured haze value greater than 90% when tested according to ASTM D1003.

If the skylight area of any space is greater than 5% of the gross roof area of that space-conditioning category, then the area of each skylight needs to be reduced in the base envelope design by the same percentage, so that the total skylight area equals exactly 5% of the gross roof area (ASHRAE 90.1, 2010).

According to ASHRAE handbook fundamentals 2009, five aspects must be considered for thermal performance of skylights:

- Transmittance and absorbance of the skylight unit
- Transmitted solar flux that reaches the aperture of the light well
- Whether or not the aperture is covered by a diffuser
- Transmitted solar flux that strikes the walls of the light well
- Reflectance on the walls of the light well

Studies show the optimal size of skylights is about 2-2.5% of the roof area (Kelsey, 1996).

**Advantages**: Some advantages of daylighting systems are:
- Payback periods for adding skylights are relatively short, ranging from 2 to 4 years.
- Cost benefits can be achieved in spite of increases in natural gas use.
- Positioning skylights on the north side of a building eliminates direct beam sunlight.
- Skylights are cost effective at each location and provide life-cycle savings that range from $0.35 to $2 per square foot of the building area.

**Disadvantages:** Some disadvantages of daylighting systems are:

- Initial cost of windows/skylights and lighting control systems is high.
- Daylighting systems add to design complexity by requiring more attention be given to siting and interior spaces to be affected by daylighting.
- Designing enough daylight to infiltrate a space without inducing glare
- Implementation of effective lighting controls and costs associated with these controls.
- Heat gains may reduce heating costs in winter, but more apertures may increase cooling demand in the summer.

**Roof Monitors and Saw-tooth Roofs:** Roof monitors and saw-tooth systems are top-lighting systems that have different shapes. These systems allow light to penetrate vertical or sloped fenestrations in the roof surface. These openings can be designed to permit sunlight during specific times of the day or of the year, according to the requirements of the building.

In general, saw-tooth roofs are most effective when oriented north, avoiding direct beam sunlight. For south-facing glazing in a saw-tooth roof, the recommended cutoff profile angle of a roof overhang for eliminating solar gains is between 16-24º off vertical. To achieve uniform illumination in the work plane, the aperture must be sized appropriately. When a saw-tooth roof is oriented south, it may be a good practice to use baffles to reduce the amount of direct beam sunlight.

Both saw-tooth and roof monitors have lower life cycle savings and longer payback periods (5-9 years) than skylights (Kelsey, 1996; Shi, 2012). The best application of rooftop monitors are office buildings. The appropriate controlling of the daylight can be achieved when the monitor’s vertical glazing allows in high quality daylight and transports it to a specific location based on the monitor’s orientation. North orientation of monitors can effectively block unwanted solar heat gain. East and west orientations are inappropriate for roof monitors. Properly sized overhangs should be considered for south orientation. For providing the same amount of daylighting, the glazing area in a south-orientated monitor is 25% less than that os a north-oriented monitor.

Applying light colors with minimum reluctance is the best option used within monitors. White is the best color. Dark colors significantly reduce efficiency. The walls and ceilings of the roof monitor should be insulated and integrated with proper
thermal barriers as recommended in order to decrease heat gain and losses (ASHRAE AEDG 50%, 2011).

Light pipe system: There are two common light pipe systems: straight and elbowed. The light pipe system usually consists of three parts: 1) a clear dome for capturing the sunlight from outdoor environment, 2) a component of several connected light reflecting tubes for reflecting the sunlight into the indoor spaces, and 3) a diffuser installed on the ceiling in the interior space for illumination (Shi, 2012). The dome should be UV and impact resistant, protecting the tube from dust and rain.

Daylights vs. thermal performance: Skylights have the potential of reducing the consumption of electricity for lighting and reducing heating requirements in winter. By controlling quantities of sunlight it has the potential to reduce cooling requirements. The lack of ability to control or manipulate the daylight within the interior environment may eliminate positive outcomes related to the presence of daylight and views. Skylights can increase heating and cooling cost if they are not sized properly.

Calculations must be performed in order to estimate annual daylighting availability, building energy use, and the effectiveness of different skylight strategies for reducing building energy demand (Johnson, 1984).

3.3.4 EQUIPMENT ALLOCATIONS

The roofs of commercial buildings are frequently used as space for HVAC equipment such as Air Handling Units (AHUs) and cooling towers. Installing HVAC equipment on a roof-top has some benefits in terms of aesthetics and noise issues. The roof is usually less visible than other parts of the building, especially when a flat roof and parapet are utilized, while placing loud equipment on the roof reduces their perceived volume relative to the ground level.

Even though installing HVAC equipment on the roof has some benefits, it may also cause some issues. Roof-mounted equipment may not be compatible with certain roof designs, and could have consequences for efficiency. A flat roof is usually necessary to accommodate roof-mounted equipment, which means roof shapes are limited for this application.

Figure 7 shows the relationship of equipment allocation strategy with other parameters such as boundary conditions and reality.

3.3.5 RAIN WATER COLLECTION

Roof surfaces consist of large impermeable areas, and can be considered as significant possibilities for rain-water collection sites. Peak demand of household water use can be reduced by collecting and storing rainwater (Villarreal, 2005). The challenge of rainwater collection may be loss from evaporation and transpiration. So, immediate collection of rainwater is important. Most types of roofs can be used as rainwater collection sites.
collectors; however, tiled roofs or roofs sheeted with corrugated mild steel are more feasible. Thatched or palm leafed surfaces have cleaning issues. Asbestos sheeting or lead-painted surfaces are inappropriate (http://www.wateraid.org/what-we-do/our-approach/delivering-services).

In general, some advantages of rainwater harvesting are:

- Construction methods are easy and straightforward, and relatively cheap materials can be used. So, local people can easily build one and minimize its costs.
- Low costs for construction, operation, and maintenance
- Rainwater harvesting offers a water source where it is required; it is owner operated and managed.
- Rainwater harvesting offers an essential backup during emergencies when there is a failure of public water supply systems, particularly during natural disasters.
- Rainwater harvesting can improve the engineering of building foundations when cisterns are built as part of the substructure of the buildings, as in the case of mandatory cisterns.
- The physical and chemical properties of rainwater may be superior to that of ground or surface water that may have been subject to pollution from unknown sources.
- Rainwater harvesting diminishes flooding, erosion, and the flow to storm water drains.
- Rainwater harvesting decreases demand on the municipal water supply.
- Rainwater harvesting can be used to recharge ground water.
- Rainwater harvesting is good for irrigation because stored rainwater is free from pollutants as well as salts, minerals, and other natural and man-made contaminants.
- Rainwater harvesting adds life to equipment dependent on water to operate, as rainwater does not produce corrosion or scale like hard water.

There are also disadvantages, such as:

- The success of rainfall harvesting depends on the frequency and amount of rainfall; therefore, it is not a dependable water source in times of dry weather or prolonged drought.
- Low storage capacities limit rainwater harvesting so that the system may not be able to provide water during a low rainfall period. Increased storage capacities add to construction and operating costs and may make the technology economically unfeasible, unless it is government subsidized.
- Leakage from cisterns can cause erosion of load bearing slopes.
- Rainfall harvesting systems may reduce revenues to public utilities.
- Rainwater may not be of potable quality. Quality depends on catchment surfaces (lead and copper are clearly unsuitable), the water needs to be boiled before drinking or subject to ultraviolet light, and this adds to cost (http://www.wateraid.org/what-we-do/our-approach/delivering-services).

The methods for collecting rainwater follow the same principles but differ in terms of aesthetics and actual water conservation effectiveness.

**Rain Barrels:** This method is the most common and involves installing a barrel at a gutter downspout to collect rainwater. Some key factors of this method are:

- Easily implemented by anyone at any residence
- Barrels are readily available in your community or at various stores & websites
- Barrels don't take up much space so they can fit any situation
- Capacity is generally only 50 to 100 gallons
- Easy overflow and waste collection opportunities

**Dry System:** Dry system involves a larger storage volume. Essentially, the collection pipe "dries" after each rain event since it empties directly into the top of the tank. Some benefits of this system are:
- Stores a large amount of rainwater
- Great for climates where rainfall happens with infrequent, large storm events
- Can be inexpensive to implement
- Is a less complicated system, so maintenance is easier

The biggest disadvantage of this system is that the storage tank must be located next to the building structure.

**Wet System:** This method involves locating the collection pipes underground in order to connect multiple downspouts from different gutters. The rainwater fills the underground piping and rises in the vertical pipes until it spills into the tank. The downspouts and underground collection piping must have water-tight connections. The elevation of the tank inlet must be below the lowest gutter of the building.

**Advantages:**
- The ability to collect from the entire collection surface
- The ability to collect from multiple gutters and downspouts
- The tank can be located away from your house

**Disadvantages:**
- More expensive to implement due to underground piping
- Sufficient elevation difference between gutters and tank inlet must be available

### 3.3.6 WATER PROOFING

Preventing uncontrolled water infiltration is a non-structural way to protect and extend the lifetime of structural components. The main concern about moisture control involves the building envelope, especially on horizontal surfaces both above and below the building. Thermal insulation and vapor retarders are the most significant parameters in energy conservation. Common issues about moisture movement through surfaces are leakage, or permeation of liquid water, and diffusion of water vapor. The desired goal of sustainable roof design is to produce a controlled membrane related to heat, light, and moisture flow that achieves a balance between internal and external loads (Ellis, 1994).

An appropriate waterproofing system protects structure, occupants, and interior content (Gumpertz, 2013). According to the American Society for Testing and Materials (ASTM) D1079-10 Standard Terminology Related to Roofing and Waterproofing, “Waterproofing is treatment of a surface or structure to prevent the passage of water under hydrostatics pressure.” Regarding the waterproof roof design, there are key parameters to consider such as cost effectiveness, light, environmental impact, installation, and durability (Abenroth, 2013).
The type of waterproofing membrane dictates how the waterproofing material will be applied to the structure. These types include:

- Applied or liquid membrane: Cold-fluid-applied membranes
- Hot-applied systems
- Film or sheet membrane
- Self-adhering membranes
- Built-up or laminate membrane
- Injectable waterproofing

Each membrane should meet specific characteristics such as:

- Low absorption of water: A level above 5 to 8% is not acceptable
- Low water vapor transmission: A perm enhance of 11 to 28 perm
- The method of field splicing or seaming must resist long-term exposure to moisture.
- Resistance to puncture and tear
- Extensibility or elongation (Abenroth, 2013)

The best waterproof roof coating will also prevent future roof leaks, protect the roof from further attacks of weathering, and allow for easy application. Today's superior waterproof roof coatings are now designed as "elastomeric roof coatings." These water resistant coatings can weather more needs and changing conditions than their predecessors. The chemistry of a roof coating largely influences outcomes. They are predominately for metal roof rustproofing and roof sealing.

Waterborne coatings can provide similar UV and cooling benefits, sometimes allow moisture to dissipate, and can be used where solvent use is prohibited.

Waterproofing membranes are made from several layered materials such as rubber, elastomer, polyethylene, polypropylene, bitumen, polyvinyl chloride (PVC), polyurethanes, silicate, bentonite clay, fabrics, fiberglass, composite layers, resin coatings, plastic sheeting, polymer liners, mastics and metal sheet. Some important properties of these materials are:

- Absorption rate (below 4%)
- Thickness (have uniform thickness)
- Can be applied smoothly (no weakness for cracks to form)
- Allow some degree of flexibility (for structure that may move)

**Vapor retarder:** This is a moisture-impervious layer applied to surfaces enclosing a humid space that prevents moisture travel to a point where it may condense due to lower temperatures (ASHRAE Handbook fundamentals, 2009). Vapor retarders and barriers decrease moisture concentration through roof structures. The lower the perm rating, the better the material avoids moisture dispersion. Vapor retarder consists of multiple-ply semi-flexible bituminous boards, which offers an economical
and easily installed waterproofing system for horizontal surfaces. These membranes stop moisture migration in footings, concrete floors and structural slabs (Malik, 2003).

Installation of vapor retarders in suitable location leads to less moisture transfer and keeps condensation to a minimum. An appropriate type of water vapor retarder and its proper location in the building is determined by climate conditions, other materials applied in the building assembly, and the building’s use (ASHRAE handbook fundamentals, 2009).

Some advantages of waterproofing systems are:

- Providing thermal comfort for occupants
- Protection of roof from weathering
- Stopping roof leaks
- Cuts waste and expense caused by a cycle of premature roof replacement
- Immediate cool roofing and air conditioning savings when using a roof coating that meets code requirements
- A seamless shield to further deflect weather, UV, and extend roof life
- Reduced maintenance caused by thermal shocks (cooled roofs no longer experience damages from cool rains on hot surfaces or the stresses of sudden temperature changes)

The most effective approach for waterproofing is to adopt standard specifications combined with strict quality control.

3.3.7 RECREATION

Buildings are built environments developed by human beings to provide people with shelter, convenience, comfort, work, and recreation. In some cases, roofs can be used as a place for recreation. If designers think ahead in this aspect of roof, building design can be an innovative process.

Roof surfaces can be applied to provide different recreation spaces such as plant roofs, vegetation production, rooftop farming, restaurants, pools, and display areas. Rooftop farming involves the cultivation of produce for food on the roof of a building. It can also be considered as green roof applied for recreational and leisure purposes (as shown in Figure 8).
Roof surfaces can also be applied for commercial purposes including display areas, restaurant terraces, therapy, and rooftop pools (as shown in Figure 9).

3.4 ROOFCONSULTANT: BOUNDARY CONDITIONS

The roof functions in seven areas discussed earlier can (or cannot) work properly depending on certain circumstances such as varying climates conditions. This chapter presents important conditions that need to be considered at the time of roof design. Climate conditions are the main parameter. There are also codes, standards, and guidelines published by professional societies. These publications are not specifically dedicated to the roof design or roof projects; however, some parts of them include useful information related to roofs. Benchmarking is another good method since existing projects or precedents can give insights to new projects.

3.4.1 CLIMATE CONDITIONS

The climate condition in which a building is situated is the one of the most important parameters that needs to be considered for efficient roof design. Code and standard
requirements vary by region, which are determined based on the climate. According to the International Energy Conservation Code (IECC, 2012), the climate zones of the United States are divided into eight temperature-oriented climate zones and sub-categorized zones based on climate conditions such as moist, dry and marine.

To develop our framework, the first step is choosing the specific climate the designer is designing the sustainable roof system for. Including sub-climate zones, there are a total of seventeen climate zones. Each of the eight major climate zones includes from one to three sub-climate zones. Figure 10 is the US climate zone map. It starts from the very south of Florida, which is a hot and humid climate, or Zone-1. Zone-8 covers some parts of Alaska including several boroughs as indicated in the map.

![Climate Zone Map](image)

Figure 10. International Energy Conservation Code (IECC) climate regions

To represent US climate zones, PNNL developed a set of typical locations which are most populous cities in each climate zone. Table 3 shows sixteen cities that represent the US climate zones. These cities were used to develop the climate-specific roof design strategies.
3.4.2 CODES, STANDARDS, AND GUIDELINE

Building codes, standards, and guidelines help building practitioners design and develop sustainable buildings. These documents were used in this study to provide important guides for roof design. The key documents used are:

- IECC-2012 (International Energy Conservation Code)
- ASHRAE Standard 90.1-2010 (American Society of Heating and Air-Conditioning Engineers)
- IgCC-2012 (International green Construction Code)
- ASHRAE AEDG 50%, (Advanced Energy Design Guide for Small to Medium Office Buildings)
- ASHRAE Handbook fundamentals, 2009

**IECC-2012**: The IECC is the current national model code for the US published by International Code Council (ICC). It is updated on a three-year cycle. The IECC focuses on the energy efficiency of building systems but is not related to the efficiency of equipment, the efficiency of industrial processing, nor renewable energy systems. Designers adopt national energy codes as the starting point by setting performance standards for the building envelope, mechanical systems and lighting systems, which help them to keep current with the most recent building practices and technology. The IECC covers new construction, additions, remodeling, window replacement, and repairs of specified buildings. The most recent version of IECC from 2012 raised energy efficiency standards of a building by approximately 30% over the 2006 version. According to 2012 edition, all the 50 states could save $40 billion annual energy costs.

### Table 3. Sixteen Cities Representing the US Climate Zones

<table>
<thead>
<tr>
<th>#</th>
<th>Climate Zone</th>
<th>Representative City</th>
<th>State</th>
<th>HDD65</th>
<th>CDD50</th>
<th>U-Value (Btu/sqft-F-hr)</th>
<th>Roof</th>
<th>Wall</th>
<th>Slab</th>
<th>U-Value</th>
<th>SHGC</th>
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</tbody>
</table>
by 2030 if they adopt it. The IECC consists of a coordinated set of model building codes which each state and government has historically adopted to regulate building design and construction (RECA, 2013, http://reca-codes.org/about-iecc.php).

**ASHRAE Standard 90.1:** The American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE), founded in 1894, is a building technology society with more than 54,000 members worldwide. The Society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration and sustainability within the industry. ASHRAE develops voluntary standards to improve energy efficiency in buildings. These standards are modified by state, federal, and other government organizations and used as codes and standards for each location. There are two such standards that address energy efficiency in new buildings: ASHRAE Standard 90.1 (standards for building except Low-rise residential Buildings) and ASHRAE Standard 90.2 (Energy-Efficient Design of New Low-Rise Residential Buildings).

**IgCC-2012:** The IgCC is the first model code to include sustainability measures for the entire construction project from design through construction. The new code is supposed to make buildings more efficient, decrease waste, and have a positive effect on health, safety and the environment. It creates a framework for new and existing projects, offering minimum green requirements for buildings and implementing voluntary rating systems.

### 3.4.3 BENCHMARKING
As mentioned in a previous section, there are some existing tools that can be benchmarked such as Climate Consultant, RoofPoint, and RoofNav. In addition to them, the EIA’s CBECs report was also referenced to show typical energy consumption levels for different building types using the metric of Energy Use Intensity (EUI).

### 3.5 ROOFCONSULTANT: REALITY TO CONSIDER

#### 3.5.1 AESTHETICS
Vitruvius’ theory of beauty emphasizes strength, functionality, and beauty as the three central aspects in architecture. Strength is related to statics, construction, and materials; functionality refers to the use of the building; beauty is about the aesthetic requirements of buildings. In some cases designers focus more on one aspect than on the others. Whatever the case beauty is most likely to be the first impression for people. Designers usually pay more attention to that aspect from very early stage of the design process.

Time, cost, and quality have long been the major criteria used to evaluate the performance of a building. However, for comprehensive evaluation of building performance, other aspects also need to be considered such as aesthetics and
psychological impact. Some designers weigh more on the aesthetics portion in the design, while others hold the opinion that the energy efficiency aspect should have primary considerations. Some beauty elements, such as glass for providing high exterior lighting, and the desire to reduce energy use and maintenance costs are two conflicting demands. But, if managed carefully, these demands do not need to be in conflict with each other. By presenting innovative ideas, we can make sustainable, beautiful, healthy places.

Figure 11. Example of Large Glazing Construction

Other aesthetic issues for developing sustainable roof involve using a renewable energy system on the roof. On site wind and solar energy sources are widely used to optimize the design in active or passive way. However, while recent design focuses on the consequences of building energy use for the environment, designers also need to consider other aspects of the design such as beauty and safety.

According to ASHRAE Fundamental 2009, the three largest complaints about wind turbines are the noise, the killing of birds, and the aesthetic appearance. Thankfully, most of these issues have been resolved or greatly reduced through technological developments, or by properly siting wind turbines (ASHRAE Fundamental 2009).

Rooftops offer the best space for installing solar PV systems and producing electricity without additional land consumption. The main concerns of these systems are aesthetic issues, i.e. how and where systems are properly placed. The basic concerns for these facilities are about suitable placement throughout the community and addressing specific requirements by location. Specific development standards usually
address location. Some communities prefer rooftop to ground-mounted systems, and many of them require rooftop panels to be situated on side or rear slopes of the roof.

Strategies for energy efficiency are often only considered by building practitioners so building components are placed without careful consideration of the aesthetic issues. The placement of the foreign elements on roof without clear relation to the scale of a building can lead to disharmony of the environment. For example, the integration of PV collectors should be consistent with the design of the roof. Solar collector design needs to be incorporated in the overall building design from the early planning process.

3.5.2 COSTS

Implementing sustainable roof design strategies can require more costs than traditional roof design. Although energy benefits and payback cycles are reasonable based on life cycle cost analysis, the initial costs are often not readily manageable by owners. Implementation cost estimates and simple payback information is provided in RoofConsultant.

3.5.3 PSYCHOLOGICAL ASPECTS

Psychological consequences are not easily measurable or quantitatively analyzed; however, there may not be reasonable assessment criteria on this issue. No clear methodology is available, but some useful information is presented in the RoofConsultant tool.

4. COMPENDIUM OF STRATEGIES

The compendium of strategies has been developed. The strategy database is organized in an Excel spreadsheet. The information included in the spreadsheet is used as the information and data sources of the RoofConsultant tool, which has been developed during Phase-2 of this research. Figure 12 shows the structure of database.
The first several columns from the left categorize the strategies. The first set of strategies is about energy efficiency, which is categorized in three main groups such as green roof, cool roof, and materials. Materials are also divided in subcategories such as thermal insulation, thermal mass, roof surface and R-value sections. The second set of strategies is related to energy generation systems on the roof, which include solar PV systems, solar thermal systems, wind turbine systems and biomass. The third section addresses daylighting systems on roof surfaces and their related strategies. It includes skylights, light pipe system, roof monitor and saw-tooth. Other sections are about equipment allocation, rainwater collection, waterproofing and recreation strategies on the roof.
The details of these strategies are categorized in several different areas as shown in Figure 13 and includes definition, codes, benchmarking, and reality. The definition columns include the definitions of individual strategies, advantages, and disadvantages. The code columns include IECC-2012, ASHRAE Standard 90.1-2010, IgCC-2012, ASHRAE AEDG 50%, and ASHRAE Handbook Fundamentals-2009. The benchmarking columns include RoofPoint, RoofNav, CBECS report, and Climate Consultant. The reality columns include the information about implementation costs, aesthetics, psychological aspect, and precedent of innovative roof designs.

The same structure is repeated for the 16 different cities that represent the 16 different climate conditions in the US. Figure 14 shows a snap-shot of the 16 spreadsheets that include individual roof design strategies.
Figure 14. Sixteen Spreadsheets, Each of Which includes Sustainable Roof Design Strategies Applicable to its Climate Conditions.

The Excel spreadsheet is included as part of the report in a separate file.
4.1 ENERGY EFFICIENCY

4.1.1 GREEN ROOF

4.1.1.1 GENERAL INFORMATION

4.1.1.1.1 Definition:

A green roof, also known as a “vegetative roof”, is defined as “an assembly of interacting components designed to waterproof and normally insulate a building’s top surface that includes, by design, vegetation and related landscaping elements.” (IgCC, 2012)

Green roofs can be categorized into three types: **Intensive, Simple Intensive, and Extensive**, depending on use, factors affecting construction, and methods used to carry out the work.

1. Intensive greening: Covers the planting of shrubs and coppices, as well as grassed areas, even an occasional tree. These may be laid out either on the same level, at different heights or in individual plantings spread about the site. Regular attention is needed to maintain sites of this type.

2. Simple intensive greening: Uses grass, shrubs and coppices as ground cover, however, the range of options available to the user is not as wide as that which intensive greening has to offer. Generally needs little watering and feeding, reducing the amount of attention required.

3. Extensive greening: Involves cultivation of vegetation in forms which creates a 'Virtual Nature' landscape and requires hardly any external input for either maintenance or propagation. Plants suited to coping with a full range of conditions are to be used.

References:


4.1.1.1.2 Advantages:

Green roof of Vancouver Convention Centre (West building), Vancouver, BC

(Source: http://ecozome.com/overhead-and-underfoot-building-a-green-roof-upside-down/)

- Added insulation offered by the green roof’s design can reduce the amount of energy needed to moderate the temperature of a building.
- A green roof can improve storm water management, water runoff quality, urban air quality, and filter out airborne pollutants.
- A green roof can aid in a reduction of the urban heat island effect, while also adding a habitat for wildlife and aesthetic appeal.
- Green roofs can extend a roof’s life, improve acoustics in a building, and enhance architectural interest and biodiversity.

References:

4.1.1.1.3 Disadvantages:

- Green roofs require a higher cost to build than traditional roofing and require a stronger structure to support the layers of the green roof. Also, maintenance issues can cause problems traditional roofs would not normally cause.

References:


4.1.1.2 CODES AND STANDARDS:

4.1.1.2.1 IECC, 2012:
N/A. There is no information about green roof available in the IECC-2012 version.

4.1.1.2.2 ASHRAE 90.1, 2010:
• Page 19: Vegetative roof system: vegetation, growth media, drainage system, and waterproofing over a roof deck.

4.1.1.2.3 IgCC, 2012:
Vegetative roofs are a specialized type of roof covering. Vegetative roofs that meet the standards provided in section 408.3.2 can be used as a method to mitigate heat island effects of a building.

• Section 405 (Page 4-8): Management of vegetation, soils and erosion control: Section 405 addresses vegetation, soil and water quality protection including the minimization of erosion.
  o Soil and water quality shall be protected in accordance with Section 405.1.1 through 405.1.6.
  o Vegetation and soils shall be protected in accordance with Section 405.2.1 and 405.2.2.

• Section 405.3 (Page 4-13): Native plant landscaping
  o Where new landscaping is installed as part of a site plan or within the building site, not less than 75 percent of the newly landscaped area shall be planted with native plant species.
  o In accordance with the definition of “Native plants species” found in Chapter 2, native species are those that are adapted to the site’s condition and climate. This reduces or eliminates the need for irrigation water, pesticides and other maintenance activities. It also helps maintain the plant biodiversity in the area and will continue the support of native animals. The 75 percent requirement is set so that, over time, sufficient quantities and areas of native vegetation will occur in the community, which will improve wildlife habitat and wildlife corridors.
**Section 408.3.2 (Page 4-19):** Vegetative roofs, where provided in accordance with Section 408.3, shall comply with the following:

- All plantings shall be selected based on their hardiness zone classifications in accordance with USDA MP1475 and shall be capable of withstanding the climate conditions of the jurisdiction and the micro climate conditions of the building site including, but not limited to wind, precipitation and temperature. Planting density shall provide foliage coverage, in the warm months, of not less than 80 percent within two years of the date of installation unless a different time period is established in the approved design. Plants shall be distributed to meet the coverage requirements. Invasive plant species shall not be planted.

The Plant Hardiness Zone Map, United States Department of Agriculture

- The engineered soil medium shall be designed for the physical conditions and local climate to support the plants and shall consist of nonsynthetic materials. The planting design shall include measures to protect the engineered soil medium until the plants are established. Protection measures include, but are not limited to, installation of pregrown vegetated mats or modules, tackifying agents, fiber blankets and reinforcing mesh. The maximum wet weight and water holding...
capacity of an engineered soil medium shall be determined in accordance with ASTM E 2399\(^4\).

- Where access to the building facades is providing from locations on the perimeter of the roof, nonvegetated buffers adequate to support associated equipment and to protect the roof shall be provided.
- Nonvegetated clearances are required for fire classification of vegetative roof systems shall be provided in accordance with the International Fire Code.
- Plantings shall be capable of being managed to maintain the function of the vegetative roof as provided in the documents required by section 904.3 (Building operations and maintenance documents).
- Where a vegetative roof is selected to achieve compliance with Section 408.3, the roof must comply with the five provisions of this section. The design of a vegetative roof must be carefully executed to address the climate of the area as well as the microclimate of the specific building and building site. The plant species selected must be sustainable through the seasons of the year. A vegetative roof of dead plants is not a vegetative roof, but a potential fire hazard. The intent of Item 5 is essentially making this point. As is stated in other parts of the chapter, invasive species are prohibited.
- As vegetative roofs can impose a significant weight on a roof, their supporting structure must be designed accordingly. Although not specifically referenced, Chapter 16 of the IBC\(^5\) provides design guidance for such roofs. Item 4 provides reference to the IFC\(^6\) for the clearances and setbacks required around vegetative roofs.

Selected information from Section 904.3 (Page 9-3: Building operations and maintenance documents): Operations and maintenance manuals for equipment, products and systems installed under or related to the provisions of chapter 4 (Site Development and Land Use) including, but not limited to, the following, as applicable:

- 2.1. Vegetative shading, vegetative roofs and natural resource protections and setbacks.
- 2.2. Water-conserving landscape and irrigation systems.
- 2.3. Storm Water management systems.
- 2.4. Permanent erosion control measures.
- 2.5. Landscape or tree management plans.

1 USDA MP1475: (U.S. Department of Agriculture), USDA Miscellaneous Publication No. 1475
2 A pre-grown (vegetated) green roof container holding green roof media and plant material. Modules are generally a rectangular shape covering 2 – 8 ft\(^2\) of roof area. Containers are placed side by side on the roof in a grid system.
3 The landscaping industry sometimes uses tackifiers to stabilize embankments until landscaping can take root and mature.
Vegetated roofing is mentioned in two sections of RoofPoint.

**Section 1 (Page 14, 15): Energy Management**

E3 Roof Surface Thermal Contribution: Vegetated roof surface is offered as a possible roof surface option for all climate zones (1-8), and fulfills requirements E3A (Optimizing net annual energy efficiency), E3B (Optimizing peak energy demand), and E3C (Reducing heat island effects).

**Section 3 (Page 28, 29): Water Management**

W1 Roof Storm Water Retention: Requirement W1A (A water retaining roofing system) can be met using one of the following water-retaining roofing system options:

- Installed a self-sustaining vegetated roof covering over 75% of the roof surface
- Install a non-vegetated water-retaining roof, covering over 75% of the roof surface area
- Install a hybrid combination of #1 and #2 over 75% of the roof surface area.

Note: According to RoofPoint, a “self-sustaining vegetated roof” requires no potable water to maintain the vegetation after an initial establishment period and under normal climatic conditions for the location of the roof. However, severe drought or other unusual local conditions may require the use of other water sources in order to maintain the long-term functionality of the roof vegetation.

**Section 3.11.2, 1-35 (Page 15): Extensive Green Roof Vegetation**

Extensive green roof vegetation is typically limited to a few families of specialized hardy plants that thrive in shallow soil. Extensive green roofs usually are not intended as accessible roofs since the vegetation does not support foot traffic.

Plants used successfully on an Extensive green roof system have characteristics such as wind resistance, frost resistance, drought resistance, resistance to radiation, a shallow root system, and good regenerative capabilities. The combination of direct and reflected radiation, as well as higher wind velocity, can create a challenging environment above grade. The lack of such things as ground water (accessed through capillary action), natural soil aeration devices, and a deep thermal mass also can create a difficult environment for plant growth. For these reasons, planting Extensive green
roofs with local native vegetation is frequently unsuccessful. However, specialty plants, such as Sedums, have exhibited good success rates due to their hardiness.

Sedums are succulent alpine plants that are regenerative, have shallow, non-aggressive root systems, are drought- and wind-resistant, and are relatively resistant to fire. Fire-resistant plants have foliage with a high moisture / low resin content; this is exhibited by supple leaves with watery sap. Sedums can be propagated using seeds or cuttings. Sedums can also be cultivated off-site, then planted in the form of plugs or pre-vegetated mats. Plugs have a higher up-front cost, but are preferred over cuttings and seed due to a better propagation success rate (roughly 80% for plugs, 50% for cuttings) and the resulting enhancement of erosion control against wind and water.

**Section 3.11.3, 1-35 (Page 16): Intensive Green Roof Vegetation**

Intensive green roof vegetation typically is more diverse and less specialized than Extensive green roof vegetation. Intensive green roof vegetation includes ground covers, grasses, shrubs, and even small trees.

**Section 2.1.2, 1-35, (Page 4): Roofing Assembly**

2.1.2.1. A green roof system consists of two major groups of components:

- **Above-membrane vegetated roof system:**
  - These components include the vegetation, growth media, moisture retention mat, geotextile filter fabric, drainage / retention panel, protection fabric, and root barrier. For systems with deep layers of growth media (i.e., Intensive systems), a layer of rigid insulation is often added below the root barrier (protective layer). The above-membrane components typically are loose-laid.

- **Roofing base assembly:**
  - These components include the waterproofing roof membrane, protection board, thermal barrier, and the supporting structural roof deck. The components can be fully adhered, mechanically attached, or loose-laid and ballasted.
Sample Extensive green roof assembly, RoofNav

Source: [https://www.roofnav.com/DataSheets.aspx](https://www.roofnav.com/DataSheets.aspx)

Sample Intensive green roof assembly, RoofNav

Source: [https://www.roofnav.com/DataSheets.aspx](https://www.roofnav.com/DataSheets.aspx)
Section 2.2, 1-35 (Page 5): Construction and Location

2.2.1 Building Height Restriction, 1-35 (Page 5): For green roof systems on buildings over 150 ft (46 m) height, use concrete pavers in non-vegetated border zones; do not use roof gravel or stone ballast.

- For building heights not exceeding 150 ft (46 m), stone ballast or concrete pavers may be used in non-vegetated border zones.

2.2.2. Wind speed restriction, 1-35 (Page 5): Install green roof systems only in geographical locations where the basic wind speed (3-second gust), as determined from Data Sheet 1-28 Wind Design, is less than 100 mph (45 m/s). This applies to all building heights.

2.2.5. Gravity Loads, 1-35 (Page 6): Ensure the supporting roof structure is designed to properly support the loads associated with the green roof system in a fully-saturated condition, as well as any additional supported environmental loads, suspended or supported dead loads, and superimposed-roof live loads. In addition, ensure the roof structure can adequately support the hardscape roof features such as stone ballast, pavers, and curbing.

2.2.5.1. Dead Loads: Ensure that the design dead load of the green roof system has been determined in conformance with ASTM E2397 and ASTM E2399 or equivalent rigorous test standards. If conformance with these test standards cannot be verified, then base the design dead load of growth media on a saturated density of not less than 100 lb/ft3 (134 kg/m3) for maximum gravity load combinations. In addition to the typical components comprising the dead load, consider captured and retained water to be part of the dead load.

2.2.5.2. Live Loads: Sometimes green roof systems are incorporated into roof areas where people are expected or encouraged to congregate. In such assembly areas (similar to balconies, terraces, etc.), ensure the supporting roof structure is designed to support a minimum roof live load of 100 psf (4.8 kPa).

- Determine minimum design roof live load with the following restrictions:
  - For extensive green roofs, ensure the minimum roof live load is no less than 12 psf (0.58 kPa), even when considering live load reduction.
  - For intensive and simple-intensive green roofs, ensure the minimum roof live load is no less than 20 psf (0.96 kPa), even when considering live load reduction.

2.2.5.3. Environmental Loads: Consider snow load and rain load as an environmental load. Transient water is part of the total rain load.
2.2.6. Future Load Allowances, 1-35 (Page 7): To account for future additions of growth media and inconsistencies in grading, increase the specified depth of saturated growth media by not less than 15% for the purpose of structural load calculations.

2.2.7. Design Surface Loads of Vegetation, 1-35 (Page 7): Surface loads of vegetation are provided by the green roof supplier or installer. The following can be used as reasonable minimum design loads:

<table>
<thead>
<tr>
<th>Succulents (Sedums), herbs, grasses</th>
<th>2 psf (10 kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasses and bushes up to 6 in. (150 mm)</td>
<td>3 psf (15 kg/m²)</td>
</tr>
<tr>
<td>Shrubs and bushes up to 3 ft (1 m)</td>
<td>4 psf (20 kg/m²)</td>
</tr>
</tbody>
</table>

2.2.9 Roof Drainage, 1-35 (Page 8):

- **2.2.9.1** Provide a primary roof drainage system capable of removing rainwater from the roof at a rate equal to or greater than that resulting from a 60-minute duration, 100-year mean recurrence interval (MRI) rainfall event².
- **2.2.9.2** Provide a secondary drainage system completely independent of the primary drainage system. Ensure the secondary drainage system is capable of removing rainwater from the roof at a rate equal to or greater than that resulting from the 15-minute duration, 100-year MRI rainfall event.
  - Ensure the base (invert) of the secondary drainage inlets are at least 2 in. (50 mm), but no more than 6 in. (150 mm), in elevation above the base of the primary drainage inlets.

2.2.10. Roof Slope, 1-35 (Page 8):

- **2.2.10.1** Provide a minimum roof slope of 2% (1/4 in./ft, or 1.1 degrees) for all green roofs supported by structural concrete decks. For green roofs supported by other structural systems (e.g., metal roof deck), provide a minimum roof slope of 3% (3/8 in./ft or 1.8 degrees).
- **2.2.10.2** For roof slopes greater than 20% (11 degrees) but less than 40% (22 degrees), provide additional anti-shear stability layers or anchorage, and erosion control. Do not use roof slopes greater than 40% (22 degrees) as they will pose a significant challenge regarding stability and erosion.
- **2.2.10.3** Ensure shear loads induced by the roof slope do not damage any underlying layers (e.g., the drainage panel, protection fabric, root barrier, or membrane). Ensure growth media is placed and cultivated in such a way as to protect against sliding in both dry and saturated conditions. This may be achieved by the use of crushed aggregate (e.g., brick, expanded shale, pumice) in the mineral soil, which will provide good shear resistance due to
the rough angular nature of the particles. Limiting fine aggregate content in the growth media, combined with good root penetration, will also promote stability and limit wash-out.

2.2.11. Supporting Structure, 1-13 (Page 9)

- **2.2.11.1** Use structural concrete deck for all green roofs with over 6 in. (150 mm) of growth media. Acceptable structural concrete deck includes cast-in-place concrete, post-tensioned concrete, pre-cast concrete, and structural concrete on metal deck. *Ensure concrete has a 28-day compressive strength of no less than 3,000 psi (21,000 kPa), and a density of no less than 110 lb/ft³ (1,760 kg/m³).*
- **2.2.11.2** For green roof systems with less than 6 in. (150 mm) of growth media, structural concrete deck or metal roof deck is acceptable.
- **2.2.11.3** Provide a galvanized finish for all exposed steel elements, steel anchors, and steel deck. Provide minimum G90 galvanizing (0.90 oz/ft² [275 g/m²] zinc coating, per ASTM standard A653 or equivalent) for steel deck. Provide concrete cover for top reinforcing based on permanent exposure to weather, according to ACI standard 318 or equivalent.
- **2.2.11.4** Do not install green roof systems on structural deck materials other than structural concrete or metal.
- **2.2.11.5** Ensure the supporting structure has been designed and checked by a registered structural engineer to properly support all dead, live, and environmental loads (e.g., snow, rain, ice, flood, wind, seismic) associated with green roof systems, including the effects of ponding.

2.2.13 Maximum Foreseeable Loss (MFL)³ Fire Walls, 1-35 (Page 9): Extend vegetation-free border zones not less than 50 ft (15 m) on each side of a MFL wall and cover with stone ballast, concrete paver blocks, or a gravel-surfaced roof cover. Refer to Data Sheet 1-22 for additional provisions regarding roof surfacing and parapets at MFL walls.

2.2.14 Non-Vegetated Border Zones, Fire Breaks, and Parapet Walls, 1-35 (Page 9): Provide stone ballast or concrete paver blocks to cover all border zones that are designated to be free of vegetation and growth media.

2.2.14.1 Perimeter and Corner Zones: Ensure border zones (as defined by perimeter and corner zones in Data Sheet 1-28, Wind Design) are free of vegetation and growth media.

2.2.14.2.1 Provide a minimum 1.5 ft (0.5 m) wide continuous border zone (free of vegetation and growth media) surrounding all rooftop equipment, penetrations (e.g., ducts, drains, pipe, conduit), skylights, solar panels, antenna supports, expansion joints, roof area dividers, and interior parapet walls (unless part of an MFL Fire wall). Consider wider vegetation free zones in cases where HVAC intake or exhaust could be expected to affect or be affected by plant growth; for instance, where taller plant growth might restrict intake, or high velocity exhaust emissions could cause plant damage.
2.2.14.2.2 Provide a minimum 3 ft (0.9 m) wide continuous border zone (free of vegetation and growth media) around rooftop structures, including but not limited to mechanical and machine rooms, penthouses, and adjacent façade walls.

2.2.14.2.3 Provide 3 ft (0.9 m) wide continuous border zone strips (free of vegetation and growth media) to partition the roof area into sections not exceeding 15,625 ft² (1,450 m²), with each section not exceeding 125 ft (39 m) in length. Incorporate the border zones into expansion joints or roof area dividers wherever possible.

2.2.14.3 Parapet Walls:

2.2.14.3.1 Provide perimeter parapet walls for all green roof systems.

2.2.14.3.2 Provide parapet walls that extend at least 6 in. (150 mm) in elevation above the top of the growth media, stone ballast, or concrete pavers.

2.2.14.3.3 For roof elevations above 150 ft (46 m), provide a perimeter parapet wall not less than 30 in. (760 mm) in height.

2.2.14.3.4 Where parapet walls 30 in. (760 mm) in height or greater are provided, the adjacent border zones specified to be free of vegetation and growth media (see Section 2.2.14.1, Perimeter and Corner Zones) may be reduced to not less than 3.0 ft (0.9 m) wide.

1 Protective layer: The roof’s membrane needs protection, primarily from damage during green roof installation, but also from fertilizers and possible root penetrations. The protective layer can be a slab of lightweight concrete, sheet of rigid insulation, thick plastic sheet, copper foil, or a combination of these, depending on the particular design and green roof application. Intensive green roof systems may require a protective layer (Wark, 2003).

2 The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year. For example, assume there is a 1 in 50 chance that 6.60 inches of rain will fall in a certain area in a 24-hour period during any given year. Thus, a rainfall total of 6.60 inches in a consecutive 24-hour period is said to have a 50-year recurrence interval.

3 Maximum Foreseeable Loss (MFL) is the largest loss that may be expected from a single fire to a facility as defined by Factory Mutual Engineering Corporation (FM)

References:

4.1.1.3 REALITY

4.1.1.3.1 Implementation costs:
Cost-effectiveness in design and implementation of installing a green roof should be accomplished thoughtfully and without compromising system performance for the life of the roof. Cost factors are generally project scope and building-dependent. A new building project will avoid the significant expense of a structural retrofit to accommodate a green roof.

Installation costs of green roofs can be estimated to add from $10 to $25 per square foot ($10 per square foot for simpler extensive roofing to $25 per square foot for intensive roofs) to the cost of the primary roof membrane. Costs depend on many factors, such as the growing medium, the depth, the green roof size, and increased structural costs.

Annual maintenance costs of simpler extensive roofing as well as intensive roofs may range from $0.75 - $1.50 per square foot. The higher initial and annual costs associated with a green roof can be justified by life-cycle and reduced energy costs.

While the current cost in British Columbia, Canada for a standard extensive green roof varies from $130/m²- $165/m² ($12/ft²- 15/ft²); the cost of a standard intensive green roof starts around $540/m² ($50/ft²). This fact is one of the major reasons that influence owner’s decisions to build one type or the other.

References:

4.1.1.3.2 Aesthetics
Greening has long been promoted as an easy and effective strategy for beautifying the built environment and increasing investment opportunity.

References:
Psychological aspects: Greened roof areas can add a great deal of value to buildings, with improved views making buildings easier to let. Accessible roofs that are designed to allow people to relax, attend events or participate in gardening can make a real difference to how people use and enjoy buildings. Applying the green roof can effectively influence ecosystems as well as human health. Green roofs can be part of a comprehensive therapeutic environment.

References:

4.1.1.3.3 Precedents of innovations:

- **HYDROPACK green roof system**: HYDROPACK is a new green roof module, which contains all the essential layers of a successful green roof system. It is simple and already assembled. It includes a permanent water reserve that maximizes storm-water retention and minimizes irrigation needs, making it ideal for almost any climate. It is designed for both flat and sloped roof (up to 200% gradient).

![HYDROPACK green roof system](image)
4.1.1.4 GENERAL RECOMMENDATIONS:

Recommendations for ideal green roof design depend on unique characteristics of each project and program objective. For instance, in hot spot area like Chicago and New York City green roofs may be the most appropriate solution to provide an effective amount of vegetation in densely urban core. In this section, general recommendations for green roofs are presented for each specific climate.

4.1.1.4.1 Climate Zones (1-8)

1A_ Miami

Miami has a tropical monsoon climate with hot and humid summers and short, warm winters.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

In hot and humid climate, the green roof has an important role in the climate control and energy use decrease. The vegetated system is recommended to control the sun radiation and heat transfer through the building. The thickness of the soil can have impact on thermal performance of roof and building. Extensive green roofs with shallow soil profiles is not appropriate for warm climate. In order to avoid plant failure, extensive green roofs need regular irrigation.

