Report

Analysis of The Potential Applications of Solar Thermal and Photovoltaic Systems for Northwest Vista College

ESL-TR-13-06-01

June 21, 2013

Prepared for

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ALAMO COLLEGES

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DISCLAIMER

ACKNOWLEDGEMENTS

The Energy Systems Laboratory (ESL) greatly appreciates the Alamo Colleges and the Facility Division at Northwest Vista College for their cooperation and assistance in collecting the information required to complete this report.

The ESL would also like to acknowledge Dr. Juan-Carlos Baltazar Manager of the ESL's Energy Analysis Group, Dr. Ahmet Ugursal, Continuous Commissioning® Engineer at the ESL, and Mr. Joseph Martinez, PCC, Associate Director of the ESL and the Principal Investigator of this study, for their participation in this report. All questions regarding the content of this report should be directed to Mr. Martinez. Contact information is provided below:

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EXECUTIVE SUMMARY

The Energy Systems Laboratory (ESL) of The Texas A&M University System is under contract with Alamo Colleges to conduct energy management, implement the Continuous Commissioning® (CC®)[1] process and assist with various sustainability projects. As part of these efforts, the ESL was tasked to evaluate and analyze the potential applications of renewable energy (RE) technologies at the Northwest Vista College (NVC) of the Alamo Colleges. Based on the evaluation and analysis, the ESL recommends the following RE technologies as viable: ground source heat pump (GSHP) systems, closed loop solar thermal system and photovoltaic (PV).

GSHP is one of the most reliable and durable of the RE sources due to the minimal number of moving parts. The initial cost of GSHP is usually the determining factor and is tied to the amount of drilling required for the piping. In this case, the Lago Vista (the pond) of the NVC campus presents a potential for a water-source GSHP system in which the pond is used as the heat sink. This eliminates the drilling requirements which would significantly reduce the capital costs. The GSHP analysis showed that 30% of the cooling loads of the Cypress Campus Center can be met using the 18% of the cooling capacity of the GSHP. The rest of the capacity can be used for other buildings since campus buildings have different load profiles throughout the day. The heat rejection capacity of the pond can be utilized to reduce the cooling tower load by installing the GSHP system in parallel to the cooling towers.

A **closed loop solar thermal system**, which can be used for space heating, absorption air conditioning, water heating and process heating, was analyzed using simulation tools. A parametric study of the solar thermal system showed that between 75 and 100 panels, or approximately 2000 ft^2 of solar collectors, can provide more than 80% of the hot water requirements of the Cypress Campus Center. The **photovoltaic (PV)** analysis showed that the annual fraction of the loads that can be met is approximately 50%. The Solar PV system also shows that their potential of application is feasible and considering that the NVC is an all-electric campus their impact should be observed immediately

The proposed systems showed significant potential to offset the loads at the Cypress Campus Center. A more detailed life-cycle cost analysis is required to determine the economic feasibility of the systems.

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INTRODUCTION

Renewable energy (RE), with the correct integration of the systems, can supply a substantial part of the energy use in any building under the right circumstances. The application of the RE systems are constrained by economic decisions rather than the technical challenges. The Energy Systems Laboratory (ESL) was contracted to conduct an analysis of RE potential of the Northwest Vista College (NVC) of the Alamo Community College District in San Antonio, Texas. This report presents an analysis of the application potential of three RE systems on one of the buildings at the NVC campus. The systems analyzed in this report are solar thermal, photovoltaic and ground source heat pump systems. The report discusses the novel approaches for the application of RE systems at the NVC campus as well as the potential of those systems to offset the electricity use and hot water consumption (thermal component) of the selected buildings. This report details the description of the typical solar systems, energy modeling calculations, and the site-specific aspects of the proposed RE systems.

GROUND SOURCE HEAT PUMP

The ESL team analyzed the potential for geothermal heat pump applications using the pond as the heat sink and source. This section details the specific system, calculation, analysis and the recommendations specific to the NVC campus.

Ground Source Heat Pump Analysis

This section of the report discusses the geothermal energy basics, the ground source heap pump (GSHP) systems, and the potential of geothermal system applications to offset the energy requirements of the NVC. In addition, geothermal energy basics and various application types are explained in this section. The energy analysis was conducted for the shallow pond GSHP which is the proposed system for the NVC campus.

Direct utilization of geothermal energy is one of the oldest technologies 47% of which constitutes geothermal heat pumps according to 2010 data. The total global installed capacity of ground source heat pump systems is 48,493 MWatts which equals to 37.5 million tons of fuel oil per year. In the US only, the calculated savings is 20.2 million barrels of oil per year. Contrary to the global figures, 84% of the direct geothermal systems is geothermal heat pumps in the US and the size of installed units varies from 5.5 kW for residential use to 150 kW for commercial and institutional uses (Lund 2010).

There are several benefits of the geothermal heat pump systems. According to the US Department of Energy (2011), they can reduce energy consumption by up to 44% compared to air-source heat pumps and by up to 72% compared to electric resistance heating of conventional HVAC systems. Geothermal systems can be installed as a part of new construction or retrofit project and have less moving parts which makes them durable and reliable with underground piping warranties ranging from 25 to 50 years.

Ground Source Heap Pump (GSHP) and the Northwest Vista College

GSHP systems require drilling and trenching which constitute a major portion of the investment costs. Due to this reason, the installation of GSHP systems for buildings with existing HVAC systems is rarely justified on the basis of energy use only (RETScreen International 2005). The Northwest Vista College (NVC) has a shallow pond with a surface area of 115,000 ft^2. This pond presents an opportunity to be used as a heat rejection/extraction medium since spell out what SWHP is (SWHP) systems minimize the need for drilling and trenching. The pond is 6 ft deep and has the water capacity of 690,000 ft^3.

The pond is located in a central location of the campus with direct access from Juniper Hall, Redbud Hall, Live Oak Hall, and Cypress Campus Center (Figure 1). This report focuses on the Cypress Campus Center which is the multi-use building with offices, conference rooms, bookstore, and a restaurant area. The Campus Center is a 56,814 ft^2 building with an average energy use of 4,845 Btu/ft^2. In the energy analysis, the heat rejection/extraction capacity of the pond is calculated using the hourly weather data. This capacity was compared to the Cypress' building load profiles which were derived from the trend log data. Therefore, energy savings is based on the actual building energy usage.

Figure 1. The pond and the surrounding buildings at the Northwest Vista College (Image credit: google.com).

GSHP Model

The heat rejection capacity of the pond is calculated using Chiasson's equations 1 through 11 (1999). The heat rejection capacity calculation is based on the steady-state heat transfer between the GSHP loop fluid and the pond. It is also based on the worst case scenario: the peak cooling load during the summer, which is also the time with the highest annual pond temperature that reduces its heat rejection capacity.

