PASSIVE DESIGN HANDBOOK

2016

A step-by-step guide to integrating passive solar design strategies into your green portfolio
The Passive Design Guide for Existing Buildings offers a resource to building designers so they may better understand the opportunities and business case for low- and no-energy building renovation solutions. Passive design solutions, which addresses the local climate and site conditions to maximize the comfort and health of building users while minimizing energy use, are often overlooked. However, building designers should consider passive design solutions in all building renovations as they often provide energy-efficient options at low cost.

Existing building renovation offers an interesting challenge for implementing passive design solutions. While it often costs very little to incorporate passive design elements into a new building, it is more challenging and often more costly to incorporate these solutions into existing buildings. That being said, existing buildings offer the greatest opportunity for change. The average commercial building has a lifespan of 70 to 75 years,¹ which means that most of the buildings that will be around during our lives have already been built. These buildings will undergo multiple renovations during their lifetimes and at each renovation opportunities to optimize the passive design solutions to take advantage of low-cost energy efficiency opportunities often exist.

The Passive Design Guide for Existing Buildings focuses on solutions that are most likely to be usable for existing buildings in the Southern California climate. This design guide provides background information and tools for building designers to better incorporate passive design solutions into renovation projects. Focusing on passive design solutions will help Southern California design a more sustainable future while also improving the comfort of the people who live and work in its buildings.
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SECTION 1

PASSIVE DESIGN STRATEGIES

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PASSIVE DESIGN STRATEGIES

Passive design is an approach to building design that responds to the local climate and site conditions to maximize the comfort and health of building users while minimizing energy use. Building designers carefully consider the building structure and systems when following a passive design approach in order to optimize their interaction with the local microclimate. The ultimate goal of passive design is to eliminate the need for any active mechanical systems to maintain occupant comfort, though this is not a realistic goal for most commercial building projects.

Passive design solutions are most cost-effectively and easily employed in new buildings, and strategies are best implemented during the initial design phase for new construction projects. However, they can also play an important role during retrofits of existing buildings but may be more challenging. Because the average commercial building has a lifespan of 70-75 years, there are more opportunities to renovate existing buildings than there are to influence new buildings, which only replace or add a few percent to the existing building stock each year. Each renovation that follows a passive design approach offers an opportunity to optimize the interaction of buildings and their local microclimates, taking advantage of energy efficiency opportunities for relatively low cost.

The proper application of passive design solutions can greatly reduce building energy requirements before the consideration of mechanical systems. Even the most efficient mechanical systems will use more energy to maintain thermal comfort in a poorly designed building than in a well-designed building.

To successfully implement passive design approaches in existing buildings, design teams must:

- Review the characteristics of the existing building, including organization, structure, systems, operational schedules
- Analyze the local microclimate, with as close to site-specific data as possible (see a discussion of Southern California climate on page 7)
- Define acceptable thermal comfort criteria (see a discussion of thermal comfort criteria on page 17)
- Establish clear and measurable energy performance targets

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LOCAL CLIMACTIC CONSIDERATIONS

Understanding local climatic considerations serves as the basis for determining the applicability of all passive design solutions. A design strategy that makes sense in northern California, where heating in the winter is a larger concern for occupant comfort than is cooling during the summer, does not make sense in Southern California, where cooling in the summer is more critical than heating in the winter. Depending on building location, how it is sited, and its proximate features, microclimate considerations might lead design to block direct sunlight during both summer and winter months when the sun can be very low. This may be counterintuitive to many passive design principles but is critical to human comfort.

Southern California is described as a Mediterranean climate with winter rains and hot, dry summers. While the casual observer may consider the climate to be generally unified across the entirety of Southern California, microclimatic differences are actually quite large in terms of their impact on passive design approaches. The specific climatic information presented in this section provides an overview of Southern California climates. More detailed microclimatic information should be collected for any design project.

Los Angeles

The Los Angeles climate zone is characterized by beaches at the foot of the Southern California hills. The proximity to the Pacific Ocean maintains a very mild climate and creates winds that provide summer cooling. Average high temperatures range from about 68°F in the winter months to 84°F in the summer, while average low temperatures range from 47°F to 64°F. During the winter, rainfall is typically between two and four inches each month. Figure 1 shows average monthly precipitation and temperature. The prevailing winds come from the west-southwest during the summer, and from the east during the winter. As one moves east of the coast into the mountains, the average temperatures rise and humidity declines. Solar radiation is relatively abundant year-round.

Figure 1. Los Angeles Monthly Average Precipitation and Temperature

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San Diego

San Diego is located in the southernmost coastal region of California. The climate is very mild due to the proximity to warm ocean water. The summer weather is warm and comfortable, and the area is naturally cooled during evenings due to dense fogs. Winters are cool, but the winter design temperature is still relatively warm at 44°F. As Figure 2 shows, average high temperatures range from 65°F in the winter months to 77°F in the summer, while average low temperatures range from 48°F to 67°F. Typical rainfall amounts to between one and two inches per month during the winter months. Figure 2 shows the average monthly precipitation and temperature. The prevailing winds come from the west-northwest during the summer and the northeast during the winter. 4

Figure 2. San Diego Monthly Average Precipitation and Temperature

Brawley

The climate in Brawley consists of extremely hot, dry summers, and moderately cold winters. In the summer, average temperatures are much higher than those of other Southern California climate zones and humidity is below the comfort range for most of the year. The low humidity causes large temperature swings between day and night. Average high temperatures range from 70°F in the winter months to 107°F in the summer, while average low temperatures range from 40°F to 77°F. The prevailing winds come from the north in the summer and the southeast during the winter. Brawley receives moderate solar radiation, though less than the other Southern California climate zones. Unlike Los Angeles and San Diego, occasional summer storms provide some precipitation, although the majority of the annual precipitation still occurs during the winter. Average rainfall throughout the year is typically between 0.2 and 0.5 inches each month. Figure 3 shows average monthly precipitation and temperatures. 5

The climate in Southern California is also affected by heat islands. An urban heat island describes a metropolitan area that is warmer than surrounding rural areas because of a higher concentration of manufactured materials that collect heat. The temperature difference as a result of the heat island effect is more pronounced during the summer and winter and when winds are weak. In Southern California, the Los Angeles area is most affected by the heat island effect because of the high concentration of population in this area. Passive design strategies for cooling-dominated climates in regions with strong heat

5 Ibid.
island effects include increasing tree and vegetation cover, creating green and reflective roofs, and using cool pavements to combat the heat gain from these urban environments.

**MEASURING THE HEAT ISLAND EFFECT**

The heat island effect is very difficult to accurately measure. Landsat satellite images are often used to classify land cover and identify heat islands, but they do not fully capture radiant emissions. Landsat satellite images primarily observe emissions from horizontal surfaces such as streets, rooftops, and treetops; they do not completely depict radiant emissions from such vertical surfaces as walls. The data from Landsat satellite images must also be corrected to accurately represent the effects of surface properties such as solar reflectance and temperature.

The University of Minnesota conducted a study to determine the variations in temperature and urban heat island effect across Minneapolis and St. Paul. Researchers recorded temperatures during all seasons from 180 sensors distributed across the metro area from 2011 through 2014. The study concluded that temperatures in urban areas averaged 2 °F higher in the summer and in the winter when snow cover is low. The study also found that the temperature differences were higher at night during the summer and higher during the day in winter. This type of information can be used to inform green infrastructure projects to help offset surface warming.

PASSIVE COOLING AND VENTILATION

Passive cooling describes passive design strategies that are used to reduce heat gain or remove internal heat from a building. Passive ventilation describes passive design strategies that are used to ventilate an interior space to maintain thermal comfort. Passive cooling strategies are often enhanced when they are designed in parallel with passive ventilation strategies, which provide increased air flow when the outdoor air temperature is low enough to flush heat from the building.

Technologies and strategies that contribute to passive cooling include:

- **Insulation**, to reduce heat gain
- **Thermal mass**, to store heat
- **Radiative cooling**, to decrease demand for air conditioning
- **Natural ventilation**, to reduce energy use
- **Increased air movement**, to expand the thermal comfort zone
- **Evaporative cooling**, to provide a more efficient and comfortable cooling method
- **Shading strategies and glazing properties**, to control solar heat gain
- **Massing and orientation**, to maximize the effectiveness of other passive cooling strategies

**Insulation**

Insulation describes products that reduce heat loss or heat gain and provide a barrier between areas of different temperatures. Effective insulation is one of the most important materials in passive cooling design because its contribution to reducing heat gain in the summer can help keep a building cool. Some of the most common insulation types include cellulose, glass wool, polystyrene, polypropylene, recycled cotton denim, and earth. The effectiveness of insulation is determined by its R-value, which is the material’s resistance to conductive heat flow. Minimum R-values for key building components (e.g., roof, walls, basement walls) are prescribed in the current (2013) version of the California Building Energy Efficiency Standards, found in Title 24, Part II, of the California Building Code.

