SOLAR INTEGRATION: APPLYING HYBRID PHOTOVOLTAIC/THERMAL SYSTEMS

by

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Abstract

On-site energy production is becoming increasingly prevalent in building systems design with a renewed public awareness of sustainability, decreased energy resources, and an increase in the requirements of local and federal energy codes. Systems such as photovoltaics and solar thermal collectors have been implemented in designs to meet these challenges. The emerging technology of hybrid photovoltaic thermal (PVT) offers the potential to combine these systems into one contained module. A hybrid PVT system can simultaneously produce thermal and electrical energy, maximizing the use of available surface area available for energy production. Hybrid PVT can be implemented using PVT air collectors, PVT liquid collectors, and ventilated PV facades. Hybrid PVT is gaining interest at the academic level and is being applied at the residential level. Several commercial hybrid PVT products are currently manufactured, but options are limited.

This report will evaluate PV, solar thermal collector, and hybrid PVT technologies, discuss the various components required for these systems, and present advantages and disadvantages of these systems. For an example elementary school design, the report will compare monthly energy production of the various systems, evaluating their ability to supply the peak loads of an example building design. Estimated first costs and operating and maintenance costs will be evaluated. The report will also quantify the ideal balance of PV and solar thermal collectors for the example based on loads and simple payback. Conclusions will be made about the current state of hybrid PVT and what steps need to be taken for it to be effectively implemented in the commercial building market.

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Acknowledgements

I would like to acknowledge and thank my major professor, Professor Fred Hasler for his direction and review of this report. I would also like to thank Professor Carl Riblett and Professor Ray Yunk for their help and guidance.

Dedication

I dedicate this report to my family. To my parents, for giving me all the tools to succeed and for always believing I could do anything I wanted. To Scott, for supporting me and helping me in stressful times and for preparing me for the presentation. You all are so important to me and I appreciate you very much.

CHAPTER 1 - Introduction

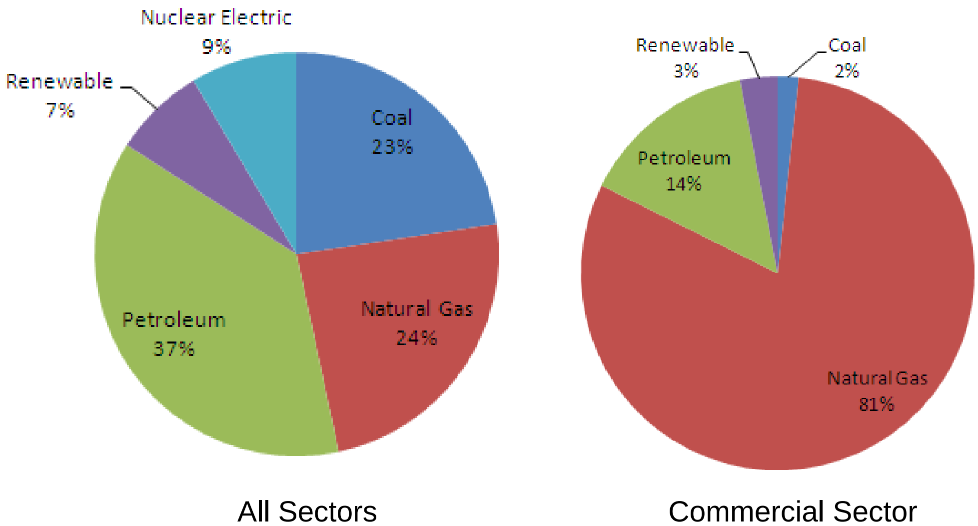
The Need for Solar Design

This section of the report addresses the growing need for energy efficient designs, and how solar energy can satisfy this need.

Energy Consumption

In 2008, the commercial sector in the United State consumed approximately 4.61 Quadrillion Btu of electricity and 18.58 Quadrillion Btu of energy in total. Of this total, only 3% of the energy consumed was generated by renewable means, with fossil fuels serving as the main source. The graphs below show the breakdown of U.S. energy consumption as a whole and in the commercial sector by source type (U.S. Energy Information Administration, 2009).

Figure 1.1 U.S. Energy Consumption by Source, 2008



By the year 2035, it is estimated that total commercial energy consumption will increase to 24.30 Quadrillion Btu annually (U.S. Energy Information Administration, 2009), which is a 30% increase from current consumption. This increase in consumption will need to be met by an increase of energy production. As one of the smallest sources currently for the commercial sector, renewable energy has the opportunity to grow and help fill this void. Renewable energy includes generation from sources such as hydropower, biomass, solar thermal collectors, photovoltaics (PV), and wind. Specifically, this report will explore how solar thermal collectors, PV, and the new technology of hybrid PVT can offset consumption of traditional fossil fuels in commercial buildings.

Energy Code Compliance

Current energy codes such as ASHRAE 90.1 and the IECC, as well many local and state codes, exist to encourage energy conservation. These codes, which aim to increase energy efficiency and limit energy consumption in commercial buildings, are becoming increasingly stringent. For example, the upcoming release of the ASHRAE 90.1-2010 is expected to increase minimum prescriptive energy efficiency requirements by 30% over the 2004 version of the standard (Silverstein & Vallart, 2009). These increases will come in the form of changes to envelope, HVAC, and lighting requirements. Even though current codes and standards work to limit energy use, most do not have provisions for required on-site energy production. A code that could more effectively combat expected increases in commercial energy consumption would merge increases in energy efficiency requirements with renewable energy requirements. There are several codes in development that are expected to require energy production, such as the International Green Construction Code (IGCC) and ASHRAE 189.1, which will be discussed further in Chapter 8 of this report.

Incentives

There are various tax credits and other incentives available to commercial building owners who choose to incorporate sustainable design into their buildings. The Investment Tax Credit (ITC) available under Title 26, Section 48 of U.S. Code is applicable for small scale renewable energy production used on a site. It provides a 30% credit toward the property's initial tax basis. A similar program, the Production Tax Credit (PTC) available under Title 26, Section 45 of U.S. Code is applicable when renewable energies generated are sold, instead of used on site. Also available is the American Recovery and Reinvestment Act of 2009, also known as Recovery Act 1603, that provides cash grants to owners in lieu of tax credits, but cannot be used in conjunction with the ITC (U.S. Department of Energy, 2009). The 2005 Energy Policy Act (EPAct) provides tax deductions up to $1.80/ft^2 for buildings that exceed ASHRAE Standard 90.1-2004 (Deru, 2007). However, since ASHRAE Standard 90.1-2004 makes no requirements for renewable energy production, the ITC is currently the best option for owners looking to implement solar thermal or photovoltaic designs.

The U.S Green Building Council's Leadership in Energy and Environmental Design (LEED®) program provides certification for sustainable buildings and is a way to more publicly display a building owner's commitment to the environment. Several credits towards certification can be earned by utilizing renewable energy, through Energy and Atmosphere Credit 1, Optimize Energy Performance and Credit 2, On-Site Renewable Energy, in the LEED 2009 for New Construction and Major Renovation rating system.

Obstacles to Solar Design

First Cost

A major consideration for an owner is the initial cost of a building. For some landlords or developers, a low first cost may even be the most important factor in the building design. The addition of a solar thermal or photovoltaic system adds a significant increase to a building's initial cost of construction. Since this cost may be offset by the equipment's lifetime energy savings and tax incentives, it is important that the owner is educated on the design options available and the trade-offs between lifetime and first costs. Determination of the estimated simple payback of a system through energy savings, or the amount of time it will take for the energy savings to equal the first cost, is useful in the early design stages and may help to convince an owner to choose a sustainable design. The costs of specific photovoltaic and solar thermal systems will be discussed further in Chapter 7.

Client Demand

Regardless of additional first costs associated with many sustainable designs, many clients desire to incorporate sustainability into their building, be it for reasons of long-term economics or social responsibility. Often, sustainable designs are pursued on a project due to specific client request. According to a survey by Autodesk, Inc. and the American Institute of Architects (AIA), about 50% of architects have a majority of clients that are interested in sustainable designs. However, only 30% of architects actually ended up implementing those green designs (Autodesk, AIA, 2007). With requests for sustainable design coming directly from the client, architects and designers should strive to meet their clients' needs. The design team should serve as an advocate of sustainable design to the client.

Design Team Knowledge

Solar technologies are new and constantly evolving and a designer must be up-to-date with current codes and recommendations. The Fundamental Canons of the NSPE Code of Ethics for engineers states that engineers shall, "Perform service only in areas of their competence," (National Society of Professional Engineers, 2007), and it is important that designers that decide to engage themselves in sustainable designs such as photovoltaics and thermal solar collectors do so because they have training and experience. While it is important for designers to pursue sustainable designs whenever possible, it is not ethical for a design team to take on a project without being honest about their competency to the owners and other designers. Training sessions and development are crucial to keep engineers current in the advancement of their skills. This development shows a commitment to the design profession, as many professional accreditations require hours of continuing education, including Professional Engineering licensure and LEED credentialing.

Site Constraints

In the early design stages, it is important to determine if PV or solar thermal collectors are even feasible for the desired location. A site is not always ideal or suitable for solar technologies. Urban buildings with a small footprint may not have enough surface area available for photovoltaics or solar collectors to warrant their installation. Neighborhoods or municipalities may have restrictions that limit the locations that thermal collectors or PV panels may be mounted, especially in historic districts. Additionally, if a site is shaded, it will be difficult to get any significant production from these systems. Solar collectors may prove to be a better option when a site is partially shaded, as PV systems see a large drop in efficiency when even partially shaded. For sites where on-site solar energy generation is not feasible or economical, the purchase of renewably-generated power, or renewable energy credits (REC), from the utility can be considered. The U.S. Department of Energy provides a helpful resource for determining the green power purchasing options by state, at: http://apps3.eere.energy.gov/greenpower/buying/buying_power.shtml (U.S. Department of Energy, 2008).

Vocabulary

The following basic vocabulary is useful when discussing solar energy systems, such as PV, thermal collectors, or hybrid PVT and is provided for clarity in this report:

Efficiency – The ratio of the energy output by a collector to the energy input by the sun

Exergy –The net energy that is available to be used, energy gains less energy losses

Insolation – The amount of solar energy per unit area that strikes the earth's surface in a given period of timed, often measured in kWh/m^2-day

Irradiance – Intensity of solar radiation incident on a surface, measured in W/m^2

Peak/Rated Power – Output of a photovoltaic module under Standard Test Conditions

Radiation – Similar to irradiance, the amount of solar energy per unit area at a specific location

Solar Constant – The fixed amount of solar radiation available, normal to the sun's rays, of 428Btu/hr-ft^2

Standard Test Conditions – 1000W/m^2 with normal incidence and a cell temperature of 25°C

Solar Technologies

There are many ways that solar insolation is converted into a usable resource for commercial buildings. These applications utilize the ideas of passive and active solar heating, daylighting, and conversion of the sun's energy into other forms, such as mechanical or electrical energy. Some examples of these applications include thermal collectors, photovoltaics, hybrid photovoltaic/thermal collectors, operable shading, daylight sensor electronic dimming, solar updraft, and roof pond systems. The main focus of this report is thermal collector, photovoltaic and hybrid photovoltaic systems, but each of these additional solar technologies is discussed briefly.

Interior daylighting is an ideal application of the sun's energy, because it does not require the sun's rays to be converted to any other type of energy. Natural light can provide a significant amount of light to a space, as well as excellent color rendering, but has significant limitations, including variability and glare associated with direct sunlight. Daylighting is best used indirectly and when combined with other systems such as operable shading or daylight sensor electronic dimming. Operable shades can be controlled by the occupants of the space to eliminate glare and direct sunlight entering into a space. When daylight sensors are combined with an electronic dimming system, light levels can be maintained uniformly in a space, while reducing energy consumption of the electric lighting system.

Solar updraft towers or solar chimneys use temperature and pressure differences in air to drive turbine generators. Air is heated under a glass roof in a large area surrounding the updraft tower. As the air is heated, it flows to the center of the collector tower, where air is cooler, at ambient temperature. The air then flows up the tower, powering the turbines. (Schlaich, Bergermann, Schiel, & Weinrebe, 2005). This system requires what is essentially a very large solar air collector to heat the air that flows in the tower. Thus, a solar updraft tower requires a vast amount of land to heat enough air for production. It is best suited for large scale applications in rural areas.

Roof ponds are a type of passive solar heating and cooling system. Roof ponds consist of water stored in thin plastic bags on the roof of a structure. They are covered with an insulator to control heat loss and gain. In the winter, a roof pond collects and stores heat from the sun. During the day, the insulated cover on the roof pond is removed, to allow the water to store heat energy. At night, the roof pond is covered, to allow the heat to be transferred to the building interior. The system operates in reverse during the summer, with the insulating cover being removed at night to reject heat to the cool air (Williams College, 2008). These systems require significant attention and maintenance, with the removal or replacement of the insulating cover every night. Roof ponds are best implemented for small-scale projects, such as residential buildings, where the maintenance for the system can be managed reasonably. The application of roof pond systems is limited to climates that do not encounter freezing temperatures and is most effective in arid climates.

CHAPTER 2 - Thermal Collector Systems

This chapter introduces thermal collector systems and presents the various types of collectors currently available, the required components of a thermal collector system, and provides an example of an effective thermal collector installation.

Definition and Overview

Solar thermal collector systems are a type of active solar heating method that utilize an absorber to transfer the sun's light energy into heating energy. Thermal collectors, usually mounted on the roof of a structure, absorb solar radiation and transfer the heat to a medium such as air or water, which in turn transfer the heat energy to a storage container, such as a hot water storage tank or rock bed. These systems can be applied in many ways, in residential, commercial and even industrial applications.

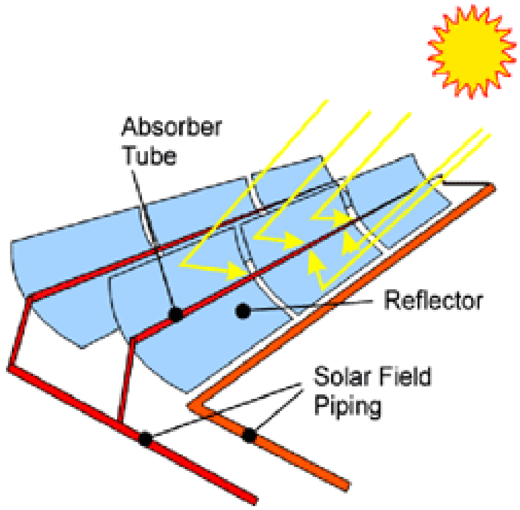
Collector Types

Thermal collector systems can be broken into two main categories: concentrating and flat-plate collectors.

Concentrating Collectors

A concentrating collector focuses the sun's rays on a specific point, using a curved surface with mirrors or reflectors. At the center of this focal point is a pipe filled with a liquid, which is heated to 200-300°F under ideal conditions. These collectors operate best when combined with mechanical solar tracking equipment to avoid shading and can be costly to manufacture (Schubert & Ryan, 1981). These systems typically generate higher temperature liquids than the flat-plate collectors and are best suited for process applications, instead of space or water heating applications. These systems are most well-suited for the utility scale, as they require a significant amount of maintenance and a large amount of surface area for mounting.