The calculations assumed that 240 slinky coils, 400 ft long, are installed to maximize the installed coil length. The pipe material is high-density polyethylene (HDPE) with a thermal conductivity of 0.28 Btu/hr-ft-°F. The flow inside the pipe was assumed to be laminar and fully developed with a Nusselt number of 4.36. A 1" diameter HDPE pipe. The convective heat transfer coefficients between the pipe fluid and the pipe and between the pipe outer surface and the pond were calculated using Equation 4. The convection coefficients were then used to calculate the total pipe heat resistance as presented in Equations 5 through 8.

$$\boldsymbol{q_{in} - q_{out} = V\rho c_p \frac{dT}{dt}} \qquad \text{(Equation 1)}$$

qin, heat transfer to the pond, Btu/h
qout, heat transfer from the pond, Btu/h
V, pond volume, ft^3
p, density of the pond water, lb/ft^3
cp, specific heat capacity of the pond water, Btu/lbm-°F
dT/dt, rate of temperature change of the pond water, °F

$$\boldsymbol{q_{fluid} = UA_{pipe}\left(T_{fluid} - T_{pond}\right)\left(N_{circuit}\right)} \qquad \text{(Equation 2)}$$

UA_{pipe}, overall heat transfer coefficient for the pipe, Btu/hr-°F
$N_{circuit}$, number of spools in the pond

$$\boldsymbol{UA_{pipe} = \frac{2\pi r_i L_{spool}}{\Sigma R_t}} \qquad \text{(Equation 3)}$$

r_i, the inner pipe radius, ft
L_{spool}, length of the one spool, ft
ΣR_t, composite thermal resistance,

$$\boldsymbol{h_c = \frac{Nu\,k}{L}} \qquad \text{(Equation 4)}$$

h_c, convection coefficient, Btu/hr-ft^2-F, calculate for both inside and outside the pipe
k, thermal conductivity of water, Btu/hr-ft-°F
L, characteristic length (ratio of the area to the perimeter L=A/P), ft
Nu, Nusselt number, 4.36 for fully developed flow inside the pipe

$$\boldsymbol{\Sigma R_t = R_i + R_{pipe} + R_o + ff} \qquad \text{(Equation 5)}$$

R_i, thermal resistance due to fluid flow in the pipe, ft^2-°F/hr-Btu
R_o, thermal resistance at the external pipe surface, ft^2-°F/hr-Btu
ff, fouling factor

$$\boldsymbol{R_i = \frac{1}{h_i}} \qquad \text{(Equation 6)}$$

$$\boldsymbol{R_{pipe} = \frac{r_i}{k_{pipe}} \ln\left(\frac{r_o}{r_i}\right)} \qquad \text{(Equation 7)}$$

$$\boldsymbol{R_o = \frac{r_i}{r_o}\left(\frac{1}{h_o}\right)} \qquad \text{(Equation 8)}$$

h_i, convection coefficient due to fluid flow in the pipe
k_{pipe}, thermal conductivity of the pipe, Btu/hr-ft-°F
h_o, convection coefficient at the outer surface of the pipe, Btu/hr-ft^2-°F
r_i, inner radius of the pipe, ft
r_o, outer radius of the pipe, ft

Calculate the Nu outside the pipe using the following equations.

$$Nu_o = \left(0.60 + \frac{0.387Ra^{\frac{1}{6}}}{\left(1+(0.559/Pr)^{\frac{9}{16}}\right)^{\frac{8}{27}}}\right)^2 \quad \text{(Equation 9)}$$

$$Ra = \frac{g\beta(\Delta T)L^3}{v\alpha} \quad \text{(Equation 10)}$$

Ra, Rayleigh number
g, acceleration due to gravity, ft/s^2
β, coefficient of thermal expansion of water
v, kinematic viscosity of water
α, thermal diffusivity of water
ΔT, temperature difference between the pipe and the water
L, characteristic length

$$Pr = \frac{c_p\mu}{k} \quad \text{(Equation 11)}$$

Pr, Prandatl number
cp, specific heat capacity of water, Btu/lbm-°F
μ, dynamic viscosity of water, lbm/ft-hr
k, thermal conductivity of water, Btu/hr-ft-°F

ASHRAE Handbook (ASHRAE 2007) specified a minimum of 20 ft. between each coil in each direction. A 20x20 ft. grid of the pond showed a potential installation for 240 coils (Figure 2). Each coil is assumed to be 400 ft. which means potentially 96,000 ft. coil can be used as heat exchanger between the pond and the buildings.

The analysis of the pond thermal capacity in comparison to the building loads shows that the pond has a heat rejection capacity of 369 MBtu/hr for a 10°F difference between the pond temperature and the GSHP loop temperature. The trend log for the Cypress Campus Center showed that the peak building load is 1,330 MBtu/hr with an annual average load of 216 MBtu/hr.

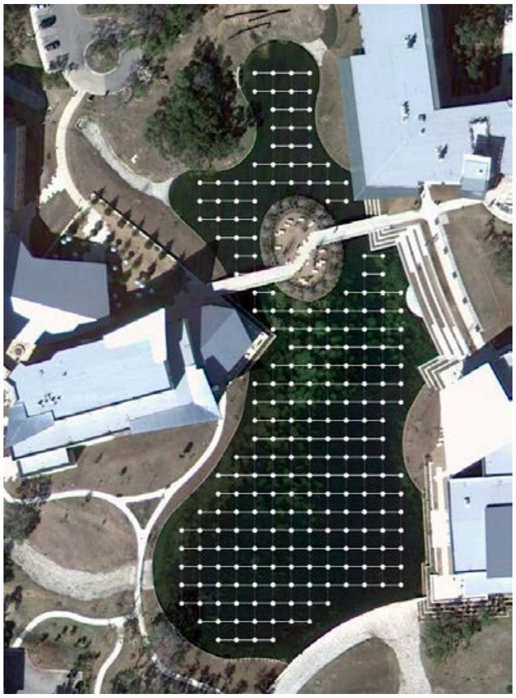

Figure 2. The 20x20 ft. grid of the potential GSHP coil installation.

The coil installation grid presented in Figure 2 represents the ideal case with the pond heat rejection capacity utilized to its maximum. In reality, the heat rejection capacity of the pond is not adequate to meet the cooling loads of all the campus buildings. In this case, a hybrid system which uses GSHP to assist and reduce the load on the cooling tower can be the alternative approach. Figure 3 shows a simplified diagram of hybrid systems which utilizes both a cooling tower and a GSHP loop.

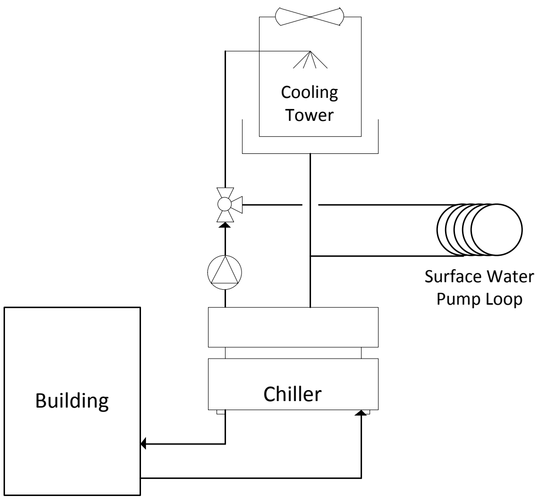

Figure 3. Simplified diagram of a hybrid GSHP system.