Insulation strategies also affect the interior surface temperature of the building envelope, which, in turn, has a direct impact on thermal comfort for building occupants. Cold surface temperatures (e.g., from lack of insulation) affect occupant thermal comfort by both radiation and convection. To achieve effective insulation of the building envelope, building assemblies must be carefully detailed to avoid thermal bridging. Thermal bridging occurs when a building material, or section of material, has a significantly higher heat transfer rate than the surrounding materials, which results in an overall reduction of the insulation value of the entire system.

**Thermal Mass**

Thermally massive materials have the ability to absorb, store, and gradually release heat. Materials with high thermal mass are typically high-density materials with high specific heat capacities. Concrete, stone, masonry, and rammed earth are the most common thermally massive materials. Because of their high specific heat properties, these materials require a large amount of energy to change their temperature.

When a material with high thermal mass is exposed to a heat source, such as the sun or heat from the building interior, the thermal mass absorbs that heat. Such material also remains at a more consistent temperature than that of a material with lower thermal mass. The high thermal mass material will continue to absorb heat until there is no longer a heat gradient.
driving that absorption. When the material is exposed to cooler air, it will release its stored heat. This process functions in reverse with cooling, where the thermally massive material is pre-cooled, such as with cooler nighttime air in the process of night flushing, and will then absorb heat as the interior space begins to warm from the sun and other internal heat gains. Night flushing is more fully described in the Natural Ventilation section below.

THERM, MODELING THERMAL PERFORMANCE

A designer can ensure effective insulation and the limiting of thermal bridging by using a tool like THERM. THERM is a modeling software tool developed by the Lawrence Berkeley National Laboratory that allows designers to adjust envelope parameters, materials, and boundary conditions, and then visualize the heat flow through the proposed wall construction. For example, in the images below, the wall/floor condition on the left shows a thermal bridge, and the wall condition on the right shows a solution to limit the thermal bridging.

![Thermal bridge and solution](image)


When using thermal mass for passive cooling in a design strategy, the designer must consider the time lag and damping that is achievable with a specific material. Time lag is the difference in time between the peak temperature on the inside surface of a building component and the peak temperature on the outside surface. Some materials, such as glass, do not have a substantial time lag, whereas materials with high thermal mass can have a time lag of multiple hours. Damping is the difference in temperature between the peak temperature on the inside surface of a building component and the peak temperature on the outside surface. Materials with high thermal mass have greater damping characteristics, which reduce the temperature fluctuations on the material’s interior surface. Figure 4 illustrates the effects of thermal mass and damping.
Radiative Cooling

Figure 5 illustrates the two main types of cooling systems used in buildings, convective and radiative cooling. The most common form of room conditioning is convective cooling by means of forced air, usually through ceiling or wall diffusers. Convection is the process of heat transfer by the movement of fluids, such as air or water, from one place to another. As air moves over a hot surface, the air gets warmer, becomes less dense, and rises. Because of the mechanics of convection, convective cooling requires high ventilation rates and low air temperatures to achieve the typical goal of fully mixed cool air. Radiative cooling is achieved through radiation rather than air movement. When a wall, floor, or ceiling surface is cooler than a heat source (e.g., occupant, computer), heat will naturally radiate from the warmer surface to the cooler surface. If all cooling is achieved through radiation rather than convection, this allows for the decoupling of ventilation and space conditioning, which in turn allows for lower ventilation rates and a wider temperature deadband, or the neutral temperature range when neither heating nor cooling is needed.

While radiative cooling is a passive design strategy, lowering the temperatures of room surfaces requires some active cooling. The two most common strategies for cooling room surfaces are thermally activated building systems (TABS) and suspended (or surface mounted) metal panels. TABS are comprised of pipes embedded in a thermally massive floor or ceiling slab. By piping cold water through the slab, the slab surface is cooled down, allowing heat that is radiated by occupants and other heat producers to be absorbed by the exposed slab. For TABS to be effective, a large exposed surface area is required. TABS take a long time to cool down due to their thermally massive properties, but the process of radiation from occupants and other heat sources is immediate. Suspended metal panels work like TABS in that they use water to cool their surface. However, unlike TABS, the metal panels cool down very quickly because they have low thermal mass and can therefore more quickly adjust to changes in the outdoor temperature. They also differ in cost; because TABS are integrated...
into the building structure, they typically cost less per unit area than metal panels. The ideal climatic conditions for radiative cooling are low outdoor humidity and a large diurnal temperature swing, or the variation between the high and low temperature during the same day.

**Natural Ventilation**

Natural ventilation is a passive cooling strategy that can be successfully implemented in moderate climates. By making windows operable or by adding more openings to the building enclosure, a building originally designed for mechanical ventilation can easily make use of natural ventilation.

Natural ventilation can be broken down into two categories: wind-driven ventilation and temperature-driven ventilation. To use wind-driven ventilation for cooling, architects must design the openings in the building to catch the wind. While single-sided wind-driven ventilation can be effective, cross ventilation allows for optimal use of the wind. Temperature-driven, or buoyancy-driven, ventilation does not require any wind to be effective. Instead, ventilation occurs due to the difference in density between cooler and warmer air. By introducing warm outdoor air into the space at a low inlet, the warm air will rise, creating an upward air stream, and leave the space at a high outlet. This method is known as the "stack effect," which is most commonly seen in solar chimneys, double-skin facades, and rooms with high ceilings. Figure 6 illustrates wind-driven and temperature-driven ventilation.
Buildings located in a climate that is not optimal for natural ventilation year-round can use both natural and mechanical ventilation. These types of buildings are considered “mixed-mode.” Mixed-mode buildings describe all buildings that use different modes of ventilation at different times of the year, different times of the day, or in different rooms at the same time. One typical strategy used in mixed-mode buildings is night ventilation, or night flushing. Night ventilation is a passive cooling technique that uses the outdoor diurnal temperature swing and the building’s thermal mass to cool the space. Windows or other openings in the building enclosure are opened at night, increasing the nighttime airflow, and are closed during the day, enhancing the radiant cooling capacity when the building is occupied during the day. Some applications of night ventilation use TABS or phase change materials, which have the ability to offset the peak cooling load. To design for natural ventilation, architects must size the envelope openings and room configurations to achieve the desired air pattern and necessary reduction in heat load.

Increased Air Movement

Increasing air movement is a very easy and inexpensive strategy for reducing energy use and increasing thermal comfort, especially in building retrofits. Because increased air speed allows occupants to maintain comfort at higher temperatures, it allows for a wider temperature deadband. To measure comfort, it is helpful to use clo, a unit used to measure the thermal insulation value of clothing. Typically a 1.0 clo value corresponds to the clothing needed for a person to feel comfortable sitting at rest at 70°F with air movement of 0.1 meters per second.\(^6\) By increasing the air movement, occupants can maintain comfort in operative temperatures as high as 82°F with a 1.0 clo value. This is further explained in Section IV under Thermal Comfort. To create an indoor environment with increased air movement, the design team can implement passive

technologies such as automated or operable windows, or low energy technologies such as ceiling fans or pedestal fans. It is also important to consider the necessity of personal control over air movement, as personal control allows the comfort range to expand to even higher operative temperatures. Ceiling fans are a very common cooling strategy in developing countries, and are gaining traction in the United States, especially in high metabolic equivalent spaces such as gyms

Evaporative Cooling

Evaporative downdraft cooling towers implement a specific application of natural ventilation in which dry outdoor air enters high inlets and passes through a series of wetted evaporative pads (or misters), which cool the air as it picks up moisture. The cooler air sinks down through the tower shaft and into the occupied space, as seen in Figure 7. This semi-passive strategy requires a simple electric water pump to feed a trickle flow through the pads. Evaporative downdraft cooling towers are most appropriate in moderately dry climates in which the wet bulb depression, or the difference between the dry bulb and wet bulb temperature, is high. The dry bulb temperature is the air temperature with no consideration of moisture in the air while the wet bulb temperature is determined by both the air temperature and the relative humidity. At 100% humidity, the wet bulb temperature equals the dry bulb temperature. The efficiency of the system also depends on the tower height, inlet size, and wind speed.

Shading Strategies

The most basic strategy for controlling solar heat gain is to incorporate shading devices into the building envelope. Horizontal overhangs, vertical fins, louvers, blinds, and shutters can serve as shading devices. Horizontal overhangs are ideal for protecting from overhead sun and are best for southern facades. Vertical fins and louvers are used to protect from low-altitude sun and are best for east and west facades. To determine the ideal depth of an overhang, the design team must consider the building height, glazing height, building orientation, and the path of the sun.

