FLORIDA SOLAR ENERGY CENTER®

CONTRACT REPORT

Assessment of Thermal Heating Requirements for Non-Industry Dependent Warm-Water Refuges for Florida Manatees

FSEC-CR-1481-04

Revised Final Report
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Submitted to:

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Disclaimer

The final report was submitted on Nov. 16, 2004. After submission, a more complete set of measured water temperature data was discovered for the site at Cape Canaveral. Requested by the sponsor, the final report was revised based on the discovery.

ACKNOWLEDGMENT

The author thanks the Marine Mammal Commission for funding this work, and the project manager, David Laist. The author also thank Winifred Perkins, Florida Power and Light Company (FPL), for providing water temperature data measured from FPL power plants. Sincere appreciation is expressed to Kent Smith and Ron Mezich, Florida Fish & Wildlife Conservation Commission, and Jim Valade, U.S. Fish and Wildlife Service, for providing valuable guidance for the project. A special thanks is to Jim Huggins at Florida Solar Energy Center (FSEC) for providing performance curves of solar collectors, and to Charles Cromer at FSEC for providing measured data in a heated pool in Cocoa Beach, FL.

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EXECUTIVE SUMMARY

About two-thirds of all Florida manatees now depend on warm water outfalls from power plants to survive cold winter periods. Many of these plants may be retired in the next 10-20 years. These closures and the loss of their heated outfalls could cause high levels of cold-stress-related manatee deaths. To help identify possible steps to prevent such deaths, this study was undertaken to determine if non-industry dependent warm-water refuges for Florida manatees could be created using solar water heating technology. This approach assumes manatees would find and begin using these refuges as they have found and used power plant outfalls. Providing a steady source of freshwater, a known manatee attractant, might facilitate such use. A previous modeling study funded by Florida Power & Light Company (FP&L) examined the possible creation of a solar heated refuge at an embayment in West Palm Beach Florida in the central part of the manatee's current winter range along Atlantic coast. The study, using average daily water temperature and weather data, concluded that solar water heating technology could be used at that site to create a 20^{o}C warm-water refuge, but that a more detailed analysis should be undertaken using hourly winter water temperature and weather data.

To follow up on that recommendation, the Marine Mammal Commission asked the Florida Solar Energy Center (FSEC) to assess the feasibility and cost of solar collector systems to create warm water manatee refuges using hourly water temperature and weather data for the coldest recent year at three hypothetical sites in the species' principal Atlantic coast winter range. This report provides the results. The conceptual design for the refuge, as shown in Figure 1, involves a closed solar heating system in which heat is transferred to the refuge water across a heat exchanger rather than by direct discharge of heated water. Work was divided into 5 major tasks summarized below.