An energy balance model was formulated to calculate the hourly energy savings of the Northwest Vista Campus (NVC) due to the use of GSHP system (Figure 4). In this model, the heat gain and loss due to solar radiation (Q_{solar}), ground conduction ($Q_{conduction}$), radiation ($Q_{radiation}$), evaporation ($Q_{evaporation}$), convection ($Q_{convection}$), and building loads ($Q_{building}$) are calculated.

$$V\rho c_p \Delta T = Q_{solar} + Q_{conduction} + Q_{radiation} + Q_{evaporation} + Q_{convection} + Q_{building}$$

The simplified energy balance model employs a steady-state approach in which heat gain and heat loss are equal to zero and there is no heat storage in the pool. In reality, the heat storage capacity of the pond shifts the peak pond temperature away from the peak ambient temperature. This phenomenon is reflected into the model by calculating the pond temperature at each hour and by approximating the temperature shift.

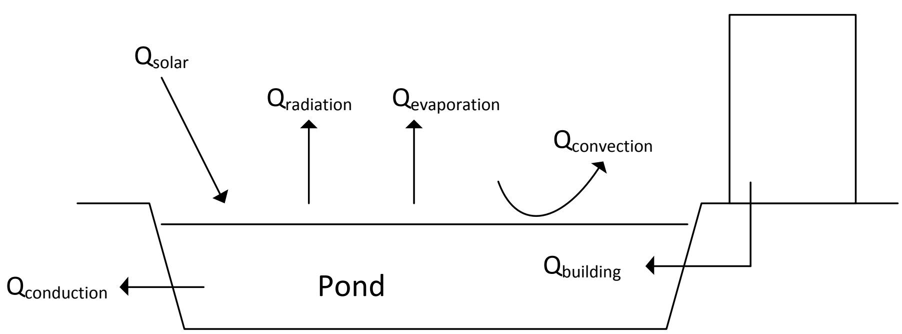

Figure 4. Energy balance model of the pond.

Energy Analysis and Results

The pond temperature is one of the major determinants of the GSHP cooling and heating capacity together with the ambient temperature. In this study, the pond temperature was calculated using the ambient temperature and the temperature data for the water bodies in the San Antonio area. The shift in the pond temperature reflects the heat capacitance of the water body in the energy balance calculations (Figure 5).

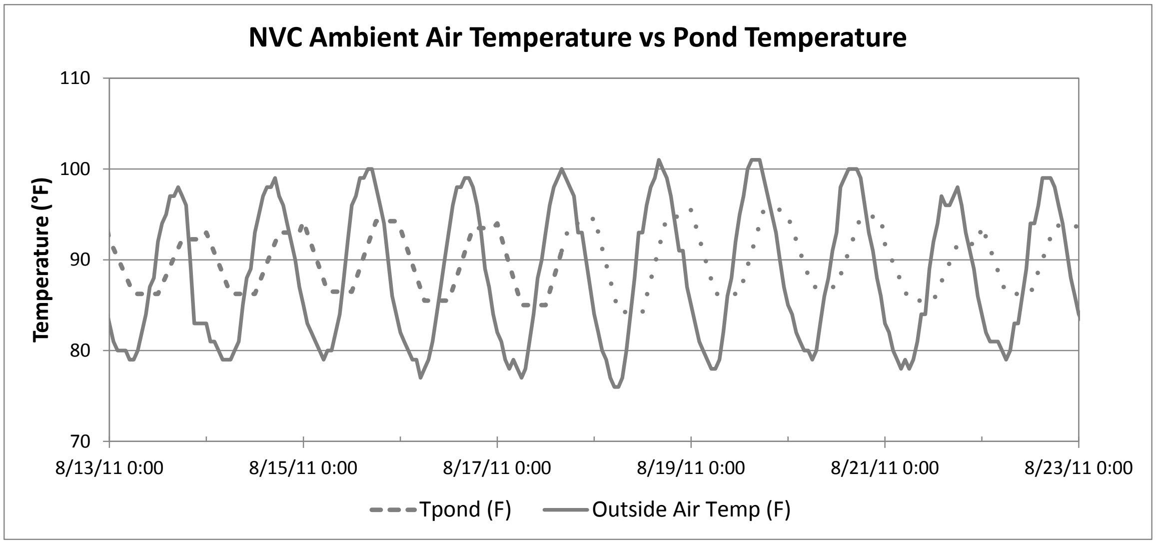

Figure 5. Typical water body and ambient temperature for NVC.

The analysis was conducted for the summer months during which the water temperature is highest. Figure 6 shows the water temperature of the San Antonio River. High water temperatures result in low heat rejection capacity of the water bodies which in turn reduces shallow water GSHP potential for cooling dominated buildings.

The month of August, which has the highest water temperature, was chosen as the sample time frame to demonstrate the GSHP potential in a worst case scenario. The ambient dry bulb, and dew point temperatures were taken from National Oceanic and Atmospheric Administration's (NOAA) database. In this analysis, the cooling potential of the whole pond was first calculated using the trend log data of the Condensate Water (CW) where

Condensate Water Return Temperature (T_{CWR}) > Pond Temperature (T_{pond})

This condition represents the times when the compressor exiting water temperature is higher than the pond temperature, which allows the heat rejection from the building into the pond. The savings for the Cypress Campus Center using the GSHP was calculated where the building load can be met using the heat rejection capacity of the pond.

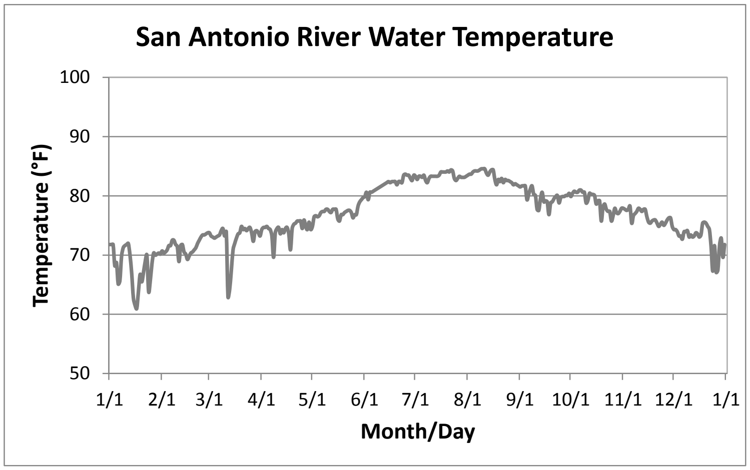

Figure 6. Cypress building load and the pond heat rejection capacity.

Figure 7 shows the cooling potential of the GSHP system on the negative side of the scale together with the building loads of the Cypress Campus Center. The continuous line shows the savings due to the use of GSHP system. The monthly calculations for August show that a total of 75,101.2 MBtu of energy can be saved for the Cypress building which corresponds with the 30% of the total monthly building loads and 18% of the GSHP cooling capacity. Savings are likely to be higher for the shoulder seasons and the winter months during which low water temperatures present a higher potential for heat rejection.