Glazing Properties

Specific types of glazing can also help control solar heat gain. Heat interacts with window glazing through transmission, reflection, and absorption, as shown in Figure 8. The design team should consider the solar heat gain coefficient (SHGC) and U-factor of any windows they select. The SHGC is the fraction of solar radiation that is transmitted through the window and/or absorbed and later released into the interior of the building. The U-factor represents the rate of conduction through the window. It is also important to consider low-emissivity glass, spectrally selective glass, and double- or triple-pane glass. Low-emissivity (low-e) coatings reduce the U-factor, which increases the insulating properties of the glass. During the summer, low-e coatings reflect incoming heat and prevent it from entering the interior of the building. If low-e, reflective, and tinted coatings are not used in conjunction with spectrally selective coatings, they will often lower a window’s visible light transmittance.
Spectrally selective coatings are designed to reflect heat, which reduces the U-factor and SHGC, while still allowing for the transmission of visible light. Double- and triple-pane glass include two or three pieces of glass, each of which is separated by a vacuum or a gas in order to reduce heat transfer and increase the insulating properties of a window. Coatings can be applied to various surfaces to achieve the desired U-factor and SHGC values. In retrofit situations, windows either can be replaced with better performing glazing or a film can be applied to existing windows.

Massing and Orientation

When designing passive cooling strategies and arranging spaces inside the building, it is important to understand how the building is oriented. This begins with climate analysis. To conduct an initial climate analysis, the design team can use Typical Meteorological Year data set 3 (TMY3) weather data, which are data sets of hourly values of solar radiation and meteorological elements over a one-year period representing typical weather conditions in a specific location.

Basic climate analysis can give insights on how to minimize solar heat gain and maximize natural ventilation capability, important goals in a cooling-dominated climate. Take advantage of existing massing and orientation. To minimize solar heat gain when orientation is set, architects should place high-occupancy spaces in low-irradiance zones of the building. Irradiance is the measure of solar energy, or brightness, on a surface. Highly occupied spaces create heat from occupants and therefore should be placed in low-irradiance zones to limit solar heat gain from interior surfaces. Wind-driven natural ventilation works best in buildings oriented for wind direction and predominant wind speed. Buoyancy-driven ventilation works best in buildings with high ceilings.
PASSIVE HEATING

The goal of passive heating strategies is to use energy from the sun to maintain adequate indoor thermal comfort without the use of energy-intensive systems. Passive heating may be less important than passive cooling in Southern California, but the climate still demands mechanical heating during the winter. Building owners can realize energy savings when mechanical heating is replaced by passive heating systems.

Direct Solar Gain

Direct solar gain is a passive design strategy that uses direct solar radiation through windows or skylights to increase the internal temperature of a building, as shown in Figure 9. The envelope surface area, building orientation, available solar radiation, and heat transmission properties of the envelope materials affect the potential for direct solar gain. Opaque surfaces have low heat transmission properties, allowing less than 12% of heat transmitted to the interior of the space. Clear surfaces have higher heat transmission properties, leading to more than 80% of heat transferred to the interior of the building. The SHGC quantifies the fraction of solar radiation that is transmitted through a window. Building codes and standards such as California Title 24 and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers’ (ASHRAE’s) Standard 90.1 set requirements or guidelines for SHGC values.

Architects can optimize the glazing properties, size, and orientation of a window to provide direct solar gain during the winter season and shade during the summer. Combining optimal orientation and shading elements can increase the performance of this strategy. Positioning the glazing area on the south-facing facade to maximize the solar heat gain during the winter and designing shade elements (such as overhangs) to fully shade this surface during the summer can reduce energy consumption for space heating and minimize heat gain during the summer, reducing the need for air conditioning. Designers should use solar simulation software when designing for solar heat gain of an envelope system. These software tools will be discussed in more detail in Section IV.

Figure 9. Direct Solar Gain System

Thermal Storage Walls

Thermal storage walls, or Trombe walls, are indirect solar heat gain systems composed of layers of glazing, air, and masonry or other materials with high thermal mass. Figure 10 shows an example of a Trombe wall. This strategy is typically applied in south-facing facades where there is more sun exposure. The thermal storage wall absorbs heat from the sun and slowly transmits it to the building interior during the day. Different from direct solar gain, this system does not allow direct sunlight into the space; rather, the sun passes through the glazing, storing heat in the air gap and heating the thermal mass wall that radiates heat to the interior of the building. The amount and rate of heat transfer depends on the thickness and material properties of the wall. This strategy requires shading elements to prevent solar heat gain during the summer.

Some Trombe walls include vents, which create air circulation and instant heating of the space. Trombe walls without vents rely on material conduction to transfer heat to the interior of the building. Designers can position vents low and high on the wall to create convective loops and induce heat circulation to reduce daytime heating loads. High-performing Trombe walls with vents are usually 12 to 16 inches thick, and those without vents are usually 10 to 14 inches thick. The wall thickness varies depending on the density of the wall material.

There is high potential for incorporating a Trombe wall in a building retrofit if the building has high-mass walls (such as concrete blocks, brick, or stone). However, Trombe wall retrofits are only a good design strategy for buildings with good southern exposure. Therefore, it is important to make sure that trees, overhangs, and adjacent buildings do not shade the south facade during the day in the winter. Another important element for maximum Trombe wall performance is building insulation. Without sufficient insulation, the heat will not be stored in the wall. Assuming that the building has a substantial southern exposure and insulation, adding a Trombe wall can be relatively simple. Typically, builders install an external frame and layer of glass on the south wall. They position the glass three to six inches from the mass wall and use low-e double pane windows with a high SHGC. Trombe walls are usually more expensive than direct gain retrofit strategies but are better suited for spaces used mainly at night or those requiring privacy, such as hotels and hospitals.

A sunspace is an alternative passive solar heat system that can improve thermal comfort. It is usually composed of glass walls and is attached to a south-facing facade. The sunspace collects solar heat during the day and transmits heat to the interior of building through windows or vents between the sunspace and the existing building. Sunspace structures can also be used for growing plants.
LIGHTING CONTROLS AND DAYLIGHTING DESIGN

The goals of incorporating lighting controls and daylighting in a building’s lighting design include using natural light to maintain adequate indoor light levels while reducing energy consumptions from electric lighting systems. Lighting controls are important for adjusting artificial lighting based on ambient light levels, occupancy, and the lighting requirements for occupants’ tasks. Potential energy savings from lighting controls and daylighting design are substantial. Natural light can also improve workers’ productivity and happiness, bringing additional benefits for the tenant.

Lighting Controls

Lighting controls can produce significant energy savings. Since most people simply do not turn off lights when they leave the room, lighting controls such as occupancy sensors will turn off lights when spaces are vacant. These controls sense the presence of people using infrared or ultrasonic motion sensors. Daylight sensors are another type of lighting control. When sufficient daylight is available, these controls dim or turn off electric lighting, resulting in additional energy savings. Furthermore, a common energy-efficient option for outdoor lights are photosensors. These electronic control devices adjust the light output of a lighting system based on the amount of light sensed at certain locations. While some controls simply turn on lights at dusk and off at dawn, photosensors can also maintain the output of light fixtures to compensate for lamp and dirt depreciation effects.

Glare is a common problem and occurs when areas of high and low brightness are located next to each other. To avoid glare, lighting must be well distributed with low contrast. Contrast is the luminance difference between an object and its background and is measured as the ratio of the luminance of the brighter color to that of the darker color. Lighting designers should avoid contrasts greater than 10:1 and an absolute illuminance value of 2,000 lux or greater to avoid glare. A contrast of 20:1 will cause occupants to see silhouettes, although this is often appropriate for corridors. Designers should always avoid a contrast of 50:1 as it causes discomfort. Architects can use light meters to measure and verify these values.

Daylighting

In conjunction with proper lighting controls, daylighting can result in significant energy savings through reduced electric lighting loads and the corresponding decreased cooling load. Through the use of daylighting strategies, the solar gains experienced during cooling load periods can be reduced and solar gains found during heating load periods can be made effective, reducing the energy requirements for both cooling and heating a space.

South-facing windows can be designed to be shaded during the summer while admitting direct sunlight during cold months when solar heat gain is desirable. North-facing windows have evenly distributed natural light with less glare from direct sunlight. Architects should minimize east- and west-facing windows to avoid glare and excessive solar heat gain.

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A building’s massing and orientation significantly affect the availability of daylighting. The daylight access of an indoor space is a function of the location and size of apertures, glazing transmissivity, ceiling reflectance, shape and size of indoor spaces, and external obstructions. Generally, the amount of light in a space is directly proportional to the glazing area. However, increasing side light and top-light area can increase heat gain and glare. A well-designed daylighting strategy uses shading elements, high-performance glass, and proper aperture sizing. ASHRAE 90.1 provides a resource for aperture sizing guidance through climate-responsive window-to-wall area ratios.

Side light apertures such as windows and glazed doors can deliver daylight a maximum of 25 feet into a space. Side light can provide not only daylight accessibility, but also views at the occupant level. Generally, the size of windows should be about 25 to 40% of the wall area. Shading elements such as light shelves or vertical louvers help control glare and heat gain, as well as reflect light deeper into the space. Figure 11 shows several daylighting strategies.