Figure 2.1 Concentrating Thermal Collector System (National Renewable Energy Laboratory, 2009)



Flat-Plate Collectors

Flat-plate collectors are usually operated in a fixed position, without the use of solar tracking equipment. In basic terms, flat-plate collectors consist of a box with a glass or plastic cover, with either ducted air or piped water as the transfer medium running through the box (Schubert & Ryan, 1981). Flat-plate collectors include an absorber to promote heat transfer from the sun's rays to the transfer medium, as well as insulation to assure that heat loss from the collector box is minimized. In an air collector system, fans are used to distribute the hot air throughout the system, while pumps are utilized in a liquid collector system. Flat-plate collectors can supply the loads of residential and commercial domestic hot water applications and commercial hydronic space heating applications.

Air and liquid systems each have advantages and disadvantages. Liquid collector systems may be prone to freezing if the appropriate protection measures are not installed. These measures include the use of an antifreeze mixture in the liquid transfer medium, installation of a drain-back tank, or water recirculation throughout the system (ASHRAE, 1988).

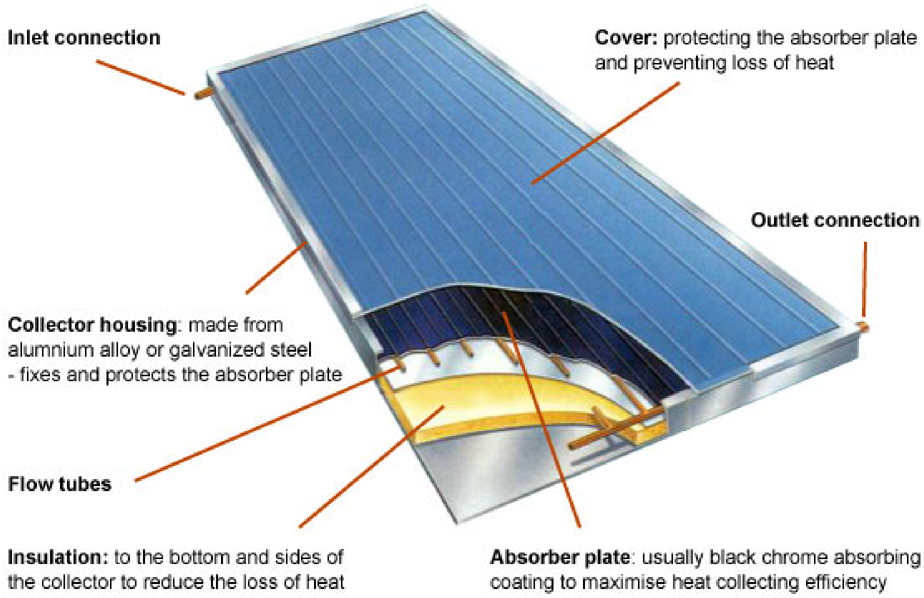
The use of antifreeze will help prevent freezing of liquid in the pipes and collectors, but will reduce the capacity for heat transfer. Systems that utilize antifreeze can be closed-loop in configuration, eliminating gravity pressure that would otherwise need to be overcome by circulating pumps. For this type of system, collector pipes do not need to be sloped back to the main storage tank, making the system more flexible in installations with space constraints.

With a drain-back tank system, water is used as the heat transfer medium. Theoretically, all of the water drains out of the collectors and piping on the building roof when solar radiation is not capable of maintaining desired operating temperatures. It is critical that pipes are sufficiently sloped in this system and that there is a sufficient elevation drop to the drain-back tank to assure that water does not remain in the pipes and freeze. As a result, pumps in a drain-back system must be sized to overcome significant elevation differences.

Finally, in a recirculating system, pumps shut down when the system is not producing adequately, or when heating is not needed, but the system does not drain, like in a drain-back tank system. When exterior temperatures approach freezing, hot water is circulated from the hot water storage tank to assure that water does not freeze in the pipes. This leads to energy lost that would otherwise have been devoted to space or water heating loads.

For an air collector system, the main disadvantage is the large size of system components. Rock storage for an air collector system requires approximately three times more area than a hot water storage tank for a liquid collector system (ASHRAE, 1988). Air collectors also require fans than consume energy to circulate air throughout the system. Duct sizes required to transfer enough air to meet space heating loads can also take up a significant amount of space. Additionally, if it is desired to utilize an air collector system for water heating loads, an air-to-water heat exchanger is required. This report will mainly focus on liquid collector systems, due to the size constraints of an air collector system. The figure below shows an example of a liquid flat-plate thermal collector.

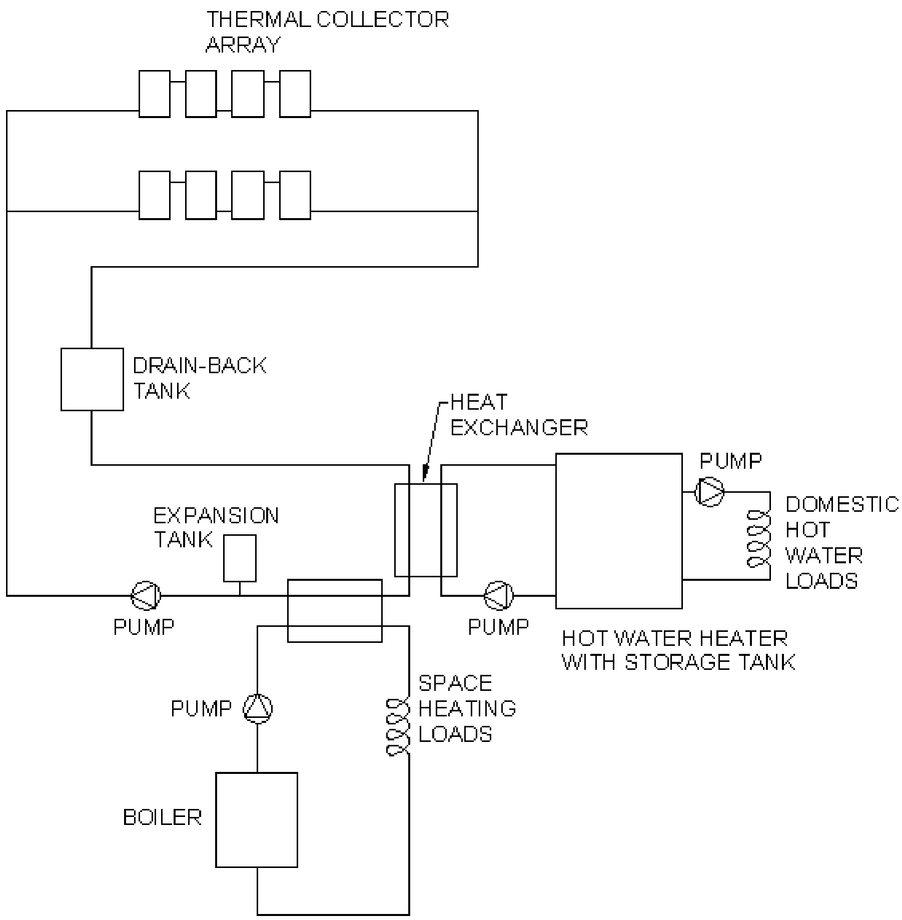
Figure 2.2 Liquid Flat-Plate Thermal Collector (National Green Specification, 2008)



System Components

A specific liquid solar thermal collector system is evaluated further in this report, with a schematic shown in Figure 2.3. In this system, a thermal collector array is piped with sets of four collectors in parallel with each other to obtain the desired operating temperature in the range of 150° to 200°. The number of collectors in series affects the outlet temperature of the collectors. A pump is necessary to overcome pressure differences and distribute water continuously throughout the system. The system must also be equipped with a drain-back tank to ensure that pipes will not freeze. The heat exchanger in the system allows the heat from the thermal collector array to be transferred with the water used for space heating and water heating loads. Since the water from the collector array will not be a constant temperature, it is important that a heat exchanger be used, in lieu of piping the collector water directly to the space heating and water heating loads. This will also allow the system to be supplemented by a boiler or conventional water heater when the collector array is not able to meet peak loads.

Figure 2.3 Liquid Flat-Plate Thermal Collector System



Case Studies and Implementation

An example of one location where a thermal collector system was successfully implemented is in Nova Scotia, Canada at the Chanterelle Inn. The two-story building (shown in Figure 2.4) has a footprint of approximately 50 ft by 50 ft (15 m by 15 m) and is designed with a solar hot water system. The system is comprised of 16 thermal collector panels as well as two photovoltaic panels to operate system pumps. The panels are mounted at a 35° angle on the roof of the building. Annually, the system is designed to produce 92 GJ or 25,600 kWh of thermal energy, with half of this energy contributing to water heating loads and the other half contributing to space heating loads through the use of radiant flooring. This satisfies approximately 50% of annual water heating loads and approximately 25% of annual space heating loads. Since the peak season for the inn is during the summer months, the reduced output of the system in winter months is not a major issue, as hot water usage is reduced with fewer guests at the inn. With a 25% incentive from the Canadian Renewable Energy Deployment Initiative (REDI), the project has a simple payback of 10.5 years (Natural Resources Canada, 2002).

Figure 2.4 Thermal Collectors at the Chanterelle Inn (Natural Resources Canada, 2002)

CHAPTER 3 - Photovoltaic Systems

This chapter introduces photovoltaic systems and their application in the commercial building industry.

Definition and Overview

Photovoltaic (PV) systems convert energy from the sun into usable electrical energy. PV systems are composed of modules or panels that receive the sun's light. These panels contain semiconductors such as silicon that generate electricity when struck with photons from the sunlight (Eiffert & Kiss, 2000). Like thermal collectors, PV systems are usually roof-mounted in commercial building applications.

Photovoltaic Types

There are several different types of photovoltaic cells, including monocrystalline, polycrystalline, and thin film modules. These classifications describe the composition of the silicon in the PV cell. Different PV types will vary in both appearance and efficiency.

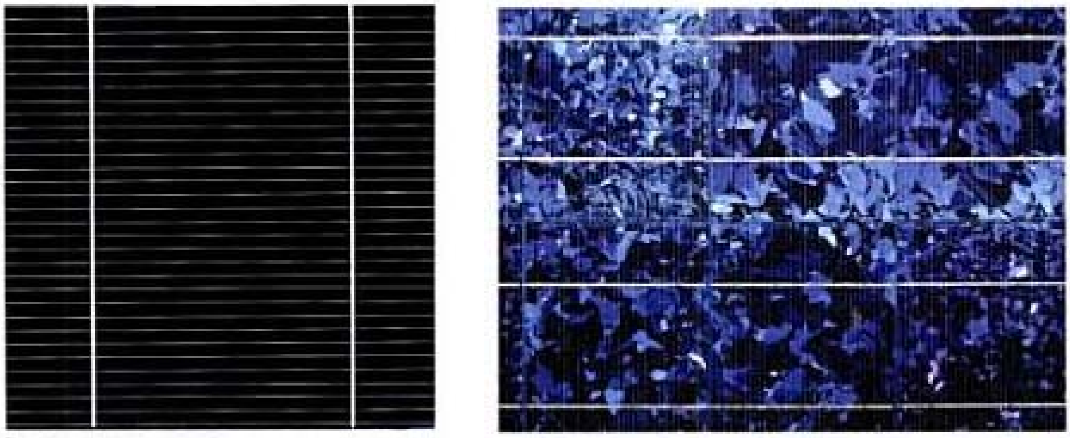
Monocrystalline

Monocrystalline cells are made from silicon with a very pure and continuous structure, in the form of a lattice. Monocrystalline cells represent the high end of photovoltaics. They offer a relatively high efficiency, at around 15%. The efficiency reflects the average amount of electrical energy produced by a PV cell versus the amount of solar energy incident on the cell. Although monocrystalline cells offer the highest efficiency of current PV cells, they have higher first costs than other photovoltaic cells (Prasad & Snow, 2005). Monocrystalline PV are usually uniform in color and are a good choice for locations where aesthetics of the panel are a concern, such as when panels will be visible from the ground.

Polycrystalline

Polycrystalline cells are made of large, irregular crystals of silicon. These cells are not as pure as the monocrystalline cells. The result is a less costly and less efficient cell, at about 12% efficiency on average (Prasad & Snow, 2005). Polycrystalline PV panels are often irregular in color and appearance, and are therefore not ideally suited for locations where aesthetics are a major concern. Figure 3.1 demonstrates the difference between monocrystalline and polycrystalline cell appearance. If aesthetics is not a major concern, the choice between monocrystalline and polycrystalline PV is based on the trade-off between energy efficiency and price, and will depend on the current PV market. A 3% difference in efficiency may not be a major concern if cost differences are significant.

Figure 3.1 Monocrystalline vs. Polycrystalline Cell Appearance (Prasad & Snow, 2005)



Monocrystalline Cell Polycrystalline Cell

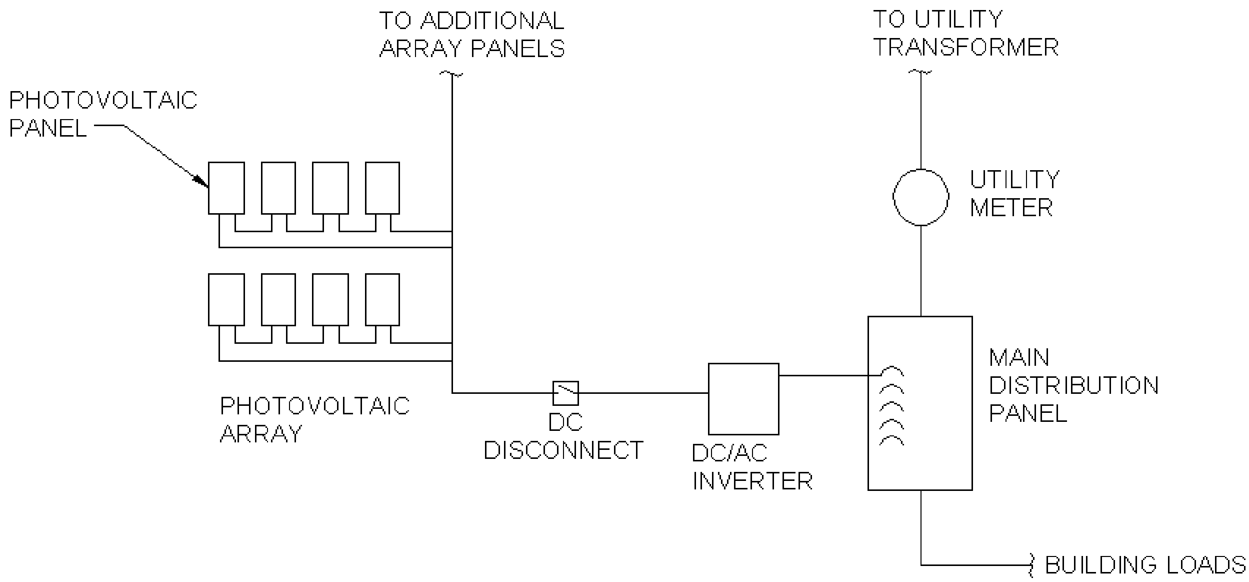
Thin Film

Thin film silicon cells are also known as amorphous silicon, and, unlike monocrystalline and polycrystalline PV, thin film cells are not created from crystals of silicon. Thin film photovoltaic cells are flexible because they are comprised of silicon arranged in a flat layer, making them very useful for application on irregular surfaces. Thin film silicon cells typically cost less than crystalline PV cells. However, these cells are significantly less efficient than crystalline silicon cells, with an average efficiency of about 6% (Prasad & Snow, 2005). Thin film photovoltaics are often utilized in building-integrated photovoltaics (BIPV) applications, and can be integrated into windows for shading. It is important to weigh the costs and gains of a thin film system, as their efficiency is half that of a typical polycrystalline cell. A significant savings in the first cost of a thin film PV system may be greatly overshadowed by a lack of energy savings over the system's lifetime.