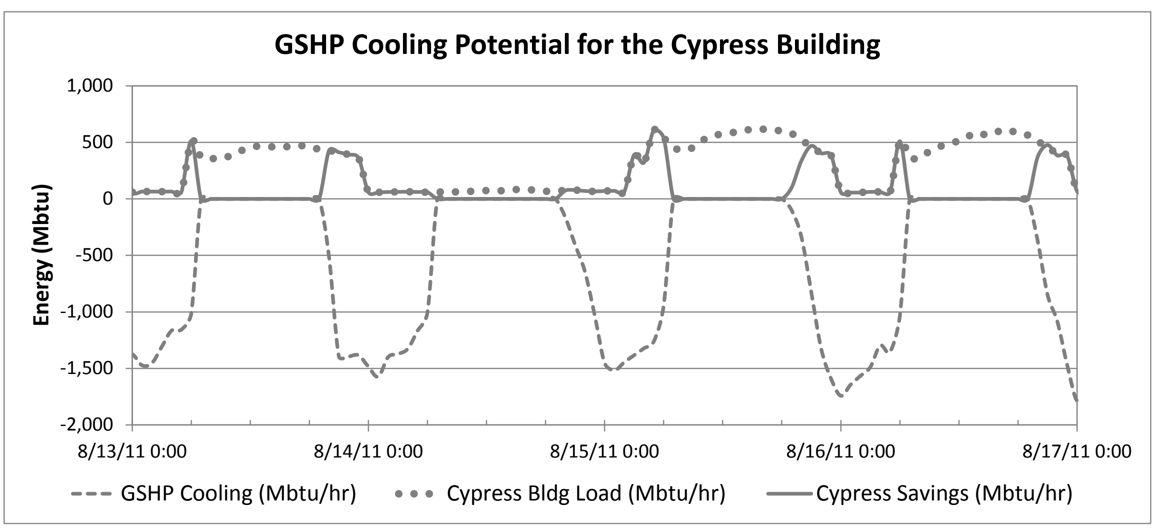

Figure 7. GSHP cooling potential and the Cypress Building Center load profile (Negative values represent cooling capacity).

One of the advantages of the GSHP is that its operation can be reversed to provide heating energy for space heating or domestic hot water heating. The heating potential of the pond was calculated using the hourly data for the month of August. According to the calculations, a net energy of 6457.4 MMBtu can be extracted from the pond for domestic hot water heating. The water temperature that can be supplied using the GSHP is limited to the highest pond temperature minus the system energy losses. Therefore, the heat extracted from the pond is more useful to preheat the domestic hot water (DHW) which will reduce the load and energy use of the DHW heaters.

Recommendations

GSHP can be installed in a horizontal loop, vertical bore or shallow water configurations. Each of these options has its advantages and disadvantages and the decision to install a system depends on the project budget, environmental factors and geological conditions. Shallow pond GSHP systems have low initial cost compared to the vertical or horizontal systems since they eliminate the need for drilling and trenching. Therefore, NVC's pond presents a potential for a relatively low cost installation of GSHPs.

The heat rejection/extraction potential of the pond depends on the pond temperature, ambient conditions and the building loads. The energy collected or rejected by the pond can be used in buildings in various forms:

1. The extra heat from the pond can be utilized for domestic hot water (DHW) heating. GSHP systems are suitable for pre-heating the DHW since pond temperatures tend to be lower than DHW temperature setpoints. This may particularly be a viable option for hot and humid climates such as in the San Antonio area. This option requires installation of heat pumps at each building since NVC buildings have their own DHW heaters.

2. In cooling mode, individual buildings can have their own GSHPs to meet the building loads. In NVC's case, this requires installation of heat pumps at the buildings. However, since one heat pump can operate in cooling and heating mode by reversing the operation, the installation of the heat pumps at each building allows them to be used for heating purposes too. Therefore, each building can use the pond energy for cooling or heating depending on the needs.

3. The heat rejection capacity of the pond can be utilized to reduce the cooling tower load by installing the GSHP system in parallel to the cooling towers. In this case, the potential of the pond can be utilized by the whole campus without the need to install individual pumps at each building. This option allows the utilization of pond energy for longer periods of the day since load profiles vary for each building throughout the day. This option also requires minimum trenching which is from the central plant to the pond.

The analysis in this chapter showed the potential of the GSHP application at the NVC campus. The ESL recommends further analysis using dedicated simulation tools and life-cycle cost analysis to determine the applicability of the GSHP at the NVC campus.

Conclusion

GSHP systems have been successfully in use throughout the United States and are considered to be one of the most environmentally friendly technologies by the Environmental Protection Agency (EPA). This chapter presented an analysis of the shallow pond GSHP system's potential for energy savings at the NVC campus. An hourly analysis was conducted for the month of August which has the highest water temperatures in the San Antonio area.

The analysis showed that 30% of the cooling loads of the Cypress Campus Center can be met using 18% of the cooling capacity of the GSHP. The rest of the capacity can be used for other buildings since campus buildings have different load profiles throughout the day. The heating potential analysis showed that a total of 6,457.4 MMBtu of energy is collected and dissipated in certain hours of the day during the month of August. This is the potential energy which can be utilized to pre-heat the domestic hot water.

The ESL concludes that NVC campus has the potential for GSHPs provided that more analysis is conducted using the detailed simulation tools dedicated for GSHP applications and that life-cycle cost analysis is performed.

SOLAR ENERGY PROJECTS

The potential applications of the solar energy systems are focused on the building service hot water, the electricity consumption and electricity demand reduction. This section includes an analysis of these components, with discussion of their design considerations.

The solar thermal and photovoltaic systems analysis was conducted for one building which can be methodologically expanded to all campus buildings. The selected building is the Cypress Campus Center (CCC), which houses the welcome center, student life center, admissions and registration, academic advising, career and transfer services, assessment and testing, and the wellness student health center. Cypress building also includes a food court with complete kitchen, server, dining area and outdoor seating. The building is located to the east of Lago Vista (the pond) and west of the Wine Cup parking lot in the vicinity of the Palmetto Center for the Arts and Live Oak Hall (Figure 8).