Selecting appropriate plant is a significant part of green roof design. Different plants have different U-value which leads to different thermal performance of the green roof. In warm conditions, it is necessary to use the plants that can stay longer without watering (Saeid, 2011).

In order to reduce weight of green roof systems, organic components of substrate is used. But, in warm, moist climate, they break down quickly and block filtration and drainage systems. So, the
expanded volcanic products like perlite or recycled waste products like polystyrene granules can be replaced in these conditions.

In subtropical and tropical conditions, green roofs are exposed to highly damaging cyclonic winds. Plants that are well rooted into support or substrate will be appropriate for this area.

In general, plants that naturally grow in specific conditions are preferable. The long lived plants which grow slowly and need low maintenance are better solutions. In order to avoid penetration by weed, a condensed planting cover is required (Ampim, 2010).

References:

2A_Houston

Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

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In subtropical and tropical conditions, green roofs are exposed to highly damaging cyclonic winds. Plants that are well rooted into support or substrate will be appropriate for this area.

In general, plants that naturally grow in specific conditions are preferable. The long lived plants which grow slowly and need low maintenance are better solutions. In order to avoid penetration by weed, a condensed planting cover is required (Ampim, 2010).

References:


2B_ Phoenix

Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.
A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

Due to low annual precipitation, low average relative humidity, and high solar radiation, the typical plants used in extensive green roof need to be assessed for their response water necessities and survivability and growth habits within several years (Klett, 2012).

The plants use in green roof system in yearly or seasonally hot and dry climates should have high leaf succulence and low water use. The lightweight substrates with increased water holding capacity are appropriate for harsh conditions (Farrell et al, 2012).

References:

3A_Atlanta

Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.
A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

In warm and humid climate, the green roof has an important role in the climate control and energy use decrease. The vegetated system is recommended to control the sun radiation and heat transfer through the building. The thickness of the soil can have impact on thermal performance of roof and building. Extensive green roofs with shallow soil profiles is not appropriate for warm climate. In order to avoid plant failure, extensive green roofs need regular irrigation.

Selecting appropriate plant is a significant part of green roof design. Different plants have different U-value which leads to different thermal performance of the green roof. In warm conditions, it is necessary to use the plants that can stay longer without watering (Saeid, 2011).

References:


3B_Los Angeles

The climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall but relatively modest transitions in temperature.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.
The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

Potential energy savings associated with green roofs have already been discussed above in terms of controlling the urban heat island effect for air quality benefits. But the potential energy reduced cooling load would be particularly advantageous in Los Angeles, given the importance of air conditioning as a fraction of total energy consumption and recent concerns about generating capacity.

References:


3b_Las Vegas

Climate Zone 3B includes areas of the United States with a characteristically dry climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).
Due to low annual precipitation, low average relative humidity, and high solar radiation, the typical plants used in extensive green roof need to be assessed for their response water necessities and survivability and growth habits within several years (Klett, 2012).

The plants use in green roof system in yearly or seasonally hot and dry climates should have high leaf succulence and low water use. The lightweight substrates with increased water holding capacity are appropriate for harsh conditions (Farrell et al, 2012).

References:

3C_Sanfrancisco

Climate Zone 3C includes areas of the United States with a characteristically marine climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

References:


4A_ Baltimore

Climate Zone 4A includes areas of the United States with a characteristically moist climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

References:


4B_ Albuquerque

Climate Zone 4B includes areas of the United States with a characteristically dry climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.
A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

Due to low annual precipitation, low average relative humidity, and high solar radiation, the typical plants used in extensive green roof need to be assessed for their response water necessities and survivability and growth habits within several years (Klett, 2012).

The plants use in green roof system in yearly or seasonally hot and dry climates should have high leaf succulence and low water use. The lightweight substrates with increased water holding capacity are appropriate for harsh conditions (Farrell et al, 2012).

References:


4C_ Seattle

Climate Zone 4C includes areas of the United States with a characteristically marine climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.
The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

References:


5A_ Chicago

Climate Zone 5A includes areas of the United States with a characteristically moist climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

Another important aspect of the rooftop in Chicago is wind speed. In general, wind speed doubles for every ten-story increase in height. The urban topography can also block and funnel winds, creating unusually weak or strong winds in unexpected locations. Strong winds can erode the rooftop media and dehydrate plants if proper precautions are not taken. In even moderately windy locations it is advisable to follow the precaution taken at the Chicago City Hall, which was to install a biodegradable mesh over the media to protect it from the wind, until the plants are sufficiently established to take over that role (City of Chicago, 2001; Peck et al, 2001).
Cold climate condition might have impact on the establishment and survival of plants of vegetated roof. So, it is necessary to know which plant species can survive in these conditions (Gorden, 2011). Using evergreens (Juniper shrubs) and a thicker soli base rather than typical green roof is helpful in these conditions (University of Toronto, 2005).

References:


5B_ Denver

Climate Zone 5B includes areas of the United States with a characteristically dry climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

Due to low annual precipitation, low average relative humidity, and high solar radiation, the typical plants used in extensive green roof need to be assessed for their response water necessities and survivability and growth habits within several years (Klett, 2012).

The plants use in green roof system in yearly or seasonally hot and dry climates should have high leaf succulence and low water use. The lightweight substrates with increased water holding capacity are appropriate for harsh conditions (Farrell et al, 2012).

Cold climate condition might have impact on the establishment and survival of plants of vegetated roof. So, it is necessary to know which plant species can survive in these conditions (Gorden, 2011). Using evergreens (Juniper shrubs) and a thicker soli base rather than typical green roof is helpful in these conditions (University of Toronto, 2005).

References:

6A_ Minneapolis

Climate Zone 6A includes areas of the United States with a characteristically moist climate.

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces heat loss and as a result the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics (Ahmed, 2014; Peck, 2008; Sonne, 2006).

Extreme Cold climate condition might have impact on the establishment and survival of plants of vegetated roof. So, it is necessary to know which plant species can survive in these conditions (Gorden, 2011). Using evergreens (Juniper shrubs) and a thicker soli base rather than typical green roof is helpful in these conditions (University of Toronto, 2005).

References:

Climate zone 7-8

In the summer, green roofs can significantly reduce solar radiation and heat gain. This helps for reduction of peak roof surface temperature and the amount of energy needed to cool the building rather than conventional roof. In winter, the added insulation provided by plants reduces heat loss and as a result the amount of energy needed to heat the space.

A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the life of the roof can be extended two or three times more.

The environmental benefits for green roofs are improvements in air quality, storm water runoff management. Other benefits of green roofs include habitat creation, sound absorption, and improved aesthetics.

Extreme Cold climate condition might have impact on the establishment and survival of plants of vegetated roof. So, it is necessary to know which plant species can survive in these conditions (Gorden, 2011). Using evergreens (Juniper shrubs) and a thicker soli base rather than typical green roof is helpful in these conditions (University of Toronto, 2005).

Green roof construction increase the insulation value of roof surface which is an important advantage in cold climate. In winter time, buildings loses large amount of heat through the roof surfaces. Green roof installation retain the heat which leads to substantial heating cost savings. (Corden, 2011).

References:


4.1.1.5 CODE RECOMMENDATIONS:

4.1.1.5.1 IECC, 2012:

4.1.1.5.2 ASHRAE90.1, 2010:

- Climate 1, 2, 3: Vegetated roof systems that contain a minimum thickness of 2.5” of growing medium and covering a minimum of 75% of the roof area with durable plantings, may not need solar reflectance and thermal emittance.

4.1.1.5.3 IgCC, 2012: Section 408.3 Roof surfaces, (P 4-8):

Climate 1, 2, 3: In Climate Zones 1, 2 and 3, 75 percent of the roof area of a building must be provided with roof coverings that mitigate the heat island effects of the building. If the roof happens to be of a parking lot shade structure, this requirement also applies in Climate Zones 4 through 5. There are two options for roof coverings:

- Traditional roof coverings
- Vegetative roof coverings complying with Section 408.3.2. Compliance can be achieved by using one type or the other, or a combination.

Section 408.3.2 Vegetative roofs, (P 4-19): Vegetative roofs, where provided in accordance with Section 408.3, shall comply with the following:

- All planting shall be selected based on their hardiness zone classifications in accordance with USDA MP1475* and shall be capable of withstanding the climate conditions of the jurisdiction and the micro climate conditions of the building site including, but not limited to wind, precipitation and temperature. Planting density shall provide foliage coverage, in the warm months, of not less than 80 percent within two years of the date of installation unless a different time period is established in the approved design. Plants shall be distributed to meet the coverage requirements. Invasive plant species shall not be planted.
- The engineered soil medium shall be designed for the physical conditions and local climate to support the plants and shall consist of nonsynthetic materials. The planting design shall include measures to protect the engineered soil medium until the plants are established. The maximum wet weight and water holding capacity of an engineered soil medium shall be determined in accordance with ASTM E 2399**.
• Where access to the building facades is providing from locations on the perimeter of the roof, nonvegetated buffers adequate to support associated equipment and to protect the roof shall be provided.

• Nonvegetated clearances are required for fire classification of vegetative roof systems shall be provided in accordance with the International Fire Code (IFL).

• Planting shall be capable of being managed to maintain the function of the vegetative roof as provided in the documents required by section 904.3. (Related to building operations and maintenance documents).

Section 408.2, Site hardscape (P 4-16): In climate zone 1-6, not less than 50 percent of the site hardscape (areas of the building site covered by man-made materials) shall be provided with one or any combination of options described in Sections 408.2.1 (Site hardscape materials) through 408.2.4 (pervious and permeable pavement). For the purposes of this section, site hardscape shall not include areas of the site covered by solar photovoltaic arrays or solar thermal collectors.

4.1.1.5.4 ASHRAE AEDG 50%
N/A

4.1.1.5.5 RoofPoint
N/A

4.1.1.5.6 RoofNav

3.11.1 Climate, 1-35 (Page 15): In the United States, vegetation can be selected based partly on the USDA Plant Hardiness Zone Map; however, the effects of solar radiation, wind, and frost can create a microclimate that will be more challenging for vegetation on a roof than for the same plants at grade level.
4.2 COOL ROOF

4.2.1 GENERAL INFORMATION

4.2.1.1 DEFINITION:

A cool roof is defined as a roof that stays cool by minimizing solar absorption and high thermal emission. There are different types of cool roofs that use different types of materials or techniques, including the following:

1. **White coatings**: White materials are a popular option for building surfaces that cannot be seen from the street, such as flat roofs and low-sloped roofs.

2. **Color coatings**: Cool-colored roofs are designed to increase reflection of sunshine while maintaining the color and aesthetic of traditional nonwhite roofing products.

3. **Roof mist cooling systems or evaporative cooling systems**: A roof misting system lowers surface temperatures by spraying an extremely small amount of water across the roof, allowing the water to cool the roof as it evaporates.

References:

4.2.1.2 ADVANTAGES:

A cool roof offers many advantages. First and foremost, a cool roof gives energy and cost savings by reducing the cooling load of a building. It also reduces electrical grid strain by reducing peak cooling demands. As a result, cool roofs give better air quality, slow smog formation, reduce carbon and power plant emissions (including carbon dioxide, sulfur dioxide, nitrous oxides, and mercury), and mitigate urban heat islands in summer. Cool roofs also increase the life cycle of the roof while increasing occupant comfort. A cool roof strategy is also relatively easy to implement.

References:


**4.2.1.3 DISADVANTAGES:**
Cool roofs have some disadvantages:

- Cool roofs slightly increase winter-heating energy use. They require water and detergents to clean the roof surface and maintain high reflectance, which incur costs. Glare can result from a bright white or shiny roof.
- Cool roofs are more appropriate options for high-rise buildings; cool-colored or nonwhite roofs may be more appropriate for low-rise buildings.
- Cool roofs can decrease winter time urban air quality: if a building is cooled with remotely generated electric power and heated with locally burned natural gas, installing a cool roof may yield increased annual local emissions from natural gas combustion even while reducing annual energy consumption.

References:


4.2.1.4 CODES AND STANDARDS:

4.2.1.4.1 IECC, 2012: IECC 2012 includes relevant information in Chapter 4 (Commercial Energy Efficiency), generally focusing on roof reflectance and emittance.

Section C402.2.1.1 (Page C-29, 30): Roof solar reflectance and thermal emittance: Low-sloped roofs, with a slope less than 2 units vertical in 12 horizontal, directly above cooled conditioned
spaces in Climate Zones 1, 2, and 3 shall comply with one or more of the options in Table C402.2.1.1 (Minimum roof reflectance and emittance options).

<table>
<thead>
<tr>
<th>TABLE C402.2.1.1 MINIMUM ROOF REFLECTANCE AND EMITTANCE OPTIONS*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-year aged solar reflectance of 0.55 and three-year aged thermal emittance of 0.75</td>
</tr>
<tr>
<td>Initial solar reflectance of 0.70 and initial thermal emittance of 0.75</td>
</tr>
<tr>
<td>Three-year aged solar reflectance index of 64</td>
</tr>
<tr>
<td>Initial solar reflectance index of 82</td>
</tr>
</tbody>
</table>

a The use of area-weighted averages to meet these requirements shall be permitted. Materials lacking initial tested values for either solar reflectance or thermal emittance, shall be assigned both an initial solar reflectance of 0.10 and an initial thermal emittance of 0.90. Materials lacking three-year aged tested values for either solar reflectance or thermal emittance shall be assigned both a three-year aged solar reflectance of 0.10 and a three-year aged thermal emittance of 0.90.

b Solar reflectance tested in accordance with ASTM C 1371 or ASTM E 903 or ASTM E 1918.

c Thermal emittance tested in accordance with ASTM C 1371 or ASTM E 408.

d Solar reflectance index (SRI) shall be determined in accordance with ASTM E 1980 using a convection coefficient of 2.1 Btu/h U ft² F (12W/m² UK). Calculation of aged SRI shall be based on aged tested values of solar reflectance and thermal emittance. Calculation of initial SRI shall be based on initial tested values of solar reflectance and thermal emittance.

Exceptions: The following roofs and portions of roofs are exempt from the requirements in Table C404.2.1.1:

1. Portions of roofs that include or covered by:
   1.1. Photovoltaic systems or components
   1.2 Solar air and water heating systems or components
   1.3 Roof gardens or landscaped roofs
   1.4 Above-roof decks or walkways
   1.5 Skylights; 1.6. HVAC systems, components, and other opaque objects mounted above the roof

2. Portions of roofs shaded during the peak sun angle on the summer solstice by permanent features of the building, or by permanent features of adjacent buildings

3. Portions of roofs that are ballasted with a minimum stone ballast of 17 pounds per square foot (psf) (74 kg/m²) or 23 psf (117 kg/m²) pavers

4. Roofs where a minimum of 75 percent of the roof area meets a minimum of one of the exceptions above
4.2.1.4.2 ASHRAE 90.1, 2010:
ASHRAE Standard 90.1 2010 includes information relevant to cool roofs from Chapter 5 (Building Envelope), related to roof insulation, solar reflectance, and thermal emittance.

Section 5.5.3.1.1 (Page 34): Roof Solar Reflectance and Thermal Emittance: Roofs, in climate zones 1 through 3 shall have one of the following:

- A minimum three-year-aged\(^2\) solar reflectance of 0.55 when tested in accordance with ASTM\(^3\) C1549 or ASTM E1918, and in addition, a minimum three-year-aged thermal emittance of 0.75 when tested in accordance with ASTM C1371 or ASTM E408.
- A minimum three-year-aged Solar Reflectance Index\(^4\) of 64 when determined in accordance with the Solar Reflectance Index method in ASTM E1980 using a convection coefficient of 2.1 BTU/h\(\cdot\)ft\(^2\).
- Increased roof insulation levels found in Table 5.5.3.1.2 (increased roof insulation levels for residential and non-residential buildings).

Exceptions:

a. Ballasted roofs with a minimum stone ballast of 17lbs/ft\(^2\) or 23 lbs/ft\(^2\) pavers.

b. Vegetated Roof Systems that contain a minimum thickness of 2.5” of growing medium and covering a minimum of 75% of the roof area with durable plantings.

c. Roofs, where a minimum of 75% of the roof area:
   1. is shaded during the peak sun angle on June 21st by permanent components or features of the building, or
   2. is covered by off-set photovoltaic arrays, building integrated photovoltaic arrays, or solar air or water collectors, or
   3. is permitted to be interpolated using a combination of parts (1) and (2) above.

d. Steep sloped roofs

e. Low sloped metal building roofs in climate zones 2 and 3

6. Roofs over ventilated attics or roofs over semi-heated spaces or roofs over conditioned spaces that are not cooled spaces

7. Asphaltic membranes in climate zones 2 and 3

\(^1\) Aged solar reflectance: We can estimate the aged solar reflectance based on the initial solar reflectance by using this formula: \(\text{Aged Reflectance} = 0.7 \times (\text{Initial Reflectance} – 0.2) + 0.2\)

\(^2\) The values for three-year-aged solar reflectance and three-year aged thermal emittance shall be determined by a laboratory accredited by a nationally recognized accreditation organization, such as
Cool Roof Rating Council CRRC-1s Product Rating Program, and shall be labeled and certified by the manufacturer.

3 **ASTM**: American Society for Testing and Materials.

4 **SRI**: The solar reflectance index is a value that incorporates both solar reflectance and emittance in a single value to represent a material’s temperature in the sun.

4.2.1.4.3  **IgCC, 2012:**

**Section 408.3 (Page 4-18): Roof surfaces**

Excerpt: In Climate Zones 1, 2 and 3, 75 percent of the roof area of a building must be provided with roof coverings that mitigate the heat island effects of the building. If the roof happens to be of a parking lot shade structure, this requirement also applies in climate zones 4 through 5.

**Section 408.3.1 (Page 4-18): Roof covering: Solar reflectance and thermal emittance**

Where roof coverings are used for compliance with Section 408.3, roof coverings shall comply with Section 408.3.1.1 (roof product testing) or 408.3.1.2 (solar reflectance index). The values for solar reflectance and thermal emittance shall be determined by an independent laboratory accredited by a nationally recognized accreditation program. Roof products shall be listed and labeled and certified by the manufacturer demonstrating compliance.

Roof coverings must provide a solar reflectance and a thermal emittance that is not less than the values provided in Table 408.3.1.

<table>
<thead>
<tr>
<th>ROOF SLOPE</th>
<th>MINIMUM AGED SOLAR REFLECTANCE</th>
<th>MINIMUM AGED THERMAL EMITTANCE</th>
<th>MINIMUM AGED SRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:12 or less</td>
<td>0.55</td>
<td>0.75</td>
<td>60</td>
</tr>
<tr>
<td>Greater than 2:12</td>
<td>0.30</td>
<td>0.75</td>
<td>25</td>
</tr>
</tbody>
</table>

The minimum requirements vary based on the slope of the roof. If a complex roof has more than one slope, each portion must comply with the appropriate value in the table. The solar reflectance and thermal emittance of roofing products must be determined by either the methodologies prescribed in Section 408.3.1.1 or those of Section 408.3.1.2. Roof products must be listed and labeled. The testing of the products must be done at a facility that is independent of the manufacturer and nationally certified. More information on testing requirements for these products can also be found in the ICC-ES Environment Criteria for Determination of Radiative Properties of Roof Coverings and Solar Reflectance of Hardscape Materials (EC103).

1 **Solar reflectance** is a key factor in determining the ability, or inability, of a material to reduce heat island impacts of a building or a building site feature. It is expressed on a scale of 0 to 1.
ASHRAE AEDG, 50%, 2011: ASHRAE AEDG discusses cool roofs in Chapter 3 (Integrated Design Strategies), as an energy conservation measure (ECM); included are several excerpts from the text:

(Page 34): Energy Conservation Measures (ECMs), Envelope: Adding cool roofs with high reflectivity in climates with more intense solar radiation is often found to be a direct benefit to reducing energy associated with cooling during the summer months.

(Page 107): Envelope, Opaque Envelope Components, EN1, Cool roofs (Climate Zones 1, 2, 3): For a roof to be considered a cool roof, a Solar Reflectance Index (SRI) of 78 or higher is recommended. A high reflectance keeps much of the sun’s energy from being absorbed while a high thermal emissivity surface radiates away any solar energy that is absorbed, allowing the roof to cool more rapidly. Cool roofs are typically white and have a smooth surface. Commercial roof products that qualify as cool roofs fall into three categories: single ply, liquid applied, and metal panels.

The solar reflectance and thermal emissivity property values represent initial conditions as determined by a laboratory accredited by the Cool Roof Rating Council (CRRC). An SRI can be determined by the following equation:

\[
SRI = 123.97 - 141.35(\chi) + 9.655(\chi^2)
\]

where

\[
\chi = \frac{20.797 \times \alpha - 0.603 \times e}{9.5205 \times e + 12.0}
\]

and

\[
\alpha = \text{solar absorptance} = 1 - \text{solar reflectance}
\]

\[
e = \text{thermal emissivity}
\]

These equations were derived from ASTM E1980 (ASTM 2011) assuming a medium wind speed. Note that cool roofs are not a substitute for the appropriate amount of insulation.

(Page 138): General Recommendations, DL15, Outdoor Solar Reflectance (Climate zones: all): High-albedo roofs reflect heat instead of absorbing it; they help lower the heat load and keep the building cooler. Also, the heat-island effect is diminished, which lowers the environmental temperature, which can support natural ventilation through courtyard fenestration.

4.2.1.4.4 ASHRAE Fundamental, 2009:
Reflective materials are available in sheets and rolls of single- or multi-layer construction, as well as in preformed shapes with integral air spaces.
4.2.1.4.5 **RoofPoint:**
Roofing systems can reduce the peak energy required by air conditioning through the use of highly reflective roof surfaces or other cool roof strategies.

4.2.1.4.6 **RoofNav:**
N/A. There is no information about Cool roof available in the RoofNav database sheets.

4.2.1.5 **REALITY**

4.2.1.5.1 **Implementation costs:**
A cool roof does not necessarily cost more than a non-cool roof, especially if you are installing a new roof or replacing an existing one in need. However, converting a standard roof that’s in good condition into a cool roof can be expensive. Major roof costs include upfront installation (materials and labor) and ongoing maintenance (repair, recoating, and cleaning). Additional cool roof costs include specialized materials and labor.

Cool roof coatings might **cost between $0.75 and $1.50 per square foot for materials and labor**, which includes routine surface preparation like pressure-washing, but does not account for repairs of leaks, cracks, or bubbling of the existing roof surface.

Single-ply membrane costs vary from **$1.50 to $3.00 per square foot**, including materials, installation, and reasonable preparation work. This cost does not include extensive repair work or removal and disposal of existing roof layers.

For either type of cool roof, there can be a cost premium compared to other roofing products. The premium can range from zero to 5 or 10 cents per square foot for most products, or from 10 to 20 cents per square foot for a built-up roof with a cool coating used in place of smooth asphalt or aluminum coating.

As with any roofing job, costs depend on the local market and factors such as the size of the job, the number of roof penetrations or obstacles, and the ease of access to the roof. These variables often outweigh significantly the difference in costs between various roofing material options.

**References:**
4.2.1.5.2  Aesthetics:
Cool roofs easily can be incorporated into building designs to achieve cost-effective energy savings. However, most practitioners prefer the darker colors for the building’s roofs. In order to provide energy efficiency and aesthetic satisfaction, the cool-color products are developed for roofing systems. These roofing products consist of dark-colored pigments while still are considered cool because of highly reflection of sunlight instead of absorbing it.

References:

Psychological aspects:
White is not a popular color for roofs, and as a result there can be aesthetic and psychological concerns about using white materials for roofing system. In order to address this issue, cool materials have been developed in common roof colors (e.g., red, green and gray) that reflect the invisible heat component of sunlight and much of the sun’s energy away from the building.

References:
4.2.1.5.3 Precedent of Innovation

The Cool Roof Batten™ integrates three technologies including high SRI metal roofing panels, the above-sheathing ventilation, and the above-sheathing radiant barrier to create thermal resistance and reduce heat conduction within steep slope roof deck assemblies.

This system facilitates the rapid and cost effective construction of a thermally efficient Radiant above Sheathing Ventilated Roof System.

References:


➢ General recommendations:

The desirability of cool roofs depends on several parameters such as latitude, altitude, annual heating load, annual cooling load, peak energy demand, and building characteristics. The climate is important consideration for deciding whether to install a cool roof. In this section, general recommendations for cool roofs are presented for each specific climate.

4.2.1.6 CLIMATE ZONES (1-8)

1A_ Miami: Miami has a tropical monsoon climate with hot and humid summers and short, warm winters.

Cool roofs achieve great cooling loads reduction in hot climates. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Het Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

In warm, moist climate conditions, cool roofs have the potential to produce algae or mold growth. Applying coating like special chemicals can inhibit mold or algae growth for a few years.

References:


Cool Roof Rating Council and Other Cool Roof Codes and Programs. Retrieved from http://coolroofs.org/resources/overview
2A_Houston:
Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

Cool roofs achieve great cooling loads reduction in hot climates. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Het Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

In warm, moist climate conditions, cool roofs have the potential to produce algae or mold growth. Applying coating like special chemicals can inhibit mold or algae growth for a few years.

References:
Cool Roof Rating Council and Other Cool Roof Codes and Programs. Retrieved from http://coolroofs.org/resources/overview

2B_Phoenix:
Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.

Cool roofs achieve great cooling loads reduction in hot climates. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Het Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

Accumulating moisture is not a real concern in dry condition due to high evaporation.

References:
Cool Roof Rating Council and Other Cool Roof Codes and Programs. Retrieved from http://coolroofs.org/resources/overview

3A_Atlanta:
Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

Cool roofs achieve great cooling loads reduction in summer. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Het Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

In warm, moist climate conditions, cool roofs have the potential to produce algae or mold growth. Applying coating like special chemicals can inhibit mold or algae growth for a few years.

References:

Cool Roof Rating Council and Other Cool Roof Codes and Programs. Retrieved from http://coolroofs.org/resources/overview

3B_Coast_Los Angeles:
This climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall—with a dry summer and a winter rainy season—but relatively modest transitions in temperature.

Cool roofs achieve great cooling loads reduction in summer. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Het Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

References:

Cool Roof Rating Council and Other Cool Roof Codes and Programs. Retrieved from http://coolroofs.org/resources/overview

3b_Las Vegas: Climate Zone 3B includes areas of the United States with a characteristically dry climate.

Cool roofs achieve great cooling loads reduction in hot climates. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Het Island Effect
and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

Accumulating moisture is not a real concern in dry condition due to high evaporation.

References:


Cool Roof Rating Council and Other Cool Roof Codes and Programs. Retrieved from http://coolroofs.org/resources/overview

3C_San Francisco:

Climate Zone 3C includes areas of the United States with a characteristically marine climate.

Cool roofs achieve great cooling loads reduction in hot climates. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Het Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

References:


Cool Roof Rating Council and Other Cool Roof Codes and Programs. Retrieved from http://coolroofs.org/resources/overview

4A_Baltimore: Climate Zone 4A includes areas of the United States with a characteristically moist climate.

Cool roofs achieve great cooling loads reduction in summer time. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Het Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

In warm, moist climate conditions, cool roofs have the potential to produce algae or mold growth. Applying coating like special chemicals can inhibit mold or algae growth for a few years.

References:
4B_ Albuquerque:

Climate Zone 4B includes areas of the United States with a characteristically dry climate.

Cool roofs achieve great cooling loads reduction in summer time. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Heat Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

Accumulating moisture is not a real concern in dry condition due to high evaporation.

References:
Cool Roof Rating Council and Other Cool Roof Codes and Programs. Retrieved from http://coolroofs.org/resources/overview

4C_ Seattle:

Climate Zone 4C includes areas of the United States with a characteristically marine climate.

Cool roofs achieve great cooling loads reduction in summer time. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Heat Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

In moist climate conditions, cool roofs have the potential to produce algae or mold growth. Applying coating like special chemicals can inhibit mold or algae growth for a few years.

References:
5A_ Chicago:

Climate Zone 5A includes areas of the United States with a characteristically moist climate.

Cool roofs achieve great cooling loads reduction in summer time. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Heat Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

*The Chicago Energy Conservation Code includes a requirement for cool roofs as a way to mitigate the Urban Heat Island Effect.* The code requires that new residential and commercial low-slope roofs have a minimum initial solar reflectance value of 0.72 or a three-year aged value of 0.50. New medium slope roofs (2:12 to 5:12) are required to have a minimum initial reflectance value of 0.15. Steep slope roofs (greater than 5:12), are exempt from any initial reflectance requirements. All roofing products must be rated by the CRRC or by ENERGY STAR.

References:


Cool Roof Rating Council and Other Cool Roof Codes and Programs. Retrieved from [http://coolroofs.org/resources/overview](http://coolroofs.org/resources/overview)


5B_ Denver:

Climate Zone 5B includes areas of the United States with a characteristically dry climate.

Cool roofs achieve great cooling loads reduction in summer time. By reflecting solar radiation and re-emitting absorbed solar radiation back to the sky, cool roofs can reduce the Urban Heat Island Effect and smog fraction. However, it can increase energy costs in winter time due to reducing heat gain. Winter penalties are small.

Accumulating moisture is not a real concern in dry condition due to high evaporation.

References:
Climate zone 6, 7, 8:

Cool roofs may not appropriate in these climate conditions because by reducing heat gain through roof surfaces it can increase energy costs in winter.

In cold climates, accumulating moisture through condensation is an important consideration of cool roofs. Applying some design techniques can prevent condensation in roofs.

References:


4.2.1.7 CODE RECOMMENDATIONS:

4.2.1.7.1 Climates 1, 2, 3

IECC, 2012:

Roof solar reflectance and thermal emittance, low-sloped roofs, with a slope less than 2 units vertical in 12 horizontal, directly above cooled conditioned spaces shall comply with one or more of the option in C402.2.1.1.

1- Three-year aged solar reflectance of 0.55 and three-year aged thermal emittance of 0.75.
2- Initial solar reflectance of 0.70 and initial thermal emittance of 0.75.
3- Three-year-aged solar reflectance index of 64.
4- Initial solar reflectance index of 82.

ASHRAE90.1, 2010:

1- A minimum three-year-aged solar reflectance of 0.55 when tested in accordance with ASTM C1549 or ASTM E1918, and in addition, a minimum three-year-aged thermal emittance of 0.75 when tested in accordance with ASTM C1371 or ASTM E408.
2- A minimum three-year-aged solar reflectance index of 64 when determined in accordance with the solar reflectance index method in ASTM E1980 using a convection coefficient of 201 BTU/h. sqft.
3- Increased roof insulation levels found in Table 5.5.3.1.2.
IgCC, 2012:
Not less than 50 percent of the site hardscape shall be provided with one or any combination of options described in Sections 408.2.1 through 408.2.4

75 percent of the roof area of a building must be provided with roof covering that mitigates the heat island effects of the building.

ASHRAE AEDG 50%:
Cool roofs, which reduce solar heat absorption into the building, are useful.

For a roof to be considered a cool roof, a Solar Reflectance Index (SRI) of 78 or higher is recommended. A high reflectance keeps much of the sun’s energy from being absorbed while a high thermal emissivity surface radiates away any solar energy that is absorbed, allowing the roof to cool more rapidly.

Cool roofs are typically white and have a smooth surface. Commercial roof products that qualify as cool roofs fall into three categories: single ply, liquid applied, and metal panels (Table 5-1 Example of Cool Roofs).

- Single ply:
  - Reflectance:
    - White polyvinyl chloride (PVC), White chlorinated polyethylene (CPE): 0.86
    - White chlorosulfonated polyethylene (CPSE): 0.85
    - White thermoplastic polyolefin (TSO): 0.77
  - Emissivity:
    - White polyvinyl chloride (PVC): 0.86
    - White chlorinated polyethylene (CPE): 0.88
    - White chlorosulfonated polyethylene (CPSE): 0.87
    - White thermoplastic polyolefin (TSO): 0.87
  - SRI:
    - White polyvinyl chloride (PVC): 107
    - White chlorinated polyethylene (CPE): 108
    - White chlorosulfonated polyethylene (CPSE): 106
    - White thermoplastic polyolefin (TSO): 95

- Liquid applied:
  - Reflectance: 0.71
  - Emissivity: 0.85, 0.86
  - SRI: 86

- Metal panels
• Reflectance: 0.9
• Emissivity: 0.87
• SRI: 113

4.2.1.8 CLIMATE 4

IgCC, 2012:

Not less than 50 percent of the site hardscape shall be provided with one or any combination of options described in Sections 408.2.1 through 408.2.4

75 percent of the roof area of a building must be provided with roof covering that mitigate the heat island effects of the building, if the roof happens to be of a parking lot shade structure.

ASHRAE AEDG 50%:

Cool roof can be considered, but their usefulness will depend heavily on the sunniness of the local geography.

4.2.1.9 CLIMATES 5,6,7,8

IgCC, 2012:

Not less than 50% of the site hardscape shall be provided with one or any combination of options described in Sections 408.2.1 through 408.2.4

75% of the roof area of a building must be provided with roof covering that mitigates the heat island effects of the building, if the roof happens to be of a parking lot shade structure.
4.2.2 THERMAL INSULATION

4.2.2.1.1 General Information

4.2.2.1.2 Definition:

Energy efficient insulating materials & insulated systems for attics & roofs
(Source: http://www.kingspaninsulation.co.za/applications/roof-insulation/).

Thermal insulation is defined as a material or combination of materials that reduce the rate of heat transfer by processes of conduction, convection, and radiation. Thermal insulation prevents heat from exiting or entering a space, keeping it at a more constant temperature.

There are many different types of insulating materials and installation methods. Insulation materials are classified according to their chemical or their physical structure.

1. Organic materials: Expanded polystyrene, Extruded polystyrene, Polyurthane foam, Cork, Melamine foam and Phenole foam
2. Inorganic materials: Foam glass, Glass-wool and Stone-wool
3. Combined materials: Siliconated Calcium, Gypsoum foam, Wood-wool
4. New technology materials: Transparent materials and Dynamic materials

References:


4.2.2.1.3 Advantages:

Thermal insulation provides several advantages. Energy is saved, providing economic benefits, and emitted pollutants are reduced, giving environmental benefits. Costs to the customer are decreased, and there are fewer interruptions of energy services, resulting in increased customer satisfaction. Thermal insulation reduces reliance on mechanical and electrical systems, helping preserve the integrity of building structures and contents by minimizing temperature fluctuations, which extends periods of indoor thermal comfort, especially between seasons. As a result of increased energy efficiency, the life of finite energy resources is extended, conserving resources for future generations. Thermal insulation also provides noise reduction, prevents vapor condensation, and adds fire protection.

References:


4.2.2.1.4 Disadvantages:

In addition to the aforementioned advantages, there are also some disadvantages inherent to using thermal insulation.

**Moisture penetration:** According to the Building Research Establishment, cavity roof insulation does not totally prevent rainwater from penetrating the “outer leaf of masonry.” Rainwater creates moisture which then causes “dampness on internal surfaces” and physical damage. Accumulating moisture in the roof surface provides a good space for mold, mildew, and other moisture-related problems.

**Health risks:** Some materials used for insulation pose risks to health. For example, fiberglass, a commonly used material for insulation, contains chemicals used to bind fibers together that can cause skin allergies.

**Greenhouse gases:** Hydrofluorocarbon blowing agents, involved in the implementation and manufacturing of thermal insulation, can be very potent greenhouse gases.

References:


4.2.2.2 CODES AND STANDARDS:

4.2.2.2.1 IECC, 2012:
All materials, systems and equipment shall be installed in accordance with the manufacturer’s installation instruction and the International Building Code or International Residential Code, as applicable.

4.2.2.2.2 ASHRAE 90.1, 2010:
Section 5.5.3.1 (Page 34): Roof Insulation: All roofs shall comply with the insulation values specified in Table 5.5-1 through 5.5-8 (related to Building Envelope Requirements for Different Climate Zone). This information is provided in climate–based section.

Table 5.5.3.1.2 (Page 34): Increased roof insulation levels (non-residential).

<table>
<thead>
<tr>
<th>Roofs</th>
<th>Insulation Min. R-Value</th>
<th>Insulation Min. R-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opaque Elements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation Entirely Above Deck</td>
<td>U-0.030</td>
<td>R-33</td>
</tr>
<tr>
<td>Metal Buildings</td>
<td>U-0.028</td>
<td>R-35</td>
</tr>
</tbody>
</table>

Section 5.8 (Page 37): Product Information and Installation Requirements:

5.8.1 Insulation:

- 5.8.1.1 Labeling of building envelope insulation: The rated R-value shall be clearly identified by an identification mark applied by manufacturer to each piece of building envelope insulation.
Exception: When insulation does not have such an identification mark, the installer of such insulation shall provide a signed and dated certification for the installed insulation listing the type of insulation, the manufacturer, the rated R-value, and, where appropriate, the initial installed thickness, the settled thickness, and the coverage area.

5.8.1.2 Compliance with manufacturer's requirements: Insulation materials shall be installed in accordance with manufacturers’ recommendations and in such a manner as to achieve rated R-value of insulation.

Exception: Where metal building roof and metal building wall insulation is compressed between the roof or wall skin and the structure.

5.8.1.3 Loose-Fill Insulation Limitation: Open blown or poured loose-fill insulation shall not be used in attic roof spaces when the slope of the ceiling is more than three in twelve.

5.8.1.4 Baffles: When eave vents are installed, baffling of the vent openings shall be provided to deflect the incoming air above the surface of the insulation.

5.8.1.5 Substantial Contact: Insulation shall be installed in a permanent manner in substantial contact with the inside surface in accordance with manufacturers’ recommendations for the framing system used. Flexible batt insulation installed in floor cavities shall be supported in a permanent manner by supports no greater than 24 in. on center.

Exception: Insulation materials that rely on air spaces adjacent to reflective surfaces for their rated performance.

5.8.1.6 Recessed Equipment: Lighting fixtures; heating, ventilating, and air-conditioning equipment, including wall heaters, ducts, and plenums; and other equipment shall not be recessed in such a manner as to affect the insulation thickness, unless the total combined area affected (including necessary clearances) is less than 1% of the opaque area of the assembly, the entire roof, wall, or floor is covered with insulation to the full depth required, or the effects of reduced insulation are included in calculations using an area-weighted average method and compressed insulation values obtained from Table A9.4.C.

5.8.1.7 Insulation protection: Exterior insulation shall be covered with a protective material to prevent damage from sunlight, moisture, landscaping operations, equipment maintenance, and wind.

5.8.1.7.1: In attics and mechanical rooms, a way to access equipment that prevents damaging or compressing the insulation shall be provided.

5.8.1.7.2: Foundation vents shall not interfere with the insulation.

5.8.1.7.3: Insulation materials in ground contact shall have a water absorption rate no greater than 0.3% when tested in accordance with ASTM C272.

5.8.1.8 Location of roof insulation: The roof insulation shall not be installed on a suspended ceiling with removable ceiling panels.

5.8.1.9 Extent of Insulation: Insulation shall extend over the full component area to the required rated R-value of insulation, U-factor, C-factor, or F-factor, unless otherwise allowed in Section 5.8.1.

5.8.1.10 Joints in rigid insulation: Where two or more layers of rigid insulation board are used in a construction assembly, the edge joints between each layer of boards shall be staggered.
NORMATIVE APPENDIX A

Section A2 (Page 103): ROOFS

Section A2.1 (Page 103): General: The buffering effect of suspended ceilings or attic spaces shall not be included in U-factor calculations.

Section A2.2 (Page 103): Roofs with Insulation Entirely Above Deck

- **A2.2.1 General.** For the purpose of Section A1.2 (Applicant-Determined Assembly U-Factors, C-Factors, F-Factors, or Heat Capacities), the base assembly is continuous insulation over a structural deck. The U-factor includes R-0.17 for exterior air film, R-0 for metal deck, and R-0.61 for interior air film heat flow up. Added insulation is continuous and uninterrupted by framing. The framing factor is zero.

- **A2.2.2 Rated R-Value of Insulation.** For roofs with insulation entirely above deck, the rated R-value of insulation is for continuous insulation.
  - **Exception:** Interruptions for framing and pads for mechanical equipment are permitted with a combined total area not exceeding one percent of the total opaque assembly area.

- **A2.2.3 U-Factor.** U-factors for roofs with insulation entirely above deck shall be taken from Table A2.2. It is not acceptable to use these U-factors if the insulation is not entirely above deck or not continuous.

Section A2.3 (Page 104): Metal Building Roofs.

- **A2.3.1 General.** For the purpose of Section A1.2 (Applicant-Determined Assembly U-Factors, C-Factors, F-Factors, or Heat Capacities), the base assembly is a roof with thermal spacer blocks where the insulation is draped over the steel structure (purlins), spaced nominally 5 ft on center and compressed when the metal roof panels are attached to the steel structure (purlins).

- **A2.3.2 Rated R-value of Insulation:**
  - **A2.3.2.1** The first rated R-value of insulation is for insulation draped over purlins and then compressed when the metal roof panels are attached, or for insulation hung between the purlins. A minimum R-3.5 thermal spacer block between the purlins and the metal roof panels is required when specified in Table A2.3 (Assembly U-Factors for Metal Building Roofs, page 105).
  - **A2.3.2.2** For double-layer installations, the second rated R-value of insulation is for insulation installed parallel to the purlins.
  - **A2.3.2.3** For continuous insulation (e.g., insulation boards or blankets), it is assumed that the insulation is installed below the purlins and is uninterrupted by framing members. Insulation exposed to the conditioned space or semi-heated space shall have a facing, and all insulation seams shall be continuously sealed to provide a continuous air barrier.
  - **A2.3.2.4** Liner System (Ls). A continuous vapor barrier liner is installed below the purlins and uninterrupted by framing members. Uncompressed, unfaced insulation rests on top of the liner between the purlins. For multilayer installations, the first rated R-Value of insulation is for unfaced insulation draped over purlins and then compressed when the metal roof panels are attached. A minimum R-3.5 thermal
spacer block between the purlins and the metal roof panels is required when specified in Table A2.3 (Assembly U-Factors for Metal Building Roofs, page 105).

- **A2.3.3 U-factor.** U-factors for metal building roofs shall be taken from Table A2.3 (Assembly U-Factors for Metal Building Roofs, page 105). It is not acceptable to use these U-factors if additional insulated sheathing is not continuous.

**Section A2.4 (Page 104): Attic Roofs with Wood Joists.**

- **A2.4.1 General.** For the purpose of Section A1.2 (Applicant-Determined Assembly U-Factors, C-Factors, F-Factors, or Heat Capacities), the base attic roof assembly is a roof with nominal 4 in. deep wood as the lower chord of a roof truss or ceiling joist. The ceiling is attached directly to the lower chord of the truss and the attic space above is ventilated. Insulation is located directly on top of the ceiling, first filling the cavities between the wood and then later covering both the wood and cavity areas. No credit is given for roofing materials. The single-rafter roof is similar to the base attic roof, with the key difference being that there is a single, deep rafter to which both the roof and the ceiling are attached. The heat flow path through the rafter is calculated to be the same depth as the insulation. Additional assemblies include continuous insulation, uncompressed and uninterrupted by framing. The U-factors include R-0.46 for semi-exterior air film, R-0.56 for 0.625 in. gypsum board, and R-0.61 for interior air film heat flow up. U-factors are provided for the following configurations:
  - **Attic roof, standard framing:** insulation is tapered around the perimeter with a resultant decrease in thermal resistance. Weighting factors are 85% full-depth insulation, 5% half-depth insulation, and 10% joists.
  - **Attic roof, advanced framing:** full and even depth of insulation extending to the outside edge of exterior walls. Weighting factors are 90% full-depth insulation and 10% joists.
  - **Single-rafter roof:** an attic roof where the roof sheathing and ceiling are attached to the same rafter. Weighting factors are 90% full-depth insulation and 10% joists.