System Components

A photovoltaic system is comprised of many electrical components. The primary component of a PV system is the PV module or panel. PV modules consist of multiple PV cells connected in series and a grouping of multiple panels or modules is called an array. The PV array produces DC power, thus a DC/AC power inverter is required when connecting the system to a commercial building's power system. Lightning protection is also an integral part of the system, but is often incorporated into the inverter unit. For electrical safety and to meet applicable building codes, disconnects are located on both the DC and AC sides of the inverter. For the schematic shown below, the distribution panel circuit breaker serves as the disconnect for the AC side. In this system, the utility meter is capable of operating forwards and backwards, allowing the client to be credited for any excess energy produced by the array. Metering is discussed further in the Energy Savings section of Chapter 7.

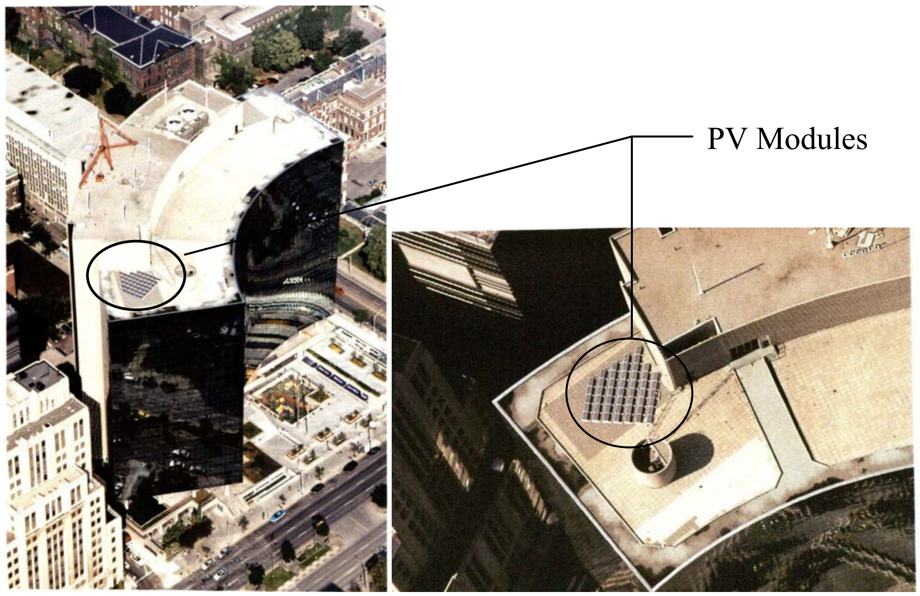
Figure 3.2 Grid-Connected Photovoltaic System



Case Studies and Implementation

One example of small-scale photovoltaics implementation is at the Ontario Power Generation building in Toronto, Canada (shown in Figure 3.3). The building is a high-rise office building. Looking to add to their sustainable image, the power company decided to implement a photovoltaic array into the existing high-rise. The roof of the structure consists of two tiers, with the majority of the upper roof already dedicated to existing equipment. Additionally, the upper roof shades a portion of the lower roof, so only a small percentage of the roof is available for a photovoltaic array. Even so, a 4.8 kW system is installed, consisting of 48 PV modules. The array is tilted at 15° to limit the effects of strong winds at the top of the 20-story building, but to still take some advantage of southern exposures. To aid in the sustainable image of the system, meters and project information are installed in the building lobby, and production data was made available online (Prasad & Snow, 2005). Overall, initial project costs were $62,500 CAD. At an exchange rate of 1 CAD = 0.95 USD, the total cost was $12,370 per kW installed.

Figure 3.3 Photovoltaics at the Ontario Power Generation Building (Prasad & Snow, 2005)



The ABZ apartment buildings in Zurich, Switzerland are an example a larger-scale PV application (shown in Figure 3.4). The project consists of 624 panels installed as a retrofit on a total of six apartment buildings. The total nominal installed power is 53.04 kW and the expected annual energy production is 43,270 kWh. The total installation cost for the system was $407,530, although 25% of the cost was offset by government incentives (Prasad & Snow, 2005). Without counting these incentives, the total cost was $7683 per kW installed. This project is unique because it involved installing photovoltaics on existing residences and the PV panels needed to blend with the existing apartment aesthetic. To do this, the project utilized monocrystalline panels that are uniform in color. This project demonstrates that a PV installation can be successful and profitable, even on existing buildings.

Figure 3.4 Photovoltaics at the ABZ Apartments (International Energy Agency, 2003)

CHAPTER 4 - Hybrid Photovoltaic/Thermal Systems

This chapter discusses the emerging technology of hybrid photovoltaic/thermal systems, including a basic overview, information about available products, and case studies of system applications.

Definition and Overview

Hybrid photovoltaic and thermal collectors (PVT) combine photovoltaic panels and thermal collectors into one unit. This allows the entire available surface area for panels to be devoted to both heat and electricity generation, since the unit is capable of producing heat and electricity simultaneously. More thermal and electrical energy can be produced in a given area with PVT collectors than by covering the area with half thermal collectors and half electrical PV panels (Cristofari, Notton, Poggi, & Mattei, 2007). The amount of production varies based on the PVT product and location. For a specific example, these values are quantified in Chapter 6.

PVT is a relatively new technology, with its development beginning in the 1970s at MIT. Research continued throughout the 1970s in the United States, Japan and Europe, but slowed greatly in the 1980s with the decline of the energy crisis. In the 1990s there was a renewed interest in PVT systems in Europe, which continues today (Zondag, Flat-plate PV-Thermal collectors and systems: A review, 2008).

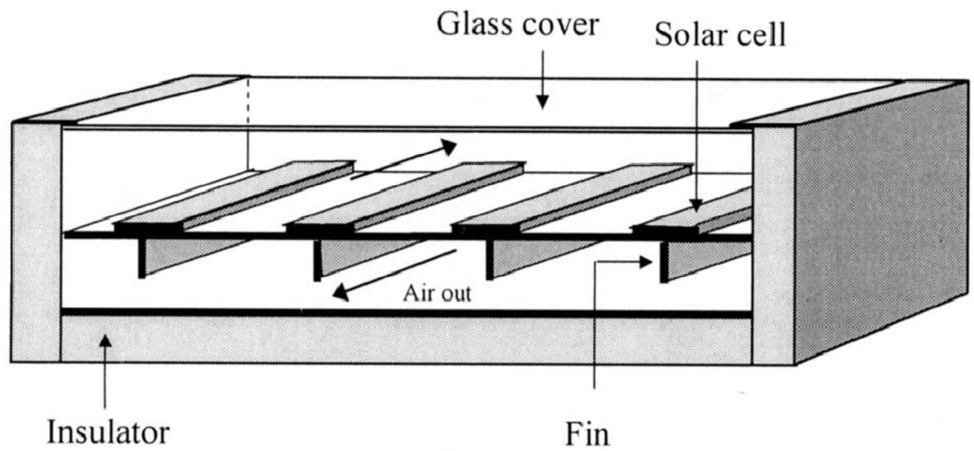
Collector Types

There are a variety of different PVT collector types, available mainly in European residential markets. These include ventilated PV façades, glazed liquid PVT, unglazed liquid PVT, PVT air collectors (Zondag, Flat-plate PV-Thermal collectors and systems: A review, 2008). For this report, the main focus will be liquid PVT, as it is the most suited to large scale commercial applications for size and efficiency reasons and provides the opportunity to use conventional hot water storage tanks as the thermal storage method.

Ventilated PV façade is a type of hybrid PVT that utilizes a building's structure. It is an application of building-integrated photovolataics (BIPV). This application utilizes air as the heat transfer medium behind semi-opaque PV modules. The modules acts as the windows, producing energy while still allowing the occupant to have exterior views (Prasad & Snow, 2005). However, it is important to note that the solar insolation on a vertical surface is much less than on a horizontal surface, so façade thermal and electrical production per square foot would be much less than a roof installation.

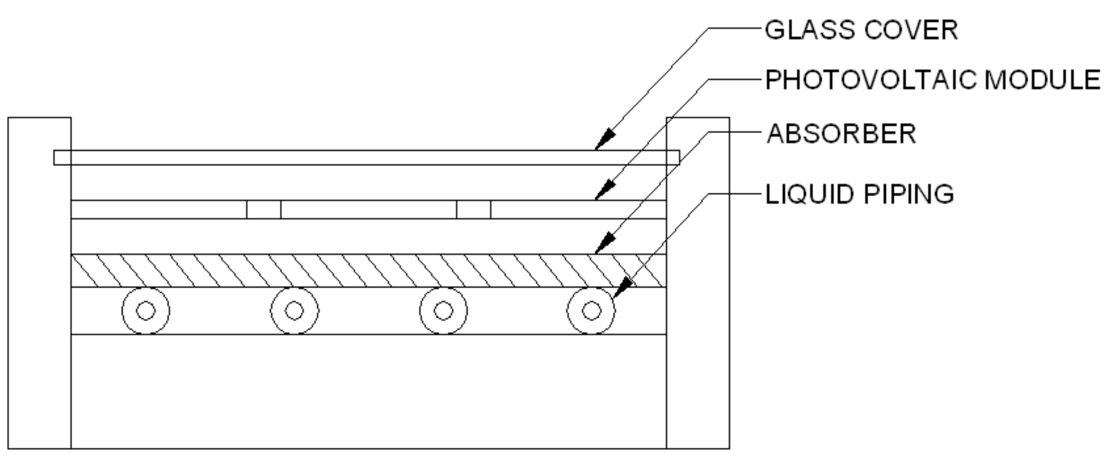
PVT air collectors use ducted air to remove heat from photovoltaic cells. An example is shown below in Figure 4.1. These collectors can be either "single-pass" or "double-pass", which refers to the layers of ducted air located in the collector module. Fins in the air stream increase the opportunity for heat transfer be increasing surface area and friction (Othman, Yatim, Sopian, & Bakar, 2006). These systems can become rather bulky, like traditional thermal air collectors. Large areas of ductwork are required for applications other than small-scale residential and also have the disadvantage of lowered efficiencies when compared to liquid PVT systems (Zondag & van Helden, PV-Thermal Domestic Systems, 2003).

Figure 4.1 PVT Air Collector (Othman, Yatim, Sopian, & Bakar, 2006)



Liquid PVT collectors are formed by placing a photovoltaic panel above a liquid thermal collector, as shown in Figure 4.2. The water in the pipes of the thermal collector is pumped through the system and heated by the energy created from the sun's light on the photovoltaic panel's glass surface (Raman, Tiwari, & Pandey, 2008). Basically, liquid PVT collectors are a combination of a traditional flat-plate liquid thermal collector and a photovoltaic cell. While the photovoltaic module covers the liquid piping, blocking it from the sun's direct insolation, heat is still transferred within the collector module.

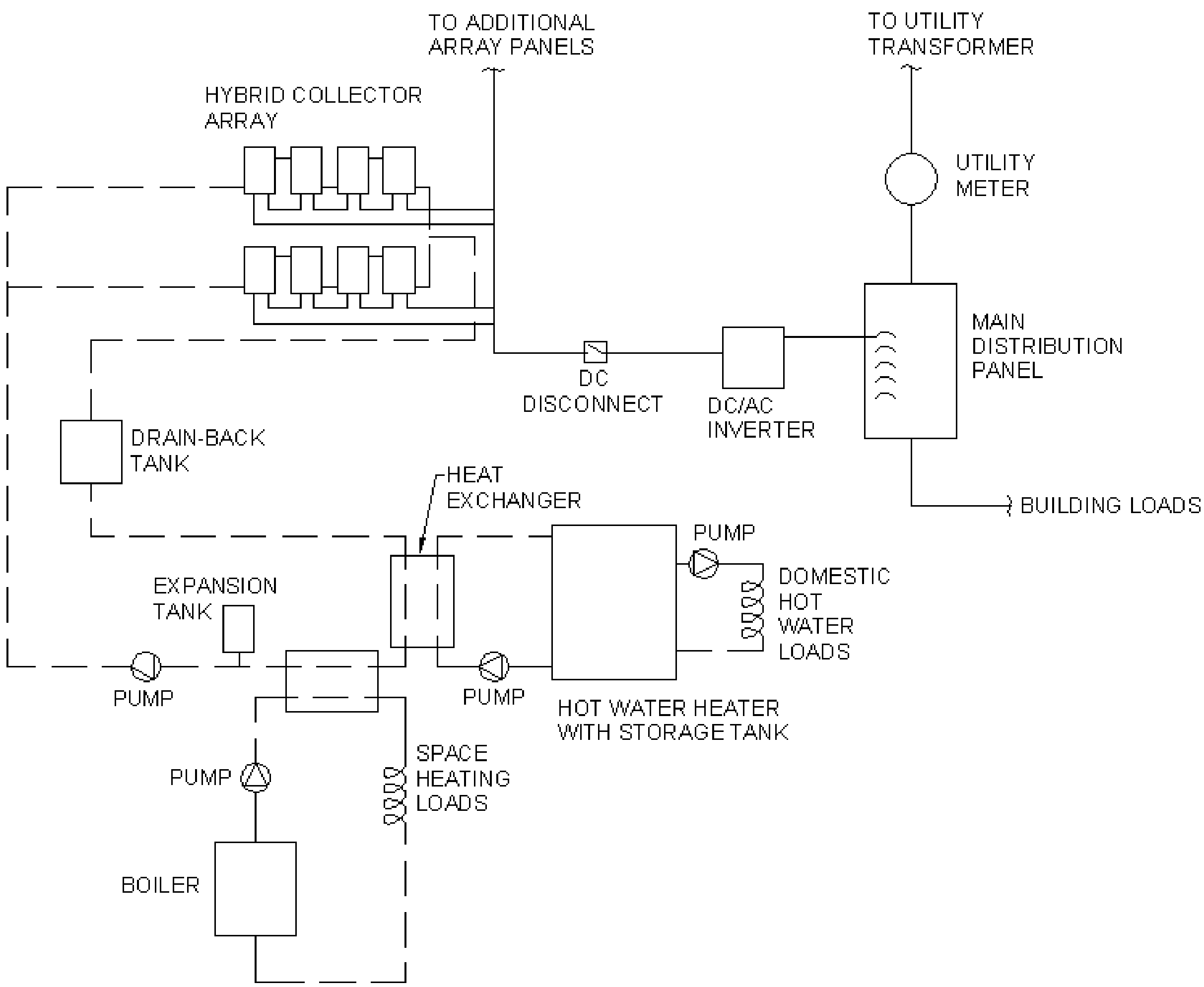
Figure 4.2 PVT Liquid Collector



System Components

Hybrid PVT collector systems incorporate components required for both photovoltaic and thermal collector systems, additionally increasing initial cost. Below is a schematic of a liquid PVT system serving electrical, space heating, and hot water heating loads in a commercial building.