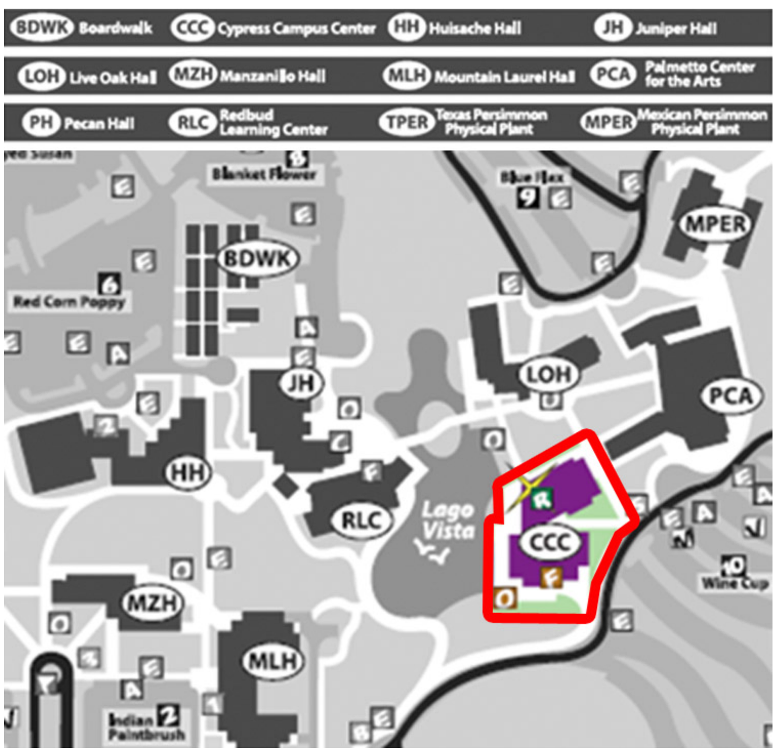

Figure 8. General map of North West vista Campus

The Cypress building is one of the newer buildings on the NVC campus, built in 2008 with 56,814 ft^2 of building area. The main entry faces the Lago Vista and connects the one story portion of the building to the angled two story portion of the building. The exterior façade consists of brick, plaster, pre-finished metal wall panels and aluminum window systems. The roof is mostly flat however there are three sloped sections. The largest is a portion from the two story section of the building sloped down toward the pond covering the main entry area, and the smallest includes a clerestory above an open office area on the second floor. In the one story section there is a sloped roof with a clerestory above the dining area as shown in the pictures included in Figure 9.

Figure 9. Cypress Campus Center main views.

Solar Thermal System Description

The solar energy system shown in Figure 10 represents the general closed-loop solar energy system which is for a variety of applications including space heating, absorption air conditioning, water heating and process heating. It is an indirect system, which means that the fluid circulating through the collector does not come into direct contact with the utility water in the storage tank and a heat exchanger is used to transfer heat from the circulating fluid to the potable water. Solar energy is collected and stored as sensible heat in a liquid storage tank. The heated liquid is pumped from storage through a heat exchanger to supply thermal energy to the load. The load is a demand for energy above a minimum useful temperature. In a water heating system, that temperature should be the main supply water temperature. Auxiliary energy is supplied if the solar energy is insufficient to meet the load. The thermal performance of the software of these general solar heating systems is calculated using the PHI_{BAR}, f-Chart (*ϕ_bar, f-chart*) method of Klein and Beckman (1979).

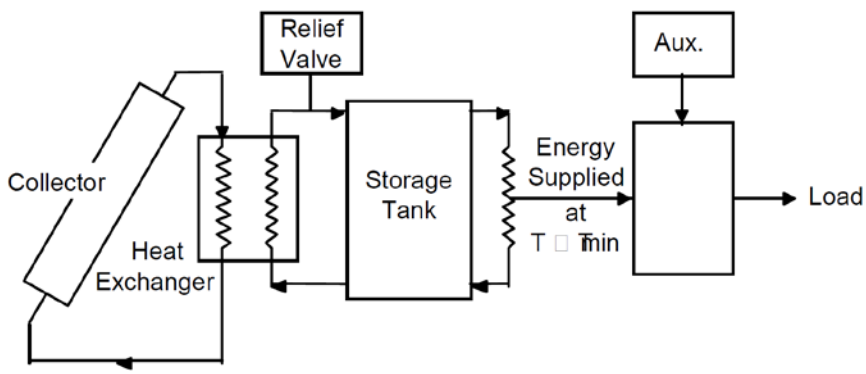

Figure 10. Solar heating close-loop system.

The FChart, which is a software to determine the performance and analysis of active and passive solar heating systems, was used to assess the performance of the proposed solar thermal system. The weather data for the San Antonio International Airport that was provided by the National Oceanic and Atmospheric Administration (NOAA) was used for the calculations. The FChart software calculates the monthly-average solar radiation on the system tilted surfaces from the horizontal solar radiation data by adding the long-term average hourly values (calculated using an isotropic sky model) and the most suitable correlations for monthly diffuse fraction.

Building Hot Water Loads

The domestic hot water requirement for the building was determined per person basis. Assuming that the daily average number of students occupying the building is 290, the amount of hot water required is approximately 552 gal/day (1.8 gal/day/student) with a peak consumption of 290 gal/hour (1 gal/hour/student). Therefore, the monthly average hot water consumption will be 11,500 gal (290 students x 1.8gal/day/student x 22day/month). Thus, the storage required for this system will be 1,250 gal (290 x 3 /0.7). In addition, 70% of the water will be usable (Table 7 of Chapter 48: Service Water heating, ASHRAE Applications 1999). These are the amounts of water that should be provided from the solar thermal system to a regular delivery temperature of 140°F.

Analysis of the Solar Thermal Simulation

Given the Cypress building's hot water requirements, a simulation was prepared and a parametric analysis was performed to estimate the required area for the solar system. The parameter that has the most impact on the solar thermal system is the solar collector. Various types of solar collectors are designed for specific temperatures. The thermal performance of a flat-plate solar collector can be expressed by Equation 12.

$$Q_u = A_c [F_R (\tau\alpha) G_T - F_R U_L (T_i - T_a)] \quad \text{(Equation 12)}$$

Where Q_u is the useful heat that the collector, F_R, is the removal heat factor, I_T, the hourly insolation, U_L, is the loss heat transfer coefficient, T_i the inlet fluid temperature and T_a is the ambient temperature.

The collector efficiency (when tested) is derived from the previous equation and the relationship between the usable heat and the amount of incident radiation (Equation 13).

$$\eta_i = \frac{Q_u}{A_c G_T} = F_R (\tau\alpha)_{av} - \frac{F_R U_L (T_i - T_a)}{G_T} \quad \text{(Equation 13)}$$

The usable heat can be also obtained, without phase change, by Equation 14.

$$Q_u = \dot{m} C_p \left(T_o - T_i\right) \quad \text{(Equation 14)}$$

The equation of the solar collector efficiency is linearly correlated to the temperature differential between the ambient temperature and the fluid inlet temperature and is shown in in Figure 11 for various types of solar collectors.

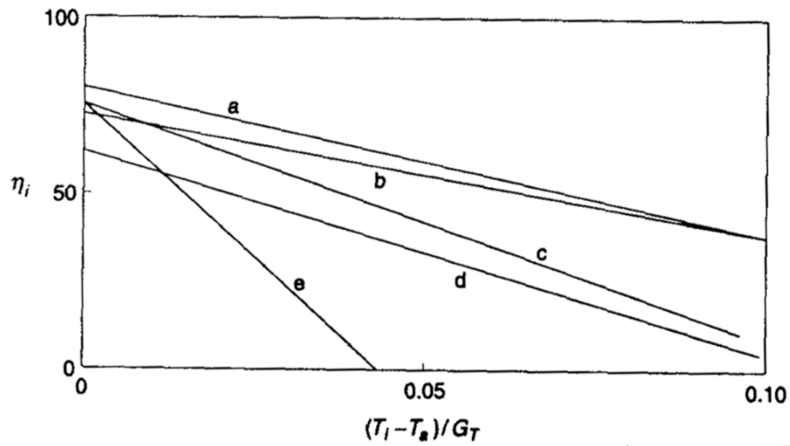

Figure 11. Characteristics of five flat-plate liquid heaters: (a) One-cover, selective black chrome absorber; (b) Two-cover, selective black chrome absorber; (c) One-cover, flat-black absorber; (d) Two polycarbonate covers, polymeric flat black absorber with close spaced tubes; (e) Unglazed flat-black absorber. Details of plate thickness, tube spacing, etc., vary among these collectors. The slope of (e) will be very sensitive to wind speed (image credit: Duffie and Beckman, 2011).