**Figure 11.** Daylighting Strategies

#### SIDE LIGHTING
- Overhang
- Light Shelf

#### TOP LIGHTING
- Reflected Light
- Diffused Light

#### ANTI-GLARE
- Summer Vegetation: Leaves block summer light
- Winter Vegetation: Bare branches allow winter light

#### ANTI-GLARE
- Screen light: Diffuses light and views
- Louvers: Blocks summer light, allows winter light, while maintaining views
In an urban context, daylight may be blocked by adjacent buildings and surrounding elements such as trees. For buildings with limited daylight availability due to external obstruction or deep floor plans, use of top-light strategies such as skylights and light tubes can increase daylighting in the space. Skylights can be passive or active, including a mirror system that tracks the sun. Most commonly, skylights are passive, including double-glazed clear glass or a diffusing acrylic medium that allows daylight into the building. Light tubes are composed of a highly reflective film that transmits daylight from a lens at the roof level to the interior of the space.

Daylighting strategies can reduce energy use when well integrated with electric lighting systems. Designers should position lighting fixtures to complement the daylighting source and circuit the fixtures in zones, allowing occupants to turn off areas of electric lighting when daylight is available. Electric lighting systems should include dimming and photocell controls to reduce the use of electricity when daylighting is available.¹⁴

PASSIVE WATER STRATEGIES

There are several ways to introduce passive design into a building’s water use. These methods apply to the use of domestic hot water as well as cold potable tap water. One such method is a solar hot water system. While solar hot water does not reduce water use, it does decrease water heater demand and the associated energy use. Buildings can also reduce their demand for potable water by capturing rainwater and reusing greywater for indoor plumbing or outdoor landscape irrigation.

Solar Hot Water

Solar hot water systems collect heat from the sun to create domestic hot water. These systems align with passive design strategies in that they use a naturally occurring heat source instead of (or in conjunction with) a gas, oil, or electric water heater. The basic components in solar heating systems include heat collectors, heat transfer fluid, and heat exchangers. Collectors take the heat from the sun and pass it to a heat transfer fluid, which is often water but is sometimes another fluid. The most common heat collectors have tubes of the fluid that are well-insulated on the bottom and sides of the tube. The top of the solar hot water panel is covered with glass designed to let light through to the heat-collecting tubes and minimize the amount of heat that can escape. As the heat transfer fluid is warmed, it is pumped through the system from the collector to the heat exchanger, which transfers heat to the building’s domestic hot water.

Solar hot water systems offer a quick payback period, as they are not very expensive to install and save considerable energy. They are also well-suited to a wide range of climates; the warm and sunny climate of Southern California is a particularly good application. Most solar hot water systems are designed and installed by solar hot water experts. Building owners that are interested in installing solar hot water should have a solar hot water technician conduct a feasibility assessment for their facility.

Rainwater Collection

Rainwater collection is the harvest of rainwater for use on site. Rainwater can be collected from building roofs or from ground surfaces such as parking lots. Rainwater collection is not an energy-intensive process; it should primarily use gravity to collect the water from roofs or other impermeable surfaces. The water can flow into reservoirs or cisterns that store the rainwater until it is needed, when the water is pumped into irrigation or plumbing systems. This water can be used for landscape irrigation or as greywater for indoor plumbing like flush fixtures in restrooms. Both of these uses reduce the demand for potable water and can help reduce monthly water bills.

Greywater

Greywater is gently used water from bathroom sinks, showers, tubs, and washing machines. It does not include water that comes from toilets. Greywater may contain traces of dirt, food, grease, hair, and certain cleaning products. It can be used indoors in flush fixtures or for landscape irrigation. Aside from the benefits of saving potable water and money on water bills, greywater reuse keeps this water out of the sewer or septic system, which reduces risks of storm overflow.
IMPLEMENTATION

There are many different passive design strategies but it is important to evaluate which are the best strategies to implement on each particular building according to the climate, existing building site conditions, and budget. This next section will inform the process for evaluating options during design and provide tools and processes for successful implementation.

EVALUATING PASSIVE DESIGN OPTIONS

The primary goal in implementing passive design strategies is to provide optimum indoor comfort while decreasing energy use. To accomplish this, designers must understand how to choose the best passive design solutions for each individual building. Designers can use a series of evaluations to determine which passive design options are ideal for each scenario. These evaluations include assessing existing building conditions, understanding desired space conditions, and analyzing building energy use. Next, designers must consider and evaluate methods for energy savings, water savings, and cost-effectiveness. The final evaluation must assess indoor environmental quality (IEQ) and thermal comfort.

Existing Building Conditions

Designers first should assess existing building conditions when considering the implementation of passive design strategies. They need to know the building’s characteristics, such as orientation and layout, building type and size, available space for additions, and the ability to modify the building structure. Building renovations incorporating passive design present a challenge because the building orientation and layout are already established and cannot be optimized in the same way that new buildings can. However, by evaluating the existing building’s orientation, the design team can select passive design strategies that take advantage of the orientation or eliminate strategies that will not be effective with the existing orientation and layout.

The design team should examine the sun path and wind rose for the site. Considering sun angles and the prevailing wind direction allows the team to most effectively design for use of passive cooling, passive heating, natural ventilation, and daylighting. Additionally, the team should evaluate the impact of nearby vegetation, land formations, and adjacent buildings, including known future developments. These factors will have a direct impact on the effectiveness of passive design strategies. For daylighting, building orientation has the largest impact on potential passive design strategies. In general, daylighting and visual comfort are most effective when the long axis of the building is aligned with the east-west axis. Existing buildings with orientation and massing that does not fit this criteria can still use daylighting via overhangs, light shelves, skylights, atria, and courtyards.15

Considering the sun path for the site allows the design team to select the most effective daylighting and passive heating and cooling strategies. Sun path diagrams indicate the sun’s altitude and azimuth for various times throughout the year. Several software programs have the ability to create sun path diagrams and allow the design team to analyze the sun path for specific days and times. Some of these programs include Vasari/Revit, Ecotect, and IES Virtual Environment (IESVE). Designers often study the sun path on the winter and summer solstices in order to evaluate the sun path at its extremes.

15 Autodesk Sustainability Workshop.
Additionally, it may be important to study the path at specific times of day, such as the afternoon when overheating and glare may be key concerns.\textsuperscript{16} Figure 12 shows two examples of a sun path diagram. The images on the top show the sun path throughout the day on June 21st, the summer solstice. The images on the bottom show the sun path throughout the year at a fixed time of 12 p.m.

\textbf{Figure 12. Sun Path Diagram Examples}

\textit{Source: Autodesk Sustainability Workshop}

\textsuperscript{16} Ibid.
Building depth, height, and orientation have a significant impact on effectiveness of passive ventilation systems. In general, wind-driven ventilation is maximized when the short axis of the building aligns with prevailing winds. Additionally, stack ventilation is most effective when the height difference between air inlets and outlets is maximized. For existing buildings where the orientation and opening locations may not be optimal, natural ventilation can still be achieved. However, this may require the modification of the building structure or the construction of additional structural elements designed to channel air in a specific direction. Before moving forward with a natural ventilation strategy, the design team should consider the necessity and feasibility of these structural modifications. Figure 13 shows two examples of wind roses. Each wind rose presents the same data: the frequency and speed of wind blowing from each direction. The example on the left shows a speed distribution, which includes frequency on the radial scale. The example on the right shows a frequency distribution, where the radial scale represents wind speed instead of frequency. Numerous software programs have the ability to create a wind rose for a specific site. These programs include both architectural and energy analysis programs such as Revit, Ecotect, IESVE, and Climate Consultant.

Along with building orientation and layout, the design team should consider the available space for building additions and the ability to modify the building structure. Both of these factors may eliminate some passive design strategies from consideration. For example, the ability to add new windows or openings for natural ventilation may not be possible for some buildings. The building conditions also may inhibit modifications to the existing building structure such as the construction of a solar chimney or the addition of thermal mass. In addition to evaluating the ability to modify the external building structure, the design team should consider the potential to alter the interior structure and layout. The building’s operational program has a substantial impact on heating and cooling loads and the strategies that can be used to address them. One strategy to minimize cooling energy use involves moving spaces with large internal gains to north- or east-facing facades. However, this may not be possible for some buildings as it could involve changes to the existing building structure.