Figure 4.3 Liquid PVT System



Case Studies and Implementation

The Renewable Energy Services (RES) complex in the UK (shown in Figure 4.4) is an example of a site that has implemented hybrid PVT. The project was a renovation of an existing farm into office spaces. The site incorporates $54m^2$ of hybrid PVT liquid collectors, along with

$74m^2$ of conventional flat-plate liquid collectors. The system utilizes ground storage of the heat produced by the thermal collectors, which is then utilized to preheat ventilation air. Electrical production of the PVT collectors is supplemented by wind turbines. Over the first year of use, the hybrid PVT liquid collectors produced 7 MWh of thermal energy, while the conventional liquid collectors produced 34 MWh of thermal energy, which makes the PVT contribution 17% of the entire thermal production (Zondag, van Helden, Bristow, & Jones, 2005). It should be noted that the collectors were not fully functional throughout the first year. Second year results yielded 62.3 MWh of total thermal energy production. At 17% of the entire thermal production, the PVT contribution is estimated at 10.6 MWh annually. Electrical production of the hybrid PVT collectors was 3.3 kWh for the second year of operation (Renewable Energy Systems Ltd., 2010). The RES complex is an excellent example of a site using many sustainable methods for energy production. The use of wind turbines and hybrid PVT allows the site to have greater total power generation and continue generated power at night or when the wind is not blowing.

Figure 4.4 PVT and Thermal Collector System (Zondag, van Helden, Bristow, & Jones, 2005)

CHAPTER 5 - Preliminary Sizing Methods

This chapter provides the sizing methods used in this report to evaluate thermal collector, photovoltaic and hybrid PVT system capacities. These methods serve as a preliminary method to evaluate potential performance of these systems at a proposed location and are not intended to serve as a detailed analysis for a specific site and specific system. These methods are intended to give the designer a general idea of system production to aid in decisions about system selection and preliminary system sizing. The preliminary sizing methods are used to determine what the average instantaneous output of each system will be, averaged over an entire day, in a given month, and serve as a basis to determine if the system will be able to support the peak load of the building. The following process assumes that the designer wishes to design the system for the worst-case situation, when the least solar energy is available.

The designer may choose to supplement with conventional power, water and space heating systems if the solar energy system cannot meet the peak load of the building, or if it is not economical to install a solar energy system that could handle the peak load. As the design process continues, as schedules and more detailed information about building loads are known, such as with the results of a building energy model, solar energy system output data could be graphed in comparison to the load, to determine when energy produced may be in excess or insufficient. This data would allow the designer to perform a more complete engineering and financial analysis.

Thermal Collector

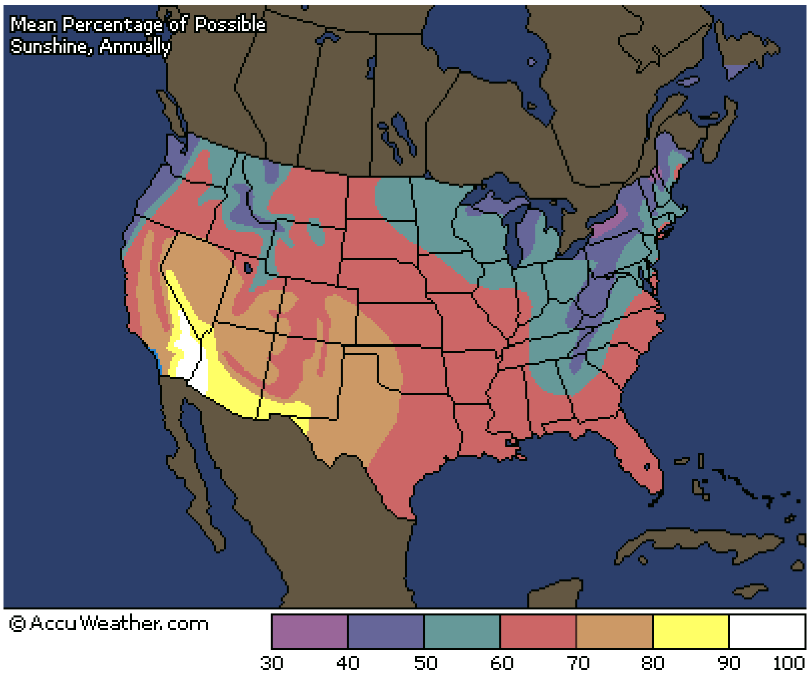
This section provides basic peak-load sizing steps for a solar thermal collector. These steps develop on the process given in *Fundamentals of Solar Heating* (Schubert & Ryan, 1981) and the *Active Solar Heating Systems Design Manual* (ASHRAE, 1988).

First, find the expected collector efficiency(η) from manufacturer's data. This needs to be in decimal form. If not given directly, η is the ratio of the collector's output to input or the thermal output per amount of solar insolation received. This is a unit-less factor.

Next, determine Q, which is the space heating and domestic hot water peak load in the building in Btu/h, using load software or spreadsheets. The collector may only be able to serve the loads for just the domestic hot water or space heating; the Q value should reflect only the system the collectors will serve. This information is required to complete the building mechanical and plumbing design, regardless of the decision to use a hybrid PVT system.

Obtain data for annual mean percent possible sunshine (X) for the location. This may be available from the National Weather Service at www.ncdc.noaa.gov/oa/climate/online/ccd/pctposrank.txt or NREL at http://www.nrel.gov/rredc/solar_data.html. The following figure also provides a general estimate (AccuWeather, 2010):

Figure 5.1 Mean Percentage of Possible Sunshine, Annually



Input mean percent possible sunshine (X), in decimal form into the following equation to find the average portion of clear sky solar insolation (F) available at the site at any given time:

$F = 0.30 + 0.65\,(X)$

Obtain clear-sky solar insolation (I_o) data from ASHRAE or other local weather data sources. To determine the worst-case situation, select the lowest daily insolation value (in Btu/day/ft^2) for the collector at the desired mounting angle. This will most likely be in December or January for locations in the Northern hemisphere. Divide this total daily value by 24 to obtain Btu/h/ft^2.

To find required collector array square footage (S) use the following equation:

$S = PQ/(FI_o\eta)$

Where:

P = % of total energy desired to be supplied by collector array, in decimal form

Q = space heating and hot water load, in Btu/h

F = percent clear sky solar insolation available, in decimal form

I_o = clear sky solar insolation, in $Btu/h/ft^2$

η = average collector efficiency, in decimal form

Refer to Chapter 6 for an example using this preliminary sizing method.

Photovoltaic

This section provides basic peak-load sizing steps for a solar photovoltaic panel.

First, find the solar panel nominal power rating (p), in kW, and solar panel area (a) from the manufacturer's cut sheet of the photovoltaic panel or hybrid PVT panel to be used on the project.

Determine the array derating factor, which is a factor of losses in the array system. The PVWatts website by NREL estimates this as 0.77 for a typical array. This factor includes losses for the inverter and transformer, DC and AC wiring, system availability, and connections made within the system (National Renewable Energy Laboratory, 2010). This rating factor is acceptable to be used for most cases, but might be reduced in cases where the array will not receive regular maintenance or when retrofitting a system. Individual designers or design firms may adjust this value based on experience on projects in their area.

Find daily peak sun hours for the location (H), in units of sun hours per day, which is the same as $kWh/m^2/day$, as sun hours are determined under "Standard Test Conditions" for solar panels. This information can be obtained from the PVWatts website or from other available weather data. For worst-case conditions, select the lowest daily value in the year, based on your mounting angle (flat or equal to latitude) so that peak load is satisfied.

The average, on a daily basis, instantaneous power per square foot (P_a) supplied, in units of W/ft^2 can be determined:

$$P_a = (H \times p \times 0.77) / (24 \times a)$$

Determine the approximate square footage (A) needed to meet the expected design load load (in units of kW):

$$A = Load / (P_a)$$

Determine the number of panels required by dividing total square footage (A) required by square footage per panel (a).

# of panels = A/a

Refer to Chapter 6 for an example using this preliminary sizing method.

CHAPTER 6 - Preliminary Sizing Examples

This chapter provides examples of preliminary sizing of thermal collector, photovoltaic, and hybrid PVT systems, using the methods presented in Chapter 5.

Assumptions

The sizing example in this chapter is based on a hypothetical single-story elementary school of approximately 50,000 SF. The school is located in Manhattan, KS, which is located at about 40° latitude, as the basis for design. It is assumed that approximately 60% of total roof area is available for collector mounting. It is also assumed that all panels and collectors are mounted at a 40° from the roof structure, facing south. Preliminary sizing is based on the peak load, to determine if the various systems would be able to produce enough energy to support the entire building electrical and/or thermal and domestic water heating or space heating loads. Subsequent calculations could be completed to determine the system's capability to handle partial loads at various times of the year.

Load Estimate

Refer to Appendix A for complete load estimate calculations. The elementary school has an estimated peak water heating demand ($Q_{domestic}$) of 529,621 Btu/h, a peak space heating demand (Q_{space}) of 1,782,688 Btu/h and an estimated peak electrical demand of 584kW.

Calculations

Calculations are based on the thermal collector and photovoltaic sizing methods presented in Chapter 5. First the production of a traditional flat plate liquid collector and a hybrid PVT collector are computed to determine the estimated thermal outputs. Thermal collector calculations determine first whether the system can meet the peak domestic water heating load, then if any excess thermal production can be applied towards the space heating load. Then, the electrical outputs of a photovoltaic system and the hybrid PVT collector are computed.

Thermal - Traditional Flat-Plate Liquid Collector

Refer to Appendix B, section B.1 for a cut sheet of a liquid flat-plate collector. For this product, the efficiency (η) is 0.784. As noted above, the estimated domestic water heating demand ($Q_{domestic}$) for the elementary school is 529,621 Btu/h. For Manhattan, KS the mean possible sunshine (X) is approximately 0.6, meaning that the sun shines approximately 60% of the time. From this, the percent clear sky solar insolation available (F) can be determined:

$$F = 0.30 + 0.65\ (X) = 0.30 + 0.65\ (0.6) = 0.69$$

Next, the clear sky solar insolation (I_o) for the worst-case month, which is December, is obtained and converted to Btu/h/ft^2:

$$I_o = (1634\ \text{Btu/ft}^2\text{-day})/(24\ \text{hours/day}) = 68.08\ \text{Btu/h/ft}^2$$

Using this data, the required collector square footage (S) to meet the peak load condition can be calculated:

$$S = PQ_{domestic}/(FI_o\eta) = (1 \times 529{,}621)\ /(0.69 \times 68.08 \times .784) = 14{,}381\ \text{ft}^2$$

Using this method, it is determined that 14,381 ft^2 of collectors would be required to meet the peak domestic water heating load in December. This leaves 15,619 ft^2 or roof area available. If this area is also covered with thermal collectors, the following contribution can be made towards the space heating load:

$$15{,}619\ \text{ft}^2 = Q\ /\ (0.69 \times 68.08 \times 0.784)$$

$$Q_{space} = \text{contribution to space heating load} = 575{,}225\ \text{Btu/h}$$

Under worst-case conditions in December, all of the domestic hot water heating load and 575,255 Btu /h, or 32% of the peak space heating load, can be satisfied. The number of collectors required to do this is:

$$30{,}000\text{ft}^2/(29\text{ft}^2\ /\ \text{collector}) = 1034\ \text{collectors}$$

Thermal – PVT Hybrid Collector

Refer to Appendix B, section B.3 for a cut sheet of a PVT hybrid collector. For this product, the efficiency (η) is 0.70. As with the traditional flat-plate collector, the estimated peak domestic water heating thermal demand ($Q_{domestic}$) is 529,621 Btu/h, the mean possible sunshine (X) is approximately 0.6, and the percent clear sky solar insolation available (F) can be determined to be 0.69. With a clear sky solar insolation (I_o) for the worst-case month of December of 68.08 Btu/h/ft^2, the required collector square footage (S) to meet the peak load condition can be calculated:

$S= PQ_{domestic}/(FI_o\eta) = (1 \times 529{,}621) /(0.69 \times 68.08 \times .70) = 16{,}106\ ft^2$

As with the flat plate collector, the entire domestic hot water heating load can be satisfied with the collectors. With 13,894 ft^2 of roof area available for additional collectors, the capacity of space heating load (Q_{space}) that can be satisfied is:

$13{,}894\ ft^2 = Q / (0.69 \times 68.08 \times 0.70)$

Q_{space} = contribution to space heating load = 456,871 Btu/h

In December, with the hybrid PVT collectors, all of the domestic water heating load and 456,871 Btu/h, or 26% of the peak space heating load, can be satisfied. The number of collectors required to do this is:

$30{,}000ft^2/(29.29ft^2/collector) = 1024$ collectors

Electric - Polycrystalline Photovoltaic Panel

Refer to Appendix B, section B.2 for a cut sheet of a polycrystalline photovoltaic panel. For the chosen panel, the nominal power rating (p) is 0.2kW, which is its production under "Standard Test Conditions." Converting from inches, the solar panel area (a) in ft^2 is:

$a= (38.6/12) X (58.5/12) = 15.68\ ft^2$

A standard derating factor of 0.77 is appropriate for this application. The worst-case daily peak sun hours (H) for Manhattan, KS in December is approximately 3.42 sun hours/day for an array mounted at 40° from the horizontal. With this data, the instantaneous power per square foot (P_a) can be estimated:

$P_a = (3.42x0.2\ x0.77) / (24\ x\ 15.68) = 0.00140\ kW/ft^2$, $1.40\ W/ft^2$

The approximate square footage (A) needed to meet the expected design load of 584 kW with this power output is:

$A = 584{,}000W / 1.40\ W/ft^2 = 417{,}143\ ft^2$

It would require more than the available square footage to meet the electrical peak load condition in December. With only 30,000 ft^2 of roof area available for collectors the capacity is computed:

$30{,}000ft^2\ x\ 1.40\ W/ft^2 = 42$ kW capacity on worst sun day

In December, with the polycrystalline photovoltaic panel, 42 kW, or only 7% of the load can be satisfied. The number of panels required to do this is:

# of panels = $30{,}000\ ft^2/15.68\ ft^2$ per panel = 1913 panels

Electric – PVT Hybrid Collector

Refer to Appendix B, section B.3 for a cut sheet of a PVT hybrid collector. For the electrical portion of the collector, the nominal power rating (p) is 0.32 kW. Converting from metrics, the solar collector area (a) is:

$(a) = (2.199m)(3.28ft/m)\ X\ (1.238m)(3.28ft/m) = 29.29\ ft^2$

Again, a standard derating factor of 0.77 is used and the worst-case daily peak sun hours (H) for Manhattan, KS in December of approximately 3.42 sun hours/day for an array mounted at 40° from the horizontal is used to estimate the instantaneous power per square foot (P_a):

$P_a = (3.42x0.32x0.77)/(24\ x\ 29.29) = 0.001199\ kW/ft^2 = 1.199\ W/ft^2$

At 1.199 W/ft^2, it is obvious, that like the photovoltaic panel, the peak load will not be satisfied with the available square footage. With only 30,000 ft^2 of roof area available for collectors the capacity is computed:

$30{,}000\ ft^2\ x\ 1.199\ W/ft^2 = 35.97$ kW capacity on worst sun day

In December, with the hybrid PVT collector, 35.97 kW, or only 6% of electrical load can be satisfied. The number of panels required to do this is:

$30{,}000 ft^2/(29.29 ft^2/panel) = 1024$ panels

Review of Results

Note that these results are instantaneous load results, and reflect the expected average minimum production of the system in the month of December. The following table summarizes the results of these calculations:

Table 6.1 Average December PV, Thermal Collector and PVT Hybrid Production for Elementary School Example

Average Worst-Case Production (December)				
System	Roof Area (ft^2)	Domestic Water Heating Load Satisfied (Btu/h)	Space Heating Load Satisfied (Btu/h)	Electrical Output (kW)
PVT Hybrid	30,000	529,621	456,871	35.97
PV	30,000	0	0	42.00
Thermal Collector	30,000	529,621	575,255	0.00

The following tables show expected instantaneous production for all months throughout the year, based on the sizing method used above, with a varying amount of solar insolation and sun-hours per day, based on the month.