The $F_R(\tau\alpha)_{av}$ is the intercept of the line on the y axis, and $F_R U_L$ is the slope, which are the characteristics of the solar collector and are obtained from experimental testing by the solar rating and certification corporation (SRCC). Equation 2 differs from Equation 1 such that the latter is based on regression and as a result, the constants are the averages of the testing conditions.

A parametric analysis was performed to determine the required area of solar collectors to cover the hot water requirements of the Cypress building (Figure 12). Analysis results showed that the number of panels that can provide more than 80% of the hot water requirements are between 75 and 100 panels or approximately 2,000 ft^2 of solar collectors (Figure 13). A more detailed life cycle study will be required to make the correct economical decision.

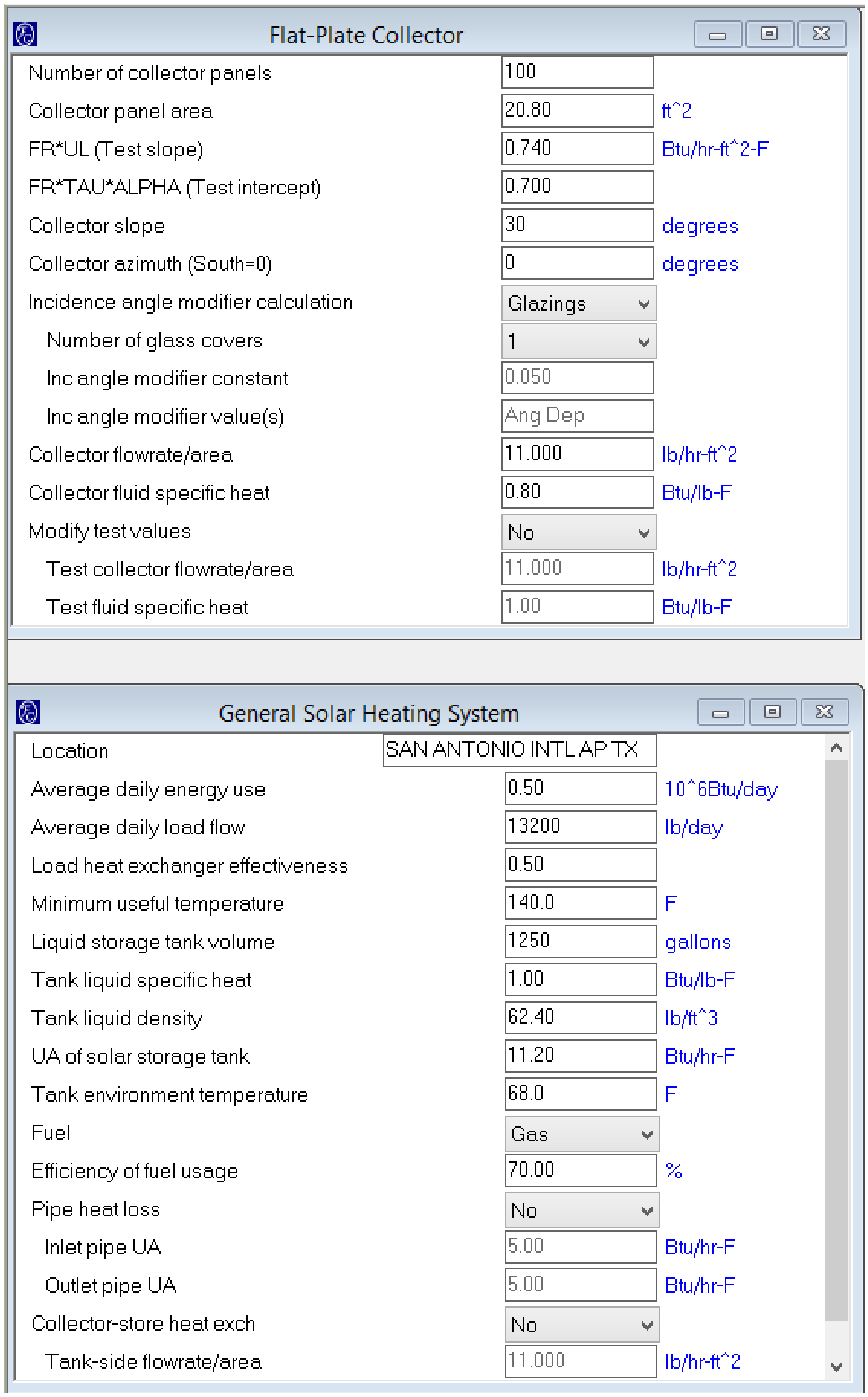

Figure 12. Characteristics of the solar thermal systems used in this study.

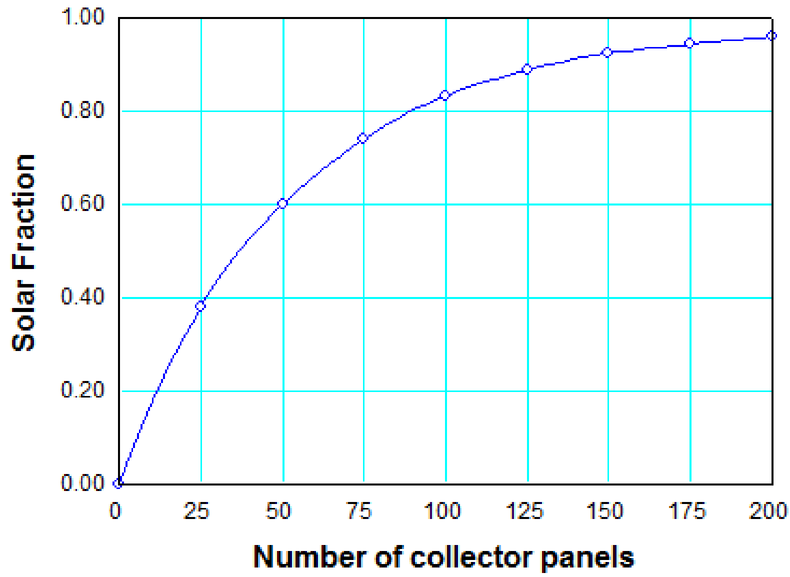

Figure 13. Parametric results of the solar system as a function of the number of collectors panels.

Table 1 presents the output of the simulation for a system that includes 100 solar collectors. The domestic hot water requirements can be met by the solar thermal system in the months of June through October and the annual fraction that the system covers is 83.3%.

Table 1. Monthly and annual simulation of the solar system with 100 solar collectors.