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17 Ibid.
18 Ibid.
Desired Space Conditions

In addition to assessing the existing building conditions, the design team should also evaluate the desired space conditions. This includes privacy and noise considerations, occupant comfort criteria, the range of acceptable thermal comfort parameters, and occupancy schedules. Some buildings may have privacy and noise requirements that restrict the use of certain passive design strategies. For example, natural ventilation strategies should be carefully considered for sites with high exterior noise levels or poor air quality. The use of air filters and ducting in conjunction with natural ventilation often requires the aid of mechanical systems, which will increase the building’s energy use. 20

In order to select appropriate passive design strategies, the design team should have an understanding of occupant comfort and behavior. This includes the consideration of comfort criteria including air temperature, air speed, brightness, humidity, metabolic rate, and occupant attire. For example, occupant thermal comfort requirements for a gym may be dramatically different from that of an office. The range of acceptable thermal comfort parameters may influence the selection of passive design strategies. In addition to occupant comfort, the team should evaluate occupant behavior, including typical occupancy schedules. Both occupant comfort and behavior can be obtained using occupant surveys. 21

Building Energy and Water Use

After evaluating the existing building conditions and the desired space conditions, the design team should analyze building energy and water use. This includes the examination of building energy use by fuel type and end use in order to target passive design options that will have a significant impact. For example, the existing building may have a large electric load due to cooling requirements. In this case, the design team may want to consider passive design options that have the potential to reduce electricity use for cooling, including daylighting, shading, evaporative cooling, and night flush cooling. Similarly, insulation and solar heat gain strategies should be considered if the existing building has a large natural gas load due to heating requirements. Heating and cooling degree days are often used to analyze energy demands for heating and cooling in buildings. Degree days for a specific location are calculated by comparing the average outdoor temperature with a defined indoor comfort temperature. For example, if the average outdoor temperature at a site in Los Angeles is 74°F for a particular day and the indoor comfort temperature is 65°F, there are nine cooling degree days for that day. Conversely, if the average outdoor temperature is 54°F, there are 11 heating degree days for that day. Depending on the analysis, degree days may be summed over a specific period such as one month or the entire year in order to evaluate potential energy use. Figure 14 shows an example of a degree day chart for Los Angeles. Heating degree days for each month are indicated in red and cooling degree days are shown in blue.

When targeting passive design options, the design team should also consider any energy performance goals indicated by the building owner or other stakeholders. Energy performance goals are often expressed as a percent reduction in energy use between the pre- and post-retrofit conditions. As a result, it may be important to evaluate the building’s current energy use in order to demonstrate that any goals have been achieved after the retrofit. Primary tools and strategies for the evaluation of building energy use include analyzing electric and gas utility bills and building energy modeling. Analyzing electric and gas utility bills informs seasonal peaks in energy use, which can help the design team select passive design strategies that will have an impact on those peaks. Building energy modeling is especially useful for projects that have energy performance goals, as the team can easily compare two models for the pre- and post-retrofit conditions. Building energy modeling will be discussed in more detail in the following section.

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The evaluation of building water use includes the analysis of indoor use, outdoor use, and any specialized use such as kitchens and cooling towers. When evaluating design options, the design team should start by developing a water balance. A water balance accounts for all water use in a building including fixtures, appliances, equipment, irrigation, and wastewater discharge. Primary tools and methods for the evaluation of building water use include the analysis of water bills and consumption data from water meters and submeters. Water metering enables the design team to track water consumption and target design options that will have a significant impact on water reduction. Although building-level metering is important for tracking total water consumption over time, the design team should also consider the metering of subsystems that may have a significant impact on water consumption. Depending on the building type and water consumption trends and expenses, these subsystems may include irrigation, indoor fixtures and equipment, domestic hot water, reclaimed water, and heating, ventilation and air conditioning (HVAC) equipment.

Energy and Water Savings

Cost savings from energy and water use are one of the primary drivers for retrofits. As a result, it is important to evaluate the energy and water savings that can be obtained through various passive design strategies, as it will have a substantial impact on cost-effectiveness.

One of the most widely used tools for evaluating energy savings is modeling software used to complete project-specific building energy modeling. Architects and engineers should use whole-building energy modeling software to evaluate energy savings because passive design strategies can have numerous interactive effects. Energy modeling can be used for several purposes including evaluating energy savings for several design strategies, complying with green building certification requirements, or evaluating the savings achieved by a final design when compared to the existing building.

Building energy modeling software often includes complex mathematical models requiring a variety of input data including building geometry, weather data, building programming, construction materials, occupant and equipment schedules,
equipment power density, and HVAC equipment specifications. Typical outputs from the software include heating and cooling loads, energy use by equipment type, and energy consumption.\textsuperscript{22} Due to the complexity of passive design strategies and the software used for the analysis, including an energy modeling expert as part of the design team throughout the entire design process is highly recommended. The building energy modeling process requires the cooperation of architects, engineers, energy modelers, and other members of the design team in order to effectively evaluate passive design strategies and the potential energy savings achieved by the final design.

There are numerous energy modeling programs, all of which have various capabilities. The Building Energy Software Tools Directory, managed by the International Building Performance Simulation Association, maintains a list of hundreds of software tools with descriptions of their capabilities. Some of the most widely used whole-building energy modeling programs are eQUEST, EnergyPlus, TRACE 700, and IESVE. The design team may also wish to use software tools that focus on specific building elements and passive design strategies. For example, Radiance and AGi32 are often used to evaluate lighting and daylighting strategies. IESVE also includes specific modules dedicated to lighting and daylighting analysis. Additionally, design teams for buildings incorporating renewable energy systems may utilize software such as PVWatts and HOMER to make estimates of the energy generated by these systems.

In addition to evaluating savings through building energy modeling, there are several factors the design team should consider when evaluating energy savings. In order to maximize savings, the team should consider the adoption of multiple passive design strategies, including integrating daylighting design and electrical lighting through advanced controls or combining solar heat gain with daylighting and internal heat load strategies. However, while some strategies have positive interactions, it is always important to evaluate synergies between each strategy to ensure that their combination does not negatively impact energy efficiency and occupant comfort.

The evaluation of water use and water reduction strategies may require a variety of data including site plans for vegetated areas and water meters, fixture/equipment locations and specifications, occupancy schedules, water meter/submeter data, and expected water quantities from alternative sources such as rainwater harvesting and greywater. For the evaluation of outdoor water use, tools such as the U.S. Environmental Protection Agency’s (EPA’s) WaterSense Water Budget Tool can be used to calculate landscape water requirements for various plant types, planting densities, and irrigation systems. When calculating the final landscape water requirement, the design team should account for any water reductions due to the use of alternative water sources. For example, rainwater harvesting potential can be estimated with the use of historical rainfall data and harvesting equipment specifications. For the evaluation of indoor water use, fixture and equipment water use is typically calculated based on equipment specifications and occupancy schedules.

\section*{Cost-Effectiveness}

Cost-effectiveness is one of the most important elements that the design team should consider when evaluating passive design strategies. Cost-effectiveness can be evaluated through several methods including simple payback, internal rate of return (IRR), and lifecycle cost analysis. The simple payback method, defined as the time required for the project’s annual cost savings to equal its investment cost, is one of the most commonly used methods to evaluate cost-effectiveness. For example, a $600,000 retrofit that saves $100,000 per year in energy costs has a simple payback of six years. Although this method is easy to use, it does not consider costs and benefits over the full lifecycle of the investment. A second method often used to evaluate cost-effectiveness is the IRR. Unlike the simple payback method, the IRR method considers a series of

Due to the substantial benefits that passive design strategies can provide over the full lifecycle of the investment, lifecycle cost analysis (LCCA) methods are recommended for the evaluation of cost-effectiveness. LCCA methods account for all cash flows over the lifetime of the project. When selecting between multiple passive design strategies, the design team should consider the strategies with the lowest lifecycle costs. Unlike the simple payback method, the LCCA method accounts for the time value of money. When using the LCCA method, each cash flow is reduced to its present value (PV). Important cash flows include the initial investment cost, energy costs, operation and maintenance (O&M) costs, rebates and incentives, and salvage value. The lifecycle cost for an investment is defined as follows:

\[
LCC = I + Repl - Res - Incent + E + W + OM&R \\ (Adapted 24,25)
\]

- **LCC** = total lifecycle cost in present value dollars
- **I** = investment costs, including material and labor costs
- **Repl** = capital replacement costs
- **Res** = residual value (resale value, salvage value) less disposal costs
- **Incent** = financial incentives (rebates, tax credits, etc.)
- **E** = energy costs
- **W** = water costs
- **OM&R** = non-fuel operation, maintenance, and repair costs

Investment costs refer to all initial costs associated with the construction of passive design strategies. This includes the purchase cost of equipment and materials as well as installation costs. Replacement costs include any equipment and materials that must be replaced when they reach the end of their useful life during the analysis period. The analysis should assume that each component is replaced with a system with the same characteristics and efficiency as the original. Financial incentives include rebates, tax credits, subsidies, and other incentives offered by the government and utilities. Residual value is not common for building retrofits but should be included for any components that have salvage or resale value. Non-fuel O&M costs associated with passive design strategies and energy-efficient equipment are often assumed to be less than

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24 Ibid.
those for traditional buildings; however, the design team should carefully consider any expected O&M costs and how these costs may vary between different design options.26,27