- **A2.4.2 Rated R-Value of Insulation:**
  - **A2.4.2.1** For attics and other roofs, the rated R-value of insulation is for insulation installed both inside and outside the roof or entirely inside the roof cavity.
  - **A2.4.2.2** Occasional interruption by framing members is allowed but requires that the framing members be covered with insulation when the depth of the insulation exceeds the depth of the framing cavity.
  - **A2.4.2.3** Insulation in such roofs shall be permitted to be tapered at the eaves where the building structure does not allow full depth.
  - **A2.4.2.4** For single-rafter roofs, the requirement is the lesser of the values for attics and other roofs and those listed in Table A2.4.2 (Single-Rafter Roofs).
### TABLE A2.4.2 Single-Rafter Roofs

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Minimum Insulation R-Value or Maximum Assembly U-Factor</th>
<th>Wood Rafter Depth, d (Actual)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>d ≤ 8 in.</td>
</tr>
<tr>
<td>1-7</td>
<td>R-19</td>
<td>R-30</td>
</tr>
<tr>
<td></td>
<td>U-0.055</td>
<td>U-0.036</td>
</tr>
<tr>
<td>8</td>
<td>R-21</td>
<td>R-30</td>
</tr>
<tr>
<td></td>
<td>U-0.052</td>
<td>U-0.036</td>
</tr>
</tbody>
</table>

**A2.4.3 U-factors for Attic Roofs with Wood Joists:** U-factors for attic roofs with wood joists shall be taken from Table A2.4 (Assembly U-Factors for Attic Roofs with Wood Joists). It is not acceptable to use these U-factors if the framing is not wood. For attic roofs with steel joists, see Section A2.5.

**Section A2.5 (Page 104): Attic Roofs with Steel Joists:**

- **A2.5.1 General.** For the purpose of Section A1.2 (Applicant-Determined Assembly U-Factors, C-Factors, F-Factors, or Heat Capacities), the base assembly is a roof supported by steel joists with insulation between the joists. The assembly represents a roof in many ways similar to a roof with insulation entirely above deck and a metal building roof. It is distinguished from the metal building roof category in that there is no metal exposed to the exterior. It is distinguished from the roof with insulation entirely above deck in that the insulation is located below the deck and is interrupted by metal trusses that provide thermal bypasses to the insulation. The U-factors include R-0.17 for exterior air film, R-0 for metal deck, and R-0.61 for interior air film heat flow up. The performance of the insulation/framing layer is calculated using the values in Table A9.2A.
A2.5.2 U-factors for attic roofs with steel joists shall be taken from Table A2.5. It is acceptable to use these U-factors for any attic roof with steel joists.

<table>
<thead>
<tr>
<th>Rated R-Value of Insulation</th>
<th>Correction Factor</th>
<th>Framing/Cavity R-Value</th>
<th>Rated R-Value</th>
<th>Correction Factor</th>
<th>Framing/Cavity R-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
<td>20.00</td>
<td>0.85</td>
<td>17.00</td>
</tr>
<tr>
<td>4.00</td>
<td>0.97</td>
<td>3.88</td>
<td>21.00</td>
<td>0.84</td>
<td>17.64</td>
</tr>
<tr>
<td>5.00</td>
<td>0.96</td>
<td>4.80</td>
<td>24.00</td>
<td>0.82</td>
<td>19.68</td>
</tr>
<tr>
<td>8.00</td>
<td>0.94</td>
<td>7.52</td>
<td>25.00</td>
<td>0.81</td>
<td>20.25</td>
</tr>
<tr>
<td>10.00</td>
<td>0.92</td>
<td>9.20</td>
<td>30.00</td>
<td>0.79</td>
<td>23.70</td>
</tr>
<tr>
<td>11.00</td>
<td>0.91</td>
<td>10.01</td>
<td>35.00</td>
<td>0.76</td>
<td>26.60</td>
</tr>
<tr>
<td>12.00</td>
<td>0.90</td>
<td>10.80</td>
<td>38.00</td>
<td>0.74</td>
<td>28.12</td>
</tr>
<tr>
<td>13.00</td>
<td>0.90</td>
<td>11.70</td>
<td>40.00</td>
<td>0.73</td>
<td>29.20</td>
</tr>
<tr>
<td>15.00</td>
<td>0.88</td>
<td>13.20</td>
<td>45.00</td>
<td>0.71</td>
<td>31.95</td>
</tr>
<tr>
<td>16.00</td>
<td>0.87</td>
<td>13.92</td>
<td>50.00</td>
<td>0.69</td>
<td>34.30</td>
</tr>
<tr>
<td>19.00</td>
<td>0.86</td>
<td>16.34</td>
<td>55.00</td>
<td>0.67</td>
<td>36.85</td>
</tr>
</tbody>
</table>

**TABLE A2.5 Assembly U-Factors for Attic Roofs with Steel Joists (4.0 ft on Center)**

<table>
<thead>
<tr>
<th>Rated R-Value of Insulation Alone</th>
<th>Overall U-Factor for Entire Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-6</td>
<td>U-0.1282</td>
</tr>
<tr>
<td>R-4</td>
<td>U-0.215</td>
</tr>
<tr>
<td>R-5</td>
<td>U-0.179</td>
</tr>
<tr>
<td>R-8</td>
<td>U-0.120</td>
</tr>
<tr>
<td>R-10</td>
<td>U-0.100</td>
</tr>
<tr>
<td>R-11</td>
<td>U-0.093</td>
</tr>
<tr>
<td>R-12</td>
<td>U-0.086</td>
</tr>
<tr>
<td>R-13</td>
<td>U-0.080</td>
</tr>
<tr>
<td>R-15</td>
<td>U-0.072</td>
</tr>
<tr>
<td>R-16</td>
<td>U-0.068</td>
</tr>
<tr>
<td>R-19</td>
<td>U-0.058</td>
</tr>
<tr>
<td>R-20</td>
<td>U-0.056</td>
</tr>
<tr>
<td>R-21</td>
<td>U-0.054</td>
</tr>
<tr>
<td>R-24</td>
<td>U-0.049</td>
</tr>
<tr>
<td>R-25</td>
<td>U-0.048</td>
</tr>
<tr>
<td>R-30</td>
<td>U-0.041</td>
</tr>
<tr>
<td>R-35</td>
<td>U-0.037</td>
</tr>
<tr>
<td>R-38</td>
<td>U-0.035</td>
</tr>
<tr>
<td>R-40</td>
<td>U-0.033</td>
</tr>
<tr>
<td>R-45</td>
<td>U-0.031</td>
</tr>
<tr>
<td>R-50</td>
<td>U-0.028</td>
</tr>
<tr>
<td>R-55</td>
<td>U-0.027</td>
</tr>
</tbody>
</table>
Section A9.4.3 (Page 133): Building Material Thermal Properties: R-values used for building materials shall be taken from table A9.4D (related to R-values for building materials).

<table>
<thead>
<tr>
<th>Material</th>
<th>Nominal Size, in.</th>
<th>Actual Size, in.</th>
<th>R-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal deck</td>
<td>—</td>
<td>—</td>
<td>0</td>
</tr>
<tr>
<td>Roofing, built-up</td>
<td>—</td>
<td>0.375</td>
<td>0.33</td>
</tr>
<tr>
<td>Sheathing, vegetable fiber board; 0.78 in.</td>
<td>—</td>
<td>0.78</td>
<td>2.06</td>
</tr>
<tr>
<td>Soil at R-0.104/in.</td>
<td>—</td>
<td>12</td>
<td>1.25</td>
</tr>
<tr>
<td>Steel, mild</td>
<td>1</td>
<td>0.0031807</td>
<td></td>
</tr>
<tr>
<td>Stucco</td>
<td>—</td>
<td>0.75</td>
<td>0.08</td>
</tr>
<tr>
<td>Wood, 2 × 4 at R-1.25/in.</td>
<td>4</td>
<td>3.5</td>
<td>4.38</td>
</tr>
<tr>
<td>Wood, 2 × 4 at R-1.25/in.</td>
<td>6</td>
<td>5.5</td>
<td>6.88</td>
</tr>
<tr>
<td>Wood, 2 × 4 at R-1.25/in.</td>
<td>8</td>
<td>7.25</td>
<td>9.06</td>
</tr>
<tr>
<td>Wood, 2 × 4 at R-1.25/in.</td>
<td>10</td>
<td>9.25</td>
<td>11.56</td>
</tr>
<tr>
<td>Wood, 2 × 4 at R-1.25/in.</td>
<td>12</td>
<td>11.25</td>
<td>14.06</td>
</tr>
<tr>
<td>Wood, 2 × 4 at R-1.25/in.</td>
<td>14</td>
<td>13.25</td>
<td>16.56</td>
</tr>
</tbody>
</table>

- Concrete block R-values shall be calculated using the isothermal planes method or a two-dimensional calculation program, thermal conductivities from table A9.4E (related to thermal conductivity of concrete block material), and dimensions from ASTM C90. The parallel path calculation method is not acceptable.
  - **Exception**: R-values for building materials or thermal conductivities determined from testing in accordance with section A9.3 (explain about testing procedures).

<table>
<thead>
<tr>
<th>Concrete Block Density, lb/ft³</th>
<th>Thermal Conductivity, Btu·in/h·ft²·°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>3.7</td>
</tr>
<tr>
<td>85</td>
<td>4.2</td>
</tr>
<tr>
<td>90</td>
<td>4.7</td>
</tr>
<tr>
<td>95</td>
<td>5.1</td>
</tr>
<tr>
<td>100</td>
<td>5.5</td>
</tr>
<tr>
<td>105</td>
<td>6.1</td>
</tr>
<tr>
<td>110</td>
<td>6.7</td>
</tr>
<tr>
<td>115</td>
<td>7.2</td>
</tr>
<tr>
<td>120</td>
<td>7.8</td>
</tr>
<tr>
<td>125</td>
<td>8.9</td>
</tr>
<tr>
<td>130</td>
<td>10.0</td>
</tr>
<tr>
<td>135</td>
<td>11.8</td>
</tr>
<tr>
<td>140</td>
<td>13.5</td>
</tr>
</tbody>
</table>
4.2.2.2.3 IgCC, 2012:
IgCC 2012 includes the following relevant information to thermal insulation:

- **Section 202, Definitions (Page 2-14): R-VALUE (THERMAL RESISTANCE):** Thermal resistance measures how well a material or series of materials retards heat flow. Insulation thermal resistance is rated using R-values. As the R-value of an element or assembly increases, the heat loss or gain through that element or assembly decreases. Thus, a higher R-value is considered better than a lower R-value.

- **Section 1003.2.6 (Page 10-4): Insulation of unconditioned attics:** In buildings with three or fewer stories above grade plane, ceiling insulation with a minimum R-value as required by this code shall be installed in accessible attic spaces that are directly above conditioned spaces. For the purposes of this section, accessible attic space is the space between ceiling joists and roof rafters where the vertical clear height from the top of a ceiling joist or the bottom chord of a truss, to the underside of the roof sheathing at the roof ridge, is greater than 24 inches (610 mm). Where the required R-value insulation cannot fit in the attic space, the maximum amount of insulation compatible with available space and existing uses shall be installed.

- **Section 1003.2.7 (Page 10-4): Roof replacement insulation:** For roof replacement on an existing building with insulation entirely above the deck and where the roof slope is less than two units vertical in 12 units horizontal (16-percent slope), the insulation shall conform to the energy conservation requirements for insulation entirely above deck in the International Energy Conservation Code.
  o **Exception:** Where the required R-value cannot be provided due to thickness limitations presented by existing rooftop conditions, including heating, ventilating and air conditioning equipment, low door or glazing heights, parapet heights, proper roof flashing heights, the maximum thickness of insulation compatible with the available space and existing uses shall be installed.

4.2.2.2.4 ASHRAE AEDG, 50%, 2011:
N/A. There is no information about thermal insulation available in the ASHRAE AEDG, 50%, 2011 database sheets.

4.2.2.2.5 ASHRAE Fundamental, 2009:
ASHRAE Fundamentals includes the following information relevant to thermal insulation and calculating R-values:

- Steady-state thermal resistances (R-values) of building assemblies (walls, floors, windows, roof systems, etc.) can be calculated from thermal properties of the materials in the component, provided by Table 4, or heat flow through the assembled component can be measured directly with laboratory equipment such as the guarded hot box (ASTM Standard C236) or the calibrated hot box (ASTM Standard C976). Direct measurement is the most
accurate method of determining the over-all thermal resistance for a combination of building materials assembled as a building envelope component. However, all combinations may not be conveniently or economically tested in this manner. For many simple constructions, calculated R-values agree reasonably well with values determined by hot-box measurement. Table 4’s values were developed by testing under ideal conditions. In practice, overall thermal performance can be reduced significantly by factors such as improper installation, quality of workmanship and shrinkage, settling, or compression of the insulation (Tye 1985, 1986; Tye and Desjarlais 1983).

4.2.2.6 RoofPoint:
RoofPoint Credit E2 addresses the challenges of thermal “shorts” or discontinuities within the roofing system that reduce the effectiveness of thermal insulation. To address such discontinuities, Credit E2 identifies a number of strategies, including application of multiple, staggered layers of insulation, the elimination of through-fasteners, and the use of a monolithic insulation application.

4.2.2.7 RoofNav:
RoofNav includes the following information relevant to thermal insulation:

- Industrial and commercial consumers around the world rely on products and services that are FM approved and specification-tested to protect their properties from loss. The FM APPROVED mark, which is backed by scientific research and testing, tells customers the product conforms to the highest standards.

1 Factory Mutual (FM): FM’s Approval certifies products and services with a unique focus on:
  - Objectively testing property loss prevention products and services and certifying those that meet rigorous loss prevention standards.
  - Encouraging the development and use of FM approved products and services that improve and advance property loss prevention practices.

4.2.2.3 REALITY

4.2.2.3.1 Implementation costs:
For a pitched roof, on a roof of 100m², costs will be between $1,300 to $1,700 for ceiling level insulation and 5,000 to $6,700 for insulating between the roof rafters. Insulating a flat or low sloping roof will cost more; an official quote will give a better idea of prices. As a rough guide, though, it could cost between around $130/m² to $215/m² for 100mm thick, high-density insulation blocks covered with an impermeable membrane.

- Insulating flat or low sloping roofs is very much more expensive and should be carried out by professional contractors. One of the main costs is accommodating skylights, access hatches, vent outlets, ducting, drainage channels, aerials and masts.
4.2.2.3.2 Aesthetics:

Roofs and roof coverings shall be of materials that are compatible with each other and with the building or structure to which the materials are applied. New roof covering systems offer a complete, light and safe covering with high value thermal insulation which can aesthetically comply with landscape constraints.

Psychological aspects: Thermal insulation has been shown to increase indoor thermal comfort for occupants of a building and improve the quality of life.

Precedents of innovation: Reflective insulation consists of lightweight metalized film, which has effectively lifetime insulation, depending upon the desired end result.

- Products like Super R® brand radiant barrier and Tempshield® brand foil bubble reflective insulation offer better comfort for occupants with substantially less fuel costs. They decrease the investment dollars required for heating and cooling equipment.

References:

4.2.2.4 GENERAL RECOMMENDATION:

4.2.2.4.1 Climate Zones (1-8)

1A_ Miami:

- Miami has a tropical monsoon climate with hot and humid summers and short, warm winters. Thermal insulation can significantly decrease the amount of heat lost or gained through a roof system. Proper use of thermal insulation with other retrofitting techniques leads to enhance the thermal comfort at less operating cost. Applying additional insulation is often the first measure for energy-saving design due to its comparatively low cost, high return on investment. The magnitude of energy savings due to thermal insulation vary based on climate conditions. In warm and humid climate, most of energy is used for air-conditioning and ventilation system, which directly depends on building thermal load. Reducing heat transfer by conduction through roofs can significantly decrease the total thermal load of a building and consequently its energy needs. The placement of insulation also can influence its thermal performance. Placement of insulation close to the place of entry of heat flow can offer a better result. This means placement of insulation to the outside in cooling dominated climates. In moist climates, condensation can happen within the insulation material, which reduces its effectiveness. Ventilation and dehumidification can help control condensation within roofs during warm seasons. However, the entering ventilation air should not contain more moisture than indoor air. Controlling infiltration and sealing all air leakage also are important for reducing energy consumption. A well-sealed building envelope requires less energy to maintain thermal comfort of occupants.
References:


2A_Houston:
- Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.
- Thermal insulation can significantly decrease the amount of heat lost or gained through a roof system. Proper use of thermal insulation with other retrofitting techniques leads to enhance the thermal comfort at less operating cost. Applying additional insulation is often the first measure for energy-saving design due to its comparatively low cost, high return on investment. The magnitude of energy savings due to thermal insulation vary based on climate conditions. In warm and humid climate, most of energy is used for air-conditioning and ventilation system, which directly depends on building thermal load. Reducing heat transfer by conduction through roofs can significantly decrease the total thermal load of a building and consequently its energy needs. The placement of insulation also can influence its thermal performance. Placement of insulation close to the place of entry of heat flow can offer a better result. This means placement of insulation to the outside in cooling dominated climates. In moist climates, condensation can happen within the insulation material, which reduces its effectiveness. Ventilation and dehumidification can help control condensation within roofs during warm seasons. However, the entering ventilation air should not contain more moisture than indoor air. Controlling infiltration and sealing all air leakage also are important for reducing energy consumption. A well-sealed building envelope requires less energy to maintain thermal comfort of occupants.

References:


2B_Phoenix:
• Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.

• Thermal insulation can significantly decrease the amount of heat lost or gained through a roof system. Proper use of thermal insulation with other retrofitting techniques leads to enhance the thermal comfort at less operating cost. Applying additional insulation is often the first measure for energy-saving design due to its comparatively low cost and high return on investment. The magnitude of energy savings due to thermal insulation vary based on climate conditions. In warm and dry climate with large diurnal range of temperature, the mass of roof components and the location of insulation have considerable impact on thermal performance of the building and thermal comfort of people. The placement of insulation material also can influence its thermal performance. Placement of insulation close to the place of entry of heat flow can offer better result. This means placement of insulation material to the outside in cooling dominated climate. Controlling infiltration and sealing all air leakage also are important for reducing energy consumption. A well-sealed building envelope requires less energy to maintain thermal comfort of occupants.

References:


3A_Atlanta:

• Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

• Thermal insulation can significantly decrease the amount of heat lost or gained through a roof system. Proper use of thermal insulation with other retrofitting techniques leads to enhance the thermal comfort at less operating cost. Applying additional insulation is often the first measure for energy-saving design due to its comparatively low cost, high return on investment. The magnitude of energy savings due to thermal insulation vary based on climate conditions. In warm and humid climate, most of energy is used for air-conditioning and ventilation system, which directly depends on building thermal load. Reducing heat transfer by conduction through roofs can significantly decrease the total thermal load of a building and consequently its energy needs. The placement of insulation also can influence its thermal performance. Placement of insulation close to the place of entry of heat flow can
offer a better result. This means placement of insulation to the outside in cooling dominated climates. In moist climates, condensation can happen within the insulation material, which reduces its effectiveness. Ventilation and dehumidification can help control condensation within roofs during warm seasons. However, the entering ventilation air should not contain more moisture than indoor air. Controlling infiltration and sealing all air leakage also are important for reducing energy consumption. A well-sealed building envelope requires less energy to maintain thermal comfort of occupants.

References:

3B_Coast_Los Angeles:
- The climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall but relatively modest transitions in temperature.
- Thermal insulation can significantly decrease the amount of heat lost or gained through a roof system. Proper use of thermal insulation with other retrofitting techniques leads to enhance the thermal comfort at less operating cost. Applying additional insulation is often the first measure for energy-saving design due to its comparatively low cost and high return on investment. Controlling infiltration and eliminating air leakage are also important for reducing energy consumption. A well-sealed building envelope requires less energy to maintain thermal comfort of occupants.

References:

3b_Las Vegas:
Climate Zone 3B includes areas of the United States with a characteristically dry climate. Thermal insulation can significantly decrease the amount of heat lost or gained through a roof system. Proper use of thermal insulation with other retrofitting techniques leads to enhance the thermal comfort at less operating cost. Applying additional insulation is often the first measure for energy-saving design due to its comparatively low cost, and the best return on investment. The magnitude of energy savings due to thermal insulation vary based on climate conditions. In hot and dry climate with large diurnal range of temperature, the mass of roof components and the location of insulation have considerable effects on thermal performance of the building and thermal comfort of people. The placement of insulation material also can influence its thermal performance. Placement of insulation close to the place of entry of heat flow can offer better result. This means placement of insulation material to the outside in cooling dominated climate. Controlling infiltration and preventing air leakage are also important for reducing energy consumption. A wellsealed building envelope requires less energy to maintain thermal comfort of occupants.

References:


3C_San Francisco:

Climate Zone 3C includes areas of the United States with a characteristically marine climate. Thermal insulation can significantly decrease the amount of heat lost or gained through a roof system. Proper use of thermal insulation with other retrofitting techniques leads to enhance the thermal comfort at less operating cost. Applying additional insulation is often the first measure for energy-saving design due to its comparatively low cost and high return on investment. Controlling infiltration and preventing air leakage are also important for reducing energy consumption. A well-sealed building envelope requires less energy to maintain thermal comfort of occupants.

References:
4A_ Baltimore:

- Climate Zone 4A includes areas of the United States with a characteristically moist climate.
- Thermal insulation can significantly decrease the amount of heat lost or gained through a roof system. Proper use of thermal insulation with other retrofitting techniques leads to enhance the thermal comfort at less operating cost. Applying additional insulation is often the first measure for energy-saving design due to its comparatively low cost and high return on investment. The magnitude of energy savings due to thermal insulation vary based on climate conditions. The placement of insulation material also can influence its thermal performance. Placement of insulation close to the place of entry of heat flow can offer better result. This means placement of insulation material to the outside in cooling dominated climate and to the outside for heating dominated climate. In moist climate, condensation can happen within the insulation material, which reduces its effectiveness. Ventilation and dehumidification can control condensation within roof during warm season. However, the entering ventilation air should not contain more moisture than indoor air. Controlling infiltration and preventing air leakage are also important for reducing energy consumption. A well-sealed building envelope requires less energy to maintain thermal comfort of occupants.

References:


4B_ Albuquerque:

- Climate Zone 4B includes areas of the United States with a characteristically dry climate.
- Thermal insulation can significantly decrease the amount of heat lost or gained through a roof system. Proper use of thermal insulation with other retrofitting techniques leads to
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References:


4C_ Seattle:

- Climate Zone 4C includes areas of the United States with a characteristically marine climate.
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References:
5A_ Chicago:

- Climate Zone 5A includes areas of the United States with a characteristically moist climate.
- Thermal insulation can significantly decrease the amount of heat lost or gained through a roof system. Proper use of thermal insulation with other retrofitting techniques leads to enhance the thermal comfort at less operating cost. Applying additional insulation is often the first measure for energy-saving design due to its comparatively low cost and high return on investment. The placement of insulation material also can influence its thermal performance. Placement of insulation close to the place of entry of heat flow can offer better result. This means placement of insulation material to the inside for heating dominated climate. In moist climate, condensation can happen within the insulation material, which reduces its effectiveness. Ventilation and dehumidification can control condensation within roof during warm season. However, the entering ventilation air should not contain more moisture than indoor air. Controlling infiltration and preventing air leakage are also important for reducing energy consumption. A well-sealed building envelope requires less energy to maintain thermal comfort of occupants.

References:


5B_ Denver:

- Climate Zone 5B includes areas of the United States with a characteristically dry climate.
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References:

4.2.2.4 Climate zone 6, 7, 8:
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References:
4.2.2.5 CODE RECOMMENDATIONS:

All roofs shall comply with the insulation values specified in following tables for different climate zones.

1A. Miami

IECC, 2012:

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ASHRAE90.1, 2010:

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Recommendation Table for Small to Medium Office Buildings

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2A_Houston

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Table 5.5-2 Building Envelope Requirements for Climate zone 2 (A,B)

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**2B Phoenix**

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Table 5.5-2 Building Envelope Requirements for Climate zone 2 (A,B)

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3A_Atlanta

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ASHRAE90.1, 2010:

Table 5.5-3 Building Envelope Requirements for Climate zone 3 (A,B)

Nonresidential

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![TABLE A2.4.2 Single-Rafter Roofs](image)

ASHRAE AEDG 50%:

Recommendation Table for Small to Medium Office Buildings

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**ASHRAE 90.1, 2010:**

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**ASHRAE AEDG 50%:**

**Recommendation Table for Small to Medium Office Buildings**

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3b_Las Vegas

IECC, 2012:

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ASHRAE90.1, 2010:

**Table 5.5-3 Building Envelope Requirements for Climate zone 3 (A,B)**

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#### 3C_San Francisco

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</table>
Attic and other | U-0.027 | R-38

ASHRAE 90.1, 2010:

Table 5.5-3 Building Envelope Requirements for Climate zone 3 (A, B, C)

Nonresidential

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<td>U-0.055</td>
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ASHRAE AEDG 50%:

Recommendation Table for Small to Medium Office Buildings

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<tr>
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RoofPoint:

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<td>Attic and other</td>
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### 4A Baltimore

**IECC, 2012:**

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<td>U-0.027</td>
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**ASHRAE90.1, 2010:**

**Table 5.5-4 Building Envelope Requirements for Climate zone 4 (A,B,C)**

**Nonresidential**

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<td>R-20.0 c.i.</td>
</tr>
<tr>
<td>Metal building</td>
<td>U-0.055</td>
<td>R-13.0 + R-13.0</td>
</tr>
<tr>
<td>Attic and other</td>
<td>U-0.027</td>
<td>R-38.0</td>
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ASHRAE AEDG 50%:

Recommendation Table for Small to Medium Office Buildings

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<td>R-30.0 c.i.</td>
</tr>
<tr>
<td></td>
<td>Attic and other</td>
<td>R-49.0</td>
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<tr>
<td></td>
<td>Metal building</td>
<td>R-19.0 +R-11.0 FC</td>
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RoofPoint:

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<td>Insulation entirely above deck</td>
<td>R-25.0 c.i.</td>
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<td></td>
<td>Attic and other</td>
<td>R-49.0</td>
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4B_Albuquerque
IECC, 2012:

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ASHRAE90.1, 2010:

Table 5.5-4 Building Envelope Requirements for Climate zone 4 (A,B,C)

Nonresidential

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ASHRAE AEDG 50%:

Recommendation Table for Small to Medium Office Buildings

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<th>Recommendation</th>
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### 4C_Seaattle

**IECC, 2012:**

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**ASHRAE90.1, 2010:**

**Table 5.5-4 Building Envelope Requirements for Climate zone 4 (A,B,C)**

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### ASHRAE AEDG 50%:

**Recommendation Table for Small to Medium Office Buildings**

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### 5A Chicago

**IECC, 2012:**

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</table>
Attic and other  
U-0.027  
R-38

ASHRAE90.1, 2010:

Table 5.5-5 Building Envelope Requirements for Climate zone 5 (A,B,C)

Nonresidential

<table>
<thead>
<tr>
<th>Opaque Elements</th>
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<td>U-0.055</td>
<td>R-13.0 + R-13.0</td>
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<td>Attic and other</td>
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ASHRAE AEDG 50%:

Recommendation Table for Small to Medium Office Buildings

<table>
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<td>Attic and other</td>
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RoofPoint:

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<td>R-25.0 c.i.</td>
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</table>
Roof | U-value | R-value  
---|---|---  
Attic and other | | R-49.0  
Metal building | | R-19.0 + R-11.0 FC

5B Denver

IECC, 2012:

<table>
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<th>Opaque thermal envelope assembly requirements</th>
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| Roof | U-value | R-value  
Insulation above deck | U-0.039 | R-25 ci  
Metal building | U-0.035 | R-19 + R-11 LS  
Attic and other | U-0.027 | R-38

ASHRAE90.1, 2010:

Table 5.5-5 Building Envelope Requirements for Climate zone 5 (A,B,C)

| Nonresidential |
|---|---|---|
| Opaque Elements | Assembly Maximum | Insulation Min. R-Value  
Insulation above deck | U-0.048 | R-20.0 c.i.  
Metal building | U-0.055 | R-13.0 + R-13.0  
Attic and other | U-0.027 | R-38.0

| Table A2.4.2 Single-Rafter Roofs |
|---|---|---|---|
| Climate Zone | Minimum Insulation R-Value or Maximum Assembly U-Factor  
| | Wood Rafter Depth, d (Actual) | 8 d ≤ 8 in. | 8 < d ≤ 10 in. | 10 < d ≤ 12 in.  
| --- | --- | --- | --- | --- |
| 1-7 | R-19 | R-30 | R-38  
| | U-0.055 | U-0.036 | U-0.028  
| 8 | R-21 | R-30 | R-38  
| | U-0.052 | U-0.036 | U-0.028
### ASHRAE AEDG 50%:

**Recommendation Table for Small to Medium Office Buildings**

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<td>Attic and other</td>
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<td>Metal building</td>
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<td>Attic and other</td>
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<tr>
<td></td>
<td>Metal building</td>
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### Climate zone 6

**IECC, 2012:**

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<td>Attic and other</td>
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<tr>
<td>Component</td>
<td>U-value</td>
<td>R-value</td>
</tr>
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Table 5.5-1 Building Envelope Requirements for Climate zone 1 (A,B)

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ASHRAE90.1, 2010:

Table 5.5-6 Building Envelope Requirements for Climate zone 6 (A,B)

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TABLE A2.4.2 Single-Rafter Roofs

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<tr>
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<td>d ≤ 8 in.</td>
</tr>
<tr>
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<td>R-19</td>
</tr>
<tr>
<td></td>
<td>U-0.055</td>
</tr>
<tr>
<td>8</td>
<td>R-21</td>
</tr>
<tr>
<td></td>
<td>U-0.052</td>
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ASHRAE AEDG 50%:
### Recommendation Table for Small to Medium Office Buildings

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<td>Metal building</td>
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### RoofPoint:

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<td></td>
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### Climate zone 7

### IECC, 2012:

#### Table C402.1.2
Opaque thermal envelope assembly requirements

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#### Table C402.2
Opaque thermal envelope requirements

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AEDG
### RoofPoint

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### ASHRAE90.1, 2010:

#### Table 5.5-7 Building Envelope Requirements for Climate zone 7

#### Nonresidential

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<td>U-0.027</td>
<td>R-38.0</td>
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</tbody>
</table>

**TABLE A2.4.2  Single-Rafter Roofs**

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Minimum Insulation R-Value</th>
<th>Maximum Assembly U-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>d ≤ 8 in.</td>
<td>8 &lt; d ≤ 10 in.</td>
</tr>
<tr>
<td>1-7</td>
<td>R-19</td>
<td>R-30</td>
</tr>
<tr>
<td>8</td>
<td>R-31</td>
<td>U-0.055</td>
</tr>
</tbody>
</table>

### ASHRAE AEDG 50%:

#### Recommendation Table for Small to Medium Office Buildings

<table>
<thead>
<tr>
<th>Item</th>
<th>Component</th>
<th>Recommendation</th>
</tr>
</thead>
</table>
RoofPoint:

<table>
<thead>
<tr>
<th>Item</th>
<th>Component</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation entirely above</td>
<td>Roof</td>
<td>R-32.0 c.i.</td>
</tr>
<tr>
<td>deck</td>
<td>Attic and other</td>
<td>R-49.0</td>
</tr>
<tr>
<td>Metal building</td>
<td></td>
<td>R-19.0 +R-11.0 FC</td>
</tr>
</tbody>
</table>

**Climate zone 8**

IECC, 2012:

<table>
<thead>
<tr>
<th>Table C402.1.2 Opaque thermal envelope assembly requirements</th>
<th>Table C402.2 Opaque thermal envelope requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>U-value</td>
</tr>
<tr>
<td>Insulation above deck</td>
<td>U-0.028</td>
</tr>
<tr>
<td>Metal building</td>
<td>U-0.029</td>
</tr>
<tr>
<td>Attic and other</td>
<td>U-0.021</td>
</tr>
</tbody>
</table>

Table 5.5-8 Building Envelope Requirements for Climate zone 8

<table>
<thead>
<tr>
<th>Nonresidential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opaque Elements</td>
</tr>
<tr>
<td>Insulation above deck</td>
</tr>
<tr>
<td>Metal building</td>
</tr>
<tr>
<td>Attic and other</td>
</tr>
</tbody>
</table>
AEDG

<table>
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<th>Component</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation entirely above deck</td>
<td></td>
<td>R-35.0 c.i.</td>
</tr>
<tr>
<td>Roof</td>
<td>Attic and other</td>
<td>R-60.0</td>
</tr>
<tr>
<td>Metal building</td>
<td></td>
<td>R-25.0 +R-11.0 FC</td>
</tr>
</tbody>
</table>

RoofPoint

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<td>R-19.0 +R-11.0 FC</td>
</tr>
</tbody>
</table>

ASHRAE90.1, 2010:

Table 5.5-8 Building Envelope Requirements for Climate zone 8

Nonresidential

<table>
<thead>
<tr>
<th>Opaque Elements</th>
<th>Assembly Maximum</th>
<th>Insulation Min. R-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation above deck</td>
<td>U-0.048</td>
<td>R-20.0 c.i.</td>
</tr>
<tr>
<td>Metal building</td>
<td>U-0.035</td>
<td>R-13.0 + R-19.0</td>
</tr>
<tr>
<td>Attic and other</td>
<td>U-0.021</td>
<td>R-49.0</td>
</tr>
</tbody>
</table>

ASHRAE AEDG 50%:

Recommendation Table for Small to Medium Office Buildings
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<tr>
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<td></td>
<td>Metal building</td>
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</tr>
</tbody>
</table>
4.2.3 THERMAL MASS

4.2.3.1 GENERAL INFORMATION

Thermal mass material
(Source: http://thermalcoating.com/thermal-mass-building-materials/).

4.2.3.1.1 Definition:
Thermal mass is a property that enables materials to absorb and store thermal energy, and delay heat transfer from outdoor to indoor space. Materials suitable for thermal mass are heavy (or dense) materials with the ability to store large amounts of heat energy.

Thermal masses work well in commercial buildings by shifting the peak summer load to later in the day, which helps mitigate demand and peak power consumption.

References:
4.2.3.1.2 Advantages:
By using materials with thermal mass capabilities, the benefits of solar gain are maximized, and the heating load is reduced. Energy consumption is reduced for climates with large daily temperature fluctuations due to reduced and delayed heat transfer. Reductions in energy for both heating and cooling reduce carbon dioxide emissions. Energy demand is reallocated to off-peak periods, while peak temperatures and peak loads are reduced. The benefits may be so significant that applying thermal mass strategies in association with night ventilation cycles can eliminate the need for daytime cooling. Using thermal mass materials will be useful for adapting future buildings to climate change.

References:
4.2.3.1.3 Disadvantages:

Despite the significant advantages associated with thermal mass materials, there are also some disadvantages. These materials are most suitable for heavy weight construction. When thermal mass strategies are used inappropriately, they will increase the energy demand of a building. If a building is used intermittently for specific days of the week (e.g. religious institutions), it will take longer than a low-mass building to achieve the desired temperature within the building.

References:


4.2.3.2 CODES AND STANDARDS:

4.2.3.2.1 IECC, 2012:
All materials, systems and equipment shall be installed in accordance with the manufacturer’s installation instruction and the international Building Code or International Residential Code, as applicable.

4.2.3.2.2 ASHRAE 90.1, 2010:
N/A. There is no information about thermal insulation available in the ASHRAE 90.1, 2010 database sheets.

4.2.3.2.3 IgCC, 2012:
N/A. There is no information about thermal insulation available in the IgCC, 2012 database sheets.

4.2.3.2.4 ASHRAE AEDG, 50%, 2011:
Building thermal mass, furthermore, can absorb solar heat gain with reduced temperature, rise and store that heat for later use for space heating after sunset. Similarly, during periods of lower humidity and low overnight temperatures, overnight ventilation with outdoor air (OA) can be used to cool a thermally massive building, offsetting subsequent daytime sensible cooling loads.

4.2.3.2.5 ASHRAE Fundamental, 2009:
N/A. There is no information about thermal insulation available in the ASHRAE Fundamental, 2009 database sheets.

4.2.3.2.6 RoofPoint:
N/A. There is no information about thermal insulation available in the RoofPoint database sheets.

4.2.3.2.7 RoofNav:
N/A. There is no information about thermal insulation available in the RoofNav database sheets.

4.2.3.3 REALITY

Because of additional masonry and structural support, the cost of thermal mass and other passive design systems can exceed that of conventional designs.

Phase change materials (PCMs) and water filled containers are much lighter than masonry and have much greater thermal storage capacity; therefore, PCMs are effective mass substitutes. Water has double the thermal storage capacity of concrete and, because of convection within the container,
heat penetration rates are substantially higher. Thus water can supply similar storage capacity to masonry with significantly less mass and bulk. Accordingly, both can be cost effective mass options for upper stories because they require little to no additional structural support.

Unlike many active solar heating systems, passive solar heating systems involving thermal mass elements have relatively low initial costs while lacking long-term payback periods. With the help of experienced passive solar designers and builders, passive solar design costs little more than conventional building design and saves money over the long term.

References:


### 4.2.3.3.1 Aesthetics:

Applying thermal mass may cause some aesthetic issues due to increased membrane thickness. This issue can be solved in lightweight structures by using isolated masonry materials, water filled containers, or Phase Change Materials (PCMs).

Thermal mass affects personal comfort by radiant heat exchanges with the skin. In fact, radiant exchange with mass surfaces is the singularly most efficient way of maintaining comfort compared to other techniques because the body is more than twice as sensitive to radiant changes than all other heat-exchange pathways combined (conduction, convection, respiration, evaporation), and more than four times as sensitive than any other single pathway.

In summer, the thermal mass effect is the most important of only three common means of 'actively' cooling a structure without the use of externally sourced energy or fuel. (The other two are ventilation and evaporation.) In many climate conditions, thermal mass effects are the only means of cooling a building.

In winter, thermal mass storage effects can create comfort by releasing large amounts of solar energy collected and stored during daylight hours to later emit low-level radiant heat via a 'thermal flywheel' effect. In doing so, the thermal comfort of occupants can be maintained while achieving energy savings of up to 100% in heating and cooling loads (in some building types).

References:

4.2.3.3.2 Psychological aspects:
Thermal insulation has been shown to increase indoor thermal comfort for occupants of a building and improve the quality of life. Thermal masses influence bodily comfort by providing heat sources and heat-sink surfaces to facilitate heat exchange processes. *Thermal comfort is achieved using thermal mass by three strategies: stabilization of internal temperatures, management of insulation and shading, and time lag.*

References:

4.2.3.3.3 Precedents of innovation:
Phase change material (PCM), the new generation of thermal mass: Using PCMs for thermal mass materials in buildings developed from their specific characteristics to absorb great amount of energy (latent heat of fusion) changing from solid to liquid phase. In reversible process, PCM can be applied as a thermal energy battery which is passive, reliable and maintenance free.

The DuPont Energain thermal mass panel can be installed like plasterboard, which reduces temperature peaks and fluctuations in low-inertia buildings.

Install DuPont™ Energain® PCM panels


**4.2.3.4 GENERAL RECOMMENDATIONS:**

Benefit of thermal mass has the most impact when daily temperature fluctuation are above and below the balance point of indoor space. So, in cold climate, during summer and in warm climate, during the winter thermal mass has the most benefit.

**4.2.3.4.1 Climate Zones (1-8)**

**1A_ Miami:**

Miami has a tropical monsoon climate with hot and humid summers and short, warm winters. Thermal mass is effective in this climate, particularly since commercial buildings are typically not occupied during evening hours.

Thermal mass increases thermal comfort in buildings, especially when combined with passive solar design. By decreasing the temperature fluctuations of interior spaces, thermal mass can also moderate exterior temperature fluctuations. Additionally, conduction of temperature peaks is delayed and can be designed to coincide with opposing daily temperature cycles. Using thermal mass in warm climates can have a useful daytime cooling function and provide thermal comfort for occupants with less energy consumption. Providing the night ventilation can help to recharge the thermal mass for the following day. Seasonally, there are greater energy savings during winter. In cooler months, using thermal mass can store daytime heat within the building and keep the building warm in the evening (Ghattas. et al, 2013; Baggs, 2006; Spaeh, 2012).

Hot and humid climates display the same characteristics for thermal mass as hot and dry climates, but the benefit of thermal mass is lower (Ghattas. et al, 2013).

Inappropriate use of thermal mass can magnify the unpleasant aspects of a climate. Defining the appropriate amount of mass required for each design and climate and creating a balance between glass, mass, and insulation is important. This is determined by how much heat energy the space requires (based on the climate, massing, and program), and the solar income (based on climate, orientation, and surroundings (Baggs, 2006; Holladay, 2013).
In the Miami climate, the thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).

References:

2A_Houston:

Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate. Thermal mass is effective in this climate, particularly since commercial buildings are typically not occupied during evening hours.

Thermal mass increases thermal comfort in buildings, especially when combined with passive solar design. By decreasing the temperature fluctuations of interior spaces, thermal mass can also moderate exterior temperature fluctuations. Additionally, conduction of temperature peaks is delayed and can be designed to coincide with opposing daily temperature cycles. Using thermal mass in warm climates can have a useful daytime cooling function and provide thermal comfort for occupants with less energy consumption. Providing the night ventilation can help to recharge the thermal mass for the following day. Seasonally, there are greater energy savings during winter. In cooler months, using thermal mass can store daytime heat within the building and keep the building warm in the evening (Ghattas. et al, 2013; Baggs, 2006; Spaeh, 2012).

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The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).
2B_ Phoenix:

Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate. Thermal mass is effective in this climate, particularly since commercial buildings are typically not occupied during evening hours.

Thermal mass increases thermal comfort in buildings, especially when combined with passive solar design. By decreasing the temperature fluctuations of interior spaces, thermal mass can also moderate exterior temperature fluctuations. Additionally, conduction of temperature peaks is delayed and can be designed to coincide with opposing daily temperature cycles. Using thermal mass in warm climates can have a useful daytime cooling function and provide thermal comfort for occupants with less energy consumption. Providing the night ventilation can help to recharge the thermal mass for the following day. Seasonally, there are greater energy savings during winter. In cooler months, using thermal mass can store daytime heat within the building and keep the building warm in the evening (Ghattas. et al, 2013; Baggs, 2006; Spaeh, 2012).

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The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).

References:


3A_Atlanta:

Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate. Thermal mass is effective in a climate with a large diurnal temperature difference. So, we have to be careful about the amount of thermal mass that can be used in this climate.

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The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).

References:


3B_Coast_Los Angeles:

The climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall but relatively modest transitions in temperature.

Thermal mass is effective in a climate with a large diurnal temperature difference. So, we have to be careful about the amount of thermal mass that can be used in this climate.

Inappropriate use of thermal mass can magnify the unpleasant aspects of a climate. Defining the appropriate amount of mass required for each design and climate and creating a balance between
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The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).

References:

3b_Las Vegas:

Climate Zone 3B includes areas of the United States with a characteristically dry climate. Thermal mass is effective in this climate, particularly since commercial buildings are typically not occupied during evening hours.

Thermal mass increases thermal comfort in buildings, especially when combined with passive solar design. By decreasing the temperature fluctuations of interior spaces, thermal mass can also moderate exterior temperature fluctuations. Additionally, conduction of temperature peaks is delayed and can be designed to coincide with opposing daily temperature cycles. Using thermal mass in warm climates can have a useful daytime cooling function and provide thermal comfort for occupants with less energy consumption. Providing the night ventilation can help to recharge the thermal mass for the following day. Seasonally, there are greater energy savings during winter. In cooler months, using thermal mass can store daytime heat within the building and keep the building warm in the evening (Ghattas. et al, 2013; Baggs, 2006; Spaeh, 2012).

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The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).
References:


3C_San Francisco:
Climate Zone 3C includes areas of the United States with a characteristically marine climate.

Thermal mass is effective in climate with a large diurnal temperature difference. So, we have to be careful about the amount of thermal mass can be used in this climate.

Inappropriate use of thermal mass can magnify the unpleasant aspects of a climate. Defining the appropriate amount of mass required for each design and climate and creating a balance between glass, mass, and insulation is important. This is determined by how much heat energy the space requires (based on the climate, massing, and program), and the solar income (based on climate, orientation, and surroundings (Baggs, 2006; Holladay, 2013).

The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).

References:


4A_Baltimore:
Climate Zone 4A includes areas of the United States with a characteristically moist climate.
Thermal mass is effective in climate with a large diurnal temperature difference. So, we have to be careful about the amount of thermal mass can be used in this climate.

Inappropriate use of thermal mass can magnify the unpleasant aspects of a climate. Defining the appropriate amount of mass required for each design and climate and creating a balance between glass, mass, and insulation is important. This is determined by how much heat energy the space requires (based on the climate, massing, and program), and the solar income (based on climate, orientation, and surroundings (Baggs, 2006; Holladay, 2013).

The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).

References:

4B_ Albuquerque:

Thermal mass is effective in climate with a large diurnal temperature difference. So, we have to be careful about the amount of thermal mass can be used in this climate.