	Solar [MMBtu]	Load [MMBtu]	QTank [MMBtu]	Aux [MMBtu]	*f* [%]
Jan	83.1	15.50	0.989	6.306	0.593
Feb	83.6	14.00	0.961	4.409	0.685
Mar	107.4	15.50	1.241	2.460	0.841
Apr	106.5	15.00	1.235	2.046	0.864
May	109.3	15.50	1.246	2.415	0.844
Jun	115.8	15.00	1.442	0.597	0.960
Jul	120.1	15.50	1.581	0.199	0.987
Aug	130.7	15.50	1.630	0.000	1.000
Sep	121.4	15.00	1.577	0.000	1.000
Oct	112.6	15.50	1.536	0.402	0.974
Nov	83.9	15.00	1.030	4.716	0.686
Dec	76.9	15.50	0.958	6.954	0.551
Year	1,251.3	182.50	15.427	30.503	0.833

Solar Photovoltaic System Description

The operation analysis of solar cells and design of power systems based on solar cells are based on the voltage-current relationships under solar radiation and the cell temperature. The solar photovoltaic system models should provide means to calculate the current, voltage and power relationships of cell arrays in different operating conditions. Most of the required characteristics for the modeling are provided by the manufacturer, thus a detailed model is not needed. The typical current-voltage characteristics of a PV module is presented in Figure 14. Ideally, cells would always operate at the maximum power point, but in practice, the cells operate at a point on the I-V curve that corresponds to the characteristics of the load.

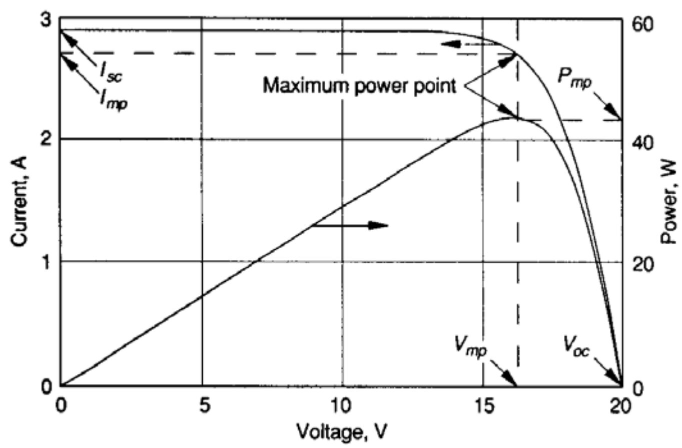

Figure 14. Typical I-V and P-V curves for a PV module (image credit: Duffy and Beckman, 2011).

In this study, the analyzed system is the PV system with the utility interface as explained in Figure 15. This configuration allows the possibility to sell the excess that could be produced in the system if the load is not present in the building. Inversely, the utilities will provide the load in the building when the system could not provide it due to intermittent characteristics of the solar resource or imponderable situations.

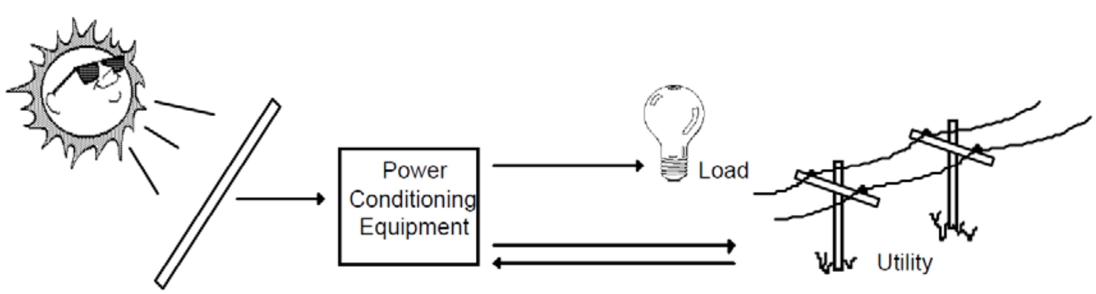

Figure 15. Utility Feedback System (image credit: PVFChart manual).

The system integration to the utilities and the diversity load distribution of the building need to be considered in the operation of the system. The electricity profile for Cypress building is obtained from the period of July 2010 thru June 2011, for simplicity and for the type of the profile displayed, an average value for all the months is used (Figure 16 and Figure 17).

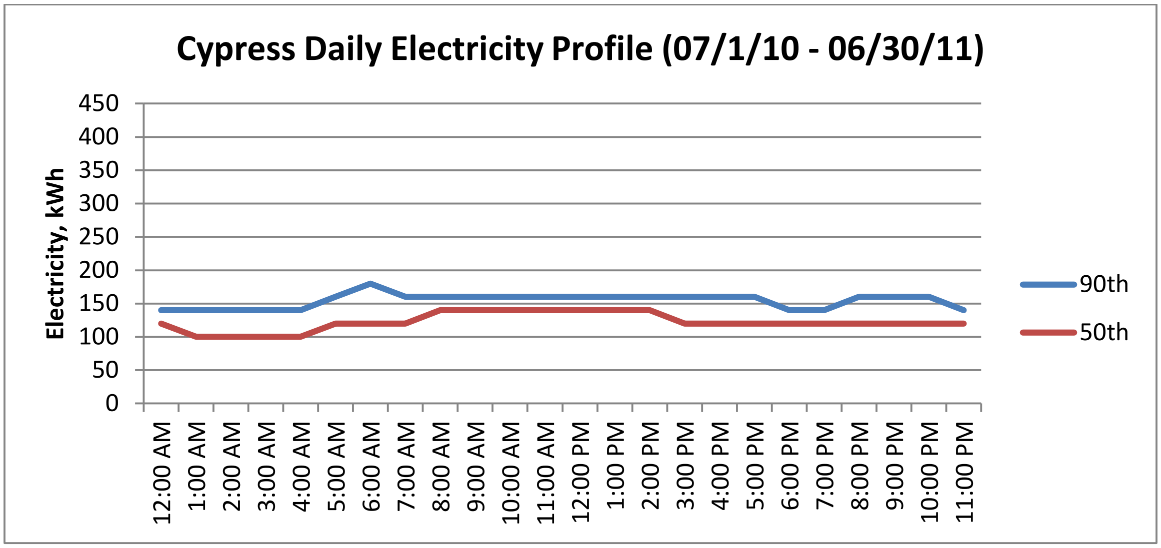

Figure 16. Electric profile for Cypress Campus Center building

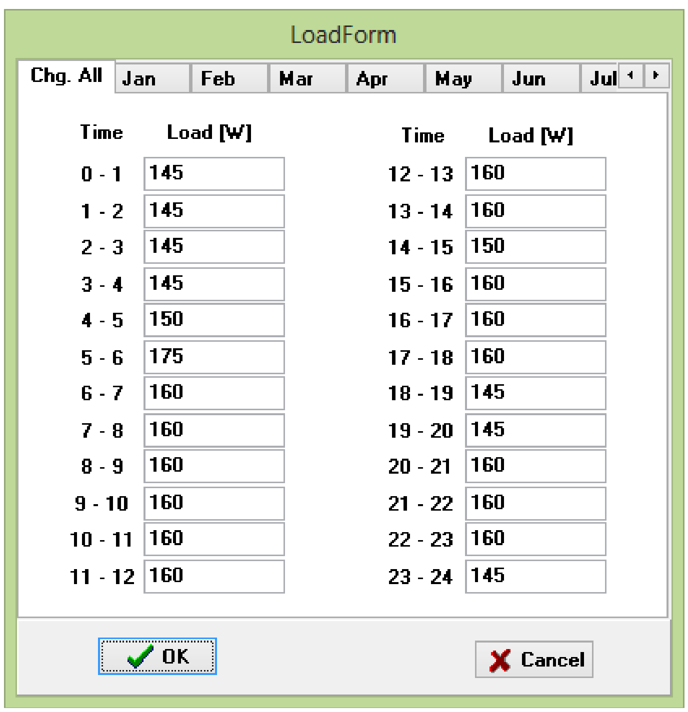

Figure 17. Diversity of the electricity use in cypress Campus Center.