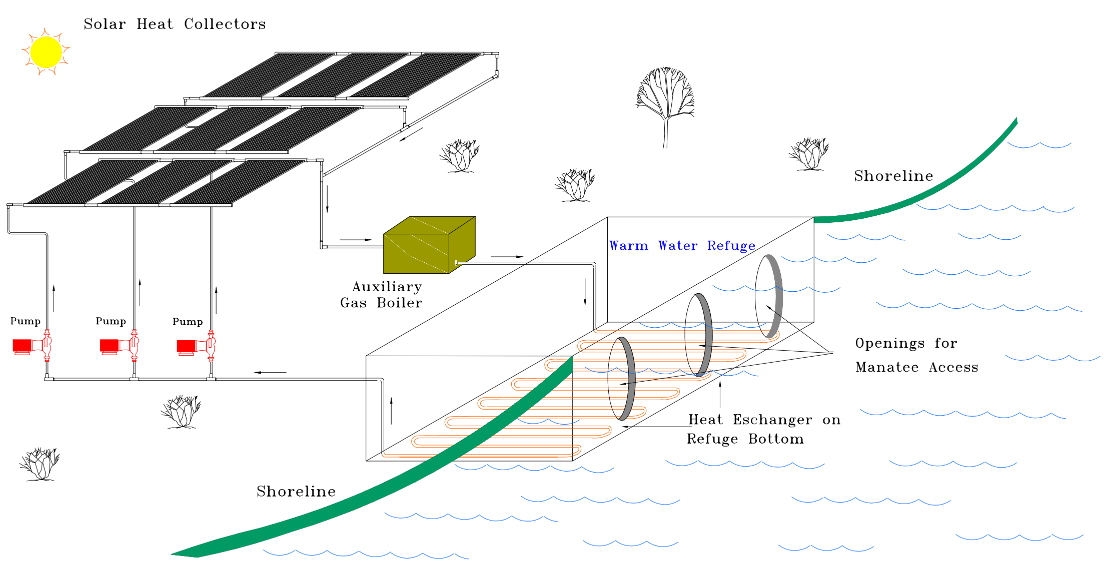

Figure 1 Schematic of proposed solar water heating system

Task 1 involved selecting the general location and physical configuration. The general areas selected during a January 2004 project planning meeting involving representatives of the Marine Mammal Commission, Fish and Wildlife Service, Florida Fish and Wildlife Commission, and Florida Power & Light Company (FPL). The three locations identified, chosen to reflect the northern, central, and southern parts of the species Atlantic coast winter range on the Atlantic coast, were in Brevard County (Cape Canaveral), Palm Beach County (West Palm Beach), and Dade County (Miami). Two physical configurations were also identified: a small refuge (50 ft x 50 ft or 0.04 acres) that might support about 50 animals, and a large refuge (100 ft x150 ft or 0.3 acres) that might support several hundred manatees. Two depths were considered for each refuge size: 6 ft at mean low tide and 9 ft at mean low tide. The latter was suggested as a potential buffer against rapidly declining temperatures in the event of a severe cold or prolonged cloudy weather. The agreed target refuge temperature was 22^{o}C, chosen to match the temperature of natural springs used by large aggregations of manatees in winter.

Task 2 involved identifying weather and water temperature data for each site. At the initial planning meeting it was agreed that weather data for the winter of 1989-90 should be used for model simulations because the highest rates of cold-stress related manatee deaths were recorded that winter. Weather data for the three locations was obtained from FSEC and the National Climatic Data Center (NCDC) for 1989 and 1990. It was anticipated that inland coastal water temperatures for the three sites could be provided by FP&L plants from temperature probes in cooling water intakes at their power plants in Brevard County (i.e., the Cape Canaveral Plant), Palm Beach County (i.e., the Riviera Plant) and southern Broward County a few miles north of Miami (i.e., the Fort Lauderdale and Port Everglades Plant). Unfortunately very little temperature data was available for 1989 and 1990. A bi-quadratic equation using 1989 and 1990 ocean water and ocean air temperatures recorded by the National Oceanographic Data Center (NODC) off Cape Canaveral and West Palm Beach was therefore used to predict 1989-90 inland water temperatures near the three sites. Predicted temperatures compared closely with available measured inland water temperatures provided by FP&L for 1989 and later years. For the winter of 1989-90, they fell to 11^{o}C at Cape Canaveral, 18^{o}C at West Palm Beach and 19^{o} C at Miami. At the end of the study a more complete set of measured temperature data was discovered for the site at Cape Canaveral. That data was compared to predicted temperatures. Although the predicted and measured temperatures tracked each other closely, the measured minimum temperatures were up to 7.7^{o}C cooler than predicted temperatures were in December and January.

Task 3 involved developing and calibrating a model to calculate the amount of heat required to maintain a minimum water temperature of 22^{o}C within the two refuge sizes (i.e., small and large) at all three sites. The governing equation included factors for multiple sources of heat loss and gain, including conduction of heat through the bottom and sides of the refuge, solar radiation added through the refuge surface, night sky radiation, evaporation, convection (i.e. heat loss to air due wind), and exchange of water between the refuge and surrounding bays due to tides or artificial circulation designed to maintain water quality. The model was validated against measured temperature data from a heated pool in Cocoa Beach. In addition, performance curves were added to the model for three different types of commonly used solar collectors: unglazed, glazed, and evacuated. Simulations were then conducted to predict heat requirements for (1) maintaining refuge temperatures at 22°C for 100%, 99% and 95% of the time under 1989-90 winter conditions. A final simulation was then performed to determine the amount of time and extent to which water temperatures fell below 22°C under the 95% and 99% scenarios.