Inappropriate use of thermal mass can magnify the unpleasant aspects of a climate. Defining the appropriate amount of mass required for each design and climate and creating a balance between glass, mass, and insulation is important. This is determined by how much heat energy the space requires (based on the climate, massing, and program), and the solar income (based on climate, orientation, and surroundings (Baggs, 2006; Holladay, 2013).

The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).

References:
4C_ Seattle:

Climate Zone 4C includes areas of the United States with a characteristically marine climate. Thermal mass is effective in climate with a large diurnal temperature difference. So, we have to be careful about the amount of thermal mass can be used in this climate.

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The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).

References:


5A_ Chicago:

Climate Zone 5A includes areas of the United States with a characteristically moist climate.

Thermal mass is effective in this climate, particularly since commercial buildings are typically not occupied during evening hours.

By decreasing the temperature fluctuations of interior spaces, thermal mass can also moderate exterior temperature fluctuations. Additionally, conduction of temperature peaks is delayed and can be designed to coincide with opposing daily temperature cycles. Using thermal mass in warm climates can have a useful daytime cooling function and provide thermal comfort for occupants with less energy consumption. Providing the night ventilation can help to recharge the thermal mass for the following day. Seasonally, there are greater energy savings during winter. In cooler months, using thermal mass can store daytime heat within the building and keep the building warm in the evening (Ghattas. et al, 2013; Baggs, 2006; Spaeh, 2012).
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The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).

References:

5B_ Denver:
Climate Zone 5B includes areas of the United States with a characteristically dry climate.

Thermal mass is effective in this climate, particularly since commercial buildings are typically not occupied during evening hours.

By decreasing the temperature fluctuations of interior spaces, thermal mass can also moderate exterior temperature fluctuations. Additionally, conduction of temperature peaks is delayed and can be designed to coincide with opposing daily temperature cycles. Using thermal mass in warm climates can have a useful daytime cooling function and provide thermal comfort for occupants with less energy consumption. Providing the night ventilation can help to recharge the thermal mass for the following day. Seasonally, there are greater energy savings during winter. In cooler months, using thermal mass can store daytime heat within the building and keep the building warm in the evening (Ghattas. et al, 2013; Baggs, 2006; Spaeh, 2012).

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4.2.3.4.2 Climate zone 6, 7, 8:
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By decreasing the temperature fluctuations of interior spaces, thermal mass can also moderate exterior temperature fluctuations. Additionally, conduction of temperature peaks is delayed and can be designed to coincide with opposing daily temperature cycles. Using thermal mass in warm climates can have a useful daytime cooling function and provide thermal comfort for occupants with less energy consumption. Providing the night ventilation can help to recharge the thermal mass for the following day. Seasonally, there are greater energy savings during winter. In cooler months, using thermal mass can store daytime heat within the building and keep the building warm in the evening (Ghattas. et al, 2013; Baggs, 2006; Spaeh, 2012).

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The thermal mass should be installed inside the insulation, and there shouldn’t be any insulation between the thermal mass and the indoor space (Holladay, 2013).
References:


4.3 ENERGY GENERATION
4.3.1 SOLAR POWER (PV)
4.3.1.1 GENERAL INFORMATION

Solar PV industry, Sunset Reservoir, San Francisco, CA
(Source: https://www.flickr.com/photos/thesolarindustry/8467605019/in/photostream/)

4.3.1.1.1 Definition:
Solar photovoltaic (PV) systems convert light from the sun directly into electricity and generate pollution-free energy. They can be installed on the roof as well as on the walls of commercial buildings as a grid-connected photovoltaic (PV) application.

The solar cells of PV systems consist of light-absorbing materials in the cell structure which captures photons and generates electricity through the photovoltaic effect; there are several types of PV materials, including but not limited to various silicon technologies, hybrid photovoltaic cells (combinations of different silicon materials), thin-film technology (semiconductor layers applied to backing materials), organic and polymer cells, and cadmium telluride (CDTE) and cadmium sulfide (CDS).

Of these materials, silicon technology has been the dominant material in supplying power modules in PV applications. Silicon’s proportion among solar cells is growing, and advances in production and solar cell efficiency are increasing. Silicon technologies can include amorphous silicon (with cell efficiency of 8-10%), and crystalline silicon (with cell efficiency around 14-19%).

References:


4.3.1.1.2 Advantages:
The greatest attraction of PV systems is that they produce electric power without negative environmental consequences. A PV system provides green, renewable power by using solar energy; it is a reliable, industrially matured technology that requires minimum operating or maintenance costs compared to other renewable energy technologies. Maintenance consists of keeping the panels relatively clean and ensuring objects like trees do not begin to shade them. A solar PV system is able to assist in balancing and smoothing out the energy load curve and facilitate increased penetration of renewable energy technologies within the power matrix.

PV systems incorporate no moving mechanical parts, operating autonomously and avoiding noise generation. PV systems are especially ideal for distributed or on-site power generation, as they are highly suitable for remote applications. Annual periods of high-energy demand for cooling also
happen to be annuals periods of high solar energy availability; this allows PV panels to provide an effective solution to meeting peak energy demands. Finally, PV systems are a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions. They play a significant role in offsetting the continuous growth of greenhouse gas emissions associated with traditional electricity generation.

References:


4.3.1.1.3 Disadvantages:
Despite high projected growth and price decreases, PV panels are currently still too expensive to guarantee commercial competitiveness.

Efficiency levels are also currently limited, through many ways. For example, PV systems produce direct electric current (DC) which must be converted to alternating current (AC), reducing efficiency. Low voltage output or fluctuation in the PV electric current may lead to increased waste of electricity due to inability to be transmitted onto the network (intermittent output). These panels deliver only in direct sunlight, and cannot store excess amounts of produced energy for later use.

While there are low maintenance and operating costs, PV panels are fragile and can be damaged relatively easily. A large portion of cost comes from batteries which are large, dangerous and short lived, and whose production requires a lot of poisonous chemicals.

References:
4.3.1.2 CODES AND STANDARDS:

4.3.1.2.1 IECC, 2012:
N/A. There is no information about solar power (PV) available in the IECC-2012 version.

4.3.1.2.2 ASHRAE 90.1, 2010:
N/A. There is no information about solar power (PV) available in the ASHRAE 90.1, 2010 version.

4.3.1.2.3 IgCC, 2012:
Devices such as photovoltaic (PV) modules and inverters are used to transform solar radiation into energy.

Section 603.3.7.1 (Page 6-9): Solar electric: Equipment and systems providing electric power through conversion of solar energy directly to electric power shall be capable of being metered so that the peak electric power (kilowatts, kW) provided to the building and its systems or to off-site entities can be determined at 15-minute intervals and the amount of electric power (kW) provided to the building and its systems can be determined at intervals of 1 hour or less.

The intent of this section is the monitor the actual output of onsite solar electric systems. The code requires onsite renewable energy systems to meet a specific percentage of the building’s annual energy needs, and the metering will ensure that the requirements are met on an annual basis. The data can also be used by building owners to track daily, weekly and monthly performance of these systems.

4.3.1.2.4 ASHRAE AEDG, 50%, 2011:
Renewable energy section (Page 194): RE1, Photovoltaic (PV) Systems (All climate zones)
Photovoltaic (PV) systems have become an increasingly popular option for on-site electric energy production. These systems require very little maintenance and generally have long lifetimes.

Options for installing PV systems include on rooftops (including collectors integrated with the roofing membrane), ground mounted, or as the tops of covered parking systems. The systems may be fixed-mounted or tracking. Each installation method offers different combinations of advantages and disadvantages.

Collectors can still function on cloudy days to varying degrees depending on the design, but they perform better in direct sunlight; collectors should not be placed in areas that are frequently shaded. Solar systems in most climates require freeze protection. The two common types of freeze protection are drain back systems and systems that contain antifreeze.

**Using solar energy (Page 195):** Where solar energy is prevalent, it can be used to create electricity from PV panels or hot water from evacuated-tube solar heaters. Photovoltaics are now commonplace in most markets as a renewable energy source, with many municipalities and utilities allowing a net-metering approach that allows the building owner to push electricity into the grid during daytime hours and remove it at other times as needed. There is little maintenance other than cleaning, which is required for PV panels.

**4.3.1.2.5 ASHRAE Fundamental, 2009:**

Chapter 34: Energy resources

**On-site energy / energy resource relationships (Page 34.2):**

Solar energy normally on the site (and on the facilities to be put there), so it affects the facility’s energy consumption. The designer must account for this effect and may have to decide whether to make active use of solar energy. Other naturally occurring and distributed renewable forms such as wind power and earth heat (if available) might also be considered. The designer should be aware of the relationship between on-site energy sources and raw energy resources, including how these resources are used and what they are used for.

The relationship between energy sources and energy resources involves two parts:

1. Quantifying the energy resource units expended.
2. Considering the social effect of depletion of one energy resource (caused by on-site energy use) with respect to others.

**4.3.1.2.6 RoofPoint:**

Section 1, Energy management (Page 18): E5, Rooftop energy systems

RoofPoint Credit E5 identifies several rooftop energy strategies that may be deployed to provide a renewable energy source for the building.
These strategies include rooftop photovoltaic arrays and solar-thermal installations. Rooftop PV systems are evaluated within the calculator based on the Standard Test Condition (STC) rating of the system in kW and the conversion of this rating into total annual estimated power in Kwh for each location using the PV Watts on-line calculator for an array installed at the optimal tilt and azimuth factor for the location. Total annual estimated power is also reduced by the recommended DC-to-AC derate factor in PV Watts (0.77). Finally, total annual estimated power is converted from kWh to BTU to allow comparison with other energy inputs.

Install one or more of the following rooftop energy alternatives:

1. **Solar Photo-voltaic (PV):** Install a roof-mounted or roof-integrated photovoltaic system with a minimum STC power rating of at least 10 kW.
2. **Solar thermal:** Install a roof-mounted solar thermal system generating a portion of building hot water requirements with a total collector panel area of at least 60 sq. ft.
3. **Wind:** Install roof-mounted wind power unit(s) with a total Instantaneous Power Rating (IPR) at 28 mph of at least 10 kW.

**Requirement E5b: roof Energy-ready roof:** As an alternative to installing a rooftop energy option, install a roofing system suitable for future installation of a specific renewable energy technology (as documented by the roofing system manufacture’s agreement to continue the originally-issued roof warranty coverage after the installation of the renewable energy system(s) at a later date, subject to the terms and conditions of the roofing manufacturer’s warranty).

**Coordination with credit d1 durable Roof Insulation, credit d3 Roof traffic Protection and credit l1 Roof Maintenance Program:** Because rooftop energy systems require frequent maintenance and associated roof traffic, credits available under this section are allowed only if l1 Roof Maintenance Program and d4 Roof traffic protection are also included as part of the roofing system application. In addition, credit d1 durable Roof Insulation must be included if the rooftop energy system is supported directly or indirectly on the roof insulation.

**Special Note:** In order to qualify for credit E5, the installation of the rooftop energy system or energy-ready system must be installed or coordinated by a roofing professional knowledgeable in the integration of rooftop energy with the selected roofing system. In particular, the following roofing industry guidelines shall be incorporated into the design and installation of the rooftop energy system:

- “Guidelines for Roof-Mounted Photovoltaic System Installations” (NRCA, 2009)
- “Successful Rooftop Photovoltaics: how to achieve a high-Quality, Well-Maintained, compatible Rooftop PV System.” (CEIR, 2009)
4.3.1.2.7 RoofNav:
N/A. There is no information about Cool roof available in the RoofNav database sheets.

4.3.1.3 REALITY

4.3.1.3.1 Implementation costs:
Costs of implementing a solar PV system involve several possibilities depending on the project; the number of panels used, the amount of energy generation desired, area of roof space available, the type of system (off-grid or grid-tied), infrastructure integration, and many other components, can vary widely. Additionally, pricing of solar PV panels, or their accompanying accessories or services, are not currently stagnant, making costs hard to estimate.

Listed below are several resources available online that can offer more tailored insight into pricing when project parameters are known:

- ROI payback calculator, courtesy Minnesota Department of Natural Resources: [http://www.dnr.state.mn.us/energysmart/why/calculator.html](http://www.dnr.state.mn.us/energysmart/why/calculator.html)

Payback periods will depend on price paid per watt for the solar panel as well as the local energy bill. For example, if the installed PV system were priced at $4/W, while the electricity rate is $0.50/W, the payback period could be only five years. Cheaper local electricity and higher prices of installed systems can push payback periods higher several years or decades.

According to Solar Energy Industries Association’s (SEIA) U.S. Solar Market Insight (Q1 2014) Report, commercial PV system prices have fallen over $1 since reporting period Q1 of 2012. Non-residential system prices were shown to have fallen 5.7% year-over-year, to most recently $3.72/W in Q1 2014.

According to a 2013 report from Lawrence Berkeley National Laboratory, from 2008 to 2012, the decline in the average price of modules represented 80% of the total decline in PV system price in that time period. Modules, as a set, are what make up a solar panel; the price decrease in modules is currently responsible for the general decrease in PV systems. Average module prices between 2008 and 2012 feel by $2.60/W. Further price decreases are expected to depend upon soft costs, such as marketing or policies removing market barriers or accelerating deployment. Currently, there is also a federal tax credit available in the United States that offers assistance to those interested in installing solar PV systems.

Installation costs vary between installers and products. Other factors that affect PV installation costs include:
- The more electricity the system can generate, the more it costs, but the more it could save.
- Larger systems are usually more cost-effective than smaller systems (up to 4kWp, where "p" refers to the peak level of performance).
- PV panels are all around the same price per kWp, but PV tiles cost much more than a typical system made up of panels.
- Panels built into a roof (integrated into the structure as the roof itself, or part of it) are generally more expensive than those that sit on top. This is most likely due to lack of general knowledge on how to go about doing so, rather than complexity or costs of actual materials.

References:


4.3.1.3.2 Aesthetics:
The horizontal roofs of buildings can be effectively used for conversion of solar radiation to electricity, while having minimum effects on an anticipated loss of visual amenity. Some communities encourage rooftop over ground-mounted systems and many communities require rooftop panels to be located on side or rear roof slopes rather than street-facing roof slopes, when possible, for aesthetic reasons.

Some regulations limit the height that rooftop panels may extend above the roofline (often 2 or 3 feet), while others exempt solar panels altogether from district height restrictions, along with other typical rooftop structures such as chimneys, air conditioning units, or steeples. Many ordinances also address system appearance, requiring neutral paint colors and screening of no panel system components.

References:
4.3.1.3.3 Psychological aspects:
Installing renewable energy systems on the roof, increases the awareness of occupants in environment and energy savings and consequently affects their behavior in energy consumption.

References:

4.3.1.3.4 Precedents of innovation:
**Building-Integrated Photovoltaic** (BIPV): BIPV contains combining solar photovoltaic electricity technology with the building envelope and construction. There are several advantages to BPIV systems. The building construction becomes the PV support structure. Because BIPV components consists conventional building materials and labor, the installation cost of the PV system can be decreased; however, as this is not a conventional roof (like mounting panels on a roof), the costs may still be higher. It can create well-designed architecture with highly public recognition of its environmental commitment (Parsad, 2014).

**Alternating Current Photovoltaic Building Block:**
This technology offers a self-containing interchanging current (AC) photovoltaic (PV) Building Block device, which allows photovoltaic systems to become true plug-and-play devices. The Building Block removes the traditional DC voltage issues of PV systems by placing elements inside structure. This system is Compatible with all known PV module systems.
4.3.1.4 GENERAL RECOMMENDATION:

4.3.1.4.1 Climate Zones (1-8)

1A. Miami:

Miami has a tropical monsoon climate with hot and humid summers and short, warm winters.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: fixed, seasonally adjustable and sun tracking version:
- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adj. 2 seasons**, adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adj. 4 seasons**, adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**, always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but provides less power than adjusting the angle.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is **below 25°**, use (latitude x 0.87)
- If your latitude is **between 25° and 50°**, use (latitude x 0.76 + 3.1 degrees).

![Optimum Tilt of Solar Panels](http://www.solarpaneltilt.com/)

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. So, PV systems in hot climates have better performance than those in other climates due to the higher solar radiation and the higher percentage of direct beam of sun. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Like other electrical systems, solar PV systems present some risk of fire. Specially, in hot climates, the panels get hot in the sun and increase the risk of burns. Firefighting on roofs has some difficulties because of the limited access. Additionally, arrays elevated off the roof may create a channeling effect, which may intensify fire. Thus, it is important that PV systems are designed correctly and installed carefully with properly tested components, and then maintained regularly.

**References:**


2A Houston:

Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: fixed, seasonally adjustable and sun tracking version:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adj. 2 seasons**, adjusting the tilt twice a year gives you a meaningful boost in energy.
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**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is below 25°, use (latitude x 0.87)
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Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. So, PV systems in hot climates have better performance than those in other climates due to the higher solar radiation and the higher percentage of direct beam of sun.
However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Like other electrical systems, solar PV systems present some risk of fire. Specially, in hot climates, the panels get hot in the sun and increase the risk of burns. Firefighting on roofs has some difficulties because of the limited access. Additionally, arrays elevated off the roof may create a channeling effect, which may intensify fire. Thus, it is important that PV systems are designed correctly and installed carefully with properly tested components, and then maintained regularly.

References:

2B Phoenix: Climate Zone 2B includes southern areas of the United States, with a characteristically hot and dry climate.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: fixed, seasonally adjustable and sun tracking version:
- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adj. 2 seasons**, adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adj. 4 seasons**, adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**, always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but provides less power than adjusting the angle.

The best angle from the horizontal at which the panel should be tilted:
- If your latitude is **below 25°**, use (latitude x 0.87)
- If your latitude is **between 25° and 50°**, use (latitude x 0.76 + 3.1 degrees).
Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. So, PV systems in hot climates have the best performance than those in other climates due to the higher solar radiation and the higher percentage of direct beam of sun. However, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Like other electrical systems, solar PV systems present some risk of fire. Specially, in hot climates, the panels get hot in the sun and increase the risk of burns. Firefighting on roofs has some difficulties because of the limited access. Additionally, arrays elevated off the roof may create a channeling effect, which may intensify fire. Thus, it is important that PV systems are designed correctly and installed carefully with properly tested components, and then maintained regularly.

References:

3A Atlanta: Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: fixed, seasonally adjustable and sun tracking version:
- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adj.2 seasons**, adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adj. 4 seasons**, adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**, always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but provides less power than adjusting the angle.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is **below 25°**, use \((\text{latitude} \times 0.87)\)
- If your latitude is **between 25° and 50°**, use \((\text{latitude} \times 0.76 + 3.1 \text{ degrees})\).

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*Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation.* So, PV systems in warm climates have better performance than those in other climates due to the higher solar radiation and the higher percentage of direct beam of sun. However, **excessive humidity can decrease the efficiency of the system.** In addition, the **efficiency of PV system can decrease due to increasing temperature.** So, cooling is often required for the places with high illumination and concentrated sunlight.

Like other electrical systems, solar PV systems present some risk of fire. Specially, in hot climates, the panels get hot in the sun and increase the risk of burns. Firefighting on roofs has some difficulties because of the limited access. Additionally, arrays elevated off the roof may create a channeling effect, which may intensify fire. Thus, it is important that PV systems are designed correctly and installed carefully with properly tested components, and then maintained regularly.

**References:**


**3B Coast Los Angeles:** The climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall—with a characteristically warm and dry climate.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: fixed, seasonally adjustable and sun tracking version:

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- **Adj.2 seasons,** adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adj. 4 seasons,** adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker,** always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but provides less power than adjusting the angle.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is below 25°, use (latitude x 0.87)
- If your latitude is between 25° and 50°, use (latitude x 0.76 + 3.1 degrees).

![Optimum Tilt of Solar Panels](http://www.solarpaneltilt.com/)

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. So, PV systems in hot and dry climates have the best performance than those in other climates due to the higher solar radiation and the higher percentage of direct beam of sun. However, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.
Like other electrical systems, solar PV systems present some risk of fire. Specially, in hot climates, the panels get hot in the sun and increase the risk of burns. Firefighting on roofs has some difficulties because of the limited access. Additionally, arrays elevated off the roof may create a channeling effect, which may intensify fire. Thus, it is important that PV systems are designed correctly and installed carefully with properly tested components, and then maintained regularly.

References:

**3b_Las Vegas:** Climate Zone 3B includes areas of the United States with a characteristically hot and dry climate.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: fixed, seasonally adjustable and sun tracking version:

- **Fixed:** simplest way to mount your solar panels, less efficiency.
- **Adj.2 seasons,** adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adj. 4 seasons,** adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker,** always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but provides less power than adjusting the angle.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is **below 25°,** use (latitude x 0.87)
- If your latitude is **between 25° and 50°,** use (latitude x 0.76 + 3.1 degrees).
Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. So, PV systems in hot and dry climates have the best performance than those in other climates due to the higher solar radiation and the higher percentage of direct beam of sun. However, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Like other electrical systems, solar PV systems present some risk of fire. Specially, in hot climates, the panels get hot in the sun and increase the risk of burns. Firefighting on roofs has some difficulties because of the limited access. Additionally, arrays elevated off the roof may create a channeling effect, which may intensify fire. Thus, it is important that PV systems are designed correctly and installed carefully with properly tested components, and then maintained regularly.

References:


3C San Francisco: Climate Zone 3C includes areas of the United States with a characteristically marine climate.
In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: **fixed, seasonally adjustable and sun tracking** version:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adj. 2 seasons**, adjusting the tilt twice a year gives you a meaningful boost in energy.
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References:
4A Baltimore: Climate Zone 4A includes areas of the United States with a characteristically mild, humid climate.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: fixed, seasonally adjustable and sun tracking version:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adj. 2 seasons**, adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adj. 4 seasons**, adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**, always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but provides less power than adjusting the angle.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is **below 25°**, use \((\text{latitude} \times 0.87)\)
- If your latitude is **between 25° and 50°**, use \((\text{latitude} \times 0.76 + 3.1 \text{ degrees})\)

Optimum Tilt of Solar Panels
(Source: [http://www.solarpaneltilt.com/](http://www.solarpaneltilt.com/))
Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. However, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

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References:

4B: Albuquerque: Climate Zone 4B includes areas of the United States with a characteristically mild, dry climate.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: fixed, seasonally adjustable and sun tracking version:
- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adj. 2 seasons**, adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adj. 4 seasons**, adjusting four times a year produces only a little more, optimize production in spring and fall.
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Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. However, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Like other electrical systems, solar PV systems present some risk of fire. Specially, in hot climates, the panels get hot in the sun and increase the risk of burns. Firefighting on roofs has some difficulties because of the limited access. Additionally, arrays elevated off the roof may create a channeling effect, which may intensify fire. Thus, it is important that PV systems are designed correctly and installed carefully with properly tested components, and then maintained regularly.

References:

**4C, Seattle:** Climate Zone 4C includes areas of the United States with a characteristically marine climate.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: **fixed, seasonally adjustable and sun tracking** version:
- **Fixed:** simplest way to mount your solar panels, less efficiency.
- **Adj. 2 seasons,** adjusting the tilt twice a year gives you a meaningful boost in energy.
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**References:**


5A_Chicago: Climate Zone 5A includes areas of the United States with a characteristically cold, moist climate.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: fixed, seasonally adjustable and sun tracking version:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adj.2 seasons**, adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adj. 4 seasons**, adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**, always points the panel directly at the sun, maximum efficiency.

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**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is **below 25°**, use (latitude x 0.87)
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![Optimum Tilt of Solar Panels](http://www.solarpaneltilt.com/)

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. However, the efficiency of PV system can decrease due to increasing temperature. Cold weather conditions can remove the heat from solar radiation and increase the efficiency and lifespan of the PV systems. On the other hand, types of solar water heating systems can damage in cold climate in freezing temperature.
Like other electrical systems, solar PV systems present some risk of fire. Firefighting on roofs has some difficulties because of the limited access. Additionally, arrays elevated off the roof may create a channeling effect, which may intensify fire. Thus, it is important that PV systems are designed correctly and installed carefully with properly tested components, and then maintained regularly.

References:


5B_Denver: Climate Zone 5B includes areas of the United States with a characteristically cold, dry climate.

In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: fixed, seasonally adjustable and sun tracking version:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adj.2 seasons**, adjusting the tilt twice a year gives you a meaningful boost in energy.
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Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. However, the efficiency of PV system can decrease due to increasing temperature. Cold weather can remove the heat from the solar radiation and increase the efficiency and lifespan of the PV systems. On the other hand, types of solar water heating systems can damage in cold climate in freezing temperature.

Like other electrical systems, solar PV systems present some risk of fire. Specially, in hot climates, the panels get hot in the sun and increase the risk of burns. Firefighting on roofs has some difficulties because of the limited access. Additionally, arrays elevated off the roof may create a channeling effect, which may intensify fire. Thus, it is important that PV systems are designed correctly and installed carefully with properly tested components, and then maintained regularly.

References:


4.3.1.4.2 Climate zone 6, 7, 8:
In order to have an efficient PV panel, we need to find the direction and angle which capture most of the solar rays. Different types of PV panel are: **fixed, seasonally adjustable and sun tracking** version:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
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- If your latitude is **between 25° and 50°**, use \((\text{latitude} \times 0.76 + 3.1 \text{ degrees})\).

![Optimum Tilt of Solar Panels](http://www.solarpaneltilt.com/)

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. So, PV systems in hot climates have better performance than those in other climates due to the higher solar radiation and the higher percentage of direct beam of sun. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Like other electrical systems, solar PV systems like other electrical systems present some risk of fire. Specially, in hot climates, the panels get hot in the sun and increase the risk of burns. Firefighting on roofs has some difficulties because of the limited access. Additionally, arrays elevated off the roof may create a channeling effect, which may intensify fire. Thus, it is important that PV systems are
designed correctly and installed carefully with properly tested components, and then maintained regularly.

References:


4.3.2 SOLAR THERMAL SYSTEM

4.3.2.1 GENERAL INFORMATION

Solar thermal panels

4.3.2.1.1 Definition:
Solar thermal energy (STE) is a technology for harvesting solar energy for thermal energy (heat). Solar thermal systems use thermal energy to heat water or air. This thermal energy can be used for various applications including providing hot water, heating and cooling buildings, and generating electric power.

The major component of any solar system is the solar collector, which absorbs the incoming solar radiation and converts it into heat. Solar collectors can use air or water as the medium to transfer the heat to their destination.

Solar thermal collectors are categorized into low, medium, or high temperature collectors. Low-temperature collectors are flat plates and are generally used to heat swimming pools and preheat ventilation air. Medium-temperature collectors are also usually flat plates but are used for heating water or space, or for supplying heat for industrial processes. High-temperature collectors concentrate sunlight using mirrors or lenses and are generally used for electric power generation and heating industrial processes.
The solar energy collected is carried from the circulating fluid either directly to hot water or indirectly to space conditioning equipment, or stored in a tank from which it can be drawn for use at other times.

References:


Chicago


Solar water heating system

4.3.2.1.2 **Advantages:**
Solar thermal systems offer high efficiency in heating applications and can easily store thermal energy for use when required. The payback period of a PV-Thermal (PVT) combined collector is short and usually expected to be within five years. Solar thermal panels can be used in a wide range of technological configurations. Solar thermal is a mature technology offering high-energy contributions at a low cost. It is also a renewable energy source, reducing fossil fuel consumption and CO₂ emissions.

**References:**

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Photovoltaic thermal system

(Source: [http://www.carbonfreegroup.com/photo-voltaic-thermal-panels.html](http://www.carbonfreegroup.com/photo-voltaic-thermal-panels.html))
4.3.2.1.3 Disadvantages:
The reliability of solar thermal systems can be highly influenced by variation in solar radiation. Solar thermal systems require regular maintenance, including antifreeze replacement. Problems can develop with the system, including damage from hot summer or cold winter temperatures, as well problems with fluid circulation and leaks. In PV systems, sun-tracking mechanisms are sometimes used to improve efficiency, however they are currently not installed on solar thermal collectors.

References:

4.3.2.2 CODES AND STANDARDS:
4.3.2.2.1 IECC, 2012:
N/A. There is no information about solar thermal available in the IECC-2012 version.

4.3.2.2.2 ASHRAE 90.1, 2010:
N/A. There is no information about solar thermal available in the ASHRAE 90.1, 2010 version.

4.3.2.2.3 IgCC, 2012:
IgCC 2012 contains the following information relevant to solar thermal systems:

Section 603.3.7.2 (Page 6-9): Solar thermal: Equipment and systems providing heat to fluids or gases through the capture of solar energy shall be capable of being metered so that the peak thermal energy (Btu/h) provided to the building and its systems, or to off-site entities, can be determined at 15-minute intervals and the amount of heat captured (Btu) for delivery to the building and its systems can be determined in intervals of 1 hour or less.

- Exception: Systems with a rated output of less than 100 KBtu/hr shall not be required to have the capacity to be metered.

- The code requires onsite renewable energy systems to meet a specific percentage of the building's annual energy needs, and the metering will ensure that the requirements are met on an annual basis. The data can also be used by building owners to track daily, weekly, and monthly performance of these systems. The measurement chart for the meter is in 15-minute increments to record the amount of heat from solar energy delivered to the building. Systems with a rated output of less than
100 KBtu/hr are exempt from measurement because the energy used is minimal and difficult to read on a meter chart.

**4.3.2.2.4 ASHRAE AEDG, 50%, 2011:**
ASHRAE AEDG discusses solar thermal systems in the following excerpt:

*Renewable energy section (Page 194): RE2, Solar Hot Water Systems (Climate Zones: all)*

Simple solar systems are most efficient when they generate heat at low temperatures. General suggestions for solar domestic hot water heating systems include the following:

- It is typically not economical to design solar systems to satisfy the full annual Solar Water Heating (SWH) load.
- **Systems are typically most economical if they furnish 50%–80% of the annual load.**
- Properly sized systems will meet the full load on the best solar day of the year.
- **Approximately 1–2 gallons of storage should be provided per square foot of collector.**
- In general, 1 ft<sup>2</sup> of collector heats about 1 gal/day of service water at 44° latitude.
- Glazed flat-plate systems often cost in the range of $100–$150/ft<sup>2</sup> of collector.
- **Collectors do not have to face due south;** they receive 94% of the maximum annual solar energy if they are 45° east or west of due south.
- The optimal collector tilt for service water applications is approximately equal to the latitude where the building is located; however, variations of ±20° only reduce the total energy collected about 5%. This is one reason that many collector installations are flat to a pitched roof instead of being supported on stands.
- The optimal collector tilt for building heating (not domestic water heating) systems is approximately the latitude of the building plus 15°.

Collectors can still function on cloudy days to varying degrees depending on the design, but they perform better in direct sunlight; **collectors should not be placed in areas that are frequently shaded.**

**Solar systems in most climates require freeze protection.** The two common types of freeze protection are drainback systems and systems that contain antifreeze. Drainback solar hot water systems are often selected in small applications where the piping can be sloped toward a collection tank. By draining the collection loop, freeze protection is accomplished when the pump shuts down, either intentionally or unintentionally. This avoids the heat transfer penalties of antifreeze solutions.

Closed-loop, freeze-resistant solar systems should be used when piping layouts make drainback systems impractical. In both systems, a pump circulates water or antifreeze solution through the collection loop when there is adequate solar radiation and a need for service water heat.

**Solar collectors for service water applications are usually flat-plate or evacuated-tube type.** Flat-plate units are typically less expensive. Evacuated-tube designs can produce higher temperatures because they have less standby loss but also can pack with snow and if fluid flow stops are more likely to reach temperatures that can degrade antifreeze solutions.
Annual savings can be estimated using performance data from the Solar Rating and Certification Corporation web site (SRCC 2011). A free downloadable program called RETScreen from Natural Resources Canada (NRCan 2010) can assist with economic feasibility analysis, and many utility rebate programs use it in calculating rebates or determining eligibility. The initial cost of the system must be estimated.

4.3.2.2.5 ASHRAE Fundamental, 2009:
ASHRAE Fundamentals includes the following relevant information to PV systems:

Chapter 34: Energy resources

Page 34.2: On-site energy/energy resource relationships

Solar energy normally impinges on the site (and on the facilities to be put there), so it affects the facility’s energy consumption. The designer must account for this effect and may have to decide whether to make active use of solar energy. Other naturally occurring and distributed renewable forms such as wind power and earth heat (if available) might also be considered. The designer should be aware of the relationship between on-site energy sources and raw energy resources, including how these resources are used and what they are used for. The relationship between energy sources and energy resources involves two parts:

1. Quantifying the energy resource units expended.
2. Considering the social effect of depletion of one energy resource (caused by on-site energy use) with respect to others.

4.3.2.2.6 RoofPoint:
Section 1, Energy management (Page 18): E5, Rooftop energy systems

RoofPoint Credit E5 identifies several rooftop energy strategies that may be deployed to provide a renewable energy source for the building.

These strategies include rooftop photovoltaic arrays and solar-thermal installations. Rooftop PV systems are evaluated within the calculator based on the Standard Testing Condition (STC) rating of the system in kW and the conversion of this rating into total annual estimated power in Kwh for each location using the PVWatts on-line calculator for an array installed at the optimal tilt and azimuth factor for the location. Total annual estimated power is also reduced by the recommended DC-to-AC derate factor in PV Watts (0.77). Finally, total annual estimated power is converted from kWh to BTU to allow comparison with other energy inputs.

Install one or more of the following rooftop energy alternatives:

4. Solar Photo-voltaic (PV): Install a roof-mounted or roof-integrated photo-voltaic system with a minimum STC power rating of at least 10 kW.
5. **Solar thermal**: Install a roof-mounted solar thermal system generating a portion of building hot water requirements with a total collector panel area of at least 60 sq. ft.

6. **Wind**: Install roof-mounted wind power unit(s) with a total Instantaneous Power Rating (IPR) at 28 mph of at least 10 kW.

**Requirement E5b: roof Energy-ready roof**: As an alternative to installing a rooftop energy option, install a roofing system suitable for future installation of a specific renewable energy technology (or technologies), as documented by the roofing system manufacture’s agreement to continue the originally-issued roof warranty coverage after the installation of the renewable energy system(s) at a later date, subject to the terms and conditions of the roofing manufacturer’s warranty.

**Coordination with credit d1 durable Roof Insulation, credit d3 Roof traffic Protection and credit l1 Roof Maintenance Program**: Because rooftop energy systems require frequent maintenance and associated roof traffic, credits available under this section are allowed only if l1 Roof Maintenance Program and d4 Roof traffic protection are also included as part of the roofing system application. In addition, credit d1 durable Roof Insulation must be included if the rooftop energy system is supported directly or indirectly on the roof insulation.

**Special Note**: In order to qualify for credit E5, the installation of the rooftop energy system or energy-ready system must be installed or coordinated by a roofing professional knowledgeable in the integration of rooftop energy with the selected roofing system. In particular, the following roofing industry guidelines shall be incorporated into the design and installation of the rooftop energy system:

- “Guidelines for Roof-Mounted Photovoltaic System Installations” (NRCA, 2009)
- “Successful Rooftop Photovoltaics: how to achieve a high-Quality, Well-Maintained, compatible Rooftop PV System.” (CEIR, 2009)

**4.3.2.2.7 RoofNav:**
N/A. There is no information about solar thermal systems available in the RoofNav database sheets.

**4.3.2.3 REALITY**

**4.3.2.3.1 Implementation costs:**
Solar thermal system pricing can change depending upon the size and other specifications of the project (see Solar PV Implementation Costs for related information). Savings depend on the amount
of hot water used by building occupants, system performance, geographic location and solar resource, available financing and incentives, comparative cost of conventional energy (gas, oil, and electricity), cost of fuel for backup thermal systems, etc. For specific information on determining operating costs or payback periods of solar water heating systems, the US Department of Energy provides the following resource:


According to the US Department of Energy, in the US, the first (or prime) cost summary (including a collector, installation, and marketing) of a solar water heating system can reach almost $3,000 per household. Other sources, such as in Europe, may cite the cost of installing a typical solar water heating system to be around £3,000 to £5,000 per household (including VAT at 5%).

**Savings are moderate:** a solar thermal system could provide most hot water needs in the summer, but provide much less during colder weather. It is also clear that collector and installation costs decrease hugely per unit as the total project volume installed increases. This makes larger scale projects much more cost-effective and feasible. Large commercial buildings with good solar exposure and temperatures above freezing year round can experience payback periods as low as 18 months, while small commercial buildings with average residence levels of energy use will have payback periods closer to 5 to 10 years.

**References:**


**4.3.2.3.2 Aesthetics:**

The horizontal roofs of buildings can be effectively used for conversion of solar radiation to electricity, while having minimal effects on anticipated loss of visual amenity.

Some communities encourage rooftop over ground-mounted systems and many communities require rooftop panels to be located on side or rear roof slopes rather than street-facing roof slopes, when possible, for aesthetic reasons.

Some regulations limit the height that rooftop panels may extend above the roofline (often 2 or 3 feet), while others exempt solar panels altogether from district height restrictions, along with other typical rooftop structures such as chimneys, air conditioning units, or steeples. Many ordinances also
address system appearance, requiring neutral paint colors and screening of no panel system components.

The integration of collectors should be consistent with the design of the roof. The solar collector design should be incorporated in the overall building design early on in the planning process.

References:

4.3.2.3.3 Psychological aspects:
Installing renewable energy systems on a roof, increases the awareness of occupants in environment and energy savings, consequently affecting energy consumption behavior.

References:

4.3.2.4 PRECEDENT OF INNOVATION
4.3.2.4.1 Photovoltaic Thermal (PVT) Hybrid Solar System:
PVT combines photovoltaic and solar thermal systems that create both electricity and heat in the same system. This technology can apply to both air-type systems and liquid-type systems as collectors. Using PVT technology is advantageous. These systems are highly efficiency and have high conversion rates with respect to absorbed radiation. PVT systems also save space because a single panel is used to create both heat and electricity. Additionally, PVT hybrid systems improve the payback period.
Combining solar PV with solar thermal system


References:


4.3.2.5 GENERAL RECOMMENDATION:

4.3.2.5.1 Climate Zones (1-8)

1A Miami: Miami has a tropical monsoon climate with hot humid summers and short, warm winters.

In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

There are different types of panels:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adjustable, 2 seasons**: adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adjustable, 4 seasons**: adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**: always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but offers less power than an adjustable version.
The best angle from the horizontal at which the panel should be tilted:

- If your latitude is below 25°, use the \( \text{latitude} \times 0.87 \).
- If your latitude is between 25° and 50°, use the \( \text{latitude} \times 0.76 + 3.1° \).

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Solar PV systems like other electrical systems present some risk of fire. The panels can get hot from the sun and increase the risk of burns in hot climates. Firefighting on the roof has some difficulties because of the limited access. In addition, arrays that stand above the roof may create a channeling effect, which may intensify fires. Thus, it is important that PV systems are designed correctly, installed carefully with properly tested components, and maintained regularly.

References:


2A_Houston: Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

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A fixed angle is convenient, but offers less power than an adjustable version.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is below 25°, use the **latitude x 0.87**.
- If your latitude is between 25° and 50°, use the **latitude, x 0.76 + 3.1°**.

Optimum Tilt of Solar Thermal Roof Panels

(Source: http://www.copybook.com/environmental/stokvis_industrial_boilers_international_ltd/stokvis_energy_systems-gallery/solar_thermal_01)
Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Solar PV systems like other electrical systems present some risk of fire. The panels can get hot from the sun and increase the risk of burns in hot climates. Firefighting on the roof has some difficulties because of the limited access. In addition, arrays that stand above the roof may create a channeling effect, which may intensify fires. Thus, it is important that PV systems are designed correctly, installed carefully with properly tested components, and maintained regularly.

References:

2B Phoenix: In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

There are different types of panels:
- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adjustable, 2 seasons**: adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adjustable, 4 seasons**: adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**: always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but offers less power than an adjustable version.

**The best angle from the horizontal at which the panel should be tilted:**
If your latitude is below 25°, use the \textit{latitude} \times 0.87. 
If your latitude is between 25° and 50°, use the \textit{latitude} \times 0.76 + 3.1°.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{solar_panels.jpg}
\caption{Optimum Tilt of Solar Panels}
\end{figure}

(Source: \url{http://www.solarpaneltilt.com/})

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for \textbf{solar PV installation}. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, \textit{excessive humidity can decrease the efficiency of the system}. In addition, \textit{the efficiency of PV system can decrease due to increasing temperature}. So, cooling is often required for the places with high illumination and concentrated sunlight.

Solar PV systems like other electrical systems present some risk of fire. The panels can get hot from the sun and increase the risk of burns in hot climates. Firefighting on the roof has some difficulties because of the limited access. In addition, arrays that stand above the roof may create a channeling effect, which may intensify fires. Thus, it is important that PV systems are designed correctly, installed carefully with properly tested components, and maintained regularly.

\textbf{References:}


202
3A Atlanta: Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

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- If your latitude is below 25°, use the latitude \( \times 0.87 \).
- If your latitude is between 25° and 50°, use the latitude, \( \times 0.76 + 3.1^\circ \).

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Solar PV systems like other electrical systems present some risk of fire. The panels can get hot from the sun and increase the risk of burns in hot climates. Firefighting on the roof has some difficulties because of the limited access. In addition, arrays that stand above the roof may create a channeling
effect, which may intensify fires. Thus, it is important that PV systems are designed correctly, installed carefully with properly tested components, and maintained regularly.

References:

3B Coast Los Angeles: The climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall—with a characteristically warm and dry climate.

In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

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- **Adjustable, 4 seasons**: adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**: always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but offers less power than an adjustable version.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is below 25°, use the latitude x 0.87.
- If your latitude is between 25° and 50°, use the latitude, x 0.76 + 3.1°.
Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Solar PV systems like other electrical systems present some risk of fire. The panels can get hot from the sun and increase the risk of burns in hot climates. Firefighting on the roof has some difficulties because of the limited access. In addition, arrays that stand above the roof may create a channeling effect, which may intensify fires. Thus, it is important that PV systems are designed correctly, installed carefully with properly tested components, and maintained regularly.

References:


**3b Las Vegas:** Climate Zone 3B includes areas of the United States with a characteristically hot and dry climate.
In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

There are different types of panels:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adjustable, 2 seasons**: adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adjustable, 4 seasons**: adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**: always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but offers less power than an adjustable version.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is below 25°, use the \( \text{latitude} \times 0.87 \).
- If your latitude is between 25° and 50°, use the \( \text{latitude} \times 0.76 + 3.1° \).

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

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References:


3C_San Francisco: 3C includes areas of the United States with a characteristically marine climate.

In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

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- If your latitude is below 25°, use the latitude \( \times 0.87 \).
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Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

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References:


4A_ Baltimore: Climate Zone 4A includes areas of the United States with a characteristically mild, humid climate.

In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

There are different types of panels:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adjustable, 2 seasons**: adjusting the tilt twice a year gives you a meaningful boost in energy.
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![Optimum Tilt of Solar Panels](http://www.solarpaneltilt.com/)

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

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**References:**


4B_ Albuquerque: Climate Zone 4B includes areas of the United States with a characteristically mild, dry climate.

In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

There are different types of panels:

- Fixed: simplest way to mount your solar panels, less efficiency.
- Adjustable, 2 seasons: adjusting the tilt twice a year gives you a meaningful boost in energy.
- Adjustable, 4 seasons: adjusting four times a year produces only a little more, optimize production in spring and fall.
- 2-axis tracker: always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but offers less power than an adjustable version.

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**References:**


**4C Seattle:** Climate Zone 4C includes areas of the United States with a characteristically marine climate.

In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

There are different types of panels:

- **Fixed:** simplest way to mount your solar panels, less efficiency.
- **Adjustable, 2 seasons:** adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adjustable, 4 seasons:** adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker:** always points the panel directly at the sun, maximum efficiency.

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- If your latitude is below 25°, use the **latitude x 0.87**.
- If your latitude is between 25° and 50°, use the **latitude, x 0.76 + 3.1°**.
Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Solar PV systems like other electrical systems present some risk of fire. The panels can get hot from the sun and increase the risk of burns in hot climates. Firefighting on the roof has some difficulties because of the limited access. In addition, arrays that stand above the roof may create a channeling effect, which may intensify fires. Thus, it is important that PV systems are designed correctly, installed carefully with properly tested components, and maintained regularly.

References:


5A Chicago: Climate Zone 5A includes areas of the United States with a characteristically cold, moist climate.
In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

There are different types of panels:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adjustable, 2 seasons**: adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adjustable, 4 seasons**: adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**: always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but offers less power than an adjustable version.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is below 25°, use the \( \text{latitude} \times 0.87 \).
- If your latitude is between 25° and 50°, use the \( \text{latitude} \times 0.76 + 3.1° \).