Analysis of the Solar Photovoltaic System Simulation

Similar to the thermal system analysis, the software used for the general performance of the photovoltaic system is the PVFChart, which is used for the analysis of long-term average performance of photovoltaic systems. The San Antonio International Airport weather station data was used for the analysis in this section. Assuming 14.9% efficiency for the PV modules and using the corresponding parameters shown in Figure 18 and the area of the slope to the west of the Cypress building (tilted approximately 30 degrees), the annual fraction of the loads that can be met is approximately 50%. A more detailed analysis is required if the goal is to use the whole roof of the building. In this case as well a life cycle cost analysis will determine the best possibility that would provide the best cost effective application.

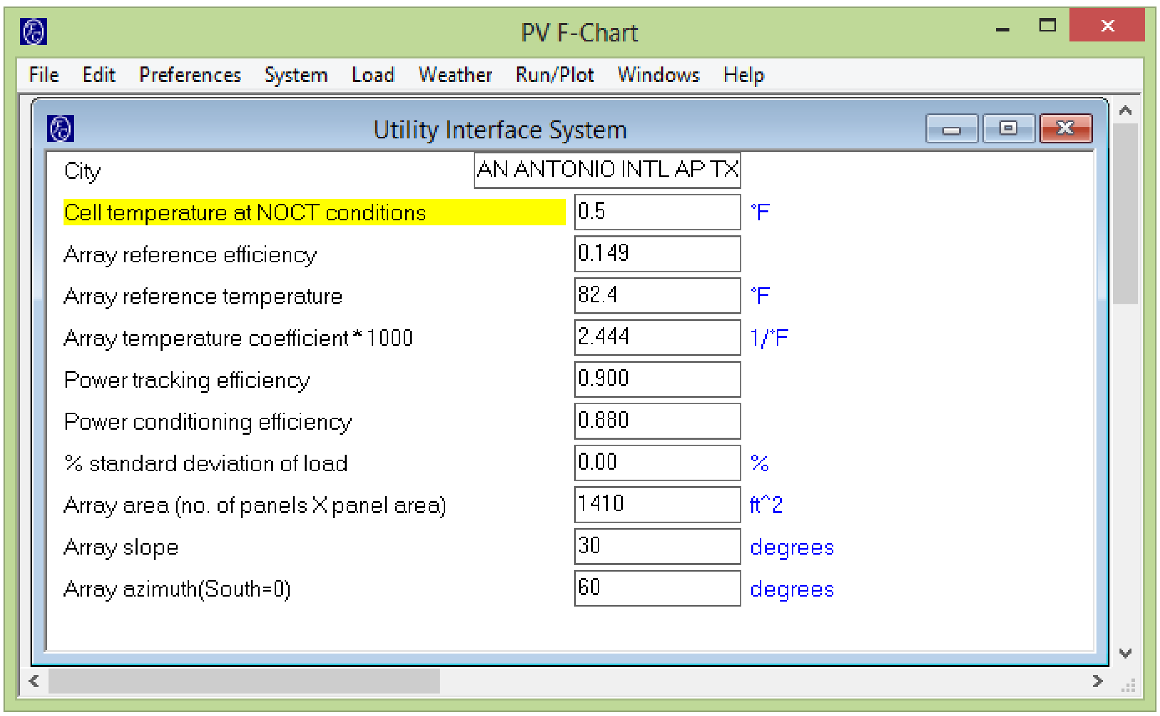

Figure 18. PVFchart inputs for the characteristics of the cell suggested on this study.

Table 2. Monthly and annual solar fraction for 100 (1410 ft2) solar photovoltaic modules.

	Solar [kW-hrs]	Efficiency [%]	Load [kW-hrs]	f [%]	Sell [kW-hrs]	Buy [kW-hrs]
Jan	13,957.1	14.70	115.6	42.1	1,757.4	67.0
Feb	14,451.1	14.81	104.4	42.3	1,838.8	60.3
Mar	19,848.1	14.72	115.6	50.4	2,513.2	57.3
Apr	20,481.2	14.55	111.9	50.8	2,566.0	55.1
May	22,180.1	14.27	115.6	58.2	2,717.7	48.3
Jun	23,872.1	14.06	111.9	59.1	2,887.1	45.8
Jul	24,670.4	14.09	115.6	58.9	2,991.1	47.5
Aug	25,855.5	14.17	115.6	51.6	3,164.9	55.9
Sep	22,661.5	14.36	111.9	50.8	2,806.0	55.0
Oct	20,002.0	14.40	115.6	48.7	2,478.6	59.3
Nov	14,195.0	14.42	111.9	42.2	1,754.0	64.7
Dec	12,862.6	14.53	115.6	41.9	1,596.2	67.1
Year	235,036.6	14.42	1,361.4	49.8	29,071.1	683.4

Table 3. Annual Consumption and Construction Dates of the Buildings of Northwest Vista campus.

Building	Annual kWh	Area	kWh/sf	Year Built Renovation
Mount Laurel	2,573,469	74,048	34.75	1998,2009
Huisache	1,238,381	71,996	17.20	1998,2009,2010
Manzanillo	838,458	30,935	27.10	1998,2010
Pecan	764,557	29,439	25.97	2004
Cypress	1,042,963	56,814	18.36	2008
Juniper	1,062,349	76,184	13.94	2008
Live Oak	1,219,959	85,848	14.21	2008
Redbud	724,744	52,344	13.85	2008
Palmetto	743,535	60,464	12.30	2009

Conclusion and Recommendations

Solar thermal and solar photovoltaic systems show a high potential to meet the energy and domestic hot water requirements of the Cypress building (CCC) and the NVC campus in general. Further analysis is recommended to estimate the potential of all the solar systems in all campuses and combined with the results of a GSHP study to convey a complete potential of renewable systems technologies.

The thermal system shows a potential to meet all the hot water needs and could also be designed to assess how much of the heating building loads could be covered. The amount of roof area that is possible to use for solar energy in Cypress are enough and without any significant obstruction. Storage tank(s) may need a specific location but the infrastructure and mechanical rooms, which are already in the building, could answer that need, as the volume that is required in less than 2,000 gal in the case of the CCC building.

The application of the Solar PV system is feasible, and considering that the NVC is an all-electric campus its impact should be observed immediately. Because the proposed system is related to the utility, two factors should be considered; the reduction in consumption and the reduction in peak use. These factors need to be complemented with the life cycle analysis results and with the analysis of possible expansion on all campus roofs.

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