Task 4 included a sensitivity analysis to determine the relative importance of different heat loss variables at all three locations. The largest source of heat loss was caused by the exchange of water between the refuge and adjacent rivers and bays due to tides and/or pumping water into the refuge for water quality purposes. Evaporation and convection were the second and third largest sources of heat loss, respectively. Heat loss to the bottom and sides of the refuge was very small relative to other factors. If a refuge cover 1 meter above the refuge surface could be used to control evaporation and convection heat loss over all or much of the refuge surface, the amount of heat energy needed to maintain the refuge could be reduced significantly.

Task 5 involved an analysis to determine (1) the type of solar collector most economical for providing enough heat for manatees to survive a cold winter and (2) the costs of different types of solar collecting systems. Estimated costs included the initial purchase of solar collector, pumps and pipes, annual maintenance, and cumulative costs for these needs over an expected 20-year live span for the equipment. Unglazed solar collectors were found to provide the most cost effective solar collector systems. Systems designed to provide 99% of the heat requirements appear adequate to ensure that refuge temperatures in West Palm Beach and Miami would not fall more than a degree or two below 22°C for more than a day or two. For refuges in Cape Canaveral, however, a back up oil or gas fired water heating system would be necessary to prevent temperatures from dropping below 18°C for a few days. Estimated costs for unglazed solar collector systems assuming one complete turnover in water volume per day and no refuge cover are:

Case	Cost	Cape Canaveral		West Palm Beach		Miami	
		Small refuge	Large refuge	Small refuge	Large refuge	Small refuge	Large refuge
Base Case (6 ft deep without cover)	Initial cost ($)	123271	713613	29261	174997	16965	100798
	Annual cost ($)	12381	73888	3263	19505	1891	11235
	Lifetime cost ($ Million)	0.268	1.578	0.067	0.399	0.039	0.230
	# Panel	146	874	39	231	22	133
Refuge with Opaque Cover (6 ft deep)	Initial cost ($)	100397	578166	19986	119118	13483	79864
	Annual cost ($)	9945	59268	2229	13277	1503	8902
	Lifetime cost ($ Million)	0.219	1.284	0.048	0.283	0.033	0.194
	# Panel	118	701	26	157	18	105
Refuge with Transparent Cover (6 ft deep)	Initial cost ($)	74153	420532	6911	40784	3891	22817
	Annual cost ($)	7005	41633	771	4546	434	2543
	Lifetime cost ($ Million)	0.159	0.926	0.019	0.111	0.012	0.070
	# Panel	83	493	9	54	5	30

Based on estimates of the number of solar panels required for small and large size refuges at Cape Canaveral under the base case, it is estimated that the amount of land required for the solar panels would be about 1/3 ac and 1 ½ ac, respectively. The estimated initial cost of a backup water heating system for Cape Canaveral was $12,000 for the base case. Considering the lower than predicted water temperatures that were provided at the end of the study, it was determined that the additional heating requirements could be met without increasing the size of the solar panel system by increasing the size of the backup water heating system about 60 percent. The extent to which this would increase the cost estimates for the Cape Canaveral refuges was not determined, but was not thought likely to be more than about $15,000. If a translucent cover 1 m above the refuge surface could be use over most of the refuge area to allow passage of solar energy directly into the refuge water, reduce evaporation, and reduce conduction of heat loss, solar collector costs could be significantly reduced and nearly eliminated at sites in Miami and perhaps West Palm Beach.

Costs not considered in this study includes those for land, the heat exchanger, construction of the refuge embayment, the preparation of detailed construction plans, or the development of required permit applications.

OBJECTIVE

The objective of the present project is to assess the feasibility of a solar-power-based water heating system to provide reliable warm-water refuges for manatees within the principal portions of their current winter ranges along the coast. The assessment is achieved by comprehensive computer simulations. Economic analysis will be performed to provide the most economical solar-powered water heating system.

INTRODUCTION

Cold stress is a significant source of mortality for Florida manatees. In general such deaths occur when they are exposed for long periods of time to temperatures colder than about 19°C (66 °F). To survive such cold periods, most animals retreat to confined warm-water refuges (usually natural springs or power plant outfalls) that discharge water at temperatures above 19 °C. However, areas with refuges discharging water at temperatures below about 22 °C can still experience significant levels of cold stress-related deaths. Currently perhaps 85% of all manatees along Florida's Atlantic coast (not including animals using Blue Spring on the upper St. Johns River) rely principally on outfalls at five power plants built before the early 1970s to meet their thermoregulatory needs during winter months[1]. Many of these plants are reaching the end of their planned operational life. Regulations governing thermal discharges now preclude the approval of comparable thermal discharges from new plants. Thus, if these older plants are not repowered (in which case they could continue to discharge heated effluent) and are instead closed, the Atlantic coast subpopulation of Florida manatees could be significantly reduced due to winter cold stress.