Table 6.2 Average Monthly PV, Thermal Collector and PVT Hybrid Production for Elementary School Example

Month	January	February	March	April	May	June
Insolation (Btu/ft^2-h)	75.4	90.1	97.1	96.7	94.3	92.7
Sun hour/day ($kWh/m^2/day$)	4.02	4.48	5.07	5.19	5.44	5.75
	Average Instantaneous Production					
PVT Hybrid Electrical (kW)	42.3	47.1	53.3	54.6	57.2	60.5
PV (kW)	49.4	55.0	62.2	63.7	66.8	70.6
Thermal Collector (Btu/h)	1223922	1461944	1575546	1568784	1530917	1503869
PVT Hybrid Thermal (Btu/h)	1092788	1305308	1406738	1400700	1366890	1342740

Month	July	August	September	October	November	December
Insolation (Btu/ft^2-h)	92.9	94.1	92.8	85.8	74.1	68.1
Sun hour/day (kWh/m^2/day)	5.76	5.89	5.46	4.79	3.98	3.42
	Average Instantaneous Production					
PVT Hybrid Electrical (kW)	60.6	61.9	57.4	50.4	41.9	36.0
PV (kW)	70.7	72.3	67.0	58.8	48.9	42.0
Thermal Collector (Btu/h)	1507926	1526860	1506574	1392972	1202284	1104911
PVT Hybrid Thermal (Btu/h)	1346363	1363268	1345155	1243725	1073468	986528

Figure 6.1 Average Instantaneous Electrical Production, by Month for Elementary School Example

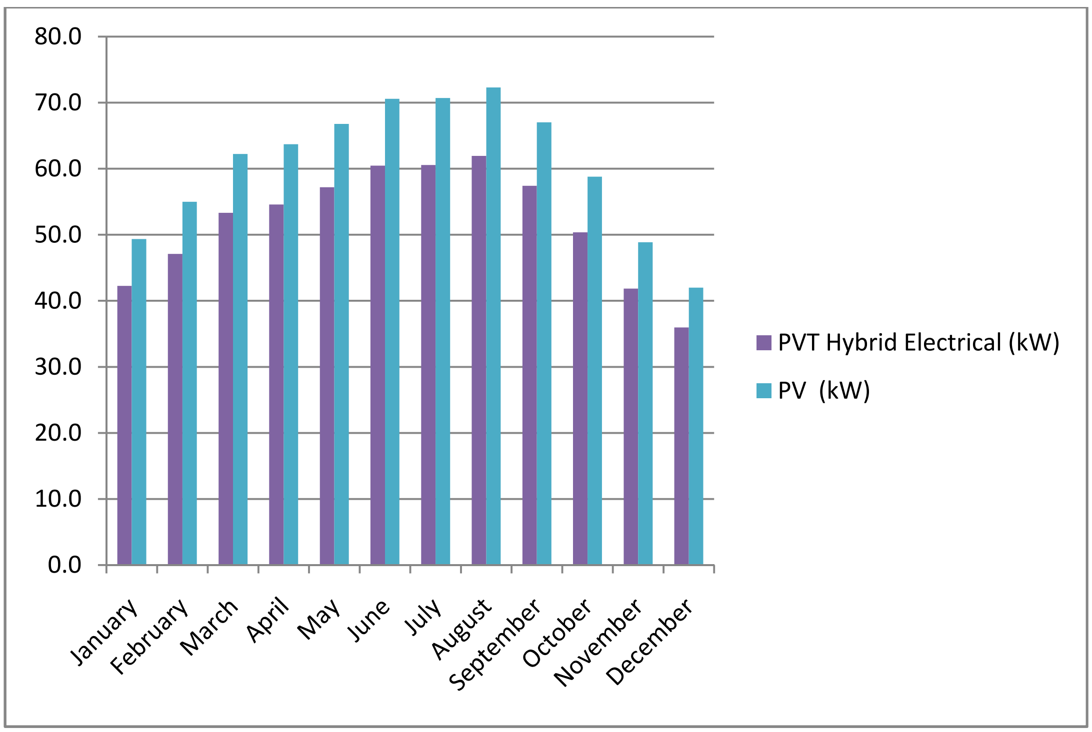
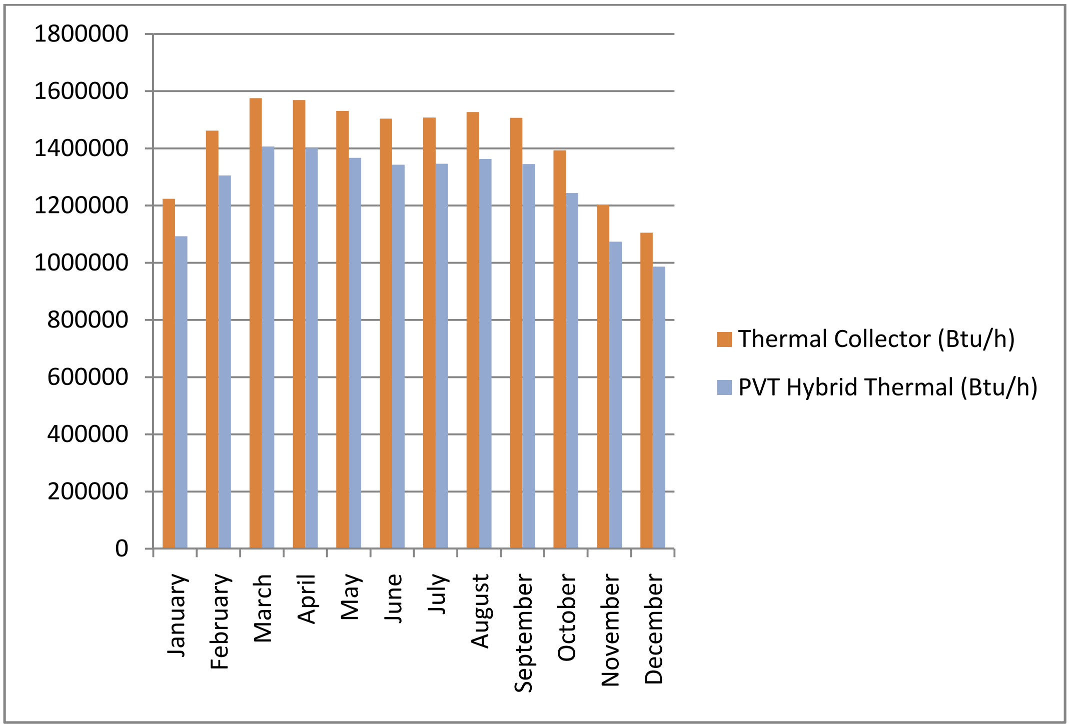


Figure 6.2 Average Instantaneous Thermal Production, by Month for Elementary School Example



Although PVT calculations resulted in a decrease in both thermal and electrical capacity independently, the combined output cannot be matched by using only photovoltaic panels and liquid thermal collectors. It would take 26,786 ft^2 of thermal collectors and 25,693 ft^2 of photovoltaic panels, or a total of 52,479 ft^2 to match the output of 30,000 ft^2 of PVT system in December. It must be noted that for this load and this location, neither system can meet the peak load demand electrically in the worst-case December situation due to the space available for the panels. If half of the available roof area was covered with PV panels, and half of the roof was covered with thermal collectors, the production in December would be 21 kW and 552 MBH, respectively. If the entire roof available roof was covered with hybrid PVT collectors, the production in December would be 35.97 kW of electrical power and 986 MBH. Thus, the use of hybrid PVT collectors leads to a 71% increase in electrical production, and a 79% increase in thermal production.

CHAPTER 7 - Costs and Gains of Solar Designs

First Costs

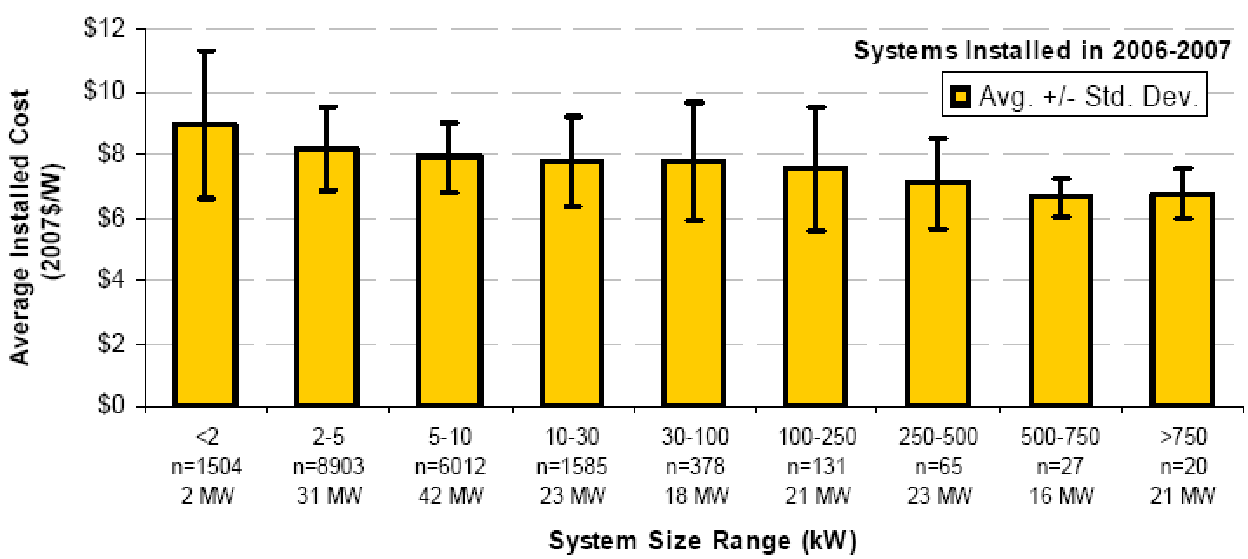
PV panels themselves account for the highest percentage of PV system installed first costs at about half of the total cost (Wiser, Barbose, & Peterman, Tracking the Sun: The Installed Cost of Photovoltaics in the U.S. from 1998-2007, 2009). Thermal collector modules also represent the highest percentage of cost in a thermal installation, at about one third of the total installation cost (Mahjouri & Nunez, 2003). The U.S. Energy Information Administration (EIA) provides average cost data for PV and thermal collector modules, but does not provide data on installed system costs. The EIA recorded the average cost of PV modules for 2007 at approximately \$3.50 per peak watt of the system (U.S. Energy Information Administration, 2008) According to the EIA, liquid flat-plate thermal collectors cost approximately \$16.8/ft^2, for the module only, in 2007 (U.S. Energy Information Administration, 2008). Approximate costs for the collector module in a hybrid PVT system are discussed in Zondag's *Commercially Available PVT Products* at approximately \$850/m^2 (or about \$79/ft^2) for a liquid collector system (Zondag, Commercially Available PVT Products, 2006). The table below lists the approximate module-only costs (which do not include installation) for the various systems designed in Chapter 6.

Table 7.1 PV, Liquid Thermal Collector, and Hybrid PVT Prices

	# Units	Ft^2	Nominal W	\$/W	\$/unit	\$/ft^2	Total Cost
PVT Hybrid (Zondag, Commercially Available PVT Products, 2006)	1024	30,000				79	2370000
PV (U.S. Energy Information Administration, 2008)	1913	30,000	382,600	3.5			1339100
Thermal Collector (U.S. Energy Information Administration, 2008)	1034	30,000				16.8	504000

First costs for these systems can vary greatly from year to year based on the economy, current tax credits, and production. For a photovoltaic system, the cost of installation will vary from location to location, based on the experience of the installer, wage rates in the area, and availability of materials. Accordingly, data varies greatly on the estimated installed costs of these systems. A 2001 study by NREL estimated installed costs of grid-connected PV systems at $7400/kW (Mortensen, 2001). At this rate, the PV system designed for the elementary school in Chapter 6 would cost approximately $2,831,420. For the case study of the ABZ apartment buildings in Zurich, Switzerland discussed in Chapter 3 of this report, installed system costs were $7683/kW. At this price, the PV system for the elementary school case would cost $2,939,516 dollars. The following figure presents average installed costs for PV systems, based on nominal kW installed (Wiser, Barbose, & Peterman, Tracking the Sun: The Installed Cost of Photovoltaics in the U.S. from 1998-2007, 2009):

Figure 7.1 Variation in Installed Cost According to PV System Size



For the elementary school example that falls between 250 and 500 kW, the figure shows the cost at approximately $7.2/W. At this pricing, the 382,600 W system would cost $2,754,720. This value, being the most recent data found, is assumed to be the most accurate, and will be used for all calculations to follow in this report.

Solar thermal system prices vary greatly as well. Using this guideline of the collector accounting for one third of the total solar thermal installation and a collector price of $504,000 obtained in Table 7.1, the installed system cost of the thermal collectors in Chapter 6 would be approximately 1.51 million dollars. Comparing this to a specific installation, the thermal solar collector installation at the Chanterelle Inn in Canada cost approximately $770CAD/m^2$ (Natural Resources Canada, 2002), which is $68/ft^2$ at an exchange rate of 1 CAD = 0.95 USD. At this cost, the entire thermal solar collector system described in Chapter 6 would cost 2.04 million dollars.   Since the installation at the Chanterelle Inn is a relatively small-scale system, it is assumed that the costs of the elementary school system per square foot would be less. Thus, 1.51 million will be used as the estimation for the purposes of this report

These estimates become even more approximate when hybrid PVT systems are discussed, as they are a new and emerging technology, with very few commercial applications currently in North America. There is currently very limited information available complete installed system costs of hybrid PVT systems. Since hybrid PVT incorporates aspects of both PV and thermal collectors, it is expected that it would have higher installation costs. If the module is assumed to be half of the total installed cost, as with PV systems, the total installed cost of the hybrid PVT system could be estimated at $4,740,000.