![Optimum Tilt of Solar Panels](http://www.solarpaneltilt.com/)

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, **excessive humidity can decrease the efficiency of the system**. In addition, **the efficiency of PV system can decrease due to increasing temperature**. So, cooling is often required for the places with high illumination and concentrated sunlight.

Solar PV systems like other electrical systems present some risk of fire. The panels can get hot from the sun and increase the risk of burns in hot climates. Firefighting on the roof has some difficulties because of the limited access. In addition, arrays that stand above the roof may create a channeling effect, which may intensify fires. Thus, it is important that PV systems are designed correctly, installed carefully with properly tested components, and maintained regularly.
References:


**5B Denver:** Climate Zone 5B includes areas of the United States with a characteristically cold, dry climate.

In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

There are different types of panels:

- **Fixed:** simplest way to mount your solar panels, less efficiency.
- **Adjustable, 2 seasons:** adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adjustable, 4 seasons:** adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker:** always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but offers less power than an adjustable version.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is below 25°, use the latitude x 0.87.
- If your latitude is between 25° and 50°, use the latitude, x 0.76 + 3.1°.
Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Solar PV systems like other electrical systems present some risk of fire. The panels can get hot from the sun and increase the risk of burns in hot climates. Firefighting on the roof has some difficulties because of the limited access. In addition, arrays that stand above the roof may create a channeling effect, which may intensify fires. Thus, it is important that PV systems are designed correctly, installed carefully with properly tested components, and maintained regularly.

References:


4.3.2.5.2 Climate zone 6, 7, 8:
In order to have an efficient PV panel, we need to find the direction and angle that captures the most solar rays. Different types of PV panels come in fixed, seasonally adjustable, and sun tracking versions.

There are different types of panels:

- **Fixed**: simplest way to mount your solar panels, less efficiency.
- **Adjustable, 2 seasons**: adjusting the tilt twice a year gives you a meaningful boost in energy.
- **Adjustable, 4 seasons**: adjusting four times a year produces only a little more, optimize production in spring and fall.
- **2-axis tracker**: always points the panel directly at the sun, maximum efficiency.

A fixed angle is convenient, but offers less power than an adjustable version.

**The best angle from the horizontal at which the panel should be tilted:**

- If your latitude is below 25°, use the \( \text{latitude} \times 0.87 \).
- If your latitude is between 25° and 50°, use the \( \text{latitude} \times 0.76 + 3.1^\circ \).

Locations that receive 5.4 peak sun hours or more of direct normal irradiance are appropriate for solar PV installation. Due to higher solar radiation and the higher percentage of direct beam sunlight, PV systems in hot climates perform better than those in other climates. However, excessive humidity can decrease the efficiency of the system. In addition, the efficiency of PV system can decrease due to increasing temperature. So, cooling is often required for the places with high illumination and concentrated sunlight.

Solar PV systems like other electrical systems present some risk of fire. The panels can get hot from the sun and increase the risk of burns in hot climates. Firefighting on the roof has some difficulties...
because of the limited access. In addition, arrays that stand above the roof may create a channeling effect, which may intensify fires. Thus, it is important that PV systems are designed correctly, installed carefully with properly tested components, and maintained regularly.

References:


4.3.3 WIND POWER

4.3.3.1 GENERAL INFORMATION

4.3.3.1.1 Definition:
The terms wind energy and wind power describe the process by which the wind is used to generate mechanical power or electricity. Turbines allow for the harnessing of wind; wind turns the blades, which spin a shaft connected to a generator where electricity is generated.

Modern wind turbines fall into two basic groups:

1. The horizontal-axis variety (older and more commonly recognized)
2. The vertical-axis design

Larger wind turbines are more cost effective and are grouped together into wind farms.

For all roof cases, wind turbines should be positioned at a height equal to or more than 1.3 times the height of the building.

In order to improve roof-top turbine performance, the following rules-of-thumb are recommended:

- The average wind speed of sites selected for turbine installation should not be less than 5.5 m/s.
• The building roof where the turbine is to be located should be approximately 50% higher than the surrounding objects.
• The turbine should be located near the center of the roof oriented towards the most common wind direction, with the lowest position of the rotor at least 30% of the building height above the roof level.

References:
4.3.3.1.2 Advantages:
Wind energy is a green, on-site power source that is always available that can be stored when winds are low. Its ubiquitous nature makes it a suitable energy source regardless of location, or wealth. Costs primarily come from installation of the wind turbine, since wind itself is free. Wind energy generation does not release harmful pollutants or carbon dioxide. It can be a great resource in remote locations especially, such as in the mountains. This technology will play an important role in future energy generation, due to its technological maturity, good infrastructure, and relative costs.

References:
4.3.3.1.3 Disadvantages:
The unreliable, unpredictable nature of wind is an important factor for consideration; air-flow can be turbulent and hard to effectively harvest, for either vertical- or horizontal-axis turbines. Large and truly integrated installations can generate significant power, but these are difficult to permit and insure in North America. Cost-effective wind turbines are often too large for building structures, and turbine structures normally require large geographic areas (consequently often leaving rooftop installations not cost-effective). Vibration and noise concerns affecting buildings and their occupants are often cited as undesired consequences of wind power. Turbines come with more maintenance costs than other energy systems. While the environmental consequences of wind power are close to none, problems include noise pollution, visual intrusion, communication interference, and dangers to wildlife like birds and bats (though wind turbines can be installed in areas of low bird utilization). Finally, obtaining actual measured performance data is very hard, increasing the difficulty of measuring true performance.

References:
4.3.3.2 CODES AND STANDARDS:

4.3.3.2.1 IECC, 2012:
N/A. There is no information about wind power available in the IECC-2012 version.

4.3.3.2.2 ASHRAE 90.1, 2010:
N/A. There is no information about wind power available in the ASHRAE 90.1, 2010 version.

4.3.3.2.3 IgCC, 2012:
N/A. There is no information about wind power available in the IgCC, 2012 version.

4.3.3.2.4 ASHRAE AEDG 50%, 2011:
ASHRAE AEDG discusses wind energy in the following context:

Chapter 5: How to implement recommendations:

Renewable energy: Section RE3 (Page 196): Wind Turbine (Climate Zones: all)

Wind energy is one of the lowest-priced renewable energy technologies available today, costing between 5 to 11 cents per kilowatt-hour, depending upon the wind resource and project financing of the particular project. Small- to medium-sized wind turbines are typically considered for small to medium office buildings. These turbines range from 4 to 200 kW and are typically mounted on towers from 50 to 100 ft tall and connected to the utility grid through the building’s electrical distribution system. One of the first steps to developing a wind energy project is to assess the area’s wind resources and estimate the available energy. From wind resource maps, you can determine if your area of interest should be further explored. Note that the wind resource at a micro level can vary significantly; therefore, you should get a professional evaluation of your specific area of interest.

The map in Figure 5-43 shows the annual average wind power estimates at 50 m above ground. It combines high- and low-resolution data sets that have been screened to eliminate land-based areas
unlikely to be developed due to land use or environmental issues. In many states, the wind resource has been visually enhanced to better show the distribution on ridge crests and other features. Estimates of the wind resource are expressed in wind power classes ranging from Class 1 (lowest) to Class 7 (highest), with each class representing a range of mean wind power density or equivalent mean speed at specified heights above the ground. This map does not show Classes 1 and 2, as Class 2 areas are marginal and Class 1 areas are unsuitable for wind energy development. In general, at 50 m, Class 4 or higher wind power can be useful for generating wind power. More detailed state wind maps are available at the U.S. Department of Energy’s Office of Energy Efficiency and Renewable Energy Web site (EERE 2011a).

![United States - Wind Resource Map](image)

**Figure 5-43 (RE3) Average Annual Wind Power Estimates**
(Source: NREL (2009))

Although wind turbines themselves do not take up a significant amount of space, they need to be installed an adequate distance from the nearest building for several reasons, including turbulence reduction (which affects efficiency), noise control, and safety. **Coordination between the owner,**
design team, and site planner is essential to establish the optimal wind turbine location relative to the other facilities on the site.

The three largest complaints about wind turbines are the noise, the killing of birds, and the aesthetic appearance. Most of these problems have been resolved or greatly reduced through technological developments or by properly siting wind turbines. Most small wind turbines today have an excellent safety record. An important factor is to consider how the wind turbine controls itself and shuts itself down. Can operators shut it off and stop the turbine when they want or need to do so? This is extremely important, and unfortunately there are very few small turbines that have reliable means to stop the rotor on command. The few that do may require you to do so from the base of the tower—not exactly where you want to be if the turbine is out of control in a wind-storm. Look for a system that offers one or more means to shut down and preferably stop the rotor remotely.

Using energy modeling, the electric energy consumption of the building can be modeled. Using this data in conjunction with the financial details of the project, including the rebates, the owner and designer must then choose the correct size turbine that meets their needs. Note that the closer the match of the turbine energy output to the demand, the more cost-effective the system will be. Make sure that all costs are listed to give a total cost of ownership for the wind turbine. This includes the wind turbine, the tower, the electrical interconnection, controls, installation, maintenance, concrete footings, guy wires, and cabling. In addition to evaluating the initial cost of the turbine, it is extremely important to consider the federal and state policies and incentive programs that are available. The Database for State Incentives for Renewables and Efficiency (DSIRE) provides a list of available incentives, grants, and rebates (EERE 2011b). Also critical to the financial success to a wind turbine project is a favorable net metering agreement with the utility.

4.3.3.2.5 ASHRAE Fundamentals, 2009:
Wind and solar energy are widely distributed (if not always continuously available) on almost any site for use in active or passive ways.

4.3.3.2.6 RoofPoint:
N/A. There is no information about wind power available in the RoofPoint.

4.3.3.2.7 RoofNav:
N/A. There is no information about wind power available in the RoofNav.
4.3.3.3 REALITY

4.3.3.3.1 Implementation costs:
Similar to other renewable energy technologies, costs to be considered for wind energy include many components, all of which change often. Wind energy is one of the lowest-priced renewable energy technologies available today, costing between 5 to 11 cents per kilowatt-hour, depending upon the wind resource and project financing of the particular project. The Department of Energy reports that while costs of wind power are low, further or continued decrease is not likely, and current policies and competitiveness of non-renewable resources will not help growth.

The cost of the wind turbine is the largest cost component of a wind power system. It can make up around 70% of the entire project cost. Installation normally makes up the remaining costs. The Department of Energy finds that “among a large sample of wind projects installed in 2012, the capacity-weighted average installed cost stood at nearly $1,940/kW, down almost $200/kW from the reported average cost in 2011 and down almost $300/kW from the reported average cost in both 2009 and 2010.”

A wind project is expected to operate for at least 20 years, but requires monitoring and maintenance from specialized operators and technicians, incurring operating costs. Additionally, performance of wind turbines can increase price and/or increase cost-effectiveness.

Wind energy consumers and utilities can lock-in known electricity rates for 20 to 30 years through Power Purchase Agreements (PPAs). The Department of Energy Wind Technologies Market Report 2012 found that average prices of wind PPAs have fallen significantly. PPAs signed for wind energy projects during 2012 range from $31 to $84 per MWh, compared to ranges of $44 to $99 per MWh in 2010.

References:

4.3.3.3.2 Aesthetics:
Aesthetic appearance is popularly cited as a concern with wind turbines. The appearance of a wind turbine is mostly determined by the external shape of the blades and the nacelle (cover housing the generating components). The shape of the rotor follows aerodynamic principles and is thus not open to discussion of aesthetics. Part of the overall aesthetic image of the nacelle and of the wind turbine
as a whole is a well thought-out coat of paint. This considerably influences the visual impact of a turbine in the landscape. **Whether the color of the turbine is intended to visually hide the turbine or to emphasize it must be taken into consideration in each individual case.** In general, most designs attempt to make the turbine as inconspicuous in the environment as possible.

References:

### 4.3.3.3 Psychological aspects:
Installing renewable energy systems on the roof, increases the awareness of occupants in environment and energy savings and consequently affects their behavior in energy consumption.

References:

The 400-watt AVX400 turbine from AeroVironment
(Source: [https://www2.buildinggreen.com/article/folly-building-integrated-wind](https://www2.buildinggreen.com/article/folly-building-integrated-wind))
4.3.3.4 Precedents of innovation:

AeroVironment AVX1000

In 2006, a 400-watt wind turbine from AeroVironment that can take advantage of concentrated wind at the parapets of commercial buildings was introduced.

The AVX1000 model, is an elegant, lightweight, 1 kW turbine that bends from a mounting base on a building’s parapet. The turbines are designed to be installed in a row. AeroVironment uses horizontal-axis, rather than vertical-axis, wind turbines due to more efficiency.

References:


4.3.3.4 GENERAL RECOMMENDATIONS:

4.3.3.4.1 Climate Zones (1-8)

1A_ Miami: Miami has a tropical monsoon climate with hot and humid summers and short, warm winters.

Heavy prevailing winds typically come from the ocean, so it is useful to install wind turbines as close to coastline cities as is possible. Wind turbines work best near the coast, or in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure optimum system performance.

References:
2A_Houston: Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

Wind turbines work best in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure you get optimum system performance.

References:


2B_Phoenix: Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.

Wind turbines work best in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure you get optimum system performance.

References:


3A_Atlanta: Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

Wind turbines work best in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure you get optimum system performance.

References:

3B_Los Angeles: The climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall but relatively modest transitions in temperature.

Heavy prevailing winds typically come from the ocean, so it is useful to install wind turbines as close to coastline cities as is possible. Wind turbines work best near the coast, or in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure optimum system performance.

References:

3b_Las Vegas: Climate Zone 3B includes areas of the United States with a characteristically dry climate.

Wind turbines work best in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure you get optimum system performance.

References:

3C_San Francisco: Climate Zone 3C includes areas of the United States with a characteristically marine climate.

Heavy prevailing winds typically come from the ocean, so it is useful to install wind turbines as close to coastline cities as is possible. Wind turbines work best near the coast, or in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure optimum system performance.

References:
4A_ Baltimore: Climate Zone 4A includes areas of the United States with a characteristically moist climate.

Heavy prevailing winds typically come from the ocean, so it is useful to install wind turbines as close to coastline cities as is possible. Wind turbines work best near the coast, or in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure optimum system performance.

References:


4B_ Albuquerque: Climate Zone 4B includes areas of the United States with a characteristically dry climate.

Wind turbines work best in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure you get optimum system performance.

References:


4C_ Seattle: Climate Zone 4C includes areas of the United States with a characteristically marine climate.

Heavy prevailing winds typically come from the ocean, so it is useful to install wind turbines as close to coastline cities as is possible. Wind turbines work best near the coast, or in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately
measuring wind speeds at different locations across your site will ensure optimum system performance.

References:


5A_ Chicago: Climate Zone 5A includes areas of the United States with a characteristically moist climate.

Wind turbines work best in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure you get optimum system performance.

Cold climate conditions offer large amounts of wind energy potential while having higher expected cost rather than other areas. In addition, wind turbines in very cold climates may have the risk of financial losses and premature mechanical failure due to three issues:

1. Affects of low temperatures on physical characteristics of materials
2. Ice on the structure
3. Presence of snow on the surface of wind turbine

In order to operate wind turbines in cold weather conditions, these issues need to be considered in turbine development. However, wind energy projects in cold climate areas are implemented.

References:


5B_ Denver: Climate Zone 5B includes areas of the United States with a characteristically dry climate.
Wind turbines work best in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure you get optimum system performance.

Cold climate conditions offer large amounts of wind energy potential while having higher expected cost rather than other areas. In addition, wind turbines in very cold climates may have the risk of financial losses and premature mechanical failure due to three issues:

1. Affects of low temperatures on physical characteristics of materials
2. Ice on the structure
3. Presence of snow on the surface of wind turbine

In order to operate wind turbines in cold weather conditions, these issues need to be considered in turbine development. However, wind energy projects in cold climate areas are implemented.

References:


**6A_ Minneapolis:** Climate Zone 6A includes areas of the United States with a characteristically moist climate.

Wind turbines work best in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure you get optimum system performance.

Cold climate conditions offer large amounts of wind energy potential while having higher expected cost rather than other areas. In addition, wind turbines in very cold climates may have the risk of financial losses and premature mechanical failure due to three issues:

1. Affects of low temperatures on physical characteristics of materials
2. Ice on the structure
3. Presence of snow on the surface of wind turbine

In order to operate wind turbines in cold weather conditions, these issues need to be considered in turbine development. However, wind energy projects in cold climate areas are implemented.
4.3.3.4.2 Climate zones 7-8
Wind turbines work best in open exposed areas where average wind speeds are high. Ideally, turbines should be mounted high up - even small turbines are often mounted about 30 feet high in order to get sufficient wind power. Accurately measuring wind speeds at different locations across your site will ensure you get optimum system performance.

Cold climate conditions offer large amounts of wind energy potential while having higher expected cost rather than other areas. In addition, wind turbines in very cold climates may have the risk of financial losses and premature mechanical failure due to three issues:

1. Affects of low temperatures on physical characteristics of materials
2. Ice on the structure
3. Presence of snow on the surface of wind turbine

In order to operate wind turbines in cold weather conditions, these issues need to be considered in turbine development. However, wind energy projects in cold climate areas are implemented.

References:
4.4 BIOMASS AND BIOELECTRICITY

4.4.1 GENERAL INFORMATION

4.4.1.1 Definition:
Biomass is biological material derived from living, or recently living organisms, from which heat energy is derived. In the context of biomass for energy, this is usually applied in reference to plant-based material. Materials used for biomass energy can include:

- **Virgin wood** (forestry)
- **Energy crops** (high yield crops grown specifically for energy use)
- **Agricultural by-products** (residues from harvesting or processing)
- **Food waste** (waste from manufacturing, preparation, processing, and post-consumer waste)
- **Industrial waste** and **co-products** (from manufacturing and industrial processes)

There are different methods by which biomass materials can be used to generate energy.

- **Thermal conversion**: This involves using heat to convert biomass into another chemical form (e.g. combustion, gasification, etc)
- **Chemical conversion**: This involves using chemical processes to produce another usable form of the biomass (e.g. anaerobic digestion, fermentation, composting, etc)

There are also different types of biomass systems available.

- Most commonly, **biomass is burned for energy**. This can be done using stoves or boilers that run on logs, pellets, or chips, or a CHP (combined heat and power) system, or even district heating (using a system to heat for several buildings).

- Biomass can also be **converted to biogas, compost, or liquid fertilizer**, using an anaerobic digester. This is normally used for processes aside from general electricity/energy.

- **Biomass for electricity**: Less common, but a viable power source for the future, is bioelectricity. Bioelectricity is the generation of electric power potential or current produced by or within living organisms. Bioelectricity can be harnessed for power through plant-microbial fuel cells. Selecting the most suitable plants is important for increasing electricity output.

  *Plant-Microbial Fuel Cell generates electricity from organic matter excreted from the roots of living plants.*

**References:**

* Biomass Energy Centre, UK, retrieved from http://www.biomassenergycentre.org.uk


4.4.1.1.2 Advantages:
Biomass produces a fraction of the carbon emissions that fossil fuels produce when combusted. When used correctly, biomass it can maintain a closed carbon cycle, sequestering as much carbon as it releases, while maintaining atmospheric CO$_2$ levels. Biomass systems tend to be exceptionally reliable. When fuels are made from low-grade wood products (like chips and pellets), it enables the enhanced growth of higher quality trees. Community based systems also contribute to a local economies, and provide economic incentives for managing woodlands, thereby improving biodiversity.

Bioelectricity also has distinct advantages from other renewable energy sources. It may allow for energy supply in remote areas, or provide an auxiliary energy source. Plant-microbial fuel cells (PMFCs)* can be implemented to treat waste-water and mitigate pollutants. They also help reduce global warming by decreasing methane emissions, making these fuel cells an attractive source for the future.

*Plant-Microbial Fuel Cell generates electricity from organic matter excreted from the roots of living plants.

References:
* Biomass Energy Centre, UK, retrieved from http://www.biomassenergycentre.org.uk
Disadvantages:
Biomass has several disadvantages as an energy source. Because biomass energy uses combustion, emissions are a concern with it when they are not a concern for other renewable energy sources such as solar and wind. It can be challenging to guarantee quality and cleanliness of biomass fuels, particularly in smaller scale projects. Additionally, fuel supply and fuel storage safety are concerns. Biomass systems require more cleaning than fossil fuel systems; normally, between 2-5 hours a week should be allocated to operation and maintenance. Using wood products for energy production may compete with other wood products, and burning of agricultural waste can deplete the soil of nutrients. There are also numerous regulations regarding the installation of solid fuel heating systems.

The most significant disadvantage of bioelectricity or plant-microbial fuel cells (PMFCs) is that the technology is in its infancy. As a new technology, it needs to be improved and developed in terms of performance and applications. Standard electric systems have efficiencies around 20% (though this can be improved with a CHP system). Because of this low efficiency, they are not competitive.
Large biomass and bioelectricity systems are expensive. On the other hand, small systems can have higher operation and maintenance costs per unit of energy generated, along with lower efficiencies than larger systems. This can make choosing an optimal system challenging in order to get the reasonable size.

References:

* Biomass Energy Centre, UK, retrieved from http://www.biomassenergycentre.org.uk


4.4.1.2 CODES AND STANDARDS:

4.4.1.2.1 IECC, 2012:
N/A. There is no information about Biomass & Bioelectricity available in the IECC-2012 version.

4.4.1.2.2 ASHRAE 90.1, 2010:
N/A. There is no information about Biomass & Bioelectricity available in the ASHRAE 90.1, 2010 version.

4.4.1.2.3 IgCC, 2012:
IgCC 2012 contains the following information relevant to biomass systems in regard to specific indoor air quality and pollutant control measures:

**Section 804.1.3 (Page 8-4): Biomass appliances:** Biomass fireplaces, stoves, and inserts shall be listed and labeled in accordance with ASTME* 1509 or UL 1482. Biomass furnaces shall be listed and labeled in accordance with CSA B366.1 or UL 391. Biomass boilers shall be listed and labeled in accordance with CSA** B366.1 or UL*** 2523.

- Biomass fuels are renewable fuels and include wood pellets, switch grass, corn, grains and fruit pits. The listing requirements are consistent with the IMC. Bio-mass fuels are considered to be
carbon neutral because the volume of carbon dioxide released from combustion of the fuels is absorbed by the plant growth that creates the fuels.

* **ASTME**: American Society of Tool and Manufacturing Engineers.

** CSA**: Canadian Standards Association Standards.

*** **UL**: Underwriters Laboratories. UL provides testing, inspection and certification services that help protect lives and property.

4.4.1.2.4  **ASHRAE AEDG 50%, 2011**:  
N/A. There is no information about Biomass & Bioelectricity available in the ASHRAE AEDG 50%, 2011.

4.4.1.2.5  **ASHRAE Fundamentals, 2009**:  
N/A. There is no information about Biomass & Bioelectricity available in the ASHRAE Fundamentals, 2009.

4.4.1.2.6  **RoofPoint**:  
N/A. There is no information about Biomass & Bioelectricity available in the RoofPoint.

4.4.1.2.7  **RoofNav**:  
N/A. There is no information about Biomass & Bioelectricity available in the RoofNav.

4.4.1.3  **REALITY**

4.4.1.3.1  **Implementation costs**:  
Costs can differ between biomass systems. Biomass is commonly used for either electricity or heating.

1. **Biomass for Heat**: Biomass heating plants have installation costs that typically average between $500 – $1500 per kW thermal heating rate capacity. As these involve mature technologies, costs are
not expected to drop significantly in the short term. Other costs include maintenance and operation system. [http://www.wbdg.org/resources/biomassheat.php](http://www.wbdg.org/resources/biomassheat.php)

2. **Biomass for Electricity**: These kinds of small-scale biomass electric plants have installation costs of $3,000 – $4,000 per kW, and a levelized cost of energy of $0.8 to $0.15 per kilowatt hour (kWh). Unlike several other kinds of energy generation systems, costs for biomass systems increase as the system grows larger. Larger systems require more material, which comes with increased transport distances and increased material costs. Small systems, however, can have higher operation and maintenance costs per unit of energy generated, along with lower efficiencies than larger systems. This can make choosing an optimal system challenging; constant evaluation is important. Incentives exist for biomass electricity; however, they vary with federal and state legislation.

This information does not apply necessarily to rooftop biomass systems, specifically, and costs of a system atop a roof may contribute to higher costs of roof infrastructure and materials for strength, etc.

**References:**


### 4.4.1.3.2 Aesthetics:

Biomass energy systems, especially those using combustion, can release emissions that may not be aesthetically pleasing.

### 4.4.1.3.3 Psychological aspects:

Besides aesthetic issues, releasing emissions can have negative health effects.

### 4.4.1.3.4 Precedents of innovations:

**Biomass CHP (Combined Heat and Power):**

- Can efficiently and simultaneously produce both heat and power, using a variety of biomass materials (wood and wood wastes, agricultural wastes, biogas, black liquor, etc.)
- Hugely increased efficiency compared to standard biomass system
- Efficiency increases with larger systems

**Plant-Microbial Fuel Cell:**
- Electricity generated from living plants; bioelectricity and biomass production combined on same surface
- Offers a more sustainable approach to biomass energy generation with lower impact on environment
- Removes competition against food/feed production on available lands.
- Currently evolving technology, as less-impactful materials are found and higher power output is explored
- Could be combined with green roof.

**References:**
* Biomass Energy Centre, UK, retrieved from http://www.biomassenergycentre.org.uk
4.4.1.4 GENERAL RECOMMENDATION

4.4.1.4.1 All climate zones (1-8)
The cost and efficiency of producing electricity and heat from organic materials depends on the feedstock quality, the availability of the material and the associated transportation costs, the power plant size, and the conversion of the material into biogas. So, if there is enough biomass available, bio power and CHP plants are a highly reliable, economic power source suitable for base-load service.

The effect of biomass energy on climate could be either cooling or warming, depending on the crop, the energy converting technology, and the difference in carbon stock and reflected solar radiation. So, in warm climates, fire retardant is required for all roofs covered with organic materials.

Climate is an important factor for plant productivity. Generally, warm and humid conditions with longer growing seasons allow the plants to grow larger faster, resulting in increased productivity of the system. On the other hand, cold and drier conditions slow down growth and decrease the mature size of the plants, resulting in decreased productivity of system.

In cold climates, biomass systems need careful maintenance. Because plants are inherently wet, they may have frozen ice particles, including loose snow. Additionally, contaminants such as dirt, which would usually be removed through screening, may freeze and remain in the plants. Thus, using biomass in cold climates requires special considerations.

References:


4.4.2 DAYLIGHTING

4.4.2.1 SKYLIGHTS

4.4.2.1.1 General Information

Design of Skylight

4.4.2.1.2 Definition:

A fenestration surface that has a slope of less than 60º from the horizontal plane is considered a skylight. All fenestration having a slope of greater than 60º, even if it is mounted on the roof of a building, is considered vertical fenestration. According to ASHRAE 90.1, 2010 the total skylight area should not exceed 5% of the gross roof area.

A skylight system is the most common type of top-lighting system. Skylight systems provide horizontal or slanted openings on the roof to allow daylight into indoor spaces, while the openings are covered with transparent materials like glass or plastic.

Skylights are available in a wide range of sizes and shapes from simple rectangles to complex polygons. They can be small enough to fit between rafters, or as large as the length of a building.

Skylight shape, fenestration glazing type, surface area, orientation and placement are major design parameters to solve the trade-off between daylighting and solar heat gains, and to achieve aesthetics and significant energy savings.

References:


4.4.2.1.3 Advantages:

Skylights have substantial potential for energy savings in building; **Over 90% of daytime lighting electricity can be replaced with appropriate skylight design.** They have the potential to reduce cooling loads by removing heat generated from lighting, and reduce heating requirements by admitting solar radiation in the winter.

Skylights allow for **uniform lighting.** Natural lighting has also been shown to have physical and psychological benefits, which improves performance in working environments. The connection with nature is another benefit of skylights, which helps to naturally reduce the production of harmful organisms.
References:


4.4.2.1.4 Disadvantages:
Inappropriate design can result in excessive light absorption, glare, or increased heating and/or cooling costs. Additionally, materials, apertures, lighting control systems, and design complexity all add to the cost of roof design.
References:


4.4.2.2 CODES AND STANDARDS:

4.4.2.2.1 IECC, 2012:

Daylight Zone (Page C-8): Part 1: Under skylight – The area under skylights whose horizontal dimension, in each direction, is equal to the skylight dimension in that direction plus either the floor-to-ceiling height or the dimension to a ceiling height opaque partition, or one-half the distance to adjacent skylights or vertical fenestration, whichever is least.

SKYLIGHT (Page C-10): Glass or other transparent or translucent glazing material installed at a slope of less than 60° (1.05 rad) from horizontal. Glazing material in skylight, including unit skylights, solariums, sunrooms, roofs and walls is included in this definition.

Solar Heat Gain Coefficient (SHGC) (Page C-10): The ratio of the solar heat gain entering the space through the fenestration assembly to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation which is then reradiated, conducted or convected into the space.

Section C303.1.3: Fenestration product rating (Page C-26): U-factor of fenestration products (windows, doors and skylights) shall be determined in accordance with NRFC 100* by an accredited, independent laboratory, and labeled and certified by the manufacturer. Product lacking such a labeled U-factor shall be assigned a default U-factor from table C303.1.3 (1).

Table C303.1.3 (1): Default glazed fenestration U-factor
Section C303.1.3: Fenestration product rating, C-26: The solar heat gain coefficient (SHGC) and visible transmittance (VT) of glazed fenestration products shall be determined in accordance with NFRC 200** by an accredited, independent laboratory, and labeled and certified by the manufacturer. Products lacking such a labeled SHGC or VT shall be assigned a default SHGC or VT from Table C303.1.3 (3).

Table C303.1.3 (3) is related to default glazed fenestration SHGC and VT.


**NFRC 200: Procedure for Determining Fenestration Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incidence, Website: www.nfrc.org

Section C402.3.1.2: Increased skylight area with daylighting controls (Page C-33): The skylight area shall be permitted to be a maximum of 5 percent of the roof area provided automatic daylighting controls are installed in daylight zones under skylights.

C402.3.2 Minimum skylight fenestration area (Page C-33): In an enclosed space greater than 10,000 square feet (929 m²), directly under a roof with ceiling heights greater than 15 feet (4.57 m), and used as an office, lobby, atrium, concourse, corridor, automotive service, manufacturing, non-refrigerated warehouse, retail store, distribution/storing area, transportation, or workshop, the total daylight zone under skylights shall be not less than half the floor area and shall provide a minimum skylight area to daylight zone under skylights of either:

- Not less than 3 percent with skylight VT of at least 0.4; or
- Provide a minimum skylight effective aperture of at least 1 percent determined in accordance with equation C4-1 as shown below.

\[
\text{Skylight Effective Aperture} = \frac{0.85 \times \text{Skylight Area} \times \text{Skylight VT} \times \text{WF}}{\text{Daylight zone under skylight}}
\]

Where,

Skylight area: Total fenestration area of skylights:

Skylight \( VT \) = Area weighted average \textbf{visible transmittance} of skylights,

\( WF \) = Area weighted average \textbf{well factor}, where well factor is 0.9 if light well depth is less than 2 feet (610 mm), or 0.7 if light well depth is 2 feet (610 mm) or greater.

Light well depth = Measure vertically from the underside of the lowest point of skylight glazing to the ceiling plane under the skylight.

**Exception:** Skylights above daylight zones of enclosed spaces are not required in:

1. Building in climate zones 6 through 8.
2. Spaces where the designed general lighting power densities are less than 0.5 W/ft\(^2\) (5.4 W/m\(^2\)).
3. Areas where it is documented that existing structures or natural objects block direct beam sunlight on at least half of the roof over the enclosed area for more than 1,500 daytime hours per year between 8 am and 4 pm.
4. Spaces where the daylight zones under rooftop monitors is greater than 50 percent of the enclosed space floor area.

**Section C402.3.2.1, (Page C-34):** Lighting controls in daylight zones under skylights. All lighting in the daylight zone shall be controlled by multilevel lighting controls that comply with section C405.2.2.3.3.

**Exception:** Skylight above daylight zones of enclosed spaces are not required in:

1. Building in climate zones 6 through 8.
2. Spaces where the designed general lighting power densities are less than 0.5 W/FT\(^2\) (5.4 W/m\(^2\)).
3. Areas where it is documented that existing structures or natural objects block direct beam sunlight on at least half of the roof over the enclosed area for more than 1,500 daytime hours per year from 8 am until 4 pm.
4. Spaces where the daylight zones under rooftop monitors is greater than 50% of the enclosed space floor area.
**C402.3.2.2 Haze factor**, *(Page C-34)*: Skylight in office, storage, automotive service, manufacturing, non-refrigerated warehouse, retail store, and distribution/storing area spaces shall have a glazing material or diffuser with a measured haze factor greater than 90 percent when tested in accordance with ASTM 1003.

**Exception**: Skylight designed to exclude direct sunlight entering the occupied space by the use of fixed or automated baffles, or the geometry of skylight and light well need not comply with Section C402.3.2.2.

**Section C402.3.3, Maximum U-factor and SHGC**, *(Page C-34)*: For skylight, the maximum U-factor and solar heat gain coefficient (SHGC) shall be as specified in Table C402.3.

<table>
<thead>
<tr>
<th>Skylight</th>
<th>U-factor</th>
<th>0.75</th>
<th>0.65</th>
<th>0.55</th>
<th>0.50</th>
<th>0.50</th>
<th>0.50</th>
<th>0.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHGC</td>
<td></td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>NR</td>
</tr>
</tbody>
</table>

(NR: No requirement)

**4.4.2.2 ASHRAE 90.1, 2010**:

**Top lighting** *(Page 19)*: lighting a building interior with daylight admitted through fenestration located on the roof such as skylights and rooftop monitors.

**Daylight area, under skylight** *(Page 6)*: The daylight area under skylights is the combined daylight area under each skylight without double counting overlapping areas. The daylight area under each skylight is bounded by the opening beneath the skylight, plus horizontally in each direction, the smallest of the following (see figure 3.1):

1. 70% of the ceiling height (0.7 × CH)
2. The distance to any primary side-lighted area, or the daylight area under rooftop monitors
3. The distance to the front face of any vertical obstruction where any part of the obstruction is farther away than 70% of the distance between the top of the obstruction and the ceiling (0.7 × [CH–OH]), where CH is the height of the ceiling at the lowest edge of the skylight, and OH is the height to the top of the obstruction.
**Figure 3.1 computing the daylight area under skylights**

**Skylight (page 10):** A fenestration surface having a slope of less than 60 degree from the horizontal plane. Other fenestration, even if mounted on the roof of a building, is considered vertical fenestration. The total skylight area shall not exceed 5% of the gross roof area.

**Skylight Effective Aperture (page 17):**

$$0.85 \text{(skylight area)} \times \text{(skylight VT)(WF)} / \text{(daylight zone under skylight)}$$

Where:

Skylight area = total fenestration area of skylights

Skylight VT = area weighted average **visible transmittance** of skylights as determined in accordance with Section 5.8.2.6.

**Section 5.8.2.6 Visible Transmittance (Page 38):** VT shall be determined in accordance with NFRC 200. VT shall be verified and certified by the manufacturer.

**Exception:** For skylights whose transmittances are not within the scope of NFRC 200, their transmittance shall be the solar photometric transmittance of the skylight glazing material(s) determined in accordance with **ASTM E972**.
**WF** = area weighted average **well factor**, where well factor is 0.9 if light well depth is less than 2 ft, or 0.7 if light well depth is 2 ft or greater.

**Light well depth** is measured vertically from the underside of the lowest point on the skylight glazing to the ceiling plane under the skylight.

**Skylight well**: the shaft from the skylight to the ceiling

**Section 5.5.4.2.2 Maximum Skylight Fenestration Area (page 35)**:
The total skylight area shall not exceed 5% of the gross roof area.

**Section 5.5.4.2.3 Minimum Skylight Fenestration Area (page 35)**:
In any enclosed space in a building that is four stories or less and that is:

a. 5,000 ft² and greater and,

b. directly under a roof with ceiling heights greater than 15 ft, and

c. one of the following space types: office, lobby, atrium, concourse, corridor, non-refrigerated warehouse or storage, gymnasium/exercise center, convention center, automotive service, manufacturing, retail, distribution/sorting area, transportation, or workshop,

the total daylight area under skylights shall be a minimum of half the floor area and either:

d. provide a minimum skylight area to daylight area under skylights of 3% with a skylight VT of at least 0.40, or

e. provide a minimum skylight effective aperture of at least 1%

These skylights shall have a glazing material or diffuser with a measured haze value greater than 90% when tested according to ASTM D1003. General lighting in the daylight area shall be controlled as described in Section 9.4.1.5.

**Exceptions to 5.5.4.2.3 (page 35)**:

a. Enclosed spaces in climate zones 6 through 8

b. Enclosed spaces with designed general lighting power densities less than 0.5 W/ft²

c. Enclosed spaces where it is documented that existing structures or natural objects block direct beam sunlight on at least half of the roof over the enclosed space for more than 1,500 daytime hours per year between 8 a.m. and 4p.m.

d. Enclosed spaces where the daylight area under rooftop monitors is greater than 50% of the enclosed space floor area

e. Enclosed spaces where it is documented that 90% of the skylight area is shaded on June 21 in the Northern Hemisphere (December 21 in the Southern Hemisphere) at noon by permanent architectural features of the building
f. The required daylight area under skylights may be reduced by the amount of primary side-lighted area with a side-lighting effective aperture greater than 0.15 and with general lighting controlled as described in Section 9.4.1.3 without the use of any exceptions in Section 9.4.1.3.

g. The required daylight area under skylights may be reduced by the amount of secondary side-lighted area with a side-lighting effective aperture greater than 0.30 and with general lighting controlled by continuous daylight dimming.

**Solar heat gain coefficient (SHGC) (page 17):** the ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted, or convected into the space. (See fenestration area.)

**U-factor (thermal transmittance) (page 19):** heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on each side, where \( U = \text{Btu/h-ft}^2-\text{°F} \).

**Section 5.8.2.4 U-factor (Page 37):** U-factor for skylights shall be determined for a slope of 20 degrees above horizontal.

**Section 5.5.4.4.2 SHGC of Skylights (page 36):** Skylights shall have an SHGC not greater than that specified for “all” orientations in Table 5.5.-1 through Table 5.5.-8 (Building envelope requirements for different climates) for appropriate total skylight area.

**Exception:** Skylights are exempt from SHGC requirements provided they:

a. Have a glazing material or diffuser with a measured haze value greater than 90% when tested according to ASTM D1003

b. Have a skylight VT greater than 0.40, and

c. Have all general lighting in the daylight area under skylight controlled by multilevel photocontrols in accordance with Section 9.4.1.5

d. For dynamic glazing, the minimum SHGC shall be used to demonstrate compliance with this section. Dynamic glazing shall be considered separately from other vertical fenestration, and area weighted averaging with other vertical fenestration that is not dynamic glazing shall not be permitted.

**Section 9.4.1.5 (page 77):** Automatic Daylighting Controls for Top Lighting: When the total daylight area under skylights plus the total daylight area under rooftop monitors in an enclosed space exceeds 900 ft², the lamps for general lighting in the daylight area shall be separately controlled by at least one multilevel photocontrol (including continuous dimming devices) having the following characteristics:

a. The light sensor for the photocontrol shall be remote from where calibration adjustments are made
b. The calibration adjustments shall be readily accessible

c. The multilevel photocontrol shall reduce electric lighting in response to available daylight with at least one control step that is between 50% and 70% of design lighting power and another control step that is no greater than 35% of design power.

Exceptions:

a. Daylighted areas under skylights where it is documented that existing adjacent structures or natural objects block direct beam sunlight for more than 1500 daytime hours per year 8 a.m. and 4 p.m.

b. Daylighted areas where the skylight effective aperture (EA) is less than 0.006 (0.6%)

c. Buildings in climate zone 8 with daylight areas totaling less than 1,500 ft² in an enclosed space

Section 5.8.2.4: U-factor (page 37): U-factor shall be determined in accordance with NFRC 100. U-factor for skylight shall be determined for a slope of 20 degree above horizontal.

Exceptions:

a. U-factor from Section A8.1 shall be an acceptable alternative for determining compliance with the U-factor criteria for skylights. Where credit is being taken for a low-emissivity coating, the emissivity of the coating shall be determined in accordance with NFRC 300. Emissivity shall be verified and certified by the manufacturer.

b. U-factors from Section A8.2 shall be an acceptable alternative for determining compliance with the U-factor criteria for vertical fenestration.

c. U-factors from Section A7 shall be an acceptable alternative for determining compliance with the U-factor criteria for opaque doors.

d. For garage doors, ANSI/DASMA105 shall be an acceptable alternative for determining U-factors.

Below is a normative appendix and is part of this standard.

Normative Appendix A: Rated R-value of Insulation and Assembly U-factor, C-factor, and F-factor.

A8.1 Unlabeled Skylights (page 125): Unlabeled skylights shall be assigned the U-factors in Table A8.1A (Assembly U-factor for Unlabeled Skylights) and are allowed to use the SHGCs and VTs in Table A8.1B (Assembly SHGC and VTs for unlabeled Skylights). The metal with thermal break frame category shall not be used unless all frame members have a thermal break equal to or greater than 0.25 in.
Table A8.1A Assembly U-factor for unlabeled skylights (Page 126):

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Sloped Installation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unlabeled Skylight with Curb</td>
</tr>
<tr>
<td></td>
<td>(includes glass/plastic, flat/domed, fixed/operable)</td>
</tr>
<tr>
<td>Frame Type</td>
<td>Aluminum without Thermal Break</td>
</tr>
<tr>
<td>ID</td>
<td>Glazing Type</td>
</tr>
<tr>
<td>1</td>
<td>1/8 in. glass</td>
</tr>
<tr>
<td>2</td>
<td>1/4 in. acrylic/poly carb</td>
</tr>
<tr>
<td>3</td>
<td>1/8 in. acrylic/poly carb</td>
</tr>
<tr>
<td>4</td>
<td>1/4 in. airspace</td>
</tr>
<tr>
<td>5</td>
<td>1/2 in. airspace</td>
</tr>
<tr>
<td>6</td>
<td>1/4 in. argon space</td>
</tr>
<tr>
<td>7</td>
<td>1/2 in. argon space</td>
</tr>
<tr>
<td>8</td>
<td>1/4 in. airspace</td>
</tr>
<tr>
<td>9</td>
<td>1/2 in. airspace</td>
</tr>
<tr>
<td>10</td>
<td>1/4 in. argon space</td>
</tr>
<tr>
<td>11</td>
<td>1/2 in. argon space</td>
</tr>
<tr>
<td>12</td>
<td>1/4 in. airspace</td>
</tr>
<tr>
<td>13</td>
<td>1/2 in. airspace</td>
</tr>
<tr>
<td>14</td>
<td>1/4 in. argon space</td>
</tr>
<tr>
<td>15</td>
<td>1/2 in. argon space</td>
</tr>
<tr>
<td>16</td>
<td>1/4 in. airspace</td>
</tr>
<tr>
<td>17</td>
<td>1/2 in. airspace</td>
</tr>
<tr>
<td>18</td>
<td>1/4 in. argon space</td>
</tr>
<tr>
<td>19</td>
<td>1/2 in. argon space</td>
</tr>
</tbody>
</table>
C1.3 For Fenestration (Page 145): The classification, area, U-factor, SHGC, VT, overhang PF for vertical fenestration, and width, depth, and height for skylight wells shall be specified. (See Figure C1.3 for definition of width, depth, and height for skylight wells.) Each fenestration element is associated with a surface (defined in Section C1.2) and has the orientation of that surface. For dynamic glazing, the SHGC and VT shall be equal to that determined in accordance with C3.5 for the base envelope design.
C3. BASE ENVELOPE DESIGN AND PROPOSED DESIGN SPECIFICATION (PAGE 145):  

C3.4 For enclosed spaces required to comply with Section 5.5.4.2.3, the skylight area in the base envelope design shall be 3% of the roof area of that enclosed space. For enclosed spaces required to comply with Section 5.5.4.2.3, the total daylight area under skylights in both the base envelope design and the proposed envelope design shall be a minimum of half the floor area.

For all other spaces the skylight area of each space category in the base envelope design shall be the same as the proposed envelope design or 5% of the gross roof area, whichever is less. This distribution of skylights among space conditioning categories shall be the same as the proposed design. If the skylight area of any space category is greater than 5% of the gross roof area of that space-conditioning category, then the area of each skylight shall be reduced in the base envelope design by the same percentage so that the total skylight area is exactly equal to 5% of the gross roof area.