A possible option to respond to this situation is the creation of alternative non-industry dependent warm-water refuges into which water heated principally by solar power is discharged into an embayment designed to retain heat for manatees, while minimizing its release into adjacent waterbodies. Such refuges might circulate water heated by solar panels through a closed system of pipes to a heat exchanger at the bottom of the refuge. The heat exchanger would transfer heat to warm water in the refuge (see Figure 1). A preliminary modeling study[2] to assess the feasibility of such an approach has been undertaken using average daily water temperature and weather data at a site in Palm Beach County in the central portion of the winter range of Atlantic coast manatees. The study concluded that a system of solar panels could be adequate to heat small embayments to levels sufficient to meet thermoregulatory needs for manatees overwintering at that site, based on simple assumptions. To further assess the feasability of this approach, the study concluded that a more detailed analysis should be undertaken using hourly winter water temperature and weather data. In addition, the study did not provide detailed cost estimation of solar water heating system components.

To address this need and further assess the feasibility of a solar-power-based water heating system to provide reliable warm-water refuges for manatees within the principal portions of their current winter range along the east coast, a study is needed to:

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1 Laist, D. W., J. E. Reynolds, "The Effect of Power Plants and other Warm-Water Refuges on Florida Manatee Abundance and Distribution," Manatee Habitat Workshop 2004, Nov. 29 - Dec. 1, 2004, Defray Beach, Florida

2 Goswami, Y., N. Goel, D. W. Kearney, 2002, "Feasibility study on solar heating of a manatee refuge in southeast Florida," Florida Manatee Refuge Heating Study

1) assess the heat loss from hypothetical warm-water areas in the northern, central, and southern portions of the manatee’s current winter range along Atlantic coast of Florida using a heat flux model that incorporates hourly water temperature and weather data;

2) estimate how much heat would be needed to create a semi-enclosed warm-water manatee refuge that would remain at or above 22 °C during the coldest winter periods a site in each of the northern, central, and southern parts of their principal winter range along the Atlantic coast;

3) assess the availability, engineering requirements, and cost-effectiveness of solar-based water heating technology and a back-up/booster water-heating system to create a warm-water embayment that could be kept at 22 °C or above during periods of exceptionally cold or cloudy winter weather or if technical problems limit operation of the solar-powered system;

4) identify a recommended cost-effective, reliable solar powered water heating system to create a warm-water manatee refuge at each location and estimate the costs to purchase, install, and maintain that equipment and the life expectancy of such a system; and

Task 1 Identify the location and physical configuration of refuges

The objective of this task involved consulting with manatee resource managers with U.S. Fish & Wildlife Service (USFWS), Florida Fish & Wildlife Conservation Commission (FFWCC), Florida Power & Light Company (FPL), and the Marine Mammal Commission (MMC) to identify the location and physical configuration for hypothetical warm-water refuges of two different sizes in each of the northern, central, and southern portions of the manatee's current principal winter range along the Atlantic coast. Based on the kickoff meeting at Florida Solar Energy Center (FSEC) in Jan. 2004, the sizes and locations to be used for modeling simulation analyses was identified as described below.

1.1 Refuge locations

For purposes of this study, it was decided to consider the development of artificial refuge in three hypothetical locations. The included sites are in Brevard County at the FP&L Cape Canaveral Power Plant, in Palm Beach County at the Riviera Beach Power Plant, and in Dade County near Miami. The locations were selected largely because they were locations where whether data included information solar radiation levels, as well as air temperatures, wind speeds, cloud cover, etc., were available.