Lifetime Costs and Maintenance

In addition to initial installation costs of photovoltaic systems, there are also lifetime operating and maintenance costs associated with these systems. For a photovoltaic system, these costs are minimal compared to initial installation costs. While these costs will vary based on who is performing the maintenance, as well as the location where the panels are mounted, they can be estimated to be 0.50-0.75% annually of initial capital costs (North Texas Renewable Energy, Inc., 2006). At this amount, annual maintenance for the elementary school PV system could be estimated at $13,774. This value may be a high, due to the very large size of the elementary school PV system, but it provides an initial approximation. Maintenance procedures include washing of the PV array to avoid buildup of particulate, inspection of the system's wiring and supports, and an annual check of the system's electrical output to assure it is operating normally.

It is recommended that thermal collector systems receive maintenance every 3-5 years to assure that the system is operating as designed. The costs are estimated at 5-10% of initial system cost (U.S. Department of Agriculture, 2009), which would mean the elementary school thermal collector maintenance costs would be approximately $75,500 every 3-5 years, at 5% of initial costs. Again, even though these calculations reflect the lower end of the range of estimated costs, this value may be high, since the elementary school system is quite large. The maintenance required for liquid thermal collectors includes regular cleaning of the collector panels and visual inspection of the various components of the system, including the absorber, structure, connections and pumps (U.S. Department of Energy, 2009).

As hybrid PVT is still an emerging technology, information is limited on operating and maintenance costs of the system. It is expected that these costs would be slightly higher than that of the PV and thermal collector systems, as hybrid PVT is essentially just a combination of the two systems, which similar maintenance needs.

Energy Savings

Although energy produced may appear to be free, it is a factor of the initial cost of the system, and attention must be given to energy rates at the site when determining if a system will be economical. For the thermal collector system and the thermal component of a hybrid PVT system, energy savings are seen for any hot water produced by the system that does not need to be generated by a hot water heater or boiler. However, this energy must be stored on site, which requires large storage tanks. Since hot water is produced only during the daylight hours, thermal collector systems would not be ideal for buildings that see a high domestic hot water or heating demand overnight.

For PV systems, and the PV component of a hybrid PVT system, any excess energy produced may be sold back to the utility through a net metering system or with multiple meters. With a net metering system, a consumer only pays for the net energy consumed, or the energy consumed from the grid less any excess energy produced by the PV system that is sent back to the grid. In this case, the electrical meter operates backwards and forwards. Thus energy sold back to the utility is paid at the same rate as energy used by the consumer. In other locations, multiple meters may be required to track the amount of energy consumed, as well as the amount of excess energy produced. In this case, consumers will pay the usual retail rate for energy consumed, but will only receive a fraction of that rate back in credit for any energy produced. The Database of State Incentives for Renewables & Efficiency, available online at http://www.dsireusa.org/, provides information on locations that offer net metering and their limitations, as well as other incentives available to business owners.

Another important consideration in the cost of PV, thermal collector and hybrid PVT systems is the simple payback period. To determine this, annual energy production is calculated, first for electrical production (Table 7.2) and then for thermal production (Table 7.4).

Table 7.2 Estimated Monthly Electric Energy Production

	Monthly Electric Energy Production					
Month	January	February	March	April	May	June
Sun hour/day (kWh/m^2/day)	4.02	4.48	5.07	5.19	5.44	5.75
PVT Production (kWh)	31443	31650	39656	39285	42550	43524
PV Production (kWh)	36713	36955	46303	45870	49682	50819
Month	July	August	September	October	November	December
Sun hour/day (kWh/m2/day)	5.76	5.89	5.46	4.79	3.98	3.42
PVT Production (kWh)	45053	46070	41329	37466	30126	26750
PV Production (kWh)	52604	53791	48256	43745	35175	31234

PV Production (kWh) = Sun hours/day x D.F. x electrical power rating x # panels x # days	
Derating Factor (D.F.)	0.77
PVT Electrical Power Rating	0.32
PV Electrical Power Rating	0.2
Number of PVT Panels	1024
Number of PV Panels	1913

Monthly energy production can be summed to provide estimated annual electric production of both PV and hybrid PVT systems. An electrical rate of $0.08/kWh is assumed to determine the annual cost savings from this electricity production. This assumes that any excess electricity produced can be sold back to the utility at the same rate.

Table 7.3 Estimated Annual Electric Energy Production and Savings

System	PVT	PV
Annual Electric Production (kWh)	454904	531147
Annual Savings at $0.08/kWh	$36,392	$42,492

The simple payback of the PV system, or the initial cost divided by the annual energy savings, would be:

Simple Payback= $2,754,720/$42,492 = 65 years

The annual return on investment, or the energy savings per year divided by the initial cost, would be:

Return on Investment= $42,492/$2,754,720= 1.54%

The payback of this system is poor, as it would take longer than the operable lifetime of the system for it to produce enough energy savings to equal the original investment. Situations that would result in a reduced payback are discussed later in this chapter. Next, the thermal production for the thermal collector and PVT systems are evaluated.

Table 7.4 Estimated Monthly Thermal Energy Production

	Monthly Thermal Energy Production					
Month	January	February	March	April	May	June
Insolation (Btu/ft^2/day)	1,810	2162	2330	2320	2264	2224
Thermal Collector Production (Btu x100,000)	9106	9824	11722	11295	11390	10828
PVT Production (Btux100,000)	8130	8772	10466	10085	10170	9668
Month	July	August	September	October	November	December
Insolation (Btu/ft2/day)	2230	2258	2228	2060	1778	1634
Thermal Collector Production(Btu x100,000)	11219	11360	10847	10364	8656	8221
PVT Production (Btux100,000)	10017	10143	9685	9253	7729	7340

Thermal Production (Btu x 100,000) = Insolation x Square Footage x Solar Fraction x Efficiency/100,000	
Thermal Collector Efficiency	0.784
PVT Thermal Efficiency	0.7
Available Square Footage (ft^2)	30,000

The monthly thermal energy production is added to provide estimated annual thermal production of both the thermal collector and hybrid PVT systems. A rate of $0.20/(Btu x 100,000) is assumed for the thermal production. This estimates the costs offset for natural gas powered space and water heating. Losses in both systems are assumed to be similar.

Table 7.5 Estimated Annual Thermal Energy Production and Savings

System	Thermal Collector	PVT
Annual Thermal Production (Btu x 100,000)	124,832	111,457
Annual Savings at $0.20/(Btu x 100,000)	$24,966	$22,291

The simple payback and annual return on investment of the thermal collector system are:

Simple Payback = $1,510,000/$24,966 = 60 years

Return on Investment = $24,966/$1,510,000 = 1.65%

The simple payback of 60 years on the thermal collector system is slightly less than that of the PV system. Nonetheless, the payback may still not be acceptable as a financial investment. As with the PV system, simple payback may be improved by utilizing available tax incentives.

For the hybrid PVT system the annual energy savings would be:

$36,392 electrical savings + $22,291 thermal savings= $58,683 total savings

With the estimated initial cost of the system of $4,740,000, the simple payback and the return on investment for the hybrid system are:

Simple Payback = $4,740,000/$58,683 = 80 years

Return on Investment = $58,683/$4,740,000 = 1.24%

The estimated annual savings of the hybrid PVT system is the greatest of the three systems evaluated, but the high estimated initial cost of the hybrid PVT installation makes it a less attractive investment than the thermal collector system. The thermal collector system is the best financial choice of these options. However, the PV system comes in at a close second. If some PV generation is desired on the site, another option would be to divide the use of the roof, using the thermal collector system to supply only the peak domestic water heating loads and applying PV panels to the other portion of the roof.

Using this design, approximately 14,381 ft^2 of the roof area would be covered in solar collectors. At 29ft^2 per collector, 496 thermal collectors should be installed. The remaining 15,619 ft^2 can be devoted to the PV panels, each measuring 15.68 ft^2, yielding 996 PV panels on the roof. Table 7.5 lists the approximate module costs of this design.

Table 7.6 Estimated PV and Thermal Collector Prices, Divided Roof

	# Units	Ft^2	Nominal W	$/W	$/unit	$/ft^2	Total Cost
PV (U.S. Energy Information Administration, 2008)	996	15,619	199,200	3.5			$697,200
Thermal Collector (U.S. Energy Information Administration, 2008)	496	14,381				16.8	$241,601

Referring to Figure 7.1, a 100-250 kW PV installation costs approximately $7.5/W. At this rate, the installed cost of the PV portion of the divided roof example would be $1,494,000. If the thermal collector module is again estimated to be one third the total cost of the solar thermal installation, its installed cost would be $724,803. The total cost for the divided roof design would be $2,218,803.

Next, annual energy production is estimated for this divided roof design.

Table 7.7 Estimated Monthly Thermal Production, Divided Roof

	Monthly Thermal Energy Production					
Month	January	February	March	April	May	June
Insolation (Btu/ft^2/day)	1,810	2162	2330	2320	2264	2224
Thermal Collector Production (Btu x100,000)	4365	5214	5619	5595	5460	5364
Month	July	August	September	October	November	December
Insolation (Btu/ft^2/day)	2230	2258	2228	2060	1778	1634
Thermal Collector Production(Btu x100,000)	5378	5446	5373	4968	4288	3941

Thermal Production (Btu x 100,000) = Insolation x Square Footage x Solar Fraction x Efficiency/100,000	
Thermal Collector Efficiency	0.784
Available Square Footage (ft^2)	14,381

The total annual thermal energy production of this system is 61,010 Btu x 100,000. At approximately $0.20/(Btu x 100,000) the annual energy savings are $12,202. This estimate assumes that all thermal energy produced will be used.

Table 7.8 Estimated Monthly Electrical Production, Divided Roof

	Monthly Electric Energy Production					
Month	January	February	March	April	May	June
Sun hour/day ($kWh/m^2/day$)	4.02	4.48	5.07	5.19	5.44	5.75
PV Production (kWh)	19115	21302	24107	24678	25867	27341
Month	July	August	September	October	November	December
Sun hour/day (kWh/m2/day)	5.76	5.89	5.46	4.79	3.98	3.42
PV Production (kWh)	27388	28006	25952	22776	18925	16262

PV Production (kWh) = Sun hours/day x D.F. x electrical power rating x # panels x #days	
Derating Factor (D.F.)	0.77
PV Electrical Power Rating	0.2
Number of PV Panels	996

The total annual electrical energy production of this system is 281,728 kWh. At $0.08/kWh, the electrical energy savings is $22,538.

The total energy savings is the sum of the thermal energy savings and the electrical energy savings: $12,202+$22,538 = $34,740

The simple payback and the return on investment are calculated:

Simple Payback = $2,218,803/$34,740 = 64 years

Return on Investment = $34,740 /$2,218,803= 1.57%

As expected, the payback falls between that of the all PV system, at 65 years, and the thermal collector system at 60 years.

In conclusion, the thermal collector system is the best option financially. However, if PV generation on the site is still desired, the roof can be divided to devote a portion of available area to thermal collectors and a portion to PV panels. For this example, if the thermal collectors are sized to handle only the domestic water heating load, 48% of the roof should be devoted to thermal collectors, with 52% of the roof devoted to PV panels. Using this method, the simple payback of the system is only increased by 4 years. Sizing the thermal collector system for only the domestic water heating load removes the complexity of interconnection with the space heating system.

Each of the systems discussed have lengthy payback periods, greater than the useful life of the systems. There are several reasons why the paybacks of these systems are quite long and the chosen location may not be suited to provide adequate payback for a solar energy system. Manhattan, KS may not receive enough annual solar insolation to produce adequate energy to contribute to the system payback. A location closer to the equator and with more days of sunshine, such as in the southwestern United States, would receive more solar insolation and thus generate more solar energy, leading to increased energy savings. Additionally, the payback of the system would be much faster in a location with a higher utility rate, such as in urban areas. For the photovoltaic system, for example, a location with an electrical rate of approximately $0.16/kWh, such as in the northeastern United States would have a payback of only 32.5 years. Finally, tax credits or other incentives could be used to reduce the initial system cost and thus the payback period if the building was a private building, rather than a public elementary school.

CHAPTER 8 - Conclusions

This chapter concludes the report and offers final suggestions and guidance for the design and implementation of hybrid photovoltaic-thermal systems.

Sustainable Image

Financial payback of a system should not be the only consideration when deciding whether to use a PV, thermal collector or hybrid PVT system. The image that the system will project to the community can also be considered as an advantage to the design. For the elementary school example used in this report, on-site production of energy provides a unique learning opportunity for students, as well as a sustainable image to the community. Teachers may incorporate education about sustainability and energy production into their curriculums as a result of the installation of a PV, thermal collector, or hybrid PVT system. Members of the community will see the systems incorporated at the school and can feel a sense of pride in the school. An elementary school is a prime example of a building that will be highly visible to the public, although many other buildings and businesses can benefit from installing sustainable systems.

Design Considerations / Enhancements

To make a hybrid photovoltaic system effective and efficient, equipment beyond the basic operating requirements may be necessary. Remote locations that are not connected to the electrical grid cannot rely on supplemental power from the grid on cloudy days, and must implement battery storage for their photovoltaic applications. Sites that do not have access to the electrical grid may require generator back-up, depending on the importance of electrical continuity at the site. PV or PVT designs may also be enhanced by further integrating the system into the building structure. The use of BIPV can help incorporate photovoltaic systems into skin of buildings, as part of the roof, walls, or windows. These systems make use of surfaces that are often overlooked as a means for electrical or thermal energy production.

One of the main considerations in a thermal solar system concerns the storage of thermal energy. Thermal energy produced must be stored in some way to assure adequate supply for nightly hot water and space heating. For a liquid thermal collector system, a hot water storage tank is a suitable solution, while a thermal collector system using air as the transfer medium may utilize mass storage in rocks or concrete.

Code Changes / Steps for Implementation

Upcoming codes such as the International Green Construction Code (IGCC) and ASHRAE 189.1 address site energy production more strictly. For example, Version 4 of the first draft of the IGCC that is set to be released in 2010, requires that roofs in warm climate areas be partially covered with photovoltaics or thermal collectors (International Code Council, 2009). ASHRAE 189.1 is expected to require provisions for on-site renewable energy production at a minimum of 3.7W/ft^2 or 13 Btu/h-ft^2 multiplied by the entire roof area of a structure, with exceptions for locations with low solar insolation values (ANSI/ASHRAE/USGBC/IES , 2009). PV, thermal collector and PVT systems will be necessary to meet the requirements of these changing codes.

Design Resources

There are many design resources available to designers of thermal and photovoltaic systems, including the following software: HOMER, RoofRay, PV WATTS and F-Chart.

Originally developed by NREL, HOMER is a software tool to analyze load, power, and storage for renewable energies. HOMER is now available commercially as HOMER Energy, but a free Beta version is available at http://www.homerenergy.com (HOMER Energy LLC, 2010). The tool allows users to analyze systems such as photovoltaics, hydro power, biomass, and fuel cells, as well as storage methods such as batteries and flywheels. HOMER helps designers optimize sustainable energy systems by showing the results of different system configurations and different system components.

RoofRay is a quick tool that helps users estimate PV array output (RoofRay, 2008). While best suited for residential applications, RoofRay can be useful in providing a preliminary estimate of solar power production. For existing buildings, users can input current energy usage, to determine how much of their energy usage will be offset by the use of PV.