Energy and water costs are some of the primary drivers for retrofits and should be carefully considered. When evaluating energy costs from electricity and gas use for any cost-effectiveness method, it is important to use the utility rate schedules for the building. This will allow for an accurate calculation of energy costs that accounts for any price variations throughout the day or year. Additionally, it is important to determine the applicable peak demand charges, which can have a significant impact on energy costs for some building types. In many cases, the modeling software that is used to complete project-specific building energy modeling can also be used to evaluate energy costs when used in conjunction with utility rates. If this is not possible due to software restrictions or complicated rate structures, hourly energy consumption results can be exported from the software for a manual calculation of energy costs. In addition to utilizing the correct utility rate schedules, the design team should also consider applying escalation rates to energy prices. Although energy prices are volatile and difficult to predict, many economic analyses often include energy price escalation. One of the most commonly used sources for escalation rates is the Annual Energy Outlook published by the U.S. Energy Information Administration.28

It is important to note that the results of LCCA depend on the discount rate and the lifetime assumed for the project. The discount rate is used to bring all cash flows occurring at different times to a common point in time. Discount rates should accurately represent the rate of return that could be earned on an investment with a similar lifetime and level of risk.29 The lifetime of the project should include the construction period as well as the occupancy period. In order to effectively compare passive design strategies, the lifetime for the economic analysis should be the same for all strategies that are considered.30

Although the LCCA method is recommended when comparing passive design strategies, it is also important to consider any stakeholder preferences when presenting cost-effectiveness. Some stakeholders may be comfortable with specific methods, including simple payback or IRR. In this case, the design team should consider presenting cost-effectiveness through several methods, with the inclusion of other elements that can build the business case for passive design strategies. In addition to direct costs and benefits, LCCA often considers factors that have social and environmental impacts. Although these factors are difficult to quantify, a complete LCCA considers social and environmental benefits and costs when presenting the final business case for passive design strategies. Section V describes the business case for passive design in detail.

Indoor Environmental Quality

Passive design strategies have the potential to provide other important benefits including the improvement of IEQ. When evaluating passive design options, the design team should start by considering any IEQ criteria indicated by the building owner or other stakeholders. Even in the absence of specific IEQ criteria or goals, it is important to evaluate the IEQ benefits that various passive design strategies can provide. IEQ has a substantial impact on occupant comfort, health, and productivity, which will be discussed in Section V.

26 Ibid.
28 Ibid.
30 National Institute of Building Sciences.
Indoor air quality (IAQ), ventilation, thermal comfort, lighting, noise, and views all influence IEQ.\(^{31}\) IAQ refers to indoor pollutant concentrations that can affect occupant comfort, health, and productivity. It is estimated that the average person spends about 90% of their time indoors, where pollutant concentrations can be higher than outdoor concentrations due to pollutants that are generated inside the building. Improving ventilation is one of the most common methods used to improve IAQ in commercial buildings. However, providing significantly more outdoor air than a space requires often increases energy requirements for HVAC equipment. A ventilation strategy incorporating natural ventilation has the potential to maintain good IAQ while reducing energy use.

Ventilation rates indicate how much outdoor air is supplied to a specific space in a building by both mechanical and natural methods. Ventilation is often described using air changes per hour, which is a function of the size of the space and the volumetric flow rate of air.\(^{32}\) One of the most widely used resources for evaluating ventilation is ASHRAE Standard 62.1 – Ventilation for Acceptable Indoor Air Quality, which includes minimum requirements for the amount of outdoor air that should be delivered to different types of spaces in a building. This ASHRAE Standard includes calculation procedures and requirements for mechanical ventilation, natural ventilation, and mixed-mode systems. Before using any standards, the design team should determine any local code requirements for building retrofits. For example, many localities adopt California Title 24 standards, which have different calculation procedures and requirements for ventilation.

Thermal comfort refers to occupants’ satisfaction with the thermal conditions inside a building. Thermal comfort will be described in detail in the following section. For buildings where thermal comfort, IAQ, and ventilation are especially important or are primary components of a passive design strategy, the design team should consider the use of specific software tools designed to evaluate these factors. Some of these tools include FloVENT and ANSYS Fluent. Both of these tools use Computational Fluid Dynamics (CFD) models to analyze airflow. If the design strategies or IEQ criteria warrant an in-depth study using these tools, engineers, building physics specialists, or other members of the team that have CFD expertise should complete the analysis.

Lighting strategies are an important consideration for any building design due to their impact on energy use and IEQ. Daylighting has the potential to significantly reduce lighting energy use; however, it is important to consider glare, illumination levels, light distribution, and brightness, all of which have impacts on IEQ. When designing a lighting system, the design team should start by determining the recommended lighting levels for the activities occurring in the building. Lighting criteria can be found in local building codes, green building certification standards, or resources such as The Illuminating Engineering Society of North America Handbook.\(^{33}\) When daylighting plays a significant role in a lighting strategy, several software tools can be used to evaluate illuminance and glare. One of the most widely used tools is Radiance, which is built in to several other software tools including Ecotect and IESVE. IESVE also includes other modules that analyze light distribution from artificial light or a combination of artificial and natural light. Another widely used software tool for artificial light analysis and visualization is AGi32. Figure 15 shows two examples of renderings produced by lighting analysis software. The image on the left is an illuminance rendering with daylighting only, while the image on the right is a rendering with electric lighting only.

Two other important elements of IEQ include noise and views. Depending on the building location, orientation, and layout, noise may be of particular concern for retrofits incorporating natural ventilation strategies. The design team should carefully consider how all strategies will affect noise and views, as both of these may have impacts on occupant productivity and satisfaction. Similar to daylighting, glare is sometimes a concern when designing for views. If views are especially important, the design team should consider utilizing daylighting tools to analyze glare.

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\(^{32}\) Autodesk Sustainability Workshop

\(^{33}\) Ibid.
Thermal Comfort

One of the most important aspects of IEQ is thermal comfort. ASHRAE Standard 55 – Thermal Environmental Conditions for Human Occupancy defines thermal comfort as “that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation.” Thermal comfort includes six parameters: air temperature, humidity, MRT, air speed, clothing level, and metabolic rate. The typical comfort range is thought to be between 68°F and 80°F and 20% and 80% relative humidity. Although thermal comfort is highly subjective, it is an important factor to evaluate for energy-efficient buildings. If occupants are not comfortable, they may utilize HVAC systems to increase building energy use.

Passive design strategies can have a significant impact on the four environmental factors that make up thermal comfort: air temperature, MRT, humidity, and air speed. The comfort of occupants depends not only on air temperature but also on the temperature of surrounding objects. The MRT is the weighted average of the temperatures of surfaces adjacent to an occupant. As a result, the MRT for an occupant near a window will be different than that for an occupant located in an interior zone. While almost all passive design strategies have an impact on air temperature and MRT, natural ventilation strategies have the most significant impact on humidity and air speed. Clothing and metabolic rate also have a substantial impact on occupant thermal comfort. Clothing level is measured in clo and refers to the amount of thermal insulation an occupant is wearing. Metabolic rate is measured in met and is defined as the energy generated by an occupant based on their activity. Typical clothing insulation values and metabolic rates for typical activities can be found in references such as the ASHRAE Handbook – Fundamentals.

When considering the incorporation of passive design strategies, it is important for the design team to evaluate the range of conditions where occupants feel comfortable, often referred to as the “comfort zone.” One of the most important tools for visualizing air conditions and the comfort zone is the psychrometric chart. Figure 16 shows a simple example of a psychrometric chart. The vertical blue lines represent dry bulb temperature, and the diagonal green lines represent wet bulb

35 Autodesk Sustainability Workshop
36 Ibid.
37 Ibid.
temperature. Relative humidity is indicated on the curved red lines. The comfort zone is often indicated by shading a portion of the psychrometric chart. This comfort zone is dependent on several factors including location, building activities, and the level of clothing worn by the occupants.\textsuperscript{38}

Passive design strategies can impact the comfort zone by shifting it to lower or higher temperature and/or humidity levels. For example, if more radiant heat is available, occupants may still feel comfortable at lower air temperatures. Conversely, occupants may still feel comfortable at higher air temperatures if more air movement is present. Figure 17 shows an example of a psychrometric chart with a comfort zone. In this case, the blue boxes indicate the comfort zone without any passive design strategies. The blue box on the left shows the comfort zone for winter clothing, while the box on the right shows the comfort zone for summer clothing. The green box indicates the comfort zone when natural ventilation is applied; with this strategy, the comfort zone shifts to include higher temperatures.