Figure 1-1 Three hypothetical refuge locations in Florida

1.2 Refuge Configurations

For purposes of this study, it also was decided to model two sizes of refuges at each location: small refuge to support about 50 animals and large refuge capable of supporting several hundred manatees. For the small refuge, the agreed size was 50x50 ft (2,500 ft^2/0.06 acre). For the larger refuge, it was agreed to use the Riviera Beach power plant embayment as a model (i.e., an embayment 100 x150 ft (15,000 sq ft/10.33 acre)). Its depth ranges from about 3 to 8 ft. with an average of about 6 ft. Although it was agreed that modeling should consider two different depths, agreement on those depths was not settled. An average of 6 ft and 9 ft. might be appropriate. The deeper alternative was suggested as a possible means of buffering the effects of heat loss during a cold period.

Task 2 Identification and Selection of Weather and Water Temperature Data

The objective of this task was to identify and compile hourly water temperature, weather, and tidal data for the months of December 1989, and January and February 1990, which was thought to characterizes local environmental conditions during the coldest year for which data are available at each of the three locations selected in Task 1.

2.1 Hourly Weather Data

Weather data sought to carry out the project include the following for each site during the coldest year in recent history: Hourly measurements of solar radiation, air temperature, dew point or relative humidity, cloudy cover, and wind conditions.

- Solar radiation was used to calculate heat gains provided directly to refuge waters and solar collectors by exposed to sunlight.
- Air temperature was used to calculate convective heat losses from refuge through air-water interface.
- Dew point or relative humidity was used to calculate refuge evaporative losses.
- Cloudy cover was used to calculate sky temperatures and sky radiation losses.
- Wind speed was used to determine heat and mass transfer coefficients for both convective and evaporative heat losses

At the initial project organizing meeting, it was agreed that weather data for the years 1989 and 1990 should be used as the winter of 1989-1990 had the highest rates of cold-stress related manatee mortality in recent years. There are several possible sources of hourly weather data for 1989 and 1990 including :Typical Meteorological Year (TMY) data from the National Renewable Energy Laboratory, Florida Solar Energy Center (FSEC) weather stations, the National Climate Data Center (NCDC), and Solar and Meteorological Surface Observation Network.

Typical Meteorological Year Weather Data

The most commonly used weather data is TMY2 weather data developed by National Renewable Energy Laboratory[3]. TMY2 data provide typical weather conditions during a 30-year period collected at about 240 locations throughout in the United States between 1961 and 1990. To assess its suitability for use in this project, TMY2 data were assessed by comparing it with the range of interannual variation in 30-year data sets from stations near selected project sites. Comparisons were made on a monthly and annual basis for global horizontal, direct normal, and south-facing latitude tilt radiation; and for heating and cooling degree days. Such comparisons show how well TMY2 data portray long-term conditions related to the solar resource and the dry bulb temperature environment for simulations of solar energy conversion systems and building systems. On an annual basis, the TMY data compare closely to the 30-year data sets. The

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3 Marion, W. & K. Urban, 1995, “User's Manual for TMY2s (Typical Meteorological Years),” National Renewable Energy Laboratory, Golden, Colorado

monthly comparisons are less favorable than the annual comparisons. The detailed description how to generate TMY2 weather data can be found 3 in Marion and Urban (1995).

Because the goal of the present project is to predict heating requirements in the coldest year, rather than a typical year, TMY2 weather data was not considered suitable for the present study.

National Climatic Data Center Weather Data

The National Climatic Data Center (NCDC) provides hourly weather measurement more than 300 stations in the United States, including locations in Daytona Beach, West Palm Beach and Miami. Most weather data are collected at airports to meet aircraft landing and take-off requirements. The data consists of air temperatures, humidity levels, wind conditions and cloudy cover. Unfortunately, solar radiation is not measured and recorded, except for a few locations. Due to lack of solar radiation data, the NCDC weather data were not considered and suitable for the present study.

Florida Solar Energy Center Meteorological Station

The FSEC meteorological station constantly monitors ambient weather conditions at FSEC's main site in Cocoa, Florida. This data is gathered primarily for FSEC testing and research activities. The station measures all the weather conditions necessary to conduct project analyses and is located within five miles of the Florida Power and Light Companies Cape Canaveral power plant, which was selected as the northern project test site. FSEC weather data was therefore used to conduct analyses for the northern test site, but was not suitable for the other two hypothetical sites (i.e. West Palm Beach County and Miami-Dade County).