C4. ZONING AND BUILDING GEOMETRY (Page 146):  

C4.5 Skylights shall be assigned to the interior zone of the space-conditioning category. If the skylight area is larger than the roof area of the interior zone, then the skylight area in the interior zone shall be equal to the roof area in the interior zone and the remaining skylight area shall be prorated among the perimeter zones based on floor area.

Table C3.5 VT Factor for the base envelope design (Page 146):

<table>
<thead>
<tr>
<th>Climate Bin</th>
<th>Vertical Fenestration</th>
<th>Glass Skylights</th>
<th>Plastic Skylights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(A, B)</td>
<td>1.00</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>2(A, B)</td>
<td>1.00</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>3(C)</td>
<td>1.00</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>3(A, B)</td>
<td>1.27</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>4(A, B, C)</td>
<td>1.27</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>5(A, B, C)</td>
<td>1.27</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>6(A, B)</td>
<td>1.27</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>7</td>
<td>1.00</td>
<td>1.00</td>
<td>1.20</td>
</tr>
<tr>
<td>8</td>
<td>1.00</td>
<td>1.00</td>
<td>1.20</td>
</tr>
</tbody>
</table>
**C6.5.2 Visible Aperture of Skylights.** The VA of a skylight shall be calculated using Equation C-8.

\[
VA = \text{Area}_{\text{sky}} \times V_{T,\text{sky}} \times 10^{\text{-0.250} \times (5 \times D \times (W + L) / (W \times L))}
\]

(C-8)

where

- \(\text{Area}_{\text{sky}}\) = *fenestration area* of the skylight assembly
- \(V_{T,\text{sky}}\) = the visible transmittance of the skylight assembly
- \(D\) = average depth of skylight well from *fenestration* to ceiling
- \(W\) = width of skylight well
- \(L\) = length of skylight well

---

**C6.9 Skylights in the Exterior Building Envelope (Page 150):** HEAT and COOL shall be calculated for skylights in nonresidential conditioned and residential conditioned zones using Equations C-17 and C-18.

\[
\text{HEAT} = \text{Area}_{\text{sky}} \times \text{HDD65} \times 
(H_2 \times U_{\text{sky}} + H_3 \times \text{SHGC}/0.86)
\]

(C-17)

\[
\text{COOL} = \text{Area}_{\text{sky}} \times C_2 \times \text{CDD50} \times \text{SHGC}/0.86
\]

(C-18)

where

- \(\text{Area}_{\text{sky}}\) = *fenestration area* of the skylight assembly
- \(\text{SHGC}\) = the *solar heat gain coefficient* of the skylight assembly
- \(U_{\text{sky}}\) = *U*-factor of skylight assembly

The coefficients used in the equations depend on the space type and shall be taken from Table C6.9.

**TABLE C6.9 Heating and Cooling Coefficients for Skylights**

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Nonresidential</th>
<th>Residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>(C_2)</td>
<td>1.09E-02</td>
<td>1.64E-02</td>
</tr>
<tr>
<td>(H_2)</td>
<td>2.12E-04</td>
<td>2.91E-04</td>
</tr>
<tr>
<td>(H_3)</td>
<td>-1.68E-04</td>
<td>-2.96E-04</td>
</tr>
</tbody>
</table>
4.4.2.2.3  IgCC

SKYLIGHTS AND SLOPED GLAZING (Page 2-17): Glass or other transparent glazing material installed at a slope of less than 60 degree (1.05 rad) from horizontal. Glazing material in skylights, including unit skylights, tubular daylighting devices, solariums, sunrooms, roofs and sloped walls, are included in this definition.

This definition is coordinated with ASHRAE 90.1 and California’s Title 24 definitions. However, it is not coordinated with the IECC and IBC* definitions, which indicate 15 degrees or more from vertical. Also see the commentary to the definition of “unit skylight” (“Skylight, unit”).

SKYLIGHT, UNIT (Page 2-17): A factory-assembled, glazed fenestration unit, containing one panel of glazing material that allows for natural lighting through an opening in the roof assembly while preserving the weather-resistant barrier of the roof.

A skylight is a glazed opening in a roof to admit daylight. Skylights are often the only method of bringing natural light into an interior, enclosed area. Unfortunately, these fixtures often do their job too well.

Installing too many skylights or those too large for the room can lead to overheating during warm-weather months. Also choosing the most energy-efficient models can compromise light transmission—the reason people buy skylights in the first place.

2-17:

- Skylights are available in a variety of sizes and shapes, though rectangular units are the most common. Although most skylights are fixed or inoperable, others can be opened and shut like a window or have hidden ventilating systems. Large operable skylights designed for the sloping ceilings of attic rooms are even marketed as “roof windows.”

- These approaches help cool the room in warm weather by venting hot air. The IBC requires either tempered or laminated glass in many skylights. Both types are designed to stand up to snow loads and provide protection against falling objects. Tempered glass breaks into small pieces, rather than large shards, if damaged laminated glass, which is fused with a thin layer of plastic, stays in place for added safety if broken. Laminated glass is also better at keeping out sound and is slightly more energy efficient, though also slightly more expensive.

- Skylights may collect little heat during the winter, which is when it is needed most—when the sun is low in the sky. Worse yet, because they’re located where the pressure difference between the inside and outside of the house is greatest, skylights are an easy escape route for heated air. Also, in the summer they can heat up a space quickly—even when it is not needed.

- But these factors can be offset by other features, such as trees or shading devices. Skylights can be used effectively as part of a passive system with proper attention to detail. Skylights can also allow natural light to penetrate deep within building spaces, which vertical glazing seldom can. This can reduce artificial lighting loads significantly and improve human health.
There are positive and negative implications that must be considered in each specific scenario.

- Like windows, skylights offer a variety of energy efficient glazing options, including low-e and tinted glass. Green tints are better than bronze tints for reducing solar heat gain while letting in plenty of visible light. And because skylights usually are not visible from the street, tinted glazing is less likely to affect aesthetics.

- It is important to note that the term “skylight” can also include glazed roofs and sloped walls. This distinction can affect the proper application of the code requirements.

- U-factor: To help determine the appropriate U-factor, this definition includes the slope limitation, which is shown. If the slope of the roof is 15 degree (0.26 rad) or more from the vertical, then the skylight U-factor is appropriate. If the slope is less than 15 degree (0.26 rad), then the glazing would be considered as a fenestration in a wall.

- SHGC: The ratio of solar heat gain entering the space through the fenestration assembly to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation which is then reradiated, conducted or convected into the space. SHGC is expressed as a number between 0 and 1. The lower a window’s SHGC, the less solar heat it transmits.

608.5 Automatic daylight controls, 6-28:

Daylighting with automated controls is one of the largest energy saving strategies available for new buildings. A variety of studies have shown that major lighting and cooling energy savings can be realized when using daylighting with automated controls. A cited example is a retail store using daylighting provided by skylights.

8-14:

- All lighting in the daylight zone must be controlled by multilevel lighting controls as daylighting can save substantial energy. With daylighting, a larger window/skylight area can actually become an energy saving measure as it reduces the need for electric lighting and reduces cooling loads, which more than makes up for thermal losses through the increased fenestration areas. Both the New Buildings Institute and the American Institute of Architects agreed that daylighting can be a major energy-efficient asset provided that electric lighting is reduced when daylight is available. Automated daylight controls are required in order to ensure this energy savings.

- There are exceptions to this section of the code based on the SHGC and -factor when daylighting controls are used. The most important feature of the skylight is its visible light transmittance. Depending upon the type of space and the lighting system and climate, the optimal energy cost savings frequently occur at skylight areas that are substantially greater than the 3 percent skylight-to-roof-area ratio limitation in the 2009 IECC.
Standard for the design of high-performance green buildings except low-rise residential buildings

Section 8.3.4.1 (page 32): Minimum Daylight Area by Toplighting

- A minimum of 50% of the floor area directly under a roof in spaces with a lighting power density or lighting power allowance greater than 0.5 W/ft² (5W/m²) shall be in the daylight area. Areas that are daylight shall have a minimum toplighting area to daylight area ratio as shown in Table 8.3.4.1. For the purpose of compliance with Table 8.3.4.1, the greater of the space lighting power density and the space lighting power allowance shall be used.

<table>
<thead>
<tr>
<th>Lighting Power Density or Lighting Power Allowances in Daylight Area, W/ft² (W/m²)</th>
<th>Minimum Toplighting Area to Daylight Area Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4 W/ft² (14 W/m²) &lt; LPD</td>
<td>3.6%</td>
</tr>
<tr>
<td>1.0 W/ft² (10 W/m²) &lt; LPD &lt; 1.4 W/ft² (14 W/m²)</td>
<td>3.3%</td>
</tr>
<tr>
<td>0.5 W/ft² (5 W/m²) &lt; LPD &lt; 1.0 W/ft² (10 W/m²)</td>
<td>3.0%</td>
</tr>
</tbody>
</table>

Section 8.3.4.2 Skylight characteristics (page 32): Skylights used to comply with section 8.3.4.1 shall have a glazing material or diffuser that has a measured haze value greater than 90% tested according to ASTMD1003 (not withstanding its scope) or other test method approved by AHJ*.

Exceptions:

1. Skylights with a measured haze value less than or equal to 90% whose combined area does not exceed 5% of the total skylight area
2. Tubular daylighting devices having a diffuser
3. Skylights that are capable of preventing direct sunlight from entering the occupied space below the well during occupied hours. This shall be accomplished using one or more of the following:
   a. Orientation
   b. Automated shading or diffusing devices
   c. Diffuser
   d. Fixed internal or external baffles
4. Airline terminals, convention centers, and shopping malls
AHJ*: Authority with jurisdiction regarding who has the job of approving the electrical materials used in electrical systems.

4.4.2.2.4 ASHRAE AEDG-50%:
North-facing clerestories are more effective than skylights to bring daylight into the building interior.

4.4.2.2.5 ASHRAE fundamentals, 2009:
Skylight solar heat gain strongly depends on the configuration of the space below or adjacent to (i.e., in sloped applications) the sky, light formed by the skylight curb and any associated light well. Five aspects must be considered:
1. Transmittance and absorbance of the skylight unit
2. Transmitted solar flux that reaches the aperture of the light well
3. Whether that aperture is covered by a diffuser
4. Transmitted solar flux that strikes the walls of the light well
5. Reflectance of the walls of the light well

Data for flat skylights, which may be considered as sloped glazing, are found in Tables 4 and 1 1.

Domed Skylights: Solar and total heat gains for domed skylights can be determined by the same procedure used for windows. Table 11 gives SHGCs for plastic domed skylights at normal incidence (Shutrum and Ozisik 1961). Manufacturers' literature has further details. Given the poorly defined incident angle conditions for domed skylights, it is best to use these values without correction for incident angle, together with the correct (angle-dependent) value of incident solar irradiance. Results should be considered approximate. In the absence of other data, these values may also be used to make estimates for skylights on slanted roofs.

U-factor: Until more conclusive results are available, U-factors for these systems can be estimated by multiplying the site-assembled sloped / overhead glazing values in Table 4 by the ratio of total product surface area (including curbs) to rough opening area. These ratios range from 1.2 to 2.0 for low-slope skylights, 1.4 to 2.1 for pyramid assemblies sloped at 45", and 1.7 to 2.9 for semicircular barrel vault assemblies.

Physical testing of double-glazed units showed U-factors of 5.74 W/(m²-K) for a thermally broken aluminum pyramidal skylight and 7.4 W/(m²-K) for an aluminum-frame half-round barrel vault (both normalized to a rough opening of 2.4 by 2.4 m).
4.4.2.6 RoofPoint:
Credit E6 identifies roof-mounted skylights and other daylighting technologies available to supplement artificial lighting within the building and offset non-renewable energy sources.

4.4.2.7 RoofVav:
An opening in a roof that is permanently covered with a translucent or transparent material.

Skylights are generally inoperable and are provided mainly as a means of admitting light while maintaining the building envelope. They are installed in the plane of the roof and are limited to installations where the slope is less than or equal to 45° degree from the horizontal. The vertical component of a saw tooth arrangement shall also be considered a skylight. Such vertical components shall not exceed 10 ft (3 m) in height.

Implementation costs: The costs for installing a new skylight will range from $450 to $1500 depending upon the style selected.

Cost by type:

- **Tubular skylights** - The cost for this type of skylight ranges from $150 to $600. These are usually intended to add a huge amount of light to an otherwise dark space. Installation fees will range from $300 to $700 depending upon the amount of finish work required by the job. For example, some tube lights must be installed in the exterior roofing and have a finished extension leading through attic space to the ceiling below. This will greatly increase total installation costs due to the need for framing, sheet rock installation, and even structural modifications.

- **Fixed skylights** - The average price of a single, high-quality fixed skylight is **$200 or higher**. The labor costs for installation will vary depending upon the size of the window and the complexity of the roofing. Generally the costs are **$400 to $1300 per window**. It is best to consult with the contractor before selecting the window because the size of any skylight should not exceed more than 15% of the total floor area in the room. Additionally, the contractor will be able to indicate if the glazing should include UV protection due to the angle of installation as well.

- **Vented skylights** - These are available in electric and remote control models, and will range from **$300 to $1200 each**. The installation costs associated with such a project are significant and will average between **$1000 and $4000**. The same selection criteria applies to this style as to the fixed skylights. Additional costs due to the need for a licensed electrician may also be incurred.

Annual energy cost savings range from $0.35 to $0.40 per square foot of dayroom area. Simple payback ranges from six to seven years. These savings include the additional cooling load resulting from increased solar gains as well as the electricity saved from reduced lighting energy requirements. Life-cycle cost reductions depend on climate and the type of lighting control.
References:


4.4.2.8 Aesthetics:
Skylights make spaces more visually pleasant. Skylights mostly are installed for aesthetic or programmatic (i.e., building purpose) reasons rather than associated energy savings.

4.4.2.9 Psychological aspects:
Skylights are desirable to increase feelings of spaciousness. In general, there is a preference for relatively high vertical luminance.

People's spirits are raised in an atmosphere with an abundance of light and color. Skylights add a new sense of freedom, and an escape from confinement.

References:


4.4.2.3 GENERAL RECOMMENDATIONS:

4.4.2.3.1 Climate Zones (1-8)

1A_ Miami: Miami has a tropical monsoon climate with hot and humid summers and short, warm winters.

Skylights can result in undesirable solar heat gain in summer and heat loss in winter if it is not designed appropriately. Designing and selecting the appropriate skylight based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

As a rule of thumb, the size of skylight shouldn’t be more than 5% of floor area with many windows and no more than 15% for spaces with few windows.

Placing the skylight on the roof is important in order to optimize performance. Skylights which are oriented north present constant but cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Skylights oriented west allow afternoon sunlight and heat gain. Skylights oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for skylight design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. Solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing heat gain from the sun, thus lowering cooling loads during the summer.

The slope of skylights also affects solar heat gain through skylights. A low slope allows more solar heat gain in the summertime and less sunlight in the wintertime. The geographical latitude plus 5 to 10° can provide an appropriate slope base on different locations.

In hot climates, glazing with a very low SHGC coefficient (lower than 0.3) is critical in order to avoid solar heat gains. Additionally, using a lot of insulation around the skylight and the skylight shaft prevents heat transfer from outside to inside. Applying protrusion elements and architectural features on the roof like chimney can prevent overheating due to direct sunlight. Installing skylights in the shade of deciduous, trees or adding movable window coverings can also help control solar heat gain.

References:

2A_Houston: Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

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References:


**2B_ Phoenix:** Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.

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3A_Atlanta: Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

Skylights can result in undesirable solar heat gain in summer and heat loss in winter if it is not designed appropriately. Designing and selecting the appropriate skylight based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

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In warm climates, glazing with a very low SHGC coefficient (lower than 0.3) is critical in order to avoid solar heat gains. Additionally, using a lot of insulation around the skylight and the skylight shaft prevents heat transfer from outside to inside. Applying protrusion elements and architectural features on the roof like chimney can prevent overheating due to direct sunlight. Installing skylights in the shade of deciduous, trees or adding movable window coverings can also help control solar heat gain.
3B_Coast_Los_Angeles: This climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall—with a dry summer and a winter rainy season—but relatively modest transitions in temperature.

Skylights can result in undesirable solar heat gain in summer and heat loss in winter if it is not designed appropriately. Designing and selecting the appropriate skylight based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

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References:


3b_Las Vegas: Climate Zone 3B includes areas of the United States with a characteristically dry climate.

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References:


3C_San Francisco: Climate Zone 3C includes areas of the United States with a characteristically marine climate.

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References:

4A_ Baltimore: Climate Zone 4A includes areas of the United States with a characteristically moist climate.

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References:


4B_ Albuquerque: Climate Zone 4B includes areas of the United States with a characteristically dry climate.

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References:


Climate Zone 4C includes areas of the United States with a characteristically marine climate. Skylights can result in undesirable solar heat gain in summer and heat loss in winter if it is not designed appropriately. Designing and selecting the appropriate skylight based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

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References:

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Water accumulation and ice dams are common problems of skylights in cold climates. Applying flashing and underlayment is important in this condition.

Proper insulation of the skylight shaft and rough opening area also prevents heat transfer from inside to outside. Applying appropriate glazing (very low U-factor, lower than 0.3) can significantly decrease heat loss through skylights.

Protecting the skylight from wind or snow is critical in cold conditions. In order to avoid snow accumulation, the skylight should be placed far enough from walls, chimneys and other protruding elements on the roof. Creating a saddle (a small roof-built above the skylight) may help snow accumulation problems, however it can create other problems.

References:


**5B_Denver:** Climate Zone 5B includes areas of the United States with a characteristically dry climate.

Skylights can result in undesirable solar heat gain in summer and heat loss in winter if it is not designed appropriately. Designing and selecting the appropriate skylight based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

As a rule of thumb, the size of skylight shouldn’t be more than 5% of floor area with many windows and no more than 15% for spaces with few windows.

Placing the skylight on the roof is important in order to optimize performance. Skylights which are oriented north present constant but cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Skylights oriented west allow afternoon sunlight and heat gain. Skylights oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for skylight design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. Solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing heat gain from the sun, thus lowering cooling loads during the summer.

The slope of skylights also affects solar heat gain through skylights. A low slope allows more solar heat gain in the summertime and less sunlight in the wintertime. The geographical latitude plus 5 to 10° can provide an appropriate slope base on different locations.

Water accumulation and ice dams are common problems of skylights in cold climates. Applying flashing and underlayment is important in this condition.

Proper insulation of the skylight shaft and rough opening area also prevents heat transfer from inside to outside. Applying appropriate glazing (very low U-factor, lower than 0.3) can significantly decrease heat loss through skylights.

Protecting the skylight from wind or snow is critical in cold conditions. In order to avoid snow accumulation, the skylight should be placed far enough from walls, chimneys and other protruding elements on the roof. Creating a saddle (a small roof-built above the skylight) may help snow accumulation problems, however it can create other problems.

**References:**

4.4.2.3.2 Climate zone 6, 7, 8:
Skylights can result in undesirable solar heat gain in summer and heat loss in winter if it is not designed appropriately. Designing and selecting the appropriate skylight based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

As a rule of thumb, the size of skylight shouldn’t be more than 5% of floor area with many windows and no more than 15% for spaces with few windows.

Placing the skylight on the roof is important in order to optimize performance. Skylights which are oriented north present constant but cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Skylights oriented west allow afternoon sunlight and heat gain. Skylights oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

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The slope of skylights also affects solar heat gain through skylights. A low slope allows more solar heat gain in the summertime and less sunlight in the wintertime. The geographical latitude plus 5 to 10º can provide an appropriate slope base on different locations.

Water accumulation and ice dams are common problems of skylights in cold climates. Applying flashing and underlayment is important in this condition.

Proper insulation of the skylight shaft and rough opening area also prevents heat transfer from inside to outside. Applying appropriate glazing (very low U-factor, lower than 0.3) can significantly decrease heat loss through skylights.

Protecting the skylight from wind or snow is critical in cold conditions. In order to avoid snow accumulation, the skylight should be placed far enough from walls, chimneys and other protruding elements on the roof. Creating a saddle (a small roof-built above the skylight) may help snow accumulation problems, however it can create other problems.
4.4.2.4 LIGHT PIPE

4.4.2.4.1 General Information

Light pipes are used to transport light from the source to another location with minimum loss of light. Light pipes distribute light over their entire length, or are designed in such a way that the light is transported so that leakage occurs only at the point where the light is to be used.

A light pipe system is made up of three parts: light collection (skylight dome), light transport (reflective tube), and light distribution (diffuser assembly).
The entrance point for natural light in a light pipe is generally a cupola or dome that collects light through glass or direct exposure to the sun. Directional collectors or reflectors then gather the light and send it through the tube.

Light loss is proportional to the length-to-width ratio of the pipe.

References:


Light pipe components
(Source: https://basc.pnnl.gov/images)
4.4.2.4.3 Advantages:
Light pipes improve indoor light quality by providing uniform daylight without excessive glare. They have high energy saving potential, and are energy efficient due to very little heat loss or gain. They can be used in underground structures with no access to light, and are easier and less costly to install than skylights and windows.

References:

Light pipe maintenance
4.4.2.4.4 Disadvantages:
Light pipe tubes must be protected from dust and rain, and can post maintenance issues. Since transmitted light can vary throughout the day, light pipes may need to be supplemented by an artificial light source. A light pipe only delivers as much light energy as it collects outside the building. A large portion of entering light may be lost through reflection, so short and straight tubes are most efficient. Condensation can also form on the light tubes in humid areas.

References:

Codes and Standards:

IECC, 2012:

**Solar Heat Gain Coefficient (SHGC), (Page C-10):** The ratio of the solar heat gain entering the space through the fenestration assembly to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted or convected into the space.

**Section C303.1.3: Fenestration product rating, (Page C-26):** U-factor of fenestration products (windows, doors and skylights) shall be determined in accordance with NRFC 100* by an accredited, independent laboratory, and labeled and certified by the manufacturer. Product lacking such labeled U-factor shall be assigned a default U-factor from table C303.1.3 (1).

**Table C303.1.3 (1): Default glazed fenestration U-factor**
Section C303.1.3: Fenestration product rating, C-26: The solar heat gain coefficient (SHGC) and visible transmittance (VT) of glazed fenestration products shall be determined in accordance with NFRC 200** by an accredited, independent laboratory, and labeled and certified by the manufacturer. Products lacing such a labeled SHGC or VT shall be assigned a default SHGC or VT from Table C303.1.3 (3).

Table C303.1.3 (3) is related to default glazed fenestration SHGC and VT.

<table>
<thead>
<tr>
<th>FRAME TYPE</th>
<th>SINGLE PANE</th>
<th>DOUBLE PANE</th>
<th>SKYLIGHT Single</th>
<th>SKYLIGHT Double</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>1.20</td>
<td>0.80</td>
<td>2.00</td>
<td>1.30</td>
</tr>
<tr>
<td>Metal with Thermal Break</td>
<td>1.10</td>
<td>0.65</td>
<td>1.90</td>
<td>1.10</td>
</tr>
<tr>
<td>Nonmetal or Metal Clad</td>
<td>0.95</td>
<td>0.55</td>
<td>1.75</td>
<td>1.05</td>
</tr>
<tr>
<td>Glazed Block</td>
<td></td>
<td></td>
<td>0.60</td>
<td></td>
</tr>
</tbody>
</table>

** NFRC 200: Procedure for Determining Fenestration Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incidence, Website: www.nfrc.org

Section C402.3.1.2, Increased skylight area with daylighting controls, (Page C-33): The skylight area shall be permitted to be a maximum of 5% of the roof area provided automatic daylighting controls are installed in daylight zones under skylights.

C402.3.2 Minimum skylight fenestration area, (Page C-33): In an enclosed space greater than 10,000 square feet (929 m²), directly under a roof with ceiling heights greater than 15 feet (4.572 m), and used as an office, lobby, atrium, concourse, corridor, automotive service, manufacturing, non-refrigerated warehouse, retail store, distribution/storing area, transportation, or workshop, the total daylight zone under skylights shall be not less than half the floor area and shall provide a minimum skylight area to daylight zone under skylights of either:
- not less than 3% with skylight VT of at least 04; or
- provide a minimum skylight effective aperture of at least 1% determined in accordance with equation C4-1.

(Equation C4-1:

\[
Skylight \text{ Effective aperture} = \frac{0.85 \times Skylight area \times skylight VT \times WF}{\text{daylight zone under skylight}}
\]

*Skylight area:* Total fenestration area of skylights,

Skylight VT = Area weighted average visible transmittance of skylights

WF = Area weighted average well factor, where well factor is 0.9 if light well depth is less than 2 feet (610 mm), or 0.7 if light well depth is 2 feet (610 mm) or greater.

Light well depth = Measure vertically from the underside of the lowest point of skylight glazing to the ceiling plane under the skylight.

**Exception:** Skylights above daylight zones of enclosed spaces are not required in:

1 - Building in climate zones 6 through 8

2 - Spaces where the designed general lighting power densities are less than 0.5 W/ft² (5.4 W/m²)

3 - Areas where it is documented that existing structures or natural objects block direct beam sunlight on at least half of the roof over the enclosed area for more than 1,500 daytime hours per year between 8 AM and 4 PM.

4 - Spaces where the daylight zones under rooftop monitors is greater than 50% of the enclosed space floor area.

Section C402.3.2.1, (Page C-34): Lighting controls in daylight zones under skylights. All lighting in the daylight zone shall be controlled by multilevel lighting controls that comply with section C405.2.2.3.3.

**Exception:** Skylights above daylight zones of enclosed spaces are not required in:

1 - Building in climate zones 6 through 8.

2 - Spaces where the designed general lighting power densities are less than 0.5 W/ft² (5.4 W/m²)

3 - Areas where it is documented that existing structures or natural objects block direct beam sunlight on at least half of the roof over the enclosed area for more than 1,500 daytime hours per year between 8 am and 4 pm.
4 - Spaces where the daylight zone under rooftop monitor is greater than 50% of the enclosed space floor area.

**C402.3.2.2 Haze factor**, *(Page C-34):* Skylights in office, storage, automotive service, manufacturing, non-refrigerated warehouse, retail store, and distribution/storing area spaces shall have a glazing material or diffuser with a measured haze factor greater than 90% when tested in accordance with ASTM 1003.

*Exception:* Skylights designed to exclude direct sunlight entering the occupied space by the use of fixed or automated baffles, or the geometry of skylight and light well need not comply with Section C402.3.2.2.

**Section C402.3.3, Maximum U-factor and SHGC, (Page C-34):** For skylights, the maximum U-factor and solar heat gain coefficient (SHGC) shall be as specified in Table C402.3.

**Table C402.3: Building envelope requirements: fenestration (Page C-33):**

<table>
<thead>
<tr>
<th>Skylight</th>
<th>U-factor</th>
<th>SHGC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.75</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>0.65</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>0.55</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>NR</td>
</tr>
<tr>
<td></td>
<td>0.50</td>
<td>NR</td>
</tr>
</tbody>
</table>

NR: No requirement

**4.4.2.4.5 ASHRAE 90.1, 2010:**

**Top lighting, (page 19):** lighting building interiors with daylight admitted through fenestration located on the roof such as skylights and rooftop monitors

**Daylight area, under skylight (Page 6):** The daylight area under skylights is the combined daylight area under each skylight without double counting overlapping areas. The daylight area under each skylight is bounded by the opening beneath the skylight, plus horizontally in each direction, the smallest of (see figure 3.1):

1. 70% of the ceiling height (0.7 × CH), or
2. The distance to any primary sidelighted area, or the daylight area under rooftop monitors, or
3. The distance to the front face of any vertical obstruction where any part of the obstruction is farther away than 70% of the distance between the top of the obstruction and the ceiling (0.7 × [CH–OH]), where CH = the height of the ceiling at the lowest edge of the skylight, and OH = the height to the top of the obstruction.
Skylight, (page 10): a fenestration surface having a slope of less than 60° from the horizontal plane. Other fenestration, even if mounted on the roof of a building, is considered vertical fenestration. The total skylight area shall not exceed 5% of the gross roof area.

Skylight Effective Aperture, (page 17): 0.85*skylight area* skylight VT*WF/ daylight zone under skylight

Where:

Skylight area = total fenestration area of skylights

Skylight VT = area weighted average visible transmittance of skylights as determined in accordance with Section 5.8.2.6.

Section 5.8.2.6 Visible Transmittance, (Page 38): VT shall be determined in accordance with NFRC 200. VT shall be verified and certified by the manufacturer.

Exception: For skylights whose transmittances are not within the scope of NFRC 200, their transmittance shall be the solar photometric transmittance of the skylight glazing material(s) determined in accordance with ASTM E972.

WF = area weighted average well factor, where well factor is 0.9 if light well depth is less than 2 ft, or 0.7 if light well depth is 2 ft or greater.
Light well depth is measured vertically from the underside of the lowest point on the skylight glazing to the ceiling plane under the skylight.

**Skylight well:** the shaft from the skylight to the ceiling.

**Section 5.5.4.2.2 Maximum Skylight Fenestration Area, (page 35):** The total skylight area shall not exceed 5% of the gross roof area.

**Section 5.5.4.2.3 Minimum Skylight Fenestration Area, (page 35):** In any enclosed space in a building that is four stories or less and that is:

- a. 5,000 ft² and greater and,
- b. directly under a roof with ceiling heights greater than 15 ft, and
- c. one of the following space types: office, lobby, atrium, concourse, corridor, non-refrigerated warehouse or storage, gymnasium/exercise center, convention center, automotive service, manufacturing, retail, distribution/sorting area, transportation, or workshop,

the total daylight area under skylights shall be a minimum of half the floor area and either:

- d. provide a minimum skylight area to daylight area under skylights of 3% with a skylight VT of at least 0.40 or
- e. provide a minimum skylight effective aperture of at least 1%.

These skylights shall have a glazing material or diffuser with a measured haze value* greater than 90% when tested according to ASTM D1003. General lighting in the daylight area shall be controlled as described in Section 9.4.1.5.

**Exceptions to 5.5.4.2.3, page 35:**

- b. Enclosed spaces with designed general lighting power densities less than 0.5 W/ft².
- c. Enclosed spaces where it is documented that existing structures or natural objects block direct beam sunlight on at least half of the roof over the enclosed space for more than 1,500 daytime hours per year between 8 AM and 4 PM.
- d. Enclosed spaces where the daylight area under rooftop monitors is greater than 50% of the enclosed space floor area.
- e. Enclosed spaces where it is documented that 90% of the skylight area is shaded on June 21 in the Northern Hemisphere (December 21 in the Southern Hemisphere) at noon by permanent architectural features of the building.
- f. The required daylight area under skylights may be reduced by the amount of primary sidelighted area with a sidelighting effective aperture greater than 0.15 and with general lighting controlled as described in Section 9.4.1.3 without the use of any exceptions in Section 9.4.1.3.
g. The required daylight area under skylights may be reduced by the amount of secondary sidelighted area with a sidelighting effective aperture greater than 0.30 and with general lighting controlled by continuous daylight dimming.

**Solar heat gain coefficient (SHGC), (page 17):** The ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted, or convected into the space. (See fenestration area.)

**U-factor (thermal transmittance), (page 19):** Heat transmission in unit of time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on each side. Units of U are BTU/h·ft²·°F.

**Section 5.8.2.4, U-factor (Page 37):** U-factor for skylights shall be determined for a slope of 20° above horizontal.

**Section 5.5.4.4.2 SHGC of Skylights, page 36:** Skylights shall have an SHGC not greater than that specified for “all” orientations in Table 5.5.1 through 5.5.8 (Building envelope requirements for different climates) for appropriate total skylight area.

**Exception:** Skylights are exempt from SHGC requirements provided they:

a. Have a glazing material or diffuser with a measured haze value greater than 90% when tested according to ASTMD1003.

b. Have a skylight VT greater than 0.40, and;

c. Have all general lighting in the daylight area under skylight controlled by multilevel photocontrols in accordance with section 9.4.1.5.

d. For dynamic glazing, the minimum SHGC shall be used to demonstrate compliance with this section. Dynamic glazing shall be considered separately from other vertical fenestration, and area weighted averaging with other vertical fenestration that is not dynamic glazing shall not be permitted.

**Section 9.4.1.5, page 77:** Automatic Daylighting Controls for Top lighting:

When the total daylight area under skylights plus the total daylight area under rooftop monitors in an enclosed space exceeds 900 ft², the lamps for general lighting in the daylight area shall be separately controlled by at least one multilevel photocontrol (including continuous dimming devices) having the following characteristics:

a. The light sensor for the photocontrol shall be remote from where calibration adjustments are made,

b. The calibration adjustments shall be readily accessible, and
c. The multilevel photocontrol shall reduce electric lighting in response to available daylight with at least one control step that is between 50% and 70% of design lighting power and another control step that is no greater than 35% of design power.

Exceptions:

a. Daylighted areas under skylights where it is documented that existing adjacent structures or natural objects block direct beam sunlight for more than 1500 daytime hours per year between 8 a.m. and 4 p.m.

b. Daylighted areas where the skylight effective aperture (EA) is less than 0.006 (0.6%).

c. Buildings in climate zone 8 with daylight areas totaling less than 1,500 ft\(^2\) in an enclosed space.

Section 5.8.2.4, U-factor (page 37): U-factor shall be determined in accordance with NFRC 100.

U-factor for skylight shall be determined for a slope of 20\(^\circ\) above horizontal.

Exception:

a. U-factor from section A8.1 shall be an acceptable alternative for determining compliance with the U-factor criteria for skylights. Where credit is being taken for a low-emissivity coating, the emissivity of the coating shall be determined in accordance with NFRC 300. Emissivity shall be verified and certified by the manufacturer.

b. U-factors from Section A8.2 shall be an acceptable alternative for determining compliance with the U-factor criteria for vertical fenestration.

c. U-factors from Section A7 shall be an acceptable alternative for determining compliance with the U-factor criteria for opaque doors.

d. For garage doors, ANSI/DASMA105 shall be an acceptable alternative for determining U-factors.

Below is a normative appendix and is part of this standard.

**Normative Appendix A: Rated R-value of Insulation and Assembly U-factor, C-factor, and F-factor.**

**A8.1 Unlabeled Skylights, (page 125):** Unlabeled skylights shall be assigned the U-factors in Table A8.1A (Assembly U-factor for Unlabeled Skylights) and are allowed to use the SHGCs and VTs in Table A8.1B (Assembly SHGC and VTs for unlabeled Skylights). The metal with thermal break frame category shall not be used unless all frame members have a thermal break equal to or greater than 0.25 inch.
Table A8.1A Assembly U-factor for unlabeled skylights, (Page 126):

<table>
<thead>
<tr>
<th>Frame Type</th>
<th>Unlabeled Skylight with Curb</th>
<th>Unlabeled Skylight without Curb</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>Sloped Installation</td>
<td>(Includes glass/plastic, flat/domed, fixed/operable)</td>
</tr>
<tr>
<td></td>
<td>Aluminum without Thermal Break</td>
<td>Aluminum with Thermal Break</td>
</tr>
<tr>
<td>1</td>
<td>1/8 in. glass</td>
<td>1.98</td>
</tr>
<tr>
<td>2</td>
<td>1/4 in. acrylic/polycarb</td>
<td>1.82</td>
</tr>
<tr>
<td>3</td>
<td>1/8 in. acrylic/polycarb</td>
<td>1.90</td>
</tr>
<tr>
<td>4</td>
<td>Single Glazing</td>
<td>1.31</td>
</tr>
<tr>
<td>5</td>
<td>1/4 in. airspace</td>
<td>1.30</td>
</tr>
<tr>
<td>6</td>
<td>1/2 in. airspace</td>
<td>1.27</td>
</tr>
<tr>
<td>7</td>
<td>1/2 in. argon space</td>
<td>1.27</td>
</tr>
<tr>
<td>8</td>
<td>Double Glazing</td>
<td>1.27</td>
</tr>
<tr>
<td>9</td>
<td>1/4 in. airspace</td>
<td>1.27</td>
</tr>
<tr>
<td>10</td>
<td>1/4 in. argon space</td>
<td>1.23</td>
</tr>
<tr>
<td>11</td>
<td>1/2 in. argon space</td>
<td>1.23</td>
</tr>
<tr>
<td>12</td>
<td>Double Glazing, e = 0.60 on surface 2 or 3</td>
<td>1.25</td>
</tr>
<tr>
<td>13</td>
<td>1/2 in. airspace</td>
<td>1.24</td>
</tr>
<tr>
<td>14</td>
<td>1/4 in. argon space</td>
<td>1.18</td>
</tr>
<tr>
<td>15</td>
<td>1/2 in. argon space</td>
<td>1.20</td>
</tr>
<tr>
<td>16</td>
<td>Double Glazing, e = 0.20 on surface 2 or 3</td>
<td>1.20</td>
</tr>
<tr>
<td>17</td>
<td>1/2 in. airspace</td>
<td>1.20</td>
</tr>
<tr>
<td>18</td>
<td>1/4 in. argon space</td>
<td>1.14</td>
</tr>
<tr>
<td>19</td>
<td>1/2 in. argon space</td>
<td>1.15</td>
</tr>
</tbody>
</table>
C1.3 For Fenestration, (Page 145): The classification, area, U-factor, SHGC, VT, overhang PF for vertical fenestration, and width, depth, and height for skylight wells shall be specified. (See Figure C1.3 for definition of width, depth, and height for skylight wells.) Each fenestration element is associated with a surface (defined in Section C1.2) and has the orientation of that surface. For dynamic glazing, the SHGC and VT shall be equal to that determined in accordance with C3.5 for the base envelope design.
C3. BASE ENVELOPE DESIGN AND PROPOSED DESIGN SPECIFICATION, (PAGE 145):

C3.4 For enclosed spaces required to comply with Section 5.5.4.2.3, the skylight area in the base envelope design shall be 3% of the roof area of that enclosed space. For enclosed spaces required to comply with Section 5.5.4.2.3, the total daylight area under skylights in both the base envelope design and the proposed envelope design shall be a minimum of half the floor area.

For all other spaces the skylight area of each space category in the base envelope design shall be the same as the proposed envelope design or 5% of the gross roof area, whichever is less. This distribution of skylights among space conditioning categories shall be the same as the proposed design. If the skylight area of any space category is greater than 5% of the gross roof area of that space-conditioning category, then the area of each skylight shall be reduced in the base envelope design by the same percentage so that the total skylight area is exactly equal to 5% of the gross roof area.

C4. ZONING AND BUILDING GEOMETRY (Page 146):

C4.5 Skylights shall be assigned to the interior zone of the space-conditioning category. If the skylight area is larger than the roof area of the interior zone, then the skylight area in the interior zone shall be equal to the roof area in the interior zone and the remaining skylight area shall be prorated among the perimeter zones based on floor area.

Table C3.5 VT Factor for the base envelope design (Page 146):

<table>
<thead>
<tr>
<th>Climate Bin</th>
<th>Vertical Fenestration</th>
<th>Glass Skylights</th>
<th>Plastic Skylights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(A, B)</td>
<td>1.00</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>2(A, B)</td>
<td>1.00</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>3(C)</td>
<td>1.00</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>3(A, B)</td>
<td>1.27</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>4(A, B, C)</td>
<td>1.27</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>5(A, B, C)</td>
<td>1.27</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>6(A, B)</td>
<td>1.27</td>
<td>1.27</td>
<td>1.20</td>
</tr>
<tr>
<td>7</td>
<td>1.00</td>
<td>1.00</td>
<td>1.20</td>
</tr>
<tr>
<td>8</td>
<td>1.00</td>
<td>1.00</td>
<td>1.20</td>
</tr>
</tbody>
</table>
C6.9 Skylights in the Exterior Building Envelope (Page 150): HEAT and COOL shall be calculated for skylights in nonresidential conditioned and residential conditioned zones using Equations C-17 and C-18:

\[
\text{HEAT} = \text{Area} \times \text{HDD65} \times \left( H_2 \times U_{sky} + H_3 \times \text{SHGC} / 0.86 \right)
\]

\[
\text{COOL} = \text{Area} \times C_2 \times \text{CDD50} \times \text{SHGC} / 0.86
\]

where

\[\text{Area} = \text{fenestration area of the skylight assembly}\]
\[\text{SHGC} = \text{the solar heat gain coefficient of the skylight assembly}\]
\[U_{sky} = \text{U-factor of skylight assembly}\]

The coefficients used in the equations depend on the space type and shall be taken from Table C6.9:

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Nonresidential</th>
<th>Residential</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_2$</td>
<td>1.09E-02</td>
<td>1.64E-02</td>
</tr>
<tr>
<td>$H_2$</td>
<td>2.12E-04</td>
<td>2.91E-04</td>
</tr>
<tr>
<td>$H_3$</td>
<td>-1.68E-04</td>
<td>-2.96E-04</td>
</tr>
</tbody>
</table>
SKYLIGHTS AND SLOPED GLAZING, (Page 2-17): Glass or other transparent glazing material installed at a slope of less than 60° (1.05 rad) from horizontal. Glazing material in skylights, including unit skylights, tubular daylighting devices, solariums, sunrooms, roofs and sloped walls, are included in this definition.

This definition is coordinated with ASHRAE 90.1 and California’s Title 24 definitions. However, it is not coordinated with the IECC and IBC* definitions, which indicate 15° or more from vertical. Also see the commentary to the definition of “unit skylight” (“Skylight, unit”).

SKYLIGHT, UNIT, (Page 2-17): A factory-assembled, glazed fenestration unit, containing one panel of glazing material that allows for natural lighting through an opening in the roof assembly while preserving the weather-resistant barrier of the roof.

A skylight is a glazed opening in a roof to admit daylight. Skylights are often the only method of bringing natural light into an interior, enclosed area. Unfortunately, these fixtures often do their job too well.

Installing too many skylights or those too large for the room can lead to overheating during warm-weather months. Also choosing the most energy-efficient models can compromise light transmission—the reason people buy skylights in the first place.

2-17:

- Skylights are available in a variety of sizes and shapes, though rectangular units are the most common. Although most skylights are fixed or inoperable, others can be opened and shut like a window or have hidden ventilating systems. Large operable skylights designed for the sloping ceilings of attic rooms are even marketed as “roof windows.”

- These approaches help cool the room in warm weather by venting hot air. The IBC requires either tempered or laminated glass in many skylights. Both types are designed to stand up to snow loads and provide protection against falling objects. **Tempered glass** breaks into small pieces, rather than large shards, if damaged. **Laminated glass**, which is fused with a thin layer of plastic, stays in place for added safety if broken. Laminated glass is also better at keeping out sound and is slightly more energy efficient, though also slightly more expensive.

- Skylights may collect little heat during the winter, which is when it is needed most—when the sun is low in the sky. Worse yet, because they’re located where the pressure difference between the inside and outside of the house is greatest, skylights are an easy escape route for heated air. Also, in the summer they can heat up a space quickly—even when it is not needed.

- But these factors can be offset by other features, such as trees or shading devices. Skylights can be used effectively as part of a passive system with proper attention to detail. Skylights can also allow natural light to penetrate deep within building spaces, which vertical glazing seldom can. This can reduce artificial lighting loads significantly and improve human health.
There are positive and negative implications that must be considered in each specific scenario.

- Like windows, skylights offer a variety of energy efficient glazing options, including low-e and tinted glass. Green tints are better than bronze tints for reducing solar heat gain while letting in plenty of visible light. And because skylights usually are not visible from the street, tinted glazing is less likely to affect aesthetics.

- It is important to note that the term “skylight” can also include glazed roofs and sloped walls. This distinction can affect the proper application of the code requirements.

- **U-factor:** To help determine the appropriate U-factor, this definition includes the slope limitation, which is shown. If the slope of the roof is 15° (0.26 rad) or more from the vertical, then the skylight U-factor is appropriate. If the slope is less than 15° (0.26 rad), then the glazing would be considered as a fenestration in a wall.

- **SHGC:** The ratio of solar heat gain entering the space through the fenestration assembly to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted or convected into the space.

- SHGC is expressed as a number between 0 and 1. The lower a window’s SHGC, the less solar heat it transmits.

**608.5 Automatic daylight controls, 6-28:** Daylighting with automated controls is one of the largest energy saving strategies available for new buildings. A variety of studies have shown that major lighting and cooling energy savings can be realized when using daylighting with automated controls. A cited example is a retail store using daylighting provided by skylights.