Although thermal comfort is subjective and difficult to measure, several methods for quantifying thermal comfort have been developed. ASHRAE Standard 55 presents two thermal comfort models: the predicted mean vote (PMV) model and the adaptive comfort model. The PMV model includes a thermal scale that ranges from -3 (Cold) to +3 (Hot), with zero representing neutral. The PMV is calculated through a heat balance mathematical model that relates thermal comfort parameters. The thermal comfort range recommended by ASHRAE Standard 55 corresponds to a PMV range between -0.5 and +0.5. The PMV model is typically used for buildings that utilize active mechanical systems. The percentage of occupants that will not be satisfied with a set of thermal conditions is represented by the predicted percentage dissatisfied (PPD). As the PMV moves away from a value of zero (neutral), the PPD increases. ASHRAE Standard 55 recommends a PPD of less than 10%.\textsuperscript{39}

\textsuperscript{38} Ibid.

\textsuperscript{39} Ibid.
The adaptive comfort model is more appropriate for buildings incorporating passive design strategies because it acknowledges a difference in expectations between occupants in a mechanically cooled building and a naturally ventilated building. The adaptive comfort model assumes that thermal discomfort will prompt occupants to take actions such as making clothing adjustments, opening or closing a window, and using controls. This assumption widens the comfort range and expands the acceptable comfort conditions for occupants. The adaptive comfort model is appropriate for a building with operable windows and no mechanical cooling system.\(^{40}\)

Several tools are available to evaluate thermal comfort. Design teams can purchase thermal comfort software such as ASHRAE’s Thermal Comfort Tool, which makes thermal comfort predictions using several existing thermal comfort models including the PMV and adaptive comfort models. Alternatively, there are free software tools that can be used to evaluate thermal comfort, including the Center for the Built Environment’s Thermal Comfort Tool. In order to utilize these thermal comfort tools, the design team should start by evaluating occupant characteristics such as clothing level and metabolic rate. Next, the design team should set comfort criteria for operative temperature, humidity, and air speed for each area of the building. The comfort criteria should consider the building’s occupancy schedules, the level of occupant control, and any energy or comfort goals established by the building owner.\(^{41}\)

\(^{40}\) Ibid.

In a conventional design and construction process, each discipline works separately to minimize costs and maximize benefits for the building systems and components for which they are responsible. With this process, synergies and relationships between building systems may be overlooked. Because passive design strategies have complex interactions with other building systems and the potential to yield substantial environmental and health benefits when optimized, an integrative design process is recommended. An integrative design process involves the participation and collaboration of several parties throughout the entire design process including the building owner, architect, mechanical engineer, lighting designer, contractor, and other members of the design and construction team. In order for the project to be successful and delivered on time and on budget, the design team should follow a process such as integrated project delivery (IPD), as illustrated by the American Institute of Architects (AIA). AIA defines IPD as “a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction.”

IPD brings all stakeholders to the table early and often to make design decisions when they are the most effective and least costly. The Macleamy curve shown in Figure 18 illustrates how the ability to affect design decreases through the design process while the cost of making these changes increases. By shifting typical design decisions to earlier phases in the schedule, project teams can influence the design in a positive way while spending less money. Including occupants in the design process can also increase acceptance at the end of the project.

Figure 18. Macleamy Curve


It is important to establish an operations cycle before designing or retrofitting a building's systems using passive design strategies. The first step is always to establish a baseline, through measuring performance data or using existing data if it is already collected. The next steps entail assessing the current building status, including the structure, systems and interiors age, identifying existing thermally passive structures, and identifying tuning opportunities within the envelope and systems. The design team should use this information and data to establish performance targets. These targets may include thermal
comfort, peak performance, annual energy, and thermal resilience. It is important to identify targets before taking any design steps, so that design decisions align with pre-established goals.

Once the building assessment is complete and performance targets are set, the design team should do a comprehensive evaluation of the site opportunities and needs, including establishing site ecology, thermal needs, and determining design solutions. The design team should use modeling tools to compare design solutions and confirm selected systems and strategies will meet the performance targets. When the passive strategies are implemented, it is important to establish an ongoing performance tracking mechanism. This ongoing feedback will allow building operators to assess functionality regularly and make changes when needed to continue to achieve performance goals. Ongoing maintenance is important for continued performance. This can be accomplished by designing for a planned life and age, identifying ways of ongoing feedback and benefits, and designing systems for future improvements and upgrades. This full timeline is illustrated in Figure X.

In addition to energy savings, one of the primary benefits of passive design is improved occupant comfort in the renovated space. To ensure that this improvement or any specific comfort goals are achieved, the design team should consider conducting pre- and post-renovation measurements. These occupant comfort evaluations can include thermal comfort, air quality, acoustic comfort, lighting comfort, and office layout.

If the building will be occupied during construction, phasing will be important to maintain worker productivity with limited disruption. Health and safety for building occupants and construction workers are also important to consider both during and after construction. It is common practice in the industry to follow the Sheet Metal and Air Conditioning National Contractors Association’s (SMACNA’s) IAQ guidelines during construction. Following these guidelines includes limiting particulates, volatile organic compounds, and microorganisms; using MERV 8 filters during construction; protecting HVAC equipment, ductwork, and absorptive materials; considering source control and pathway interruption of potential contaminants; and good housekeeping around the site. Additionally, smoking should be prohibited onsite, and vehicles should not be idling close to outdoor air intakes. These concepts are important to consider both for the health of construction workers and also for the health of occupants in cases where the building is still in use during construction.

Once the building renovation is complete or each phase is complete, a building flush out should be conducted to fully remove any remaining contaminants in the building to prepare for occupant move in. If the building is being turned over in phases, the flush out can also be conducted in phases. It is important that each flushed area is then isolated from non-flushed por-
SECTION 1

BUSINESS CASE: TRIPLE BOTTOM LINE

ENVIRONMENTAL BENEFITS
FINANCIAL BENEFITS
BUSINESS CASE: TRIPLE BOTTOM LINE

When assessing the benefits of a passive design retrofit, it is important to look deeper than just a simple cost comparison. Passive design offers diverse benefits, including improved productivity and health of occupants, environmental benefits, and financial savings. These three benefit categories together make up the triple bottom line.

Improved Productivity and Health

There are many health and wellness benefits for occupants that can result from daylighting, good IAQ quality, and other aspects of passive design. Although most people agree that improved productivity and health result from green buildings, these improvements remain difficult to quantify. In 2010, 60% of firms expected to see an increase in productivity due to sustainability efforts in their buildings. Regardless of what that increase in productivity is, the potential savings over the life of a building can be significant. It is estimated that an organization spends over 92% on human capital through salaries and benefits, 6% on operations and maintenance, and 2% on design and construction. This illustrates that even without consensus on what the increased productivity rate is, even a 1% increase could mean huge financial gains for an organization.

Workplace Productivity

Workplace productivity, or task performance, can be measured by looking at quantity of work produced as well as the quality of that work. There have been several studies on how daylight, outside views, ventilation, and other green building components can affect the productivity of workers. Figure 19, adapted from a 2013 World Green Building Council (WGBC) report, illustrates the productivity benefits of green buildings that utilize windows, daylighting, and improvements in lighting, ventilation, and temperature control. A 2003 study by Heschong Mahone looked at call center workers and established that given access to outdoor views, staff processed calls 6%-12% faster and performed 10%-25% better on mental function and memory tests than staff without views.

A Carnegie Mellon University study found the following:

- Individual thermal comfort control created a 3% increase in productivity
- Improved ventilation resulted in an 11% gain in productivity
- Improved lighting showed a 23% boost in productivity

Furthermore, connections to the environment through daylight and operable windows increased individual productivity as well as organizational productivity through retail sales.
Figure 19. Effects of Green Building Strategies on Productivity


Prevent Sick Building Syndrome

Sick Building Syndrome (SBS), defined by the EPA as “situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building,” is a widely used term in the conversation between the built environment and its impact on the health and well-being of occupants. Occupants in a building with SBS may experience eye, nose, skin, or throat irritation; coughing; headaches; and fatigue. These symptoms are usually relieved soon after exiting the building. The main causes of SBS are thought to be inadequate ventilation, chemical contaminants from indoor and outdoor sources, and biological contaminants. By addressing these issues in existing buildings it is estimated that SBS symptoms could be reduced by 70%-85%.

Reduce Stress and Depression

Studies show that improved daylight, views to the outdoors, and better IAQ can lead to reduced stress in the office and more positive moods for occupants. A study conducted by the American Council for an Energy Efficient Economy finds that positive moods can have a positive effect on job satisfaction, motivation, organizational loyalty, and reduced absenteeism.

Protect Occupant Health

There has been a large emphasis on health and wellness in the built environment due to the release of a new building certification, The Well Building Standard, in late 2014. The Well Building Standard is a good resource to provide guidance on ways to minimize the effects of the building on different body systems, including cardiovascular, digestive, endocrine, immune, integumentary, muscular, nervous, reproductive, respiratory, skeletal, and urinary systems.

In the Annual Review of Energy and the Environment, William J. Fisk concludes that, “for the United States, the estimated potential annual savings and productivity gains are $6 to $14 billion from reduced respiratory disease, $1 to $4 billion from
reduced allergies and asthma, $10 to $30 billion from reduced SBS symptoms, and $20 to $160 billion from direct improvements in worker performance that are unrelated to health." The use of passive design strategies such as daylighting, natural ventilation, and IAQ can contribute to these savings and better occupant health.