Solar and Meteorological Surface Observation Network

The Solar and Meteorological Surface Observation Network (SAMSON) 3-volume CD-ROM set is divided geographically into three regions: Eastern, Central, and Western U.S. It contains hourly solar radiation data along with selected meteorological elements for the period 1961-1990. It encompasses 237 national weather stations in the United States, Guam and Puerto Rico. The data set includes both *observational and modeled data*. The hourly solar elements are: Extraterrestrial horizontal and extraterrestrial direct normal radiation; global, diffuse, and direct normal radiation. Meteorological elements include: total and opaque sky cover, temperature and dew point, relative humidity, pressure, wind direction and speed, visibility, cloud ceiling height, present weather, precipitable water, aerosol optical depth, snow depth, days since last snowfall, and hourly precipitation. The database is a joint effort by the NCDC and National Renewable Energy Laboratory (NREL). Although the solar radiation data were modeled, it was found to be the best source for the present study, because it included a completed data set for 1989 and 1990. Therefore, the weather data of SAMSON was used in the present study for the three selected hypothetical sites.

2.2 River water temperature

River water temperatures are needed to calculate the effect of refuge basin heat gains and losses due to tidal exchange and perhaps additional water added to the refuge to increase water volume to prevent stagnation or water quality problems within the refuge. Because manatee refuges must have openings to allow manatee access, river water temperatures are a major factor for predicting required heating energy needs. Model predictions show the tidal exchange and water circulation through the refuge are the most important single parameter.

With the assistance of Florida Power & Light Company (FP&L), hourly river water temperatures were obtained from cooling water intake canals at four east coast power plants -- the Cape Canaveral Power Plant, the Riviera Power Plant, the Fort Lauderdale Power Plant, and the Port Everglades Power Plant corresponding to the approximate locations of the three hypothetical project test sites. Water temperatures from the Fort Myers cooling water effluent canal also were obtained for purposes of model calibration. These were the only locations for which long-term continuous water temperature data for inland coastal waters could be found for locations between Cape Canaveral and Biscayne Bay. Unfortunately, continuous hourly water temperature data from these sites was available only for recent years. None included data for 1989 and 1990 believed to be the coldest year in Florida recent years. The data provided covered the following periods:

Cape Canaveral Power Plant: hourly data from 1996-2003
Riviera Beach Power Plant: hourly data from 1995-2003
Port Everglades and Fort Lauderdale Power Plants: hourly data from 2001-2003

After requesting more measured data specifically for the winter of 1989-90, FP&L, also was able to provide hourly intake water temperatures from its Cape Canaveral Power Plant for one day (Dec. 23, 1989), and daily maximum and minimum water temperatures for the period between December 29, 1989 and March 31, 1990. Although this additional data was not suitable for direct use, it was very helpful for assessing the accuracy of the model described below used to generate estimates of hourly inland coastal water temperatures at all three sites during the winter of 1989-90.