**8-14:**

- All lighting in the daylight zone must be controlled by multilevel lighting controls as daylighting can save substantial energy. With daylighting, a larger window/skylight area can actually become an energy saving measure as it reduces the need for electric lighting and reduces cooling loads, which more than makes up for thermal losses through the increased fenestration areas. Both the New Buildings Institute and the American Institute of Architects agreed that daylighting can be a major energy-efficient asset provided that electric lighting is reduced when daylight is available. Automated daylight controls are required in order to ensure this energy savings.

- There are exceptions to this section of the code based on the SHGC and U-factor when daylighting controls are used. The most important feature of the skylight is its visible light transmittance. Depending upon the type of space and the lighting system and climate, the optimal energy cost savings frequently occur at skylight areas that are substantially greater than the 3% skylight-to-roof-area ratio limitation in the 2009 IECC.
Section 8.3.4.1, page 32: Minimum Daylight Area by Toplighting

- A minimum of 50% the floor area directly under a roof in spaces with a lighting power density or lighting power allowance greater than 0.5 W/ft² (5W/m²) shall be in the daylight area. Areas that are ratio as shown in Table 8.3.4.1.
- For purposes of compliance with Table 8.3.4.1, the greater of the space lighting power density and the space lighting power allowance shall be used.

<table>
<thead>
<tr>
<th>Lighting Power Density or Lighting Power Allowances in Daylight Area, W/ft² (W/m²)</th>
<th>Minimum Toplighting Area to Daylight Area Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4 W/ft² (14 W/m²) &lt; LPD</td>
<td>3.6%</td>
</tr>
<tr>
<td>1.0 W/ft² (10 W/m²) &lt; LPD &lt; 1.4 W/ft² (14 W/m²)</td>
<td>3.3%</td>
</tr>
<tr>
<td>0.5 W/ft² (5 W/m²) &lt; LPD &lt; 1.0 W/ft² (10 W/m²)</td>
<td>3.0%</td>
</tr>
</tbody>
</table>

Section 8.3.4.2 Skylight characteristics, page 32:

Skylights used to comply with section 8.3.4.1 shall have a glazing material or diffuser that has a measured haze value greater than 90% tested according to ASTMD1003 (not withstanding its scope) or other test method approved by AHJ*.

Exceptions:

1. Skylights with a measured haze value less than or equal to 90% whose combined area does not exceed 5% of the total skylight area.
2. Tubular daylighting devices having a diffuser.
3. Skylights that are capable of preventing direct sunlight from entering the occupied space below the well during occupied hours. This shall be accomplished using one or more of the following:
   e. Orientation
   f. Automated shading or diffusing devices
   g. Diffuser
   h. Fixed internal or external baffles
4. Airline terminals, convention centers, and shopping malls.

AHJ*: Authority having jurisdiction who has the job of approving the electrical materials used in an electrical systems.
4.4.2.4.7  ASHRAE AEDG-50%:
North-facing clerestories are more effective than skylights to bring daylight into the building interior.

4.4.2.4.8  ASHRAE fundamentals, 2009:
Skylight solar heat gain strongly depends on the configuration of the space below or adjacent to (i.e., in sloped applications) the sky-light formed by the skylight curb and any associated light well. Five aspects must be considered:

1) Transmittance and absorbance of the skylight unit
2) Transmitted solar flux that reaches the aperture of the light well
3) Whether that aperture is covered by a diffuser
4) Transmitted solar flux that strikes the walls of the light well
5) Reflectance of the walls of the light well. Data for flat skylights, which may be considered as sloped glazing, are found in Tables 4 and 1.1.

Domed Skylights: Solar and total heat gains for domed skylights can be determined by the same procedure used for windows. Table 11 gives SHGCs for plastic domed skylights at normal incidence (Shutrum and Ozisik 1961). Manufacturers' literature has further details. Given the poorly defined incident angle conditions for domed skylights, it is best to use these values without correction for incident angle, together with the correct (angle-dependent) value of incident solar irradiance. Results should be considered approximate. In the absence of other data, these values may also be used to make estimates for skylights on slanted roofs.

U-factor: Until more conclusive results are available, U-factors for these systems can be estimated by multiplying the site-assembled sloped/overhead glazing values in Table 4 by the ratio of total product surface area (including curbs) to rough opening area. These ratios range from 1.2 to 2.0 for low-slope skylights, 1.4 to 2.1 for pyramid assemblies sloped at 45°, and 1.7 to 2.9 for semicircular barrel vault assemblies.

Physical testing of double-glazed units showed U-factors of 5.74 W/ (m²-K) for a thermally broken aluminum pyramidal skylight and 7.4 W/ (m²-K) for an aluminum-frame half-round barrel vault (both normalized to a rough opening of 2.4 by 2.4 m).

4.4.2.4.9  RoofPoint:
Credit E6 identifies roof-mounted skylights and other daylighting technologies available to supplement artificial lighting within the building and offset non-renewable energy sources.
4.4.2.4.10 **RoofVav:**

An opening in a roof that is permanently covered with a translucent or transparent material.

Skylights are generally inoperable and are provided mainly as a means of admitting light while maintaining the building envelope. They are installed in the plane of the roof and are limited to installations where the slope is less than or equal to 45° from the horizontal. **The vertical component of a saw tooth arrangement shall also be considered a skylight.** Such vertical components shall not exceed 10 ft (3 m) in height.

---

4.4.2.5 **REALITY**

4.4.2.5.1 **Implementation costs:**

The installation of light-pipe is a costly and time-consuming process. The vertical light pipe installed on the roof slab should be protected from water leakage into inside of building. It also should be cleaned frequently in order to avoid accumulating dust on the pipe or the diffuser.

**References:**

* Wai, Kong. et al, Light Pipe In Building, Hong Kong, Retrieved March, 2015 from [http://www.academia.edu/8538229/Light_Pipe_In_Building_Hong_Kong](http://www.academia.edu/8538229/Light_Pipe_In_Building_Hong_Kong)

4.4.2.5.2 **Aesthetics:**

Natural lighting makes a space more visually pleasant. Top lighting is mostly installed for aesthetic or programmatic (i.e., building purpose) reasons rather than an energy saving purpose.

4.4.2.5.3 **Psychological aspects:**

Top lightings are desirable to increase feelings of spaciousness. In general, there is a preference for relatively high vertical luminance.

Occupant’s spirits are raised in an atmosphere with an abundance of light and color. Top lighting add a sense of freedom as an escape from confinement. People who are exposed to natural light are more positive and productive.

**References:**


4.4.2.5.4 Precedent of innovation:
Using light pipes coupled with deflecting panels can enhance the daylighting of multistory buildings. This technology is an appropriate method to enhance natural illumination of deep plans in commercial buildings.

![Light pipe coupled with deflecting panels](source)

References:

4.4.2.6 GENERAL RECOMMENDATIONS:

4.4.2.6.1 Climate Zones (1-8)

**1A_ Miami:** Miami has a tropical monsoon climate with hot and humid summers and short, warm winters.
Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not designed appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

As a rule of thumb, the size of toplighting shouldn’t be more than 5% of floor area with many windows and no more than 15% for spaces with few windows.

Placing the light pipe on the roof is important in order to better performance. North facing light pipes present constant cool illumination. Those facing east present maximum light and solar heat gain in the morning. Those oriented west present afternoon sunlight and heat gain. Those facing south present the highest potential for desirable solar heat gain in the winter than other placements, but provide undesirable heat gain in the summer.

Glazing is another significant factor for designing light pipes in different climates. The lower the glazing U-factor, the more energy-efficient the light pipe. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design; the lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thereby decreasing cooling loads during the summer.

In hot climates, glazing with a very low SHGC coefficient (lower than 0.3) is critical in order to avoid solar heat gains. Additionally, using high level of insulation around the light pipe and shaft light prevent heat transfer from outside to inside. Applying protrusion elements and architectural features on the roof like a chimney can prevent the overheating due to direct sunlight. Installing toplighting in the shade of deciduous trees or adding movable window covering can also control solar heat gain.

References:

2A_Houston: Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.
Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not designed appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

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References:

**2B_Phoenix:** Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.
Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not designed appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

As a rule of thumb, the size of toplighting shouldn’t be more than 5% of floor area with many windows and no more than 15% for spaces with few windows.

Placing the light pipe on the roof is important in order to better performance. North facing light pipes present constant cool illumination. Those facing east present maximum light and solar heat gain in the morning. Those oriented west present afternoon sunlight and heat gain. Those facing south present the highest potential for desirable solar heat gain in the winter than other placements, but provide undesirable heat gain in the summer.

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References:


3A_Atlanta: Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not design appropriately. So, designing and selecting the appropriate one based on climate...
conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

As a rule of thumb, the size of toplighting shouldn’t be more than 5% of floor area with many windows and no more than 15% for spaces with few windows.

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In warm climates, glazing with a very low SHGC coefficient (lower than 0.3) is critical in order to avoid solar heat gains. Additionally, using high level of insulation around the light pipe and shaft light prevent heat transfer from outside to inside. Applying protrusion elements and architectural features on the roof like a chimney can prevent the overheating due to direct sunlight. Installing toplighting in the shade of deciduous trees or adding movable window covering can also control solar heat gain.

References:


3B_Coast_Los_Angeles: This climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall—with a dry summer and a winter rainy season—but relatively modest transitions in temperature.

Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not design appropriately. So, designing and selecting the appropriate one based on climate
conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

As a rule of thumb, the size of toplighting shouldn’t be more than 5% of floor area with many windows and no more than 15% for spaces with few windows.

Placing the light pipe on the roof is important in order to better performance. North facing light pipes present constant cool illumination. Those facing east present maximum light and solar heat gain in the morning. Those oriented west present afternoon sunlight and heat gain. Those facing south present the highest potential for desirable solar heat gain in the winter than other placements, but provide undesirable heat gain in the summer.

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References:


3b_Las Vegas: Climate Zone 3B includes areas of the United States with a characteristically dry climate.

Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not designed appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

As a rule of thumb, the size of toplighting shouldn’t be more than 5% of floor area with many windows and no more than 15% for spaces with few windows.

Placing the light pipe on the roof is important in order to better performance. North facing light pipes present constant cool illumination. Those facing east present maximum light and solar heat gain in the morning. Those oriented west present afternoon sunlight and heat gain. Those facing
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References:

3C_San Francisco: Climate Zone 3C includes areas of the United States with a characteristically marine climate.

Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not design appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

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References:

4A_ Baltimore: Climate Zone 4A includes areas of the United States with a characteristically moist climate.

Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not design appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

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while glazing with a low SHGC rating is more effective at preventing solar heat gain, thereby decreasing cooling loads during the summer.

References:


4B_ Albuquerque: Climate Zone 4B includes areas of the United States with a characteristically dry climate.

Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not design appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

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References:
4C_ Seattle: Climate Zone 4C includes areas of the United States with a characteristically marine climate.

Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not design appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

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References:


**5A. Chicago:** Climate Zone 5A includes areas of the United States with a characteristically moist climate.

Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not design appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

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Water accumulation and ice dams are common problems of toplighting in cold climates. Applying water-tightness strategies is important in this condition.

Proper insulation of shaft light and the rough opening also prevents heat transfer from inside to outside. Applying appropriate glazing (very low U-factor, lower than 0.3) can significantly decrease heat loss through skylight.

Protecting toplighting from wind or snow is critical in cold conditions. In order to avoid snow accumulation, the light pipe should be placed far enough from walls, chimneys and other protrusion elements on the roof. Creating a saddle (a small roof-built) above toplighting may help snow accumulation problem, however it can have other negative consequences.

**References:**


5B_Denver: Climate Zone 5B includes areas of the United States with a characteristically dry climate.

Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not design appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

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Placing the light pipe on the roof is important in order to better performance. North facing light pipes present constant cool illumination. Those facing east present maximum light and solar heat gain in the morning. Those oriented west present afternoon sunlight and heat gain. Those facing south present the highest potential for desirable solar heat gain in the winter than other placements, but provide undesirable heat gain in the summer.

Glazing is other significant factor for designing light pipe in different climates. The lower the glazing U-factor, the more energy-efficient the light pipe. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design; the lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thereby decreasing cooling loads during the summer.

Water accumulation and ice dams are common problems of toplighting in cold climates. Applying water-tightness strategies is important in this condition.

Proper insulation of shaft light and the rough opening also prevents heat transfer from inside to outside. Applying appropriate glazing (very low U-factor, lower than 0.3) can significantly decrease heat loss through skylight.

Protecting toplighting from wind or snow is critical in cold conditions. In order to avoid snow accumulation, the light pipe should be placed far enough from walls, chimneys and other protrusion elements on the roof. Creating a saddle (a small roof-built) above toplighting may help snow accumulation problem, however it can have other negative consequences.

References:

4.4.2.6.2 Climate zone 6, 7, 8:
Toplighting can result in undesirable solar heat gain in summertime and heat loss in wintertime if it is not design appropriately. So, designing and selecting the appropriate one based on climate conditions, can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

As a rule of thumb, the size of toplighting shouldn’t be more than 5% of floor area with many windows and no more than 15% for spaces with few windows.

Placing the light pipe on the roof is important in order to better performance. North facing light pipes present constant cool illumination. Those facing east present maximum light and solar heat gain in the morning. Those oriented west present afternoon sunlight and heat gain. Those facing south present the highest potential for desirable solar heat gain in the winter than other placements, but provide undesirable heat gain in the summer.

Glazing is other significant factor for designing light pipe in different climates. The lower the glazing U-factor, the more energy-efficient the light pipe. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design; the lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thereby decreasing cooling loads during the summer.

Water accumulation and ice dams are common problems of toplighting in cold climates. Applying water-tightness strategies is important in this condition.

Proper insulation of shaft light and the rough opening also prevents heat transfer from inside to outside. Applying appropriate glazing (very low U-factor, lower than 0.3) can significantly decrease heat loss through skylight.

Protecting toplighting from wind or snow is critical in cold conditions. In order to avoid snow accumulation, the light pipe should be placed far enough from walls, chimneys and other protrusion elements on the roof. Creating a saddle (a small roof-built) above toplighting may help snow accumulation problem, however it can have other negative consequences.

References:
4.4.3 ROOF MONITOR AND SAWTOOTH ROOF

4.4.3.1 GENERAL INFORMATION

4.4.3.1.1 Definition:
Roof monitor and sawtooth systems are top-lighting systems formed from extensions of the roof with vertical glazing. In these systems, light is admitted through vertical or sloped fenestrations in the roof. They can be designed to permit sunlight during specific times of the day or of the year, according to building requirements. North-facing and south-facing roof monitors, in the Northern and Southern hemispheres respectively, are the most energy efficient.
References:

The roof monitor windows allow work spaces to be lit almost entirely with daylight
(Source: http://www.aiatopten.org/node/100)

4.4.3.1.2 Advantages:
Via roof monitors and sawtooth systems, users can utilize sunlight during specific times of the day, and receive uniform lighting without glare, using exterior sun control devices that diffuse direct sunlight. Roof monitors have better results even under variable sky conditions, and have the best combined results in terms of lighting and thermal effects. They come with less risk of water leakage
than conventional skylights, and can be designed to have better performance by limiting solar impact through high performance glazing.

References:

4.4.3.1.3 Disadvantages:
For the amount of daylight provided, roof monitors and sawtooth structures are relatively expensive. They have lower life cycle savings and longer payback periods (5-9 years) than skylights. They can be utilized only on top stories or in single story buildings. Orientation is critical but not always feasible, and snow, can end up lodged in these areas. Glare discomfort can occur, as east and west facing roof monitors can create direct beams of sunlight.
References:


4.4.3.2 CODES AND STANDARDS:

4.4.3.2.1 IECC, 2012:

4.4.3.2.2 ASHRAE 90.1, 2010:

4.4.3.2.3 IgCC

4.4.3.2.4 ASHRAE AEDG-50%:

Vertical fenestration Description (Climate Zones: all), (Page 121): Vertical fenestration includes sloped glazing if it has a slope equal to or more than 60° from the horizontal. This means clerestories, roof monitors, and other such fenestration fall in the vertical category.

Chapter 5, How to implement recommendations, (Page 189):

DL22 Roof Monitors (Climate Zones: all) (Page 190): Rooftop monitors are typically the top-lighting strategy best suited for office building applications. The monitor’s vertical glazing delivers excellent quality daylight and delivers it specifically to the monitor’s orientation (which is important for good controlling of the daylight). Roof monitors should not face east or west. South orientation is possible if appropriately sized overhangs are included, but undesired solar heat gain is blocked most effectively when the monitors face north.

Fenestration to floor area ratio (FFR) of rooftop monitors, (Page 191): A 10% fenestration to floor area ratio (FFR) of vertical glazing with a VT in accordance with the values for vertical fenestration in the climate-specific recommendation is sufficient to achieve good quality daylight levels and to
switch off electrical lighting during daytime in all climates. When the monitor faces south, the glazing area is typically 25% less than when it faces north to provide the same amount of daylighting.

Rooftop monitors add volume. In spaces using all-air system environments with a cubic-foot-per-minute rate based on square footage, the added volume should be taken into consideration, as the volume increase can lead to a higher cubic foot per minute rate and incur higher energy consumption.

**Figure 5-39** (DL23) *Rooftop Monitor*

**DL23: Rooftop Monitor Design (Climate Zones: all) (Page 191):** To help reduce conductive gains and losses, the walls and ceilings of the roof monitor should be insulated and should incorporate appropriate insulation barriers. Make sure that the colors used within the monitor are light and comply with the minimum reflectance in Table 5-3. White works best. Darker colors will result in a considerable loss of efficiency.

Also consider acoustic issues. If acoustical ceiling material is used, make sure that the reflectance and the acoustical properties are high. Often, in presenting the reflectance of an acoustical tile, manufacturers will specify the reflectance of the paint. Remember to account for reduced reflectance caused by the fissures in the tile.

**4.4.3.2.5 ASHRAE fundamentals, 2009:**

N\A
4.4.3.2.6 RoofPoint:
N\A

4.4.3.2.7 RoofVav:
N\A

4.4.3.3 REALITY

4.4.3.3.1 Implementation costs:
Roof monitors and sawtooth needs specific custom designed and are more expensive than skylight. Costs for roof monitors range of from $35 to $63 per square foot.

References:

4.4.3.3.2 Aesthetics:
Toplighting make spaces more visually pleasant. Toplighting is mostly installed for aesthetic or programmatic (i.e., building purpose) reasons rather than associated energy savings.

4.4.3.3.3 Psychological aspects:
Toplighting is desirable to increase feelings of spaciousness. In general, there is a preference for relatively high vertical luminance.

Spirits are raised in atmospheres of abundant light and color. Skylights add a sense of freedom and an escape from confinement.

References:
The San Diego children’s museum has a sawtooth roof which features photovoltaic panels that produce nearly half of the building’s electricity demand. North-facing fenestrations provide natural daylight to the building interior. Natural ventilation enters through lower-level fenestrations, and it heats up, rises, and exits through upper-level fenestrations.

**4.4.3.4 GENERAL RECOMMENDATIONS:**

**4.4.3.4.1 Climate Zones (1-8)**

1A. Miami: Miami has a tropical monsoon climate with hot and humid summers and short, warm winters.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.
Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

In hot climates, glazing with a very low SHGC coefficient (lower than 0.3) is critical in order to avoid solar heat gains. Additionally, using a lot of insulation around the roof monitors prevents heat transfer from outside to inside. Applying protrusion elements and architectural features on the roof like chimney can prevent overheating due to direct sunlight. Installing Roof monitors in the shade of deciduous, trees or adding movable window coverings can also help control solar heat gain.

References:

Code recommendation
AEDG, 2010

Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES, (Page 71):

Envelope (Page 72): In these climates the fenestration area, orientation, and shading are paramount, as solar radiation intensities are among the highest in the continental U.S. The goal is to reduce the heat gain through the envelope as much as possible through strategic fenestration and shading placement. Glazing type is usually double-glazed in order to protect the low-e coating in the cavity, to improve solar heat gain coefficient (SHGC), and to decouple the inner and outer faces of glass to reduce the risk of condensation on either side. SHGCs that are intentionally low are recommended—these can be achieved with interlayers or low-e coatings for spectrally selective transmission of sunlight to reduce the heat content while allowing light to enter.

Lighting, (Page 72): Daylighting open office spaces on the north and south sides of the building works well, although the sizes and positions of windows should protect occupants from direct solar heat gain and direct glare. External shading devices will work at the southern façade; however, the choice to use these devices must be considered against the regular influx of storms and hurricanes
through these areas. Internal light shelves with daylight glazing above (high visible transmittance [VT]) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control without the need for external shading devices. As the sun does come north of the east-west line in early morning and late afternoon during the summer months, perpendicular fins may be necessary to reduce solar heat and glare even on northern façades.

2A_Houston: Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

In hot climates, glazing with a very low SHGC coefficient (lower than 0.3) is critical in order to avoid solar heat gains. Additionally, using a lot of insulation around the roof monitors prevents heat transfer from outside to inside. Applying protrusion elements and architectural features on the roof like chimney can prevent overheating due to direct sunlight. Installing Roof monitors in the shade of deciduous, trees or adding movable window coverings can also help control solar heat gain.

References:


➤ Code recommendation

AEDG, 2010

Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES, (Page 71):

Envelope (Page 72): In these climates the fenestration area, orientation, and shading are paramount, as solar radiation intensities are among the highest in the continental U.S. The goal is to reduce the heat gain through the envelope as much as possible through strategic fenestration and shading placement. The glazing type is usually double-glazed in order to protect the low-e coating in the cavity, to improve solar heat gain coefficient (SHGC), and to decouple the inner and outer faces of glass to reduce the risk of condensation on either side. SHGCs that are intentionally low are recommended—these can be achieved with interlayers or low-e coatings for spectrally selective transmission of sunlight to reduce the heat content while allowing light to enter.

Lighting, (Page 72): Daylighting open office spaces on the north and south sides of a building works well, although the sizes and positions of windows should protect occupants from direct solar heat gain and direct glare. External shading devices will work at the southern façade; however, the choice to use these devices must be considered against the regular influx of storms and hurricanes through these areas. Internal light shelves with daylight glazing above (high visible transmittance [VT]) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control without the need for external shading devices. As the sun does come north of the east-west line in early morning and late afternoon during the summer months, perpendicular fins may be necessary to reduce solar heat and glare even on northern façades.

2B_ Phoenix: Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat
gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

In warm climates, glazing with a very low SHGC coefficient (lower than 0.3) is critical in order to avoid solar heat gains. Additionally, using a lot of insulation around the roof monitors prevents heat transfer from outside to inside. Applying protrusion elements and architectural features on the roof like chimney can prevent overheating due to direct sunlight. Installing Roof monitors in the shade of deciduous, trees or adding movable window coverings can also help control solar heat gain.

References:

➢ Code recommendation

AEDG, 2010

Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES:

Envelope, (Page 73): Strategic use of appropriately sized glazing and well-placed shading is highly recommended in order to reduce the influence of sun on the internal comfort and heat gain. Glazing type is usually double glazed in order to protect the low-e coating in the cavity to improve SHGC, and sometimes interpane blinds or prismatic elements are useful to offer shading while bouncing light in a certain direction. SHGCs that are intentionally low are recommended—these can be achieved with interlayers or low-e coatings for spectrally selective transmission of sunlight to reduce the heat content while allowing light to enter.

Lighting, (Page 73): Daylighting open office spaces on the north and south sides of a building works well, although the sizes and positions of windows should protect occupants from direct solar heat gain and direct glare. External shading devices will work at the southern façade; however, the choice to use these devices must be considered against the regular influx of storms and hurricanes through these areas. Internal light shelves with daylight glazing above (high visible transmittance [VT]) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control without the need for external shading devices. As the sun does come north of the east-west line in early morning and late afternoon during the summer
months, perpendicular fins may be necessary to reduce solar heat and glare even on northern façades.

3A_Atlanta: Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

In hot climates, glazing with a very low SHGC coefficient (lower than 0.3) is critical in order to avoid solar heat gains. Additionally, using a lot of insulation around the roof monitors prevents heat transfer from outside to inside. Applying protrusion elements and architectural features on the roof like chimney can prevent overheating due to direct sunlight. Installing Roof monitors in the shade of deciduous, trees or adding movable window coverings can also help control solar heat gain.

References:

Code recommendation

AEDG, 2010
Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES, (Page 71):

Envelope (Page 72): In these climates the fenestration area, orientation, and shading are paramount, as solar radiation intensities are among the highest in the continental U.S. The goal is to reduce the heat gain through the envelope as much as possible through strategic fenestration and shading placement. The glazing type is usually double-glazed in order to protect the low-e coating in the cavity, to improve solar heat gain coefficient (SHGC), and to decouple the inner and outer faces of glass to reduce the risk of condensation on either side. SHGCs that are intentionally low are recommended—these can be achieved with interlayers or low-e coatings for spectrally selective transmission of sunlight to reduce the heat content while allowing light to enter.

Lighting, (Page 72): Daylighting open office spaces on the north and south sides of a building works well, although the sizes and positions of windows should protect occupants from direct solar heat gain and direct glare. External shading devices will work at the southern façade; however, the choice to use these devices must be considered against the regular influx of storms and hurricanes through these areas. Internal light shelves with daylight glazing above (high visible transmittance [VT]) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control without the need for external shading devices. As the sun does come north of the east-west line in early morning and late afternoon during the summer months, perpendicular fins may be necessary to reduce solar heat and glare even on northern façades.

3B_Coast_Los Angeles: This climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall—with a dry summer and a winter rainy season—but relatively modest transitions in temperature.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

References:


➢ Code recommendation

AEDG, 2010

Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES:

Envelope, (Page 73): Strategic use of appropriately sized glazing and well-placed shading is highly recommended in order to reduce the influence of sun on the internal comfort and heat gain. Glazing type is usually double glazed in order to protect the low-e coating in the cavity to improve SHGC, and sometimes interpane blinds or prismatic elements are useful to offer shading while bouncing light in a certain direction. SHGCs that are intentionally low are recommended—these can be achieved with interlayers or low-e coatings for spectrally selective transmission of sunlight to reduce the heat content while allowing light to enter.

Lighting, (Page 73): Daylighting strategies that allow in light (particularly north light) without solar content are highly recommended, as these locations tend to have a high percentage of sunny days that might be exploited. The sizes and positions of windows should protect occupants from direct solar heat gain and glare, as the solar radiation in these areas is quite intense due to the relatively clear skies. External shading devices will work on the southern façade, and internal light shelves with daylight glazing above (high VT) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control. In these southern climates, care must be taken even with north-facing glass, as the sun does come north of the east-west line in early morning and late afternoon during the summer months; perpendicular fins may be necessary to reduce solar heat and glare even on northern façades.

3b_Las Vegas: Climate Zone 3B includes areas of the United States with a characteristically dry climate.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.
North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

In hot climates, glazing with a very low SHGC coefficient (lower than 0.3) is critical in order to avoid solar heat gains. Additionally, using a lot of insulation around the roof monitors prevents heat transfer from outside to inside. Applying protrusion elements and architectural features on the roof like chimney can prevent overheating due to direct sunlight. Installing Roof monitors in the shade of deciduous, trees or adding movable window coverings can also help control solar heat gain.

References:

➤ Code recommendation

AEDG, 2010

Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES:

Envelope, (Page 73): Strategic use of appropriately sized glazing and well-placed shading is highly recommended in order to reduce the influence of sun on the internal comfort and heat gain. Glazing type is usually double glazed in order to protect the low-e coating in the cavity to improve SHGC, and sometimes interpane blinds or prismatic elements are useful to offer shading while bouncing light in a certain direction. SHGCs that are intentionally low are recommended—these can be achieved with interlayers or low-e coatings for spectrally selective transmission of sunlight to reduce the heat content while allowing light to enter.
Daylighting strategies that allow in light (particularly north light) without solar content are highly recommended, as these locations tend to have a high percentage of sunny days that might be exploited. The sizes and positions of windows should protect occupants from direct solar heat gain and glare, as the solar radiation in these areas is quite intense due to the relatively clear skies. External shading devices will work on the southern façade, and internal light shelves with daylight glazing above (high VT) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control. In these southern climates, care must be taken even with north-facing glass, as the sun does come north of the east-west line in early morning and late afternoon during the summer months; perpendicular fins may be necessary to reduce solar heat and glare even on northern façades.

3C_San Francisco: Climate Zone 3C includes areas of the United States with a characteristically marine climate.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

References:


Code recommendation

AEDG, 2010

Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES:

Lighting, (Page 76): Daylighting is welcomed in these climates, as they tend to begin the morning rather gray with hopes of a burn-off. Larger expanses of glass are possible if they are double paned for heating control. Translucent exterior shading is often used in order to minimize the dark overhang of the solid shading and to maximize the amount of light entering the space. Internal or external light shelves with daylight glazing above (high VT) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control.

4A_ Baltimore: Climate Zone 4A includes areas of the United States with a characteristically moist climate.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

References:


❯ Code recommendation

**AEDG, 2010**

**Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES:**

**Envelope, (Page 74):** In these climates the goal is to reduce the heat gain and heat loss through the envelope’s glazing as much as possible through strategic fenestration placement and sizing. Glazing type is usually double glazed in order to protect the low-e coating in the cavity to improve SHGC and to decouple the inner and outer faces of glass to reduce the risk of condensation on either side. SHGCs that are intentionally low are recommended if coupled with a low-e coating to improve U-factors during the winter season. Care must be taken with regard to minimizing infiltration and moisture ingress being driven through the building envelope.

**Lighting, (Page 74):** Daylighting strategies that allow in light (particularly north light) without solar content are highly recommended, as these locations tend to have a high percentage of sunny days that might be exploited. The sizes and positions of windows should protect occupants from direct solar heat gain and glare, as the solar radiation in these areas is quite intense due to the relatively clear skies. External shading devices will work at the southern façade, and light shelves at the east and west can bounce low-angle sun deep into the building footprint. Internal or external light shelves with daylight glazing above (high VT) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control. In these southern climates, care must be taken even with north-facing glass, as the sun does come north of the east-west line in early morning and late afternoon during the summer months; perpendicular fins may be necessary to reduce solar heat and glare even on northern façades.

**4B_ Albuquerque:** Climate Zone 4B includes areas of the United States with a characteristically dry climate.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

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Glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

References:


➤ Code recommendation

AEDG, 2010

Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES:

Envelope, (Page 75): Strategic use of appropriately sized glazing and well-placed shading is highly recommended in order to reduce the influence of sun on the internal comfort and heat gain. Glazing type is usually double glazed in order to protect the low-e coating in the cavity to improve SHGC. SHGCs that are intentionally low are recommended—these can be achieved with interlayers or low-e coatings for spectrally selective transmission of sunlight to reduce the heat content while allowing light to enter.

Lighting, (Page 75): Daylighting strategies that allow in light (particularly north light) without solar content are highly recommended, as these locations tend to have a high percentage of sunny days that might be exploited. The sizes and positions of windows should protect occupants from direct solar heat gain and glare, as the solar radiation in these areas is quite intense due to the relatively clear skies. External shading devices will work at the southern façade, and light shelves at the east and west can bounce low-angle sun deep into the building footprint. Internal or external light shelves with daylight glazing above (high VT) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control. In these southern climates, care must be taken even with north-facing glass, as the sun does come north of the east-west line in early morning and late afternoon during the summer months; perpendicular fins may be necessary to reduce solar heat and glare even on northern façades.
**4C_Sea**: Climate Zone 4C includes areas of the United States with a characteristically marine climate.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

**References:**


➤ **Code recommendation**

**AEDG, 2010**

**Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES:**

**Lighting, (Page 76):** Daylighting is welcomed in these climates, as they tend to begin the morning rather gray with hopes of a burn-off. Larger expanses of glass are possible if they are double paned for heating control. Translucent exterior shading is often used in order to minimize the dark overhang of the solid shading and to maximize the amount of light entering the space. Internal or external light shelves with daylight glazing above (high VT) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control.
**5A_ Chicago:** Climate Zone 5A includes areas of the United States with a characteristically moist climate.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

Water accumulation and ice dams are common problems of toplighting in cold climates. Applying flashing and underlayment is important in this condition.

Proper insulation of the toplighting and rough opening area also prevents heat transfer from inside to outside. Applying appropriate glazing (very low U-factor, lower than 0.3) can significantly decrease heat loss through toplighting.

Protecting the toplighting from wind or snow is critical in cold conditions. In order to avoid snow accumulation, the toplighting should be placed far enough away from walls, chimneys and other protruding elements on the roof. Creating a saddle (a small roof-built above the skylight) may help snow accumulation problems, however it can create negative consequences.

**References:**


Code recommendation

AEDG, 2010

Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES:

Lighting, (Page 77):  Daylighting is welcomed in these climates. Usually there is a significant amount of exposure to clear skies during the longer summer days, and any outdoor light is welcomed in the winter. Larger expanses of glass are possible if they are double pane for heating control; however, special measures must be taken to reduce downdrafts and cold radiant surfaces at the windows. Internal or external light shelves with daylight glazing above (high VT) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control.

5B_Denver:  Climate Zone 5B includes areas of the United States with a characteristically dry climate.

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.

Water accumulation and ice dams are common problems of toplighting in cold climates. Applying flashing and underlayment is important in this condition.

Proper insulation of the toplighting and rough opening area also prevents heat transfer from inside to outside. Applying appropriate glazing (very low U-factor, lower than 0.3) can significantly decrease heat loss through toplighting.

Protecting the toplighting from wind or snow is critical in cold conditions. In order to avoid snow accumulation, the toplighting should be placed far enough from walls, chimneys and other protruding elements on the roof. Creating a saddle (a small roof-built above the skylight) may help snow accumulation problems, however it can create negative consequences.
References:


➤ Code recommendation

AEDG, 2010

Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES:

Lighting, (Page 76-77): Daylighting is welcomed in these climates. Usually there is a significant amount of exposure to clear skies during the longer summer days, and any outdoor light is welcomed in the winter. Larger expanses of glass are possible if they are double pane for heating control; however, special measures must be taken to reduce downdrafts and cold radiant surfaces at the windows. Internal or external light shelves with daylight glazing above (high VT) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control.

Climate zone 6, 7, 8:

Toplighting can result in undesirable solar heat gain in summer and heat loss in winter if designed inappropriately. Designing and selecting the appropriate toplighting based on climate conditions can help to optimize energy efficiency, daylighting, ventilation and thermal comfort of indoor spaces.

North oriented roof monitors present constant cool illumination. Those oriented east present maximum light and solar heat gain in the morning. Roof monitors oriented west allow afternoon sunlight and permit heat gain. Roof monitors oriented south allow the highest potential for desirable solar heat gain in the winter, but also provide undesirable heat gain in the summer.

Glazing is another significant factor for Roof monitors design in different climates; the lower the glazing U-factor, the more energy-efficient the skylight. The solar heat gain coefficient (SHGC) of glazing is very important in passive solar design. The lower the SHGC, the less solar radiation is transmitted. As a result, glazing with a high SHGC rating is more effective for providing solar heat gain in the winter, while glazing with a low SHGC rating is more effective at preventing solar heat gain, thus lowering cooling loads during the summer.
Water accumulation and ice dams are common problems of toplighting in cold climates. Applying flashing and underlayment is important in this condition.

Proper insulation of the toplighting and rough opening area also prevents heat transfer from inside to outside. Applying appropriate glazing (very low U-factor, lower than 0.3) can significantly decrease heat loss through toplighting.

Protecting the toplighting from wind or snow is critical in cold conditions. In order to avoid snow accumulation, the toplighting should be placed far enough from walls, chimneys and other protruding elements on the roof. Creating a saddle (a small roof-built above the skylight) may help snow accumulation problems, however it can create negative consequences.

References:

Code recommendation

AEDG, 2010

Chapter 4, CLIMATE-RELATED DESIGN STRATEGIES:

Lighting, (Page 76-77): Daylighting is welcomed in these climates. Usually there is a significant amount of exposure to clear skies during the longer summer days, and any outdoor light is welcomed in the winter. Larger expanses of glass are possible if they are double pane for heating control; however, special measures must be taken to reduce downdrafts and cold radiant surfaces at the windows. Internal or external light shelves with daylight glazing above (high VT) and view glazing below (low VT), along with horizontal blinds on the view glazing, can maximize daylighting potential and glare control.
4.4.4 EQUIPMENT ALLOCATION

4.4.4.1 HVAC SYSTEMS AND COOLING TOWERS

4.4.4.1.1 General Information

HVAC system allocation
(Source: http://www.rhpinc.net/commercial/)

4.4.4.1.2 Definition:
HVAC systems can be installed on rooftops and maintain interior thermal comfort without an intrusive footprint inside the building. When interior space is limited, a rooftop-installtion strategy is most useful. Weather conditions, appropriate materials, and using flexible products which can be installed in a range of locations for variety applications are some of the criteria which should be considered when installing an HVAC system.

References:

Advantages include increased aesthetics and reduced noise issues. Placing the system on the roof results in less visibility than in other parts of the building, and placing loud equipment on the roof reduces noise volume at ground level.
Building technology on rooftop
(Source: http://www.cse.fraunhofer.org/5cc/building-technology-showcase-media-roof)

4.4.4.1.4 Disadvantages:
Some disadvantages to consider include weight, vibration and water leakage of the HVAC system when installing it on a roof.
4.4.4.2 CODES AND STANDARDS:

4.4.4.2.1 IECC, 2012:
N/A. There is no information about HVAC equipment allocation available in the IECC-2012 version.

4.4.4.2.2 ASHRAE 90.1, 2010:
N/A. There is no information about HVAC equipment allocation available in the ASHRAE 90.1-2010 version.

4.4.4.2.3 IgCC, 2012:
N/A. There is no information about HVAC equipment allocation available in the IgCC, 2012 version.

4.4.4.2.4 ASHRAE AEDG 50%, 2011:
Chapter 3, Integrated Design Strategies, HVAC systems (Page 42):
When low first cost and simplicity are primary concerns, designers tend to select zone-by-zone distributed HVAC systems incorporating both heating and cooling capacity.

This approach tends to be used for smaller buildings or larger buildings with sufficient roof area. Distributed equipment usually consists of a fan, a cooling coil, a compressor, and an outdoor condenser. Examples of distributed systems include packaged rooftop air conditioners and heat pumps as well as refrigerant-based split-system fan-coil units (single or multiunit). Water-source heat pumps (WSHPs) are also distributed systems in that the compressor is located close to the occupied space, but they are served by a centralized water system with auxiliary boilers and heat rejection devices.

Chapter 5, How to Implement Recommendations, EN30 (Page 124):
The sizing of HVAC equipment relies on the SHGC of the glass and shading system only. The glazing of fully shaded windows can be selected with higher SHGC ratings without increasing energy use.

4.4.4.2.5 ASHRAE Fundamentals, 2009:
Consider separate HVAC systems to serve areas expected to operate on widely differing operating schedules or design conditions.
HVAC Equipment Selection:

- To allow HVAC equipment operation at the highest efficiencies, match conversion devices to load increments, and sequence the operation of modules. Oversized or large-scale systems should never serve small seasonal loads (e.g., a large heating boiler serving a summer-service water-heated load). Include specific low-load units and auxiliaries where prolonged use at minimal capacities is expected.

- Select the most efficient (or highest-COP) equipment practical at both design and reduced capacity (partial-load) operating conditions.

- When selecting large-power devices such as chillers (including their auxiliary energy burdens), economic analysis of the complete life-cycle costs should be used. See Chapter 36 of the 2007 ASHRAE Handbook-HVAC Applications for more information on detailed economic analysis.

- Keep fluid temperatures for heating equipment devices as low as practical and for cooling equipment as high as practical, while still meeting loads and minimizing flow quantities.

### 4.4.4.2.6 RoofPoint:

It is assumed that natural-gas fired heating units are used to supply building heat and that an electric air conditioning system is used to supply building cooling. System efficiencies are assumed to be 0.7 for the gas-fired heating units and a COP of 2.0 for the electric air conditioning system.

### 4.4.4.2.7 RoofNav

N/A. There is no information about HVAC equipment allocation available in the RoofNav.

### 4.4.4.3 REALITY

#### 4.4.4.3.1 Implementation costs:

Purchase and installation of comparable roof air conditioners range from $200 to $1,000 more expensive than a roof unit itself. Rooftop units first need to be hauled up the side of the building, and several well trained and harnessed technicians need to work on the roof for the better part of a day to complete the job. Installation atop an additional two or three stories results in more charges for greater safety and property risk.

**References:**

4.4.4.3.2  Aesthetics:
Placing the system on the roof results in less visibility than in other parts of the building, thus minimizing aesthetics issues.

4.4.4.3.3  Psychological aspects:
Advantages include better aesthetics and reduced noise issues. Placing the system on the roof results in less visibility than in other parts of the building, and placing loud equipment on the roof reduces noise volume at ground level.

4.4.4.3.4  Precedents of innovation:
The Advanced Design Rooftop HVAC unit offers improved energy performance compared to a typical commercial rooftop unit by enhancing the performance of individual components and configurations. Standard commercial rooftop HVAC units capture most of the market for this technology. The standard units do not compete in terms of energy efficiency, lifespan, or maintainability; however, they are significantly less expensive.

Rooftop HVAC unit
(Source: http://www.achrnews.com/articles/124204-thybar-corp-vibration-isolation-rooftop-unit-curb)

References:
4.4.4.4 GENERAL RECOMMENDATIONS:

4.4.4.4.1 Climate Zones (1-8)

1A_Miami: Miami has a tropical monsoon climate with hot and humid summers and short, warm winters.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

Many premature failures occur in warm conditions because of the high ambient temperature. These failures can be reduced by applying a light-colored coating, protruding shading elements and architectural features on the roof like a chimney, which prevents overheating due to additional heat from direct sunlight. Installing an HVAC unit in the shade of deciduous trees, or adding movable window coverings, can also help control solar heat gain and increase the efficiency of the system.

References:

2A_Houston: Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

Many premature failures occur in warm conditions because of the high ambient temperature. These failures can be reduced by applying a light-colored coating, protruding shading elements and architectural features on the roof like a chimney, which prevents overheating due to additional heat from direct sunlight. Installing an HVAC unit in the shade of deciduous trees, or adding movable window coverings, can also help control solar heat gain and increase the efficiency of the system.

References:

2B_Phoenix: Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

Many premature failures occur in warm conditions because of the high ambient temperature. These failures can be reduced by applying a light-colored coating, protruding shading elements and architectural features on the roof like a chimney, which prevents overheating due to additional heat from direct sunlight. Installing an HVAC unit in the shade of deciduous trees, or adding movable window coverings, can also help control solar heat gain and increase the efficiency of the system.

References:

3A_Atlanta: Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

Many premature failures occur in warm conditions because of the high ambient temperature. These failures can be reduced by applying a light-colored coating, protruding shading elements and architectural features on the roof like a chimney, which prevents overheating due to additional heat from direct sunlight. Installing an HVAC unit in the shade of deciduous trees, or adding movable window coverings, can also help control solar heat gain and increase the efficiency of the system.

References:
3B_Los Angeles: The climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall but relatively modest transitions in temperature.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

Many premature failures occur in warm conditions because of the high ambient temperature,. These failures can be reduced by applying a light-colored coating, protruding shading elements and architectural features on the roof like a chimney, which prevents overheating due to additional heat from direct sunlight. Installing an HVAC unit in the shade of deciduous trees, or adding movable window coverings, can also help control solar heat gain and increase the efficiency of the system.

References:

3b_Las Vegas: Climate Zone 3B includes areas of the United States with a characteristically dry climate.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

Many premature failures occur in warm conditions because of the high ambient temperature,. These failures can be reduced by applying a light-colored coating, protruding shading elements and architectural features on the roof like a chimney, which prevents overheating due to additional heat from direct sunlight. Installing an HVAC unit in the shade of deciduous trees, or adding movable window coverings, can also help control solar heat gain and increase the efficiency of the system.

References:

3C_San Francisco: Climate Zone 3C includes areas of the United States with a characteristically marine climate.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

References:

4A_Baltimore: Climate Zone 4A includes areas of the United States with a characteristically moist climate.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

References:

4B_Abuquerque: Climate Zone 4B includes areas of the United States with a characteristically dry climate.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

References:
**4C_ Seattle:** Climate Zone 4C includes areas of the United States with a characteristically marine climate.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

**References:**


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**5A_ Chicago:** Climate Zone 5A includes areas of the United States with a characteristically moist climate.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

HVAC systems in very cold climates may have the risk of financial losses and premature mechanical failure due to three issues:

4. Effects of low temperatures on physical characteristics of components  
5. Ice on the structure  
6. Presence of snow on the surface of wind turbine

In order to operate HVAC system in cold weather conditions, these issues need to be considered.