ENVIRONMENTAL BENEFITS

There are several environmental benefits that can result from using passive design strategies, particularly in existing buildings. These include reducing pollution, ecosystem benefits, and lower resource use.

Less Pollution

The current U.S. building stock consumes 40% of U.S. energy, releases 30% of U.S. greenhouse gas emissions and 38% of carbon dioxide emissions, and uses nearly 13% of all potable water in the United States. All energy- and water-reducing measures implemented in buildings help to lessen the pollution impact. Particularly, energy savings resulting from passive heating, cooling, and daylighting strategies reduce carbon dioxide emissions and the production of other pollutants associated with energy generation. This improves the air quality in the immediate vicinity of the building and has global implications by minimizing the contribution to climate change.

Ecosystem Impact

Some green building strategies such as green roofs can preserve the local ecosystem. Green roofs, which are used to grow plants on the roof as opposed to a non-permeable surface, provide a habitat for both animals and plants. They also absorb more water than hard surfaces, reducing runoff from the building to the surrounding landscape and preventing water pollution and erosion. Green roofs also minimize the urban heat island effect, as they are lighter in color and less reflective than traditional roofing materials. Other strategies similar to green roofs are cool roofs, in which the roof is painted white to reduce the heat island effect, or blue roofs, which employ a number of water-absorbing or water-slowing mechanisms to reduce runoff and the associated erosion and pollution issues.

Lower Resource Use

Nearly all retrofit projects use significantly fewer resources than new construction because they retain key elements of the original building instead of sourcing entirely new materials and structures. Though few passive design strategies actually specify resources to use, there are many applications for local and/or recycled materials in passive design. For example, adobe buildings use local earth for construction, resulting in walls with high thermal mass that insulate the space. More generally, passive design elements are often incorporated into a broader green design plan. Green buildings often focus on the durability and longevity of systems and finishes.
FINANCIAL BENEFITS

Passive design strategies also offer many financial benefits including reductions in energy costs, keeping tenants longer, and decreasing maintenance costs. When evaluating the financial benefits of a retrofit project, it is important to go beyond weighing retrofit costs against energy cost savings in order to capture the total value of the retrofit. The Rocky Mountain Institute developed a useful guide on this topic, titled “How to calculate and present deep retrofit value.” Figure 20 demonstrates this approach, which takes into account the development cost reductions, operating cost savings, tenant-based revenues, and sales proceeds in addition to the energy cost savings.

Figure 20. Deep Retrofit Value

Right-Sized Systems Mean Lower First Costs

Buildings that employ passive design strategies for heating and cooling often have smaller HVAC systems due to smaller peak demands, which reduces system first costs. This is a compelling reason for using passive design in new construction, but it can also apply to retrofits if the building is replacing its HVAC systems. In such cases, adding passive heating or cooling mechanisms can decrease the size of the HVAC system needed.

Lower Annual Costs Due to Energy Efficiency

The most obvious benefit of passive design is the decreased annual energy costs. By using passive heating, cooling, and daylighting strategies, a building consumes less energy to condition the spaces and make them comfortable for occupants. According to the WGBC, the range of estimates for the energy reductions in LEED-certified buildings is 25%-30% when compared to code-compliant buildings. This can free up significant budget allocations that were previously committed to energy costs. Although the LEED rating system evaluates all aspects of a green building, passive design strategies are commonly used to help contribute to the energy cost savings needed to gain points to achieve certification.
Lower O&M Costs

Many green buildings have lower operating costs and require less maintenance over the long-term. Since many passive design techniques do not include mechanical or electrical systems, they need less frequent maintenance when compared to traditional HVAC and lighting systems. Some passive design strategies like thermal mass and daylighting have zero operating cost. These lower costs are a compelling reason for many stakeholders to pursue these strategies; in fact, 92% of companies report being influenced by operational savings in their decision to pursue energy efficiency projects.

Protection Against Increasing Energy Prices

Future energy prices are unknown but projected to increase on the aggregate, which poses a risk for high energy use buildings. As energy prices fluctuate, buildings using passive design strategies will be less vulnerable to budget crises during price increases.

Higher Sales Price/Rental Rates

Several studies have shown a rental rate premium and higher resale value for certified green buildings. The studies attribute this difference to tenants’ interest in better indoor environments, lower operating costs, and enhanced marketability. One metastudy of this phenomenon observed increased rental rates of 2%-17% and improved resale values of 5.8%-35%. This study also found that green buildings may be able to maintain 2%-18% higher occupancy rates, as there is lower tenant turnover.

Higher Tenant Retention

Building owners want high tenant retention because it avoids costs associated with vacancy, tenant turnover, and construction and renovations for new tenants. The decrease in tenant turnover in green buildings may be due to increased employee satisfaction. A 2011 survey showed that 33% of firms consider employee/occupant satisfaction as an influence in their decision to pursue green retrofit projects.

Improved Corporate Image and Market Differentiation

Companies with high visibility may also choose to pursue green or passive design as part of their corporate image strategy. Sustainability is gaining traction as a corporate ideal, and many industries are implementing more sustainable practices, ranging from using recycled packaging to installing solar panels on their facilities. Of companies, 73% report being influenced by market differentiation in their decision to pursue energy-efficient retrofits. The desire to be seen as a green business will likely continue to increase as public opinion continues to embrace sustainability.

Improved Asset Value

All of the above-mentioned benefits contribute to the improved asset value of green buildings that use passive design strategies. In addition to saving money on energy, maintenance, and operations, green design provides higher rental rates and resale values, higher occupancy and lower tenant turnover, and market differentiation. These features contribute to both financial and non-financial benefits.
SECTION 1

OTHER DIVIDER
AS NEEDED

SUBSECTIONS HERE
SUBSECTIONS HERE
VI. Case Study

DPR San Diego Office
Callison, LLC
San Diego, California
2010

DPR achieved Net Zero Energy and LEED Platinum certification on its San Diego office by utilizing passive design features. Through a major building retrofit, DPR incorporated natural ventilation and daylighting techniques into the 1984 one-story, tilt-up concrete building. The retrofit increased daylighting by maximizing window area and adding vertical skylights and Solatube light tubes. DPR also installed rooftop monitors to control the building’s electrical lighting and mechanical systems. When the rooftop photosensors capture more than 30-foot candles of available daylight, the electric lighting fixtures automatically turn off. In order to eliminate the need for tasklighting, DPR uses a layered lighting strategy that introduces the appropriate light levels for each space’s use.

DPR’s office has operable windows that are connected to the building management system. These windows are also controlled by the rooftop monitors on the north side of the roof. When the temperature outside is within the set comfort range, the windows open and the HVAC system turns off and locks. This passive ventilation is employed in about 80% of the total square footage of the building. The remaining floor area is composed of multi-occupant spaces and utilizes occupancy sensors to control the HVAC system. Large, high-volume fans are installed to move air throughout the space when the mechanical systems are turned off.

These passive design strategies have significantly improved the overall energy consumption of the office. Since implementing these strategies and completing the retrofit, DPR’s office achieved an energy utilization index of 4 kilowatt hours per square foot. Using data from the Commercial Building Energy Consumption Survey, this value represents 25% of the national average for commercial offices resulting in an Energy Star score of 97. Through these design strategies, the building reduces energy use by 35% annually and reduces energy cost by 38% when compared to a baseline building defined by ASHRAE Standard 90.1-2007. In addition, the building also implemented high efficiency, low-flow fixtures to reduce indoor water consumption and save 40% in annual water savings when compared to a calculated baseline defined by the Uniform Plumbing Code.
ADDITIONAL RESOURCES

Partner Resources

United States Green Building Council – Los Angeles Chapter (USGBC-LA)
800 Wilshire Blvd, 16th Floor, Los Angeles, CA 90017
213.689.9707
http://usgbc-la.org/

Los Angeles Better Buildings Challenge
411 S Hewitt St, Los Angeles, CA 90013
http://la-bbc.com/

Southern California Chapter of ASHRAE
P.O. Box 80133
San Marino, CA 91118
http://www.ashrae-socal.org/index.asp

AIA Los Angeles
3780 Wilshire Blvd., Suite 800, Los Angeles, CA 90010
213.639.0777
http://www.aialosangeles.org/

Other Resources

California Building Energy Efficiency Standards – Title 24
http://www.energy.ca.gov/title24/

ASHRAE Standards
ASHRAE 90.1 – Energy Standard for Buildings Except Low-Rise Residential Buildings
ASHRAE 55 – Thermal Environmental Conditions for Human Occupancy
ASHRAE 62.1 – Ventilation for Acceptable Indoor Air Quality
ASHRAE 189.1 – Standard for the Design of High-Performance Green Buildings

Well Building Standard
http://www.wellcertified.com/well