PV WATTS by NREL, as discussed earlier, is a useful resource for basic photovoltaic system design (National Renewable Energy Laboratory, 2010). This site is free to use and contains solar data for the United States, as well as other limited locations world-wide. Users input the basic specifications of their PV systems, including tilt, derating factor, and array nominal power rating. The program outputs expected monthly production, energy savings based on entered utility rate data, and expected daily solar radiation.

F-Chart provides very detailed analyses of PV and thermal collector systems. Demonstration versions are available for free online at http://www.fchart.com (F-Chart Software, 2008). This program has many options for user inputs and is designed for a more advanced user. The program can evaluate many types of systems, including flat-plate and evacuated collectors, fixed and tracking photovoltaics, various storage or transfer methods as such as water storage and pebble storage for thermal applications and grid-interconnection and battery storage for electrical applications.

Drawbacks and Challenges

For all of the advantages of solar energy systems, there are also many disadvantages. These systems can be costly, and require specialized design and installation services beyond the typical commercial building design, with hybrid PVT systems being especially complex. PV, solar thermal collectors and hybrid PVT all suffer from intermittency when the sun is not shining during the evening, inclement weather, or winter months. Unfortunately, thermal collector production is typically lowest in the winter months, when space heating loads are the highest. For the elementary school example presented in this report, PV, liquid thermal collector, and hybrid PVT production are the highest in the months that schools are not typically in session. Thus, solar energy systems are best suited to consistent, year-round loads to avoid wasted production. Another disadvantage is that these systems also experience significant losses in efficiency when shaded, even under partial shade conditions. Additionally, photovoltaic systems require components such as inverters and liquid thermal collectors require additional components such as pumps, all of which can, and do, fail.

Final Conclusions

The emerging technology of hybrid photovoltaic-thermal has an exciting and promising future. Hybrid PVT offers the opportunity for thermal and electric cogeneration that is unmatched by photovoltaic and solar thermal systems alone and is in line with trends towards more integrated building designs. As shown in the sizing example presented in Chapter 6 of this report, to produce the same amount of electrical and thermal energy, more square footage is required using a combination of PV and liquid thermal collectors than by using hybrid PVT liquid collectors. Hybrid PVT offers a simplistic solution to the dilemma of whether to incorporate PV or solar collectors into a building design.

However, hybrid PVT is not yet ready for commercial application in the United States. Manufacturing in the U.S. of hybrid PVT is very limited, with only several commercial liquid PVT products effectively being manufactured world-wide (Hansen & Sorensen, 2006). Additional development and marketing of hybrid PVT products is necessary for designers to be comfortable with this new technology. Furthermore, with additional competition in the manufacturing of hybrid PVT competition, prices would reduce, allowing systems to be more economical for the consumer.

Further studies are needed to determine installation, operating and maintenance costs of hybrid PVT systems. Since these products are still developing, it is unclear what the operable lifetime of the modules will be and what maintenance issues may develop. In order to convince building owners to choose hybrid PVT, some basic financial analysis is necessary. An owner may be wary to select a system with an unknown payback. Installers may need additional training in installing hybrid PVT systems, with the unique consideration that both piping and conduit routed is routed to each collector in these systems.

Designers will need more training and exposure to hybrid PVT before it can be successfully implemented in commercial building design. Uniform codes and design guides would serve as a reliable basis for this training. Currently, there is a vast array of design resources available for PV design, including computer programs and commercial design guides, but much less exists for thermal collectors and very little exists for hybrid PVT. Reputable standards and guidelines are necessary to ensure that designs are efficient and operable for building owners.

Whether designers choose to implement PV, thermal collector systems, or hybrid PVT, solar energy systems will be an important aspect of building designs in the future. With energy codes being developed to require on-site power generation, designers will need to be familiar with how to determine which systems are ideal for their particular project. A renewed public interest in sustainability will drive client demands for sustainable design, and the design team must be ready to meet those demands. Increases in commercial energy consumption may necessitate the increased use of on-site energy generation. Every project poses unique challenges and problems and solar technologies such as PV, thermal collectors, and hybrid PVT should be considered in the solution.

CHAPTER 9 - Works Cited

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Appendix A - Load Estimate Calculation

This section presents the load estimate performed for Chapter 6, Preliminary Sizing Examples.

Electrical

Lighting

$50{,}000 ft^2 \times 1.2\ W/ft^2 = 60{,}000 W$

(1.2 W/ft^2 for a school or university per 2007 ASHRAE 90.1)

Power

$30{,}000 ft^2$ Classrooms / 900 ft^2 per classroom = ~33 classrooms

Each classroom

8 duplex @ 180W =	1440W
1 computer @ 300W =	300W
1 projector @ 1200W =	1200W
1 projector screen @ 800W =	800W
	3740W
	x 33
	123,420W

Computer room

30 computers @ 300W =	9000W
1 projector @ 1200W =	1200W
1 screen @ 800W =	800W
	11,000W

Library

30 computers @ 300W =	9000W
10 duplex @ 180W =	1800W
	10800W

Gymnasium

8 duplex (cleaning) @ 180W =	1440W
4 motorized baskets/etc @ 1800W=	7200W
	8640W

Kitchen

2 commercial ovens @ 8000W =	16,000W
2 comm. dishwashers @ 20,000W =	40,000W
4 warming cabinet/server @ 2000W=	8000W
8 small appliances @ 1800W =	14,400W
1 cooler @ 3000W =	3000W
1 freezer @ 4000W =	4000W
8 duplex @ 180W =	1440W
	86,840W

Hallways

Approx. 900 linear feat, duplex every 30'

30 duplex @ 180W = 5400W

Cafeteria/Performance Area

Approx. 3500ft^2

8 duplex for cleaning @ 180W =	1440W
3 AV equip @ 1800W =	5400W
	6840W

Restrooms

Approximately 1 per 10,000ft^2

5 restrooms w/ 3 duplex @ 180W ea. = 2700W

Mechanical equipment

Exhaust fans

Restroom/general- 5 @ 600W = 3000W

Kitchen – 1 @ 2000W = 2000W

MAU

Assume 20 cfm/person, 1500 people

30,000 cfm outdoor air

Bring from OA conditions to supply conditions

101/72.9 (ASHRAE 0.4% Value), to 55°, 90%RH

$Q=4.5cfm\Delta h$

$Q=4.5(30000)(36.5-22.5)=1{,}890{,}000$Btu/h

Assume EER is approximately 10.0Btu/h/W

1,890,000 Btuh (1/10.0) = 189,000W

Cooling equipment

$(1.5\ cfm/ft^2)(50{,}000ft^2)$ = 75,000cfm – 30,000cfm outdoor air

(45,000cfm)/(400 cfm/ton) = 112.5 tons

112.5 tons (12,000 Btuh/ton) = 1,350,000Btuh

Assume EER is approximately 10.0Btuh/W

1,350,000 Btu/h (1/10.0) = 135,000W

Total electrical load

584,640W

Thermal Load

Wall Perimeter Heat Loss

Assume approx. 1700’ of wall perimeter, 10’ high

1700’ x 10’ = $17{,}000ft^2$

Subtract 10% windows

$17{,}000ft^2 – 1700ft^2 = 15{,}300ft^2$

U Value:		
	0.17	OA film
	0.16	face brick
	1.00	¾" air gap
	2.10	CMU
	2x4.55	2" rigid insulation
	0.68	IA film
	13.21	

1/13.21 = 0.76 U-value

ΔT = 75° Space Air – (-5° Outside Air) = 85°

q = UxAxΔT=0.076 x 15300 x 85 = 98,838Btu/h

Glass

1700ft^2

Assume double-glazed, low e = 0.05, ½" airspace, U=0.30 per ASHRAE Fundamentals

q = U x A x ΔT = 0.30 x 1700 x 85 = 43,350 Btu/h

Roof

Assume 50,000 ft^2

Assume metal deck, U=0.045 per ASHRAE Fundamentals

q = U x A x ΔT = 0.045 x (50,000) x 85 = 191,250 Btu/h

Floor

q = P x F_p x ΔT (per ASHRAE Fundamentals)

P = perimeter = 1700'

F_p= 0.5

q = 1700 x 0.5 x 85 = 72,250 Btu/h

Outside Air

Assume approx. 20% of total cfm

75,000 cfm x 0.2 = 15,000cfm

q= 1.08 x cfm x ΔT = 1.08 x 15,000 x 85 = 1,377,000 Btu/h

Total Heating Load = 1,782,688 Btuh

Hot Water

From Table 1004.1.1 IBC:

Classroom 20ft^2/person

Use this number of people in classrooms only, since this is the maximum amount of people at a given time, with all classrooms full.

Classroom area is approximately 30,000ft^2

30,000ft^2/20ft^2/person = 1500 people

Per table 2902.1 IBC, one lavatory required per 50 people for a classroom

1500 people/50 people per lavatory = 30 lavatories

		Demand per NSPE Recommenations	Total GPH
Assume:	4 showers	225 gph	900
	30 lavatories	15 gph	450
	2 kitchen sinks	20 gph	40
	20 pantry sinks	10 gph	200
	2 dishwashers (large)	100 gph	200
	4 mop sinks	20 gph	80
			1870 gph

Demand factor for school (per NSPE) = 0.40

1870 gph x 0.40 = 748 gph

Storage factor for school (per NSPE) = 1.00, 748 gallons of storage

BTUH = GPH x ΔT x 8.33lb/gal = 748 x (140-55)=529,621 Btuh

Approximately 550MBH, neglecting heat loss, peak load

Appendix B - Product Specifications Sheets

B.1 Schüco Premium V Flat Plate Solar Collector

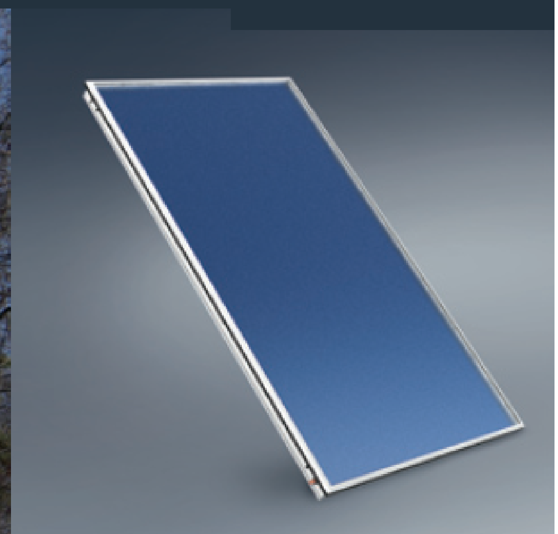
B.2 GE 200W Photovoltaic Module

B.3 Millenium Electric MSS-MIL PVT Collector

B.1 Schüco Premium V Flat Plate Solar Collector

Schüco Premium V

Flat Plate Solar Collector



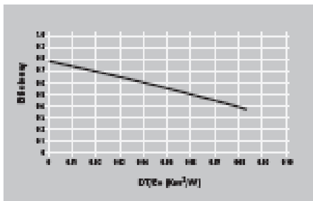
The Schüco Premium V high-performance solar collector converts solar energy into heat and is excellent for providing domestic hot water as well as for heating swimming pools. The high selectivity absorber coating and optimum thermal insulation maximize efficiency. The absorbed solar heat is transferred to a storage tank by freeze-protected, non-toxic solar fluid through a serpentine copper pipe. This aesthetically pleasing collector was developed with performance, longevity, and simple installation in mind.

Features

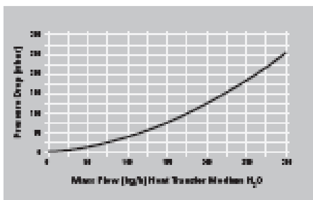
- High efficiency with high selectivity absorber coating.
- Low energy loss due to excellent thermal insulation.
- Robust silver anodized aluminum frame for maximum durability.
- Corrosion-resistant materials for high reliability and long service life.
- High transparency, low-iron glazing.
- Superior flow control over conventional header/riser designs.
- Suitable for pitched roof, flat roof, synergy roof®, awning, and façade installation.
- Tempered glass inset a full half-inch into the frame.
- Quick and simple installation with SolarEZ mounting hardware, collector connectors, and installation accessories.
- Serpentine piping, 1 connection on each long side for portrait orientation of collector.
- Certifications: SRCC OG-100, CE, DIN EN 12975-2, DIN CERTCO, EC guideline 97/23/EC.
- 10 year performance warranty.

SCHÜCO

Technical Data



Performance Characteristics



Pressure Drop Characteristics

Size: 84.7 x 49.3 x 3.6 in. (2152 x 1252 x 93 mm)
Collector surface area (A_g): 29 sq. ft. (2.69 m²)
Weight (empty): 121 lbs. (55 kg)
Efficiency: $\eta_0 = 78.4\%$
Heat loss coefficient: $k_1 = 4.28$ W/ m²K; $k_2 = 0.014$ W/m²K²
Incident angle modifier: $k_{(50)} = 0.96$
Thermal output: 2.0 kW_{th}

Piping configuration: Serpentine
Absorber long-wave emissivity: $\varepsilon = 5.0\%$
Absorber short-wave absorptivity: $\alpha = 95\%$
Net aperture area: 27.1 sq. ft. (2.52 m²)
Aperture surface area: 27.0 sq. ft. (2.51 m²)
Absorber material: Copper
Absorber coating: High selectivity

Heat transfer fluid volume: 0.53 gal. (2.0 ltr.)
Minimum volume flow: 0.66 gal./min (2.5 ltr./min)
Maximum number of collectors in series: 4
Pressure drop (0.66 gal./min solar fluid): 1.1 psi (75.0 mbar)

Connection: 12.0 mm Cu pipe, serpentine
Connector type: Compression fitting
Operating pressure: 46.4 psi (3.2 bar)
Maximum operating pressure: 145 psi (10 bar)
Test pressure: 290 psi (20 bar)
Stagnation temperature: 381°F (194°C)
Maximum operating temperature: 248°F (120°C)

Solar glazing: Low-iron, high transparency
Transmittance: >91.0%
Thickness: 0.16 in. (4mm)

Frame material: Aluminum
Gaskets: EPDM
Thermal insulation: 0.79 in. (20 mm) mineral wool

Schüco article Premium V 231 156
Schüco installation system SolarEZ

Specifications subject to change without notice.