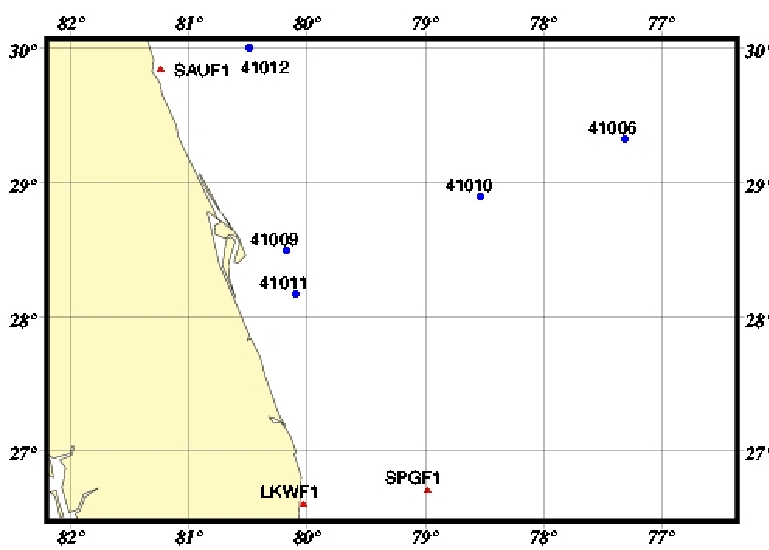

Figure 2-1 Buoy locations in Atlantic Ocean of Florida from NODC

<u>Predictive Water Temperature Model</u>

In the absence of measured hourly water temperatures for the winter of 1989-90 at the three selected project sites, a model was developed and tested to predict inland coastal water temperatures using hourly ocean water and ocean air temperatures collected at two nearby monitoring stations by the National Oceanographic Data Center (NODC). The two monitoring stations include (1) an ocean buoy located 20 miles offshore of Cape Canaveral, and (2) a station located on an ocean pier at Lake Worth nine miles south of the Riviera Power Plant. Figure 2-1 shows buoy locations in Atlantic Ocean of Florida from NODC[4]. The stations used in this study included Station 41009, 20 miles East of Cape Canaveral and Station LKWF1, located on an ocean pier in Lake Worth Pier, nine miles north of the central site considered in this study in central Palm Beach County. Ocean air and water temperatures data are available for 1989 and 1990 at both stations. Although NODC also operates a monitoring station off Miami, temperature data prior to 1994 were not available for that site.

Because of concern that ocean water temperatures, especially for the site 20 miles east of Cape Canaveral, are not equivalent to inland coastal water temperatures, it was considered inappropriate to use ocean water temperatures as a direct proxy for inland coastal water temperatures. Because of their shallow nature, winter water temperatures tend to be cooler in inland coastal waters than in the ocean during periods when air temperatures drop significantly below water temperatures. However, because of constant tidal exchange between the ocean an inland estuarine waters, it was believed they could be correlated. The following regression model was therefore developed whereby inland coastal water temperature is expressed as a bi-quadratic function of ocean air and water temperatures:

$$T_{river} = a + b * T_{air} + c * T_{ocean} + d * T_{air}^{\ 2} + e * T_{ocean}^{\ 2} + f * T_{air} * T_{ocean} \qquad \textbf{(1)}$$

where

T_{river}	River temperature [^oC]
a,b,c,d,e,f	Regression coefficients
T_{air}	Ocean air temperature [^oC]
T_{ocean}	Ocean water temperature [^oC]

To calibrate the model, predicted inland coastal water temperatures were compared with actual measured water temperatures provided by FP&L from cooling water intake openings at two inland sites (Cape Canaveral and Riviera Beach) for the years 2001 and 2002. Predicted water temperatures at the Cape Canaveral Power Plant were based on ocean air and water temperatures from the buoy 20 miles east of Cape Canaveral; the predicted water temperatures for the Riviera Power Plant were based on ocean air and water temperatures from the ocean pier in Lake Worth. Appendix A provides a comparison of the predicted and measured river water temperatures at both sites for 2001 and 2002. The comparison provides a high level of confidence that the ocean air and ocean water temperatures can be used to predict inland coastal water temperatures.

<u>Water Temperatures at the Cape Canaveral Power Plant</u>

Using Eq. (1) and the same regression coefficients developed to calibrate the model, ocean air and water temperatures for 1989 and 1990 from the ocean buoy off Cape Canaveral was used to predict inland coastal water temperatures at Cape Canaveral. (See Appendix A for the ocean air

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4 http://www.nodc.noaa.gov/BUOY/bafl.html

and ocean water temperatures used to predict water temperatures at Cape Canaveral). Figures 2-2 and 2-3 show the predicted water temperatures at Cape Canaveral for 1989 and 1990, respectively, which includes the cold winter period in late 1989 and early 1990 that had high cold-stress-related manatee mortality.