**References:**


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**5B_ Denver:** Climate Zone 5B includes areas of the United States with a characteristically dry climate.
In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

HVAC systems in very cold climates may have the risk of financial losses and premature mechanical failure due to three issues:

1. Effects of low temperatures on physical characteristics of components
2. Ice on the structure
3. Presence of snow on the surface of wind turbine

In order to operate HVAC system in cold weather conditions, these issues need to be considered.

References:


6A_ Minneapolis: Climate Zone 6A includes areas of the United States with a characteristically moist climate.

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

HVAC systems in very cold climates may have the risk of financial losses and premature mechanical failure due to three issues:

1. Effects of low temperatures on physical characteristics of components
2. Ice on the structure
3. Presence of snow on the surface of wind turbine

In order to operate HVAC system in cold weather conditions, these issues need to be considered.

References:
4.4.4.4.2 Climate zones 7-8

In general, installing HVAC units on rooftops, makes it difficult to see or hear mechanical failures. A rooftop unit has to be checked regularly and maintained properly to keep the system in appropriate condition.

HVAC systems in very cold climates may have the risk of financial losses and premature mechanical failure due to three issues:

1. Effects of low temperatures on physical characteristics of components
2. Ice on the structure
3. Presence of snow on the surface of wind turbine

In order to operate HVAC system in cold weather conditions, these issues need to be considered.

References:


4.4.4.5 CODE RECOMMENDATIONS:

4.4.4.5.1 IECC, 2012: N/A

4.4.4.5.2 ASHRAE90.1, 2010: N/A

4.4.4.5.3 IgCC, 2012: Section 408.3 Roof surfaces, (P 4-8): N/A

4.4.4.5.4 ASHRAE AEDG 50% N/A

4.4.4.5.5 RoofPoint N/A

4.4.4.5.6 RoofNav N/A
4.4.5 RAINWATER COLLECTION

4.4.5.1 RAINWATER COLLATION SYSTEMS

4.4.5.1.1 General Information

Rainwater harvesting using Magna-Loc roof panels
(Source: [http://www.metalsales.us.com/commercial/sustainability/rainwater-harvesting#.VSPsX5PeOXc](http://www.metalsales.us.com/commercial/sustainability/rainwater-harvesting#.VSPsX5PeOXc))

4.4.5.1.2 Definition:

Since roofs account for a significant percentage of the impermeable areas covered by cities, there is substantial potential for rainwater collection from them. The application of an appropriate rainwater harvesting technology can utilize the rainwater as a water resource.

Rainwater can be collected from many surfaces, but bare rooftops provide quality rainwater with lower treatment. The net collectable rainwater can be estimated as follows:

\[ \text{Collectable rainwater (gallons)} = 0.5 \times \text{rainfall (inches)} \times \text{area (square feet)} \]

One way for a green building to reduce demand for treated water is to capture rainwater onsite, in either a cistern or some other manmade catchment basin. Drains and drain flashing should be set a minimum of 1\”(25mm) below the roof level and located at least 18\”(46cm) away from all walls.
A typical roof-top Rainwater Harvesting System is comprised of

a) Roof catchment
b) Gutters
c) Downpipes
d) Rain water / Storm water drains
e) Filter chamber
f) Ground water recharge structures like pit, trench, tube well or combination of these structures.

The **four methods used in water harvesting** are:

1- **Barrel**: Installing a barrel under the downspout of the building to store rainwater collected from the roof.
2- **Dry system**: The dry system of rainwater harvesting is the barrel system scaled up in size with larger storage capacity than a barrel. Because the collection pipe dries after each rain, it gets the name dry system.
3- **Wet system**: In wet system the collection pipes are constantly full of water, since they are underground. Various collection pipes are fitted to multiple downspouts and then run underground to a storage tank.
4- **Green roof**: Instead of collecting rainwater in a storage unit for later use, applying a green roof allows rainwater to be used immediately for plants growing on the roof. With a green roof, it is necessary to use a liner to protect the roof and a drainage system for excess runoff is also necessary.

References:


4.4.5.1.3 Advantages:

Environmental advantages include, diminished flooding, erosion, and reduced storm water volume. The physical and chemical properties of rainwater may be superior to groundwater or surface waters, as they may have been subjected to pollution from unknown sources. Costs of rainwater collection are low. The quality of rainwater makes it ideal for irrigation, as it may be free from several kinds of contaminants.

Economically, rainwater collection can help reduce peak demand for water. It also provides an alternative water supply for household activities like laundry, irrigation, car washing, or flushing toilets. The quality of the water can extend equipment life and while improving the engineering of building foundations when built as part of the substructure of the building. The rainwater collection system can be maintained, owned, and managed by the building owner. Construction, operation, and maintenance are not labor-intensive and minimally expensive. It provides a useful water reserve in times of emergency, like natural disasters. Finally, the technology is flexible and can be built to meet almost any requirements.

References:


4.4.5.1.4 Disadvantages:
The success of rainwater harvesting depends upon the frequency and volume of rainfall, which are unreliable. Harvesting is limited by storage capacity, and increased storage capacity increases construction and operating costs. Leakage can cause deterioration of load-bearing slopes. Rainwater collection can reduce revenues to public utilities. Collected rainwater may not be potable, so further costs must be incurred for filtration and/or purification systems.

References:
4.4.5.2 CODES AND STANDARDS:

4.4.5.2.1  IECC, 2012:
N/A. There is no information about rainwater collection available in the IECC-2012 version.

4.4.5.2.2  ASHRAE 90.1, 2010:
N/A. There is no information about rainwater collection available in the ASHRAE 90.1-2010 version.

4.4.5.2.3  IgCC, 2012:
N/A. There is no information about rainwater collection available in the IgCC, 2012 version.

4.4.5.2.4  ASHRAE AEDG 50%, 2011:
N/A. There is no information about rainwater collection available in the ASHRAE AED, 2011 version.

4.4.5.2.5  ASHRAE Fundamentals, 2009:
Building systems’ water use can be reduced by reusing clean water from on-site – such as condensate drain water – or by using less potable water. For example, hybrid cooling towers can operate as water-to-air heat exchangers when run dry, and can operate their water sprays for additional evaporative capacity only when conditions require.

4.4.5.2.6  RoofPoint:
N/A. There is no information about rainwater collection available in the RoofPoint.

4.4.5.2.7  RoofNav
N/A. There is no information about rainwater collection available in the RoofNav.
4.4.5.3 REALITY

4.4.5.3.1 Implementation costs:
In general, the cost of a rainwater collection system as an integrated element of a new project is low. The cost of installing a system onto an existing building is lower due to many of the shared costs (roof and gutters). With careful design, the cost of a rainwater system can be decreased significantly.

A whole rainwater collection system for a typical single-family home will cost about $8,000 to $10,000 not including the roof. The largest cost of the system is the storage tank. The cost of a tank depends on its size and material which can range from $0.5 for fiberglass to more than $4 for a welded steel tank. Professionally installed gutters range from $3.50 to $12 per foot. Pre-filtration equipment ranges from $50 to over $800. Pump costs run from $385 for the low-end pump to more than $1,000 for combined high-end pump and pressure tank.

Additional components like gutters, downspout, roof washers, pumps, and pressure tanks also add to the cost of the system. If the intention of water collection is for drinking, costs for a disinfection system should be added to the total cost.

References:

4.4.5.3.2 Aesthetics:
A rainwater collection storage tank is not aesthetically appealing. So, methods like green roof and wet system, which do not require a tank, are preferred.

4.4.5.3.3 Psychological aspects:
Installing renewable energy systems on a roof increases the environmental awareness of occupants and perceived energy savings, consequently affecting energy consumption behavior.
4.4.5.3.4 Precedents of innovation:

CIRS is a new sustainability center which is built by University of British Columbia (UBC). This building is completely water-self-sufficient, getting all of its potable water through rainwater harvesting system. Rainwater is collected from roof surfaces of the building and then diverted to an underground cistern in order to apply filtering and treatment. The cistern can store a three-month water supply.

4.4.5.4 GENERAL RECOMMENDATIONS:

4.4.5.4.1 Climate Zones (1-8)

**1A_ Miami:** Miami has a tropical monsoon climate with hot, humid summers and short, warm winters.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.
2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.

4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.

6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Rainwater collection systems are prevalent in areas with high annual rainfall. Warm climates provide the opportunity for using large outdoor storage tanks with no concern of freezing issues.

References:


2A_Houston: Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.

2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.
4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.

6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Rainwater collection systems are prevalent in areas with high annual rainfall. Warm climates provide the opportunity for using large outdoor storage tanks with no concern of freezing issues.

References:

2B_Phoenix: Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.

2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.
4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.

6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Rainwater collection systems are very useful in areas with minimal annual rainfall. Warm climates provide the opportunity for using large outdoor storage tanks with no concern of freezing issues.

**References:**


**3A_Atlanta:** Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.

2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.
4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.

6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Rainwater collection systems are prevalent in areas with high annual rainfall. Warm climates provide the opportunity for using large outdoor storage tanks with no concern of freezing issues.

References:


3B_Los Angeles: The climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall but relatively modest transitions in temperature.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.

2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.

4) Collect the rainwater into a tank that is connected to a water filter.
5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.

6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Rainwater collection systems are very useful in areas with minimal annual rainfall. Warm climates provide the opportunity for using large outdoor storage tanks with no concern of freezing issues.

References:


3b_Las Vegas: Climate Zone 3B includes areas of the United States with a characteristically dry climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.

2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.

4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.
6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Rainwater collection systems are very useful in areas with minimal annual rainfall. Warm climates provide the opportunity for using large outdoor storage tanks with no concern of freezing issues.

References:


3C_San Francisco: Climate Zone 3C includes areas of the United States with a characteristically marine climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.

2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.

4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.

6) Use a small air bubbler to keep the water aerobic in the storage tanks.
7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

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The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget. Rainwater collection systems are prevalent in areas with high annual rainfall. Warm climates provide the opportunity for using large outdoor storage tanks with no concern of freezing issues.

References:


**4A_ Baltimore**: Climate Zone 4A includes areas of the United States with a characteristically moist climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.

2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.

4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.

6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

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9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Rainwater collection systems are prevalent in areas with high rate of rain. Warm climates provide the opportunity for using large outdoor storage tanks with no concern of freezing issues.

References:

4B_ Albuquerque: Climate Zone 4B includes areas of the United States with a characteristically dry climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.

2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.

4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.

6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.
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The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Rainwater collection systems are very useful in areas with minimal annual rainfall. Warm climates provide the opportunity for using large outdoor storage tanks with no concern of freezing issues.

References:

4C Seattle: Climate Zone 4C includes areas of the United States with a characteristically marine climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.
2) Do not collect rainwater in the spring pollen season.
3) Use a strainer or some other filtration system to remove leaves and large debris.
4) Collect the rainwater into a tank that is connected to a water filter.
5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.
6) Use a small air bubbler to keep the water aerobic in the storage tanks.
7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.
8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.
9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.
10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.
The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Rainwater collection systems are prevalent in areas with high rate of rain. Warm climates provide the opportunity for using large outdoor storage tanks with no concern of freezing issues.

References:

5A_Chicago: Climate Zone 5A includes areas of the United States with a characteristically moist climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.
2) Do not collect rainwater in the spring pollen season.
3) Use a strainer or some other filtration system to remove leaves and large debris.
4) Collect the rainwater into a tank that is connected to a water filter.
5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.
6) Use a small air bubbler to keep the water aerobic in the storage tanks.
7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.
8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.
9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.
10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank
include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Cold climates create more maintenance concerns for tank, pipes, valves, and other components of the collection system. They need to be inspected more often to check the conditions and potential stress points.

In cold climates, the material used for a storage tank is important. Plastic tanks are prevalent in cold climates. Larger tanks are recommended because water in these takes longer to freeze than that in a small one. A round tank is preferable because it will lose heat more slowly than a rectangular tank with the same volume. Outdoor tanks and lines should be well insulated in order to avoid freezing. Tank roofs should be strong enough to withstand snow loads. A steep angled roof allows the snow to slide off faster. Buried tanks need to be at least four feet below the grade and often need to be protected by a top layer of insulation.

Calculating the quantity of water gained with snow is a consideration for rainwater collection in cold climates. Generally, 3-4 inches of snow will equal to 1 inch of water.

If the system is not used in wintertime, the pipes should be drained and the storage system may be disconnected from the components. Valves should be located in insulated boxes. All pipes should be placed inside the building and as close as possible to the usage place. Pipes must be insulated and heat tape treated inside them or covering them. Heat tape can also be applied to downspouts, gutters, and along roof eves to avoid freezing systems during cold conditions.

References:

5B_Denver: Climate Zone 5B includes areas of the United States with a characteristically dry climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.
2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.

4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.

6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

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Cold climates create more maintenance concerns for tank, pipes, valves, and other components of the collection system. They need to be inspected more often to check the conditions and potential stress points.

In cold climates, the material used for a storage tank is important. Plastic tanks are prevalent in cold climates. Larger tanks are recommended because water in these takes longer to freeze than that in a small one. A round tank is preferable because it will lose heat more slowly than a rectangular tank with the same volume. Outdoor tanks and lines should be well insulated in order to avoid freezing. Tank roofs should be strong enough to withstand snow loads. A steep angled roof allows the snow to slide off faster. Buried tanks need to be at least four feet below the grade and often need to be protected by a top layer of insulation.

Calculating the quantity of water gained with snow is a consideration for rain-water collection in cold climates. Generally, 3-4 inches of snow will equal to 1 inch of water.

If the system is not used in wintertime, the pipes should be drained and the storage system may be disconnected from the components. Valves should be located in insulated boxes. All pipes should be placed inside the building and as close as possible to the usage place. Pipes must be insulated and heat tape treated inside them or covering them. Heat tape can also be applied to downspouts, gutters, and along roof eves to avoid freezing systems during cold conditions.

References:


6A_ Minneapolis: Climate Zone 6A includes areas of the United States with a characteristically moist climate.

Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.

2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.

4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.

6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Cold climates create more maintenance concerns for tank, pipes, valves, and other components of the collection system. They need to be inspected more often to check the conditions and potential stress points.
In cold climates, the material used for a storage tank is important. Plastic tanks are prevalent in cold climates. Larger tanks are recommended because water in these takes longer to freeze than that in a small one. A round tank is preferable because it will lose heat more slowly than a rectangular tank with the same volume. Outdoor tanks and lines should be well insulated in order to avoid freezing. Tank roofs should be strong enough to withstand snow loads. A steep angled roof allows the snow to slide off faster. Buried tanks need to be at least four feet below the grade and often need to be protected by a top layer of insulation.

Calculating the quantity of water gained with snow is a consideration for rain-water collection in cold climates. Generally, 3-4 inches of snow will equal to 1 inch of water.

If the system is not used in wintertime, the pipes should be drained and the storage system may be disconnected from the components. Valves should be located in insulated boxes. All pipes should be placed inside the building and as close as possible to the usage place. Pipes must be insulated and heat tape treated inside them or covering them. Heat tape can also be applied to downspouts, gutters, and along roof eves to avoid freezing systems during cold conditions.

References:

4.4.5.4.2 Climate zones 7-8
Effort is required in order for a rainwater collection system to successfully produce clean and safe water. Some of the important considerations are:

1) Keep the roof, eaves, and troughs as clear as possible.

2) Do not collect rainwater in the spring pollen season.

3) Use a strainer or some other filtration system to remove leaves and large debris.

4) Collect the rainwater into a tank that is connected to a water filter.

5) The water from the filter is stored in a clean water storage tank. Clean water will store for long periods, while dirty water will spoil very quickly.
6) Use a small air bubbler to keep the water aerobic in the storage tanks.

7) Use a whole house cartridge filter rated at 5 microns and UV light leaving the clean water storage tank prior to entering the home.

8) On a regular basis, add bleach to the storage tanks to prevent growth of algae.

9) Clean the water filter monthly, change the UV bulb annually, and clean the roof and troughs every 3 months if possible.

10) Do not rely on cartridge filters to protect your health unless preceded by a water filter.

The most expensive part of a rain-water collection system is the storage tank, which exist in different sizes and types. Important factors for selecting the appropriate size and type of the tank include: climate, location, rate of precipitation, demand, catchment surface area, aesthetical issue, and budget.

Cold climates create more maintenance concerns for tank, pipes, valves, and other components of the collection system. They need to be inspected more often to check the conditions and potential stress points.

In cold climates, the material used for a storage tank is important. Plastic tanks are prevalent in cold climates. Larger tanks are recommended because water in these takes longer to freeze than that in a small one. A round tank is preferable because it will lose heat more slowly than a rectangular tank with the same volume. Outdoor tanks and lines should be well insulated in order to avoid freezing. Tank roofs should be strong enough to withstand snow loads. A steep angled roof allows the snow to slide off faster. Buried tanks need to be at least four feet below the grade and often need to be protected by a top layer of insulation.

Calculating the quantity of water gained with snow is a consideration for rain-water collection in cold climates. Generally, 3-4 inches of snow will equal to 1 inch of water.

If the system is not used in wintertime, the pipes should be drained and the storage system may be disconnected from the components. Valves should be located in insulated boxes. All pipes should be placed inside the building and as close as possible to the usage place. Pipes must be insulated and heat tape treated inside them or covering them. Heat tape can also be applied to downspouts, gutters, and along roof eves to avoid freezing systems during cold conditions.

References:


4.4.5.5 CODE RECOMMENDATIONS:

4.4.5.5.1 IECC, 2012:
N/A

4.4.5.5.2 ASHRAE90.1, 2010:
N/A

4.4.5.5.3 IgCC, 2012:
N/A

4.4.5.5.4 ASHRAE AEDG 50%
N/A

4.4.5.5.5 RoofPoint
N/A

4.4.5.5.6 RoofNav
N/A
4.4.6 WATERPROOFING
4.4.6.1 WATERPROOFING SYSTEMS

4.4.6.1.1 General Information

4.4.6.1.2 Definition:
A waterproofing system is a non-structural way to protect and extend the life of structural components, by protecting the interior from uncontrolled water infiltration. Elements include waterproofing membranes, air- and water-resistant barrier materials, and all building elements outside that system.

According to American Society for Testing and Materials (ASTM) D1079-10, “Waterproofing is treatment of a surface or structure to prevent the passage of water under hydrostatics pressure.” Regarding waterproofing roof design, there are key parameters to consider such as cost effectiveness, light, environmental consequences, installation, and durability.

In general, a waterproofing membrane should withstand the temporary ponding of water on a regular basis.
Common waterproofing membrane systems include:
- Modified bitumen roofing (MBR)
- Waterproof types of single-ply roofing
- Metal roof panels
- Spray polyurethane foam (SPF) roofing
- Liquid-applied (including polyurethane-based and polymer-modified bituminous products) roofing

The roof system should have a waterproof seal along all seams in the roof membrane and in areas where mechanical devices, equipment, or other structures are affixed to the roof surface. The waterproofing system should be attached to the roof surface using adhesives or other methods approved by the manufacturer.

Vapor retardants and barriers decrease moisture concentration through roof structure. A vapor retarder consists of multiple-ply semi-flexible bituminous boards, which offer an economical and straightforward installation waterproofing system for horizontal surfaces. These membranes stop moisture migration in footings, concrete floors and structural slabs.

References:


4.4.6.1.3 Advantages:
An appropriate waterproofing system can protect structure and interior content, as well as extend the lifetime of the structure. It can increase thermal comfort for occupants and protect the interior environment from things like mold. The roof can be protected from further weathering and leaks, cutting waste and the expense of premature roof replacement. Roof coatings that meet energy requirements give the benefits of cool roofing and air-conditioning savings. There is also reduced future maintenance resulting from thermal shock; cooled roofs no longer experience damage from cool rains on hot surfaces, nor the stresses of sudden temperature changes.

References:

4.4.6.1.4 Disadvantages:
The most effective approach for waterproofing is to adopt standard specifications combined with strict quality control.
4.4.6.2 CODES AND STANDARDS:

4.4.6.2.1 IECC, 2012:
N/A. There is no information about rainwater collection available in the IECC-2012 version.

4.4.6.2.2 ASHRAE 90.1, 2010:
N/A. There is no information about rainwater collection available in the ASHRAE 90.1-2010 version.

4.4.6.2.3 IgCC, 2012:
N/A. There is no information about rainwater collection available in the IgCC, 2012 version.

4.4.6.2.4 ASHRAE AEDG 50%, 2011:
Building envelope assemblies should be designed to prevent wetting, high moisture content, liquid water intrusion, and condensation caused by diffusion of water vapor.

4.4.6.2.5 ASHRAE Fundamentals, 2009:
CHAPTER 18
NONRESIDENTIAL COOLING AND HEATING LOAD CALCULATIONS
LATENT HEAT GAIN FROM MOISTURE DIFFUSION (Page 18.15):
Vapor retarder should be specified and installed in the proper location to keep moisture transfer to a minimum, and to minimize condensation within the envelope.

CHAPTER 26
HEAT, AIR, AND MOISTURE CONTROL IN BUILDING ASSEMBLIES—MATERIAL PROPERTIES
Vapor Retarder (Page 26.14):
Water vapor retarders need to be considered in every building design. The need for and type of water vapor retarder used depends on the climate zone, construction type, and building use. Water vapor retarders were designed to protect building elements from water vapor permeating through building materials and then condensing on the interior. It is now recognized that it is just as important to allow the building assembly to dry as it is to keep the building assembly from getting wet. In some cases, to allow the building assembly to dry, a water vapor retarder may not be needed or may need to be semipermeable. In other cases, the environmental conditions, building construction, and building use may dictate that a material with very low water vapor permeability should be installed to protect the building components.

The 2007 supplement to the International Codes now lists three water vapor retarder classes:

- **Class I**: 0.1 perm or less
- **Class II**: more than 0.1 perm but less than or equal to 1.0 perm
- **Class III**: more than 1.0 perm but less than or equal to 10 perm

The designer determines the appropriate type of water vapor retarder and its proper location in the building assembly based on climate conditions, other materials used in the building assembly, and building use (e.g., intended relative humidity).

4.4.6.2.6 **RoofPoint**:

Section 3: Water Management: W1: Roof storm water retention (Page 28):

Install one of the following water-retaining roofing system options:

- Install a self-sustaining vegetated roof over 75% of the roof surface.
- Install a non-vegetated water-retaining roof over 75% of the roof surface.
- Install a hybrid combination of #1 and #2 over 75% of the roof surface area.

4.4.6.2.7 **RoofNav**:

N/A. There is no information about rainwater collection available in the RoofNav.

4.4.6.3 **REALITY**

4.4.6.3.1 **Implementation costs**:

In order to calculate the cost of a waterproofing system, three important and prevalent waterproofing methods are identified: asphalt, sheet, and membrane waterproofing. These three methods and their components are shown below:
The initial costs of these three methods are in the order of asphalt, membrane, and sheet waterproofing. For asphalt and membrane waterproofing, repair work is required at the rate of 10%, eight years after the initial installation. The repair work for sheet waterproofing work is assumed as 20%.

Below is a list of some waterproofing materials:

- 3mm APP modified bitumen waterproof membrane, FOB (Free on Board) price: US $2 - 5 / Square Meter
- Breathable and waterproof roof membrane roof underlay, FOB (Free on Board) price: US $0.9 - 5.9 / Square Meter.
- PVC roofing and waterproofing membrane, FOB (Free on Board) price: US $3 - 5 / Square Meter.
• Waterproof Membrane for Pitched Roof Felt or House wraps, FOB (Free on Board) price: US $0.3 - 0.8 / Square Meter.
• LOW PRICE EPDM Coiled Rubber Waterproof Membrane, FOB (Free on Board) price: US $1 - 4 / Square Meter.
• 1.2mm/1.5mm/2mm EPDM rubber membrane waterproof, FOB (Free on Board) price: US $2.99 - 4.99 / Square Meter.
• Cheap Price Self-adhesive Polymer Bitumen Waterproof Roofing Membrane, FOB (Free on Board) price: US $1 - 4 / Square Meter.
• 1.2mm best quality China EPDM waterproofing membrane price for roofs, FOB (Free on Board) price: US $1.5 - 6 / Square Meter.
• Breathable membrane waterproof price, FOB (Free on Board) price: US $0.25 - 0.8 / Square Meter.
• 3mm 4mm thickness roofing SBS waterproof membrane price, FOB (Free on Board) price: US $0.8 - 7.5 / Square Meter.
• Roofing Material Breathable Waterproof Membrane Price, FOB (Free on Board) price: US $0.2 - 0.8 / Square Meter.
• Polyester Base SBS/APP roof Waterproof Membrane, FOB (Free on Board) price: US $0.9 - 4.9 / Square Meter.
• High price PVC waterproof membranes for concrete roof, FOB (Free on Board) price: US $3.21 - 6.89 / Square Meter.
• Self-adhesive Polymer Bitumen Waterproof Roofing Membrane, FOB (Free on Board) price: US $0.1 - 1 / Square Meter.
• APP modified bitumen waterproof roofing membrane, FOB (Free on Board) price: US $2.15 - 3.25 / Square Meter.

References:

4.4.6.3.2 Aesthetics:
Roof waterproofing coatings are useful for meeting aesthetic issues. Most practitioners prefer the darker colors for the building’s roofs.

4.4.6.3.3 Psychological aspects:
Installing energy efficient systems on a roof increases the awareness of occupants of environmental issues and energy savings, consequently affecting energy consumption behavior.
4.4.6.3.4 Precedents of innovation:

SureCoat Waterproof Roof System
(Source: http://www.surecoatsystems.com/roofing-systems.asp)

SureCoat Waterproof Roof System is a single-component, epoxy-hybrid, elastomeric roof system, which is seamless and waterproof.

The SureCoat Roof System has great adhesion and provides protection for all types of existing roof systems and materials, including foam, metal, steel, aluminum, concrete, wood, polyurethane foams, fiberglass, all types of BUR, asphalt granulated cap sheet, EPDM, hypalon, PVC, textile fabric and masonry.

Reference:

Belonza 3111 is a cold-applied liquid coating for long-term protection of a roof. It provides great waterproofing and weatherproofing characteristics for the roof. It is a single component, solvent free roof coating, which can be applied to all types of roofing materials. It consists of a reinforcement sheet to allow easy control of the coating thickness during the implementation. This kind of water proofing system can be applied in different locations and different building types in part due to its low odor.

**Key benefits:**

- Provides long-term roof protection
- Microporous material allows trapped moisture to escape whilst providing long-term weatherproofing protection
- Reduced health and safety risks as it is solvent free
- Lightweight material – will not overload existing structures
- Excellent adhesion to a wide range of materials including felt, asphalt, lead, zinc, copper, glass, concrete and brick
- Adapts to roof movements due to its outstanding elasticity
- Can be easily applied by brush and roller with no mixing required
- Application and cure at room temperature – no hot work involved
- Energy Star approved as it incorporates special reflective fillers, which reflect sunlight and minimize air conditioning costs

**References:**

4.4.6.4 GENERAL RECOMMENDATIONS:

4.4.6.4.1 Climate Zones (1-8)

1A_ Miami: Miami has a tropical monsoon climate with hot and humid summers and short, warm winters.

Water proofing systems are critical in humid climates to prevent issues such as mold, mildew, algae and other bacteria growing in the roof surface area. These microorganisms spread rapidly in humid environments, so proper insulation and sealing all areas of the roof is significant so that water leaks do not occur.

References:

2A_Houston: Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

Water proofing systems are critical in humid climates to prevent issues such as mold, mildew, algae and other bacteria growing in the roof surface area. These microorganisms spread rapidly in humid environments, so proper insulation and sealing all areas of the roof is significant so that water leaks do not occur.

References:

2B_Phoenix: Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.

3A_Atlanta: Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

Water proofing systems are critical in humid climates to prevent issues such as mold, mildew, algae and other bacteria growing in the roof surface area. These microorganisms spread rapidly in humid
environments, so proper insulation and sealing all areas of the roof is significant so that water leaks do not occur.

References:

3B_Los Angeles: The climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall but relatively modest transitions in temperature.

3b_Las Vegas: Climate Zone 3B includes areas of the United States with a characteristically dry climate.

3C_San Francisco: Climate Zone 3C includes areas of the United States with a characteristically marine climate.

4A_Baltimore: Climate Zone 4A includes areas of the United States with a characteristically moist climate.

Water proofing systems are critical in humid climates to prevent issues such as mold, mildew, algae and other bacteria growing in the roof surface area. These microorganisms spread rapidly in humid environments, so proper insulation and sealing all areas of the roof is significant so that water leaks do not occur.

4B_Albuquerque: Climate Zone 4B includes areas of the United States with a characteristically dry climate.

4C_Sea**: Climate Zone 4C includes areas of the United States with a characteristically marine climate.

Water proofing systems are critical in humid climates to prevent issues such as mold, mildew, algae and other bacteria growing in the roof surface area. These microorganisms spread rapidly in humid
environments, so proper insulation and sealing all areas of the roof is significant so that water leaks do not occur.

References:

5A_ Chicago: Climate Zone 5A includes areas of the United States with a characteristically moist climate.

In cold climates, a continuously sealed waterproofing membrane under insulation is recommended. The potential for ice and snow should be considered.

Vapor retarders may also be mandatory to avoid condensation under white or light-colored membranes (cool roofs) because the temperatures of such membranes are so low that even occupancies with low or average interior humidity can cause condensation.

Mechanically attached systems may not be appropriate for locations with high winds. Apply an air barrier on the deck (in conjunction with a vapor retarder in cold climates with high humidity interiors or with membranes or on new concrete decks) in order to avoid wind pumping.

References:

5B_ Denver: Climate Zone 5B includes areas of the United States with a characteristically dry climate.

In cold climates, a continuously sealed waterproofing membrane under insulation is recommended. The potential for ice and snow should be considered.

Vapor retarders may also be mandatory to avoid condensation under white or light-colored membranes (cool roofs) because the temperatures of such membranes are so low that even occupancies with low or average interior humidity can cause condensation.
Mechanically attached systems may not be appropriate for locations with high winds. Apply an air barrier on the deck (in conjunction with a vapor retarder in cold climates with high humidity interiors or with membranes or on new concrete decks) in order to avoid wind pumping.

References:

6A_ Minneapolis: Climate Zone 6A includes areas of the United States with a characteristically moist climate.

In cold climates, a continuously sealed waterproofing membrane under insulation is recommended. The potential for ice and snow should be considered.

Vapor retarders may also be mandatory to avoid condensation under white or light-colored membranes (cool roofs) because the temperatures of such membranes are so low that even occupancies with low or average interior humidity can cause condensation.

Mechanically attached systems may not be appropriate for locations with high winds. Apply an air barrier on the deck (in conjunction with a vapor retarder in cold climates with high humidity interiors or with membranes or on new concrete decks) in order to avoid wind pumping.

References:

4.4.6.4.2 Climate zones 7-8
In cold climates, a continuously sealed waterproofing membrane under insulation is recommended. The potential for ice and snow should be considered.

Vapor retarders may also be mandatory to avoid condensation under white or light-colored membranes (cool roofs) because the temperatures of such membranes are so low that even occupancies with low or average interior humidity can cause condensation.

Mechanically attached systems may not be appropriate for locations with high winds. Apply an air barrier on the deck (in conjunction with a vapor retarder in cold climates with high humidity interiors or with membranes or on new concrete decks) in order to avoid wind pumping.
References:

4.4.6.5 CODE RECOMMENDATIONS:

4.4.6.5.1 IECC, 2012: N/A

4.4.6.5.2 ASHRAE90.1, 2010: N/A

4.4.6.5.3 IgCC, 2012: Section 408.3 Roof surfaces, (P 4-8): N/A

4.4.6.5.4 ASHRAE AEDG 50% N/A

4.4.6.5.5 RoofPoint N/A

4.4.6.5.6 RoofNav N/A
4.4.7 RECREATION
4.4.7.1 ROOF AS RECREATION AREA

4.4.7.1.1 General Information

TF Cornerstone, Long Island City,

4.4.7.1.2 Definition:
In some cases, the roof can be used as a place for recreation. If designers think ahead in this aspect of the roof, a building’s design can be more innovative. Rooftop recreation systems can be applied for different spaces such as a green roof, rooftop farming, restaurants, pools, or display areas. Designing an appropriate roof system and considering physical characteristics of the roof surfaces, including the slope, the roofing materials, and the loading capacity must all be considered when selecting for specific recreation strategy.
4.4.7.1.3 Advantages:
Using rooftop space for recreation provides benefits for human and social health, the environmental, and economic considerations. Rooftop recreation space is most valuable in densely populated areas where the space is at a premium. Utilizing the unused roofs of existing buildings provides full advantage of these spaces. Doing so enables and empowers occupants to make their communities healthier and more enjoyable places to live. The benefits of many different kinds of roof functions can be reaped when designed intelligently.

References:
4.4.7.1.4  Disadvantages:
In order to utilize a roof for different functions, factors relevant to the type of function must be considered. Issues such as waterproofing, dead loads, live loads, structure, and maintenance need to be considered in the design or retrofit process.

4.4.7.2 CODES AND STANDARDS:

4.4.7.2.1  IECC, 2012:
N/A. There is no information about recreation available in the IECC-2012 version.

4.4.7.2.2  ASHRAE 90.1, 2010:
N/A. There is no information about recreation available in the ASHRAE 90.1-2010 version.

The codes and standards related to green roof must be considered.
4.4.7.2.3  IgCC, 2012:
N/A. There is no information about recreation available in the IgCC, 2012 version.
The codes and standards related to green roof must be considered.

4.4.7.2.4  ASHRAE AEDG 50%, 2011:
The codes and standards related to green roof must be considered.

4.4.7.2.5  ASHRAE Fundamentals, 2009:
The codes and standards related to green roof must be considered.

4.4.7.2.6  RoofPoint:
The codes and standards related to green roof must be considered.

4.4.7.2.7  RoofNav
The codes and standards related to green roof must be considered.

4.4.7.3  REALITY

4.4.7.3.1  Implementation costs:
Vegetation roof: Installation costs of green roofs are estimated to range from $10 to $25 per square foot ($10 per square foot for simpler extensive roofing, and $25 per square foot for intensive roofs), in addition to the costs associated with the primary roof membrane. Costs depend on many factors, such as the growing medium, depth, and green roof size. Structural costs to ensure proper support of the increased green roof live load may also increase implementation costs.

Annual maintenance costs of simple extensive roofing as well as intensive roofs may range from $0.75 to $1.50 per square foot. The higher initial and annual costs associate with a green roof can be justified when life cycle costs and reduced energy costs are factored in.
The average cost for a swimming pool is $50 per square foot, which may differ depending on the location and conditions. Installation and construction due to the load imposed on the building structure also add to the total cost.

References:
4.4.7.3.2 Aesthetics:
Using different roof functions on roof is an easy and effective strategy for beautifying the built environment and increasing investment opportunity.

4.4.7.3.3 Psychological aspects:
Installing energy efficient systems, or plants on a roof, or rooftop farming, increases the awareness of occupants in environment and energy savings, consequently affecting energy consumption behavior. It enables and empowers occupants to make their communities healthier, and more enjoyable places to live.
4.4.7.3.4 Precedents of innovation:

A BrightFarms worker picked herbs at a greenhouse atop a school on West 93rd Street in Manhattan.
(Source: http://www.nytimes.com/2011/05/19/business/smallbusiness/19sbiz.html?_r=0)

BrightFarms Systems built a greenhouse atop a school on a street in Manhattan, taking advantage of a timely conjunction of technologies and user attitudes to bring rooftop farming to the fore. They use greenhouse technologies in order to provide hydroponic growing, an innovative, and cost-effective vegetation system.

4.4.7.4 GENERAL RECOMMENDATIONS:

4.4.7.4.1 Climate Zones (1-8)

1A_ Miami: Miami has a tropical monsoon climate with hot and humid summers and short, warm winters.

In warm and humid climates, the plants on roof have an important role in interior climate control and energy conservation. The vegetation space is recommended to control solar radiation and heat transfer through the building.
Selecting appropriate plants is a significant part of plant roof design. Different plants have different U-values, which leads to different thermal performance. In warm conditions, it is necessary to use the plants that require less watering (Saeid, 2011).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

References:

**2A_Houston:** Climate Zone 2A includes southern areas of the United States, with a characteristically warm and moist climate.

In warm and humid climates, the plants on roof have an important role in interior climate control and energy conservation. The vegetation space is recommended to control solar radiation and heat transfer through the building.

Selecting appropriate plants is a significant part of plant roof design. Different plants have different U-values, which leads to different thermal performance. In warm conditions, it is necessary to use the plants that require less watering (Saeid, 2011).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

References:
**2B_Phoenix:** Climate Zone 2B includes southern areas of the United States, with a characteristically warm and dry climate.

Due to low annual precipitation, low average relative humidity, and high solar radiation, the typical plants used on the roof need to be assessed for their water requirements, survivability and growth habits within several years (Klett, 2012).

The plants used on rooftops in yearly or seasonally hot and dry climates should have high leaf succulence and low water use. The lightweight substrates with increased water holding capacity are appropriate for harsh conditions (Farrell et al, 2012).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

**References:**


**3A_Atlanta:** Climate Zone 3A includes southern areas of the United States, with a characteristically warm and moist climate.

In warm and humid climates, the plants on roof have an important role in interior climate control and energy conservation. The vegetation space is recommended to control solar radiation and heat transfer through the building.

Selecting appropriate plants is a significant part of plant roof design. Different plants have different U-values, which leads to different thermal performance. In warm conditions, it is necessary to use the plants that require less watering (Saeid, 2011).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.
3B_Los Angeles: The climate is classified as a Mediterranean climate, characterized by seasonal changes in rainfall but relatively modest transitions in temperature.

Due to low annual precipitation, low average relative humidity, and high solar radiation, the typical plants used on the roof need to be assessed for their water requirements, survivability and growth habits within several years (Klett, 2012).

The plants used on rooftops in yearly or seasonally hot and dry climates should have high leaf succulence and low water use. The lightweight substrates with increased water holding capacity are appropriate for harsh conditions (Farrell et al, 2012).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

References:


3b_Las Vegas: Climate Zone 3B includes areas of the United States with a characteristically dry climate.

Due to low annual precipitation, low average relative humidity, and high solar radiation, the typical plants used on the roof need to be assessed for their water requirements, survivability and growth habits within several years (Klett, 2012).
The plants used on rooftops in yearly or seasonally hot and dry climates should have high leaf succulence and low water use. The lightweight substrates with increased water holding capacity are appropriate for harsh conditions (Farrell et al, 2012).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

References:

3C_San Francisco: Climate Zone 3C includes areas of the United States with a characteristically marine climate.

The plants used on roofs have an important role in interior climate control and energy conservation. A vegetation space is recommended to control solar radiation and heat transfer through the building.

Selecting appropriate plants is a significant part of plant roof design. Different plants have different U-values, which leads to different thermal performance. In warm conditions, it is necessary to use the plants that require less watering (Saeid, 2011).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

References:

4A_ Baltimore: Climate Zone 4A includes areas of the United States with a characteristically moist climate.

The plants used on roofs have an important role in interior climate control and energy conservation. A vegetation space is recommended to control solar radiation and heat transfer through the building.

Selecting appropriate plants is a significant part of plant roof design. Different plants have different U-values, which leads to different thermal performance. In warm conditions, it is necessary to use the plants that require less watering (Saeid, 2011).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

References:

4B_ Albuquerque: Climate Zone 4B includes areas of the United States with a characteristically dry climate.

Due to low annual precipitation, low average relative humidity, and high solar radiation, the typical plants used on the roof need to be assessed for their water requirements, survivability and growth habits within several years (Klett, 2012).

The plants used on rooftops in yearly or seasonally hot and dry climates should have high leaf succulence and low water use. The lightweight substrates with increased water holding capacity are appropriate for harsh conditions (Farrell et al, 2012).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point
loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

References:

4C_ Seattle: Climate Zone 4C includes areas of the United States with a characteristically marine climate.

The plants used on roofs have an important role in interior climate control and energy conservation. A vegetation space is recommended to control solar radiation and heat transfer through the building.

Selecting appropriate plants is a significant part of plant roof design. Different plants have different U-values, which leads to different thermal performance. In warm conditions, it is necessary to use the plants that require less watering (Saeid, 2011).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

References:

5A_ Chicago: Climate Zone 5A includes areas of the United States with a characteristically moist climate.
Cold climate conditions may affect the establishment and survival of plants of vegetated roof. So, it is necessary to know which plant species can survive in these conditions (Gorden, 2011). Using evergreens (Juniper shrubs) and a thicker soil base rather than typical green roof is helpful in these conditions (University of Toronto, 2005). Another important aspect of the rooftop in Chicago is wind speed. Strong winds can erode the rooftop media and dehydrate plants if proper precautions are not taken.

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

Installing a rooftop pool in a cold climate requires sturdier reinforcement. The damaging effects of freezing and thawing must be considered in construction.

References:


5B_Denver: Climate Zone 5B includes areas of the United States with a characteristically dry climate.

Cold climate conditions may affect the establishment and survival of plants of vegetated roof. So, it is necessary to know which plant species can survive in these conditions (Gorden, 2011). Using evergreens (Juniper shrubs) and a thicker soil base rather than typical green roof is helpful in these conditions (University of Toronto, 2005).
A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

Installing a rooftop pool in a cold climate requires sturdier reinforcement. The damaging effects of freezing and thawing must be considered in construction.

References:


6A_ Minneapolis: Climate Zone 6A includes areas of the United States with a characteristically moist climate.

Cold climate conditions may affect the establishment and survival of plants of vegetated roof. So, it is necessary to know which plant species can survive in these conditions (Gorden, 2011). Using evergreens (Juniper shrubs) and a thicker soli base rather than typical green roof is helpful in these conditions (University of Toronto, 2005).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

Installing a rooftop pool in a cold climate requires sturdier reinforcement. The damaging effects of freezing and thawing must be considered in construction.
4.4.7.4.2 Climate zones 7-8

Cold climate conditions may affect the establishment and survival of plants of vegetated roof. So, it is necessary to know which plant species can survive in these conditions (Gorden, 2011). Using evergreens (Juniper shrubs) and a thicker soil base rather than typical green roof is helpful in these conditions (University of Toronto, 2005).

A pool is another roof function that can provide an enjoyable space for occupants. One of the important concerns of installing a rooftop pool is the weight of the pool structure and the water it contains. Loads can be designed to transfer to the structural framework in order to minimize point loads and avoid any issues within horizontal structures. In order to minimize weight and concerns of leakage, steel frame reinforced structures are preferred over concrete.

Installing a rooftop pool in a cold climate requires sturdier reinforcement. The damaging effects of freezing and thawing must be considered in construction.

References:


5. TOOL DEVELOPMENT

After providing the compendium of strategies, it is imperative to develop an interactive tool so that the user can try different options for different scenarios with preliminary analysis information. A user interface tool provides easy access to information and behaves exactly how the user expects.

Python programming language is used to control the framework. JavaScript and jQuery UI are used for interactive functionalities.

For developing the tool, all the information is provided in database sheets, which are used as inputs. Based on what a user selects and what they would like to know, the tool reads the information from database sheets and selects the appropriate cell as an output.

**Climate selection:**

For developing the framework, the first step is choosing the specific climate where a designer wants to design the sustainable roof system. So, the first question is about climate zones.
After selecting the specific climate, designers should select what functions they would like the roof to perform (Energy efficiency, Energy generation, Daylighting, Equipment allocation, Rainwater collection, Waterproofing, Recreation).
Question number 2 is based on the previous selection of different roof functions. For instance, if designers chose energy efficiency, the next question would be about selecting different types of roof functions (Green roof, cool roof, thermal insulation, and thermal mass).
After choosing the roof function, general information about each specific function is presented in the next question including definition, advantages, and disadvantages.

Advantages:

- Added insulation offered by the green roof’s design can reduce the amount of energy needed to moderate the temperature of a building.
- A green roof can improve storm water management, water runoff quality, urban air quality, and filter out airborne pollutants.
- A green roof can aid in a reduction of the urban heat island effect, while also adding a habitat for wildlife and aesthetic appeal.
- Green roofs can extend a roof’s life, improve acoustics in a building, and enhance architectural interest and biodiversity.
Question number 5 is related to the type of information that users would like to know more about including codes, benchmarking, and reality aspects.
Question number 6 selects specific information based on previous selections. For instance, if the designers choose “codes”, the next question is related to different codes and standards for each roof function. Specifically, for green roofs, IgCC has a lot of information and standards.

Question number 7 is related to general recommendations from codes for each specific climate previously selected in the first question.
If designers select for recommendations from codes in previous step, question number 8 is shown for selecting specific codes and standards.
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