Schüco USA L.P.
www.schuco-usa.com

P2971/USA/08.07/Printed in USA

B.2 GE 200W Photovoltaic Module

GE Energy

GEPVp-200-M

200 WATT PHOTOVOLTAIC MODULE FOR 600 VOLT APPLICATIONS

FEATURES

- 54 poly-crystalline cells connected in series
- Peak power of 200 watts at 26.3 volts
- Designed for optimum use in residential and commercial grid-tied applications
- 20-year limited warranty on power output, 5-year limited warranty on materials and workmanship*
- Junction box and 1.8 meter cable with easy-click Solarlok Connectors included

BENEFITS

- Output power tolerance of +/- 5%
- Robust, clear anodized aluminum frame with pre-drilled holes for quick installation

CERTIFICATIONS

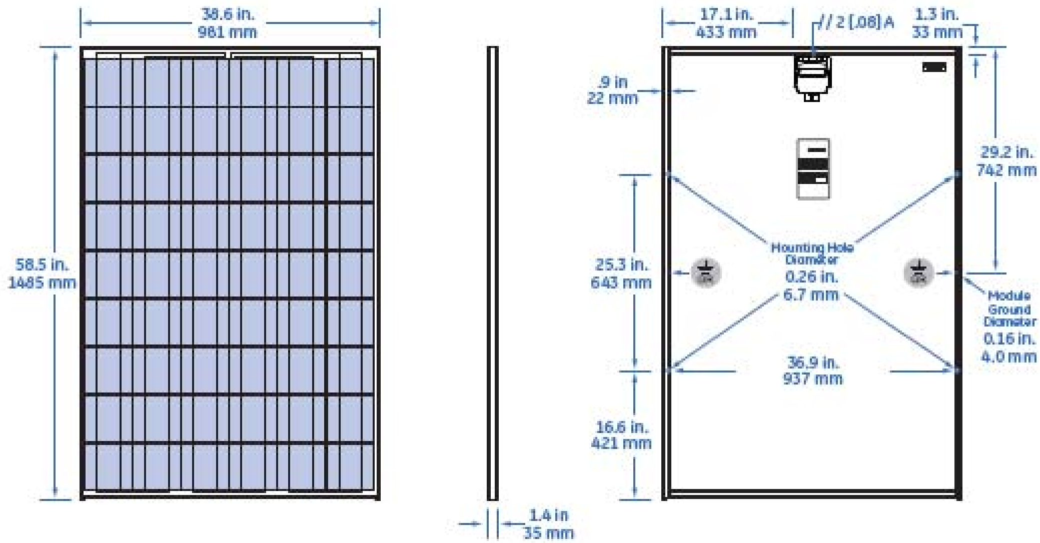
The GEPVp-200-M Module meets the following requirements:**

UL-1703 IEC-61215

*Refer to GE energy product Warranty for specific details
**Refer to GE energy product Certifications for up to date Certificates.

imagination at work

PHYSICAL CHARACTERISTICS

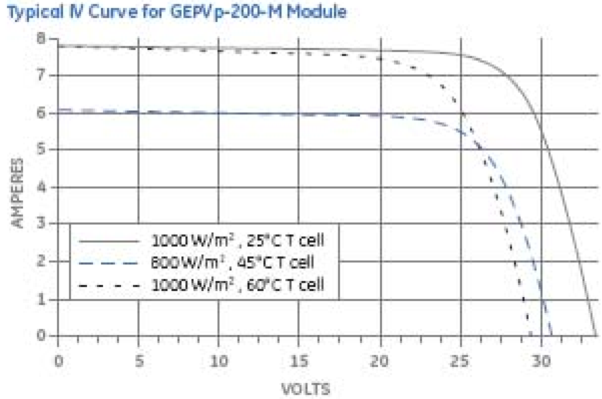


Physical Design Properties

Weight	39.0 lb (17.7 kg)
Weight (Wind) Bearing Potential	50 lbs/ft² (125 mph equivalent)
Hailstone Impact Resistance	1" @ 50 mph (25 mm @ 80 kph)

ELECTRICAL PERFORMANCE

Typical IV Curve for GEPVp-200-M Module



Typical Performance Characteristics

Peak Power (Wp)	Watts	200
Max. Power Voltage (Vmp)	Volts	26.3
Max. Power Current (Imp)	Amps	7.6
Open Circuit Voltage (Voc)	Volts	32.9
Short Circuit Current (Isc)	Amps	8.1
Short Circuit Temp. Coefficient	mA/°C	5.6
Open Circuit Voltage Coefficient	V/°C	-0.12
Max. Power Temp. Coefficient	%/°C	-0.5
Max. Series Fuse	Amps	15
Max. System Voltage	Volts	600
Normal Operating Cell Temperature [NOCT]	deg. C	50

IV parameters are rated at Standard Test Conditions (irradiance of 1000 W/m², AM 1.5G, cell temperature 25°C). As with all poly-crystalline PV Modules, during the stabilization process that occurs during the first few days in service, module power may decrease approximately 3% from typical maximum power due to a phenomenon known as Light Induced Degradation (LID). All measurements are guaranteed at the laminate leads. NOCT is measured at 800 W/m², 20 deg. C ambient, and 1 m/s windspeed.

GE Energy
231 Lake Drive
Newark, DE 19702
302-451-7500

ge-energy.com/solar

B.3 Millenium Electric MSS-MIL PVT Collector

MILLENNIUM ELECTRIC: MSS - MIL-PVT-320W-MO2 DATA SHEET

> High Performance

High-power module using 4X36 fractions of 125 mm square Mono-crystalline silicon cells.

>High Quality

High Quality Advanced EVA encapsulation.

> Efficiency 14.2%>

14.2% module conversion efficiency. PV modules with bypass diodes minimize the power drop caused by shade.

> The Most Efficient Solar Collector in the World

-Up to **30% higher PV efficiency** for production of electricity.

-Up to **70% additional thermal energy** from the same collector.

> Warranty

Warranty for module 80% performance after 25 years. 90% for additional 10 years.

Millennium's photovoltaic modules offer industry-leading performance, durability, and reliability for a variety of electrical power requirements. Using breakthrough technology, these modules use a textured cell surface to reduce reflection of sunlight. Structure to improve conversion efficiency. An anti-reflective coating provides uniform blue.

MSS

MSS, Millennium's Unique Technology:

The Multi Solar system is an innovative, patented Solar PV/Thermal System that makes it possible to **convert solar energy into Electrical energy (PV) and Thermal energy at the same time using a *single integrated* flat plate collector system.** The Multi Solar System uses air and water pipes to cool the PV cells in order to increase the relative efficiency of the electric system and at the same time produce hot water and hot air which can be channelled for further thermal use.

The **PV cells which are cooled by the water and air flow inside the pipes** can provide up to ***30% higher annual electrical production than the usual PV system under the same conditions.*** The MSS collector creates this advantage by preventing the efficiency degradation of regular PV caused by excessive heat (negative heat coefficient of half percent per degree of heat in any normal photovoltaic panel). The thermal efficiency of the MSS collector system reaches up to 70% (35% hot water and 35% hot air). With the additional 15% efficiency of the PV electrical production the MSS reaches to 85% efficiency: **The Most Efficient Solar Collector in the World.**

Common applications include:

-Solar MSS power stations
-Solar MSS Co-generation power stations
-Grid connected houses
-Solar houses
-Solar air conditioning systems

< MILLENNIUM ELECTRIC T.O.U. Ltd >

11 Hasadna St., P.O.Box 2646, Ra'anana North Industrial Zone 43650, ISRAEL
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Email: info@millenniumsolar.com Website: www.millenniumsolar.com

MILLENNIUM ELECTRIC

MSS MIL-PVT-320W-MO2: Product General Specifications

Dimensions	Length (m)	Width (m)	Area (m²)
MSS generator	2.199	1.238	2.72
PV generator	2	1.125	2.25
Thermal Output	6000 Kcal per day under average Middle East climatic conditions or 1.28 KWp Thermal energy		
Electrical Output	0.4-0.8 kW/ m^2 – per day under average climatic conditions (320 Wp)		
Maximum output temperature	50-55 °C – under normal operating conditions		
Thermal Efficiency	35% Air – 35% Hot Water (70% water if the air is not used)		
Electrical Efficiency	14.2%		
Additional comments	Overall efficiency is 84.2%		

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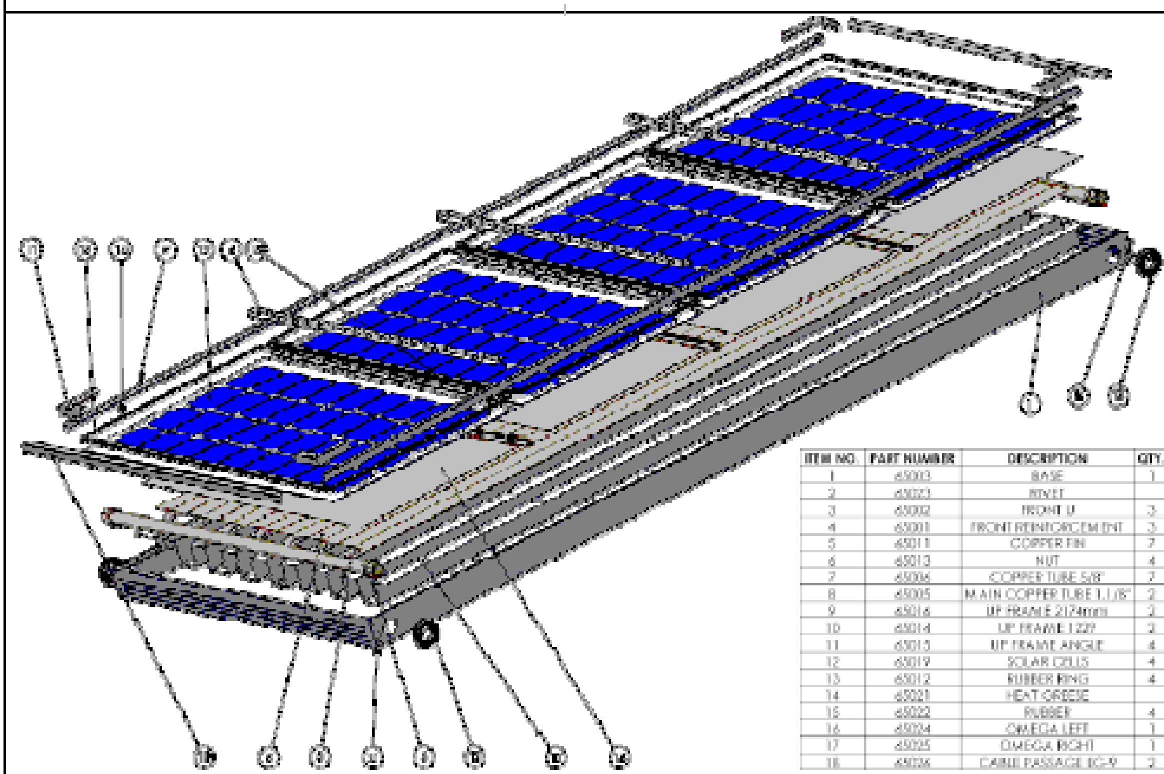

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	65003	BASE	1
2	65023	RIVET	
3	65002	FRONT U	3
4	65001	FRONT REINFORCEMENT	3
5	65011	COPPER FIN	7
6	65013	NUT	4
7	65004	COPPER TUBE 5/8"	7
8	65005	MAIN COPPER TUBE 1.1/8"	2
9	65016	UP FRAME 2174mm	2
10	65014	UP FRAME 1229	2
11	65015	UP FRAME ANGLE	4
12	65019	SOLAR CELLS	4
13	65012	RUBBER RING	4
14	65021	HEAT GREESE	
15	65022	RUBBER	4
16	65024	OMEGA LEFT	1
17	65025	OMEGA RIGHT	1
18	65026	CABLE PASSAGE IG-9	2

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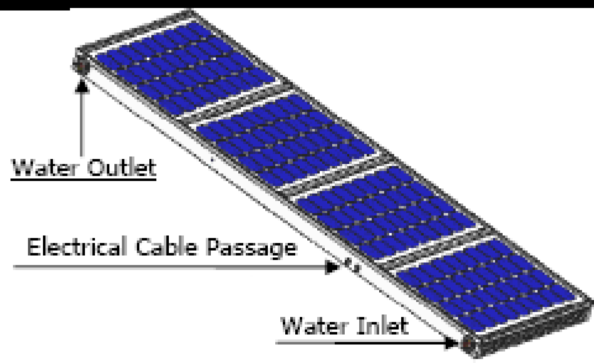
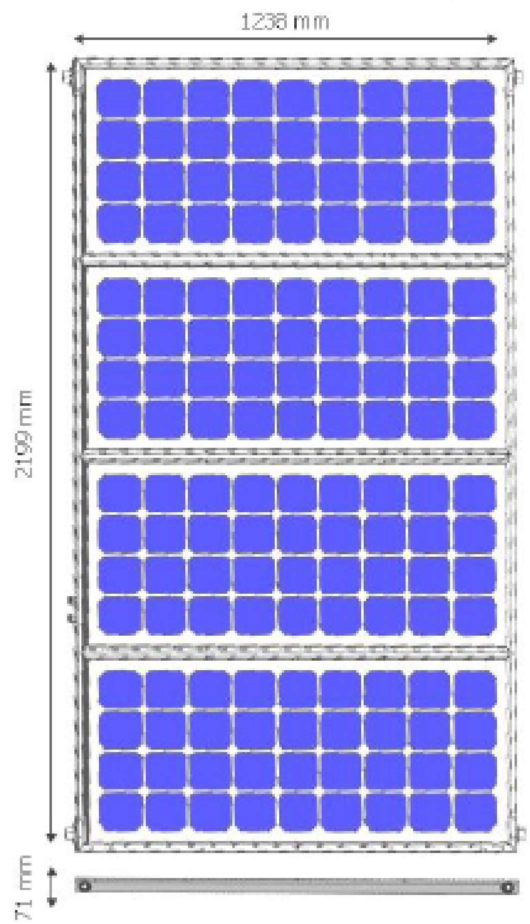
MILLENNIUM ELECTRIC

MILLENNIUM ELECTRIC
MSS - MIL-PVT-320W-MO2 DATA SHEET





Electrical Specifications

Manufacturer	Millennium Electric
Type	MIL-PV-320W-M02
Pnom	320W
Power tolerance	+/-5%
Origin	Israel/Cyprus
BIPV	No
Module efficiency	14.2%
Cell manufacturer	Motech/Gintech/Q-cell/Sharp
Cell type	Mono-crystalline, textured and anti-reflectivity layered
Cell size	125 mmX125 mm
Cell efficiency	16%
Cells per Module	144
Power guarantee	80% performance after 25 years ;90% after 10 years
Distribution	worldwide
Produced from	1991
Approvals	IEC 61215, Safety class II
Length	2.199 m
Width	1.238 m
Thickness	71mm
Frame type	aluminium
Output Terminal	junction box Tyco
Net Collector Weight	38 kg
Voc	44.2 V
Isc	9.94 A
NOCT	47 °C
Vmpp at 1000W/m2	36.72 V
Impp at 1000W/m2	9.16 A

MILLENNIUM ELECTRIC	JUNCTION BOX

COMPONENT DESCRIPTION

Connection Box	1xIP65 with built-in bypass diodes
Grounding connection	Yes
Solar Junction boxes	Solar Junction box provides the user with safety, swift and reliable way to connect. The junction box can be connected to the photovoltaic collector. It has approved TUV certificates and IEC61215 testing. Solar Junction box provided with cable and connector, PV junction box for time-saving, safe and reliable cabling.
Specification	Maximum current:16A Maximum system voltage: DC 1000 V Working temperature: -40-90 degree C Maximum working humidity:5%-95% (No coagulation) Protection degree: IP 65 Rated connecting capacity:4 mm EXP 2 Characteristic: Durable and long life time Strong capacity; Suitable for harsh environment; 2-4 combination hub could be put inside as required; Insert method is adopted
Junction boxes for MIL-PVT-320W-MO2 modules	

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