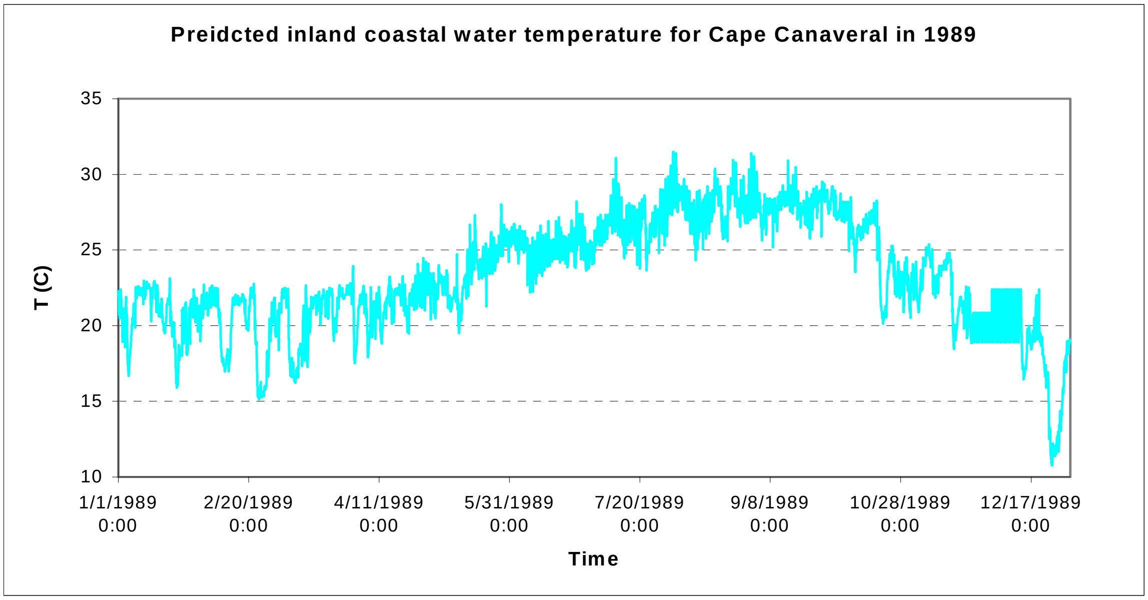


Figure 2-2 Predicted ambient water temperature at the Cape Canaveral power plant for 1989

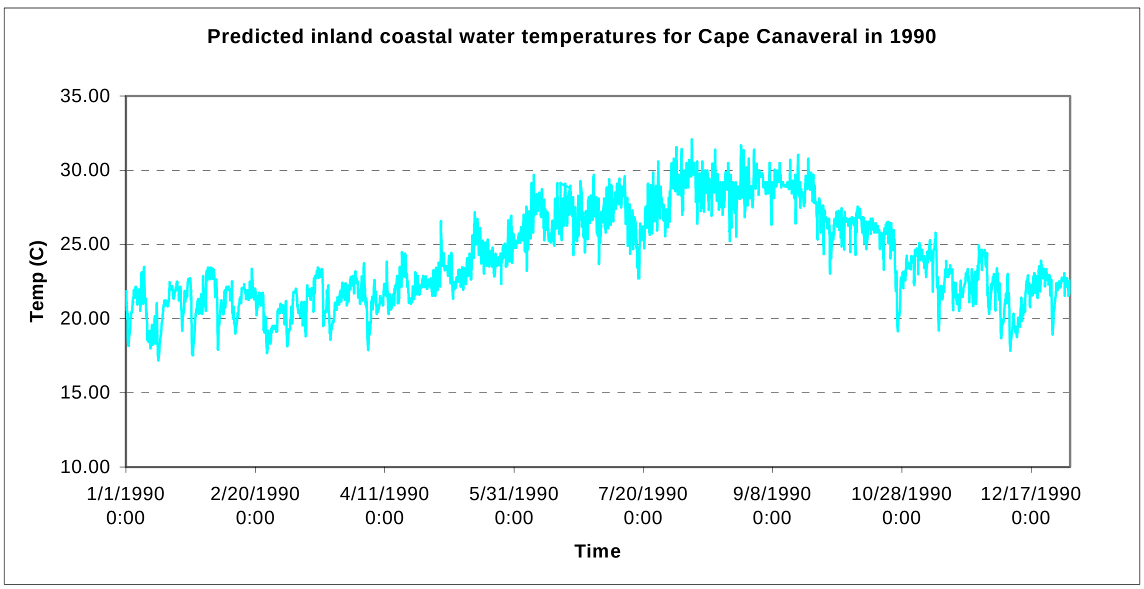


Figure 2-3 Predicted ambient water temperature at the Cape Canaveral power plant for 1990

Figures 2-4 and 2-5 compare the predicted temperatures at Cape Canaveral with the actual measured water temperatures available for the same period at that site from FP&L. Figure 2-4 shows the measured and predicted water temperatures over a 14-day period at the end of December 1989 when a very intense cold front struck Florida between 23 and 26 December, causing a large number of cold-related manatee deaths. Figure 2-4 also shows that the predicted temperatures are nearly identical to FP&L's measured hourly temperatures on 23 December, but were about a degree warmer than the measured maximum temperatures and 4 degrees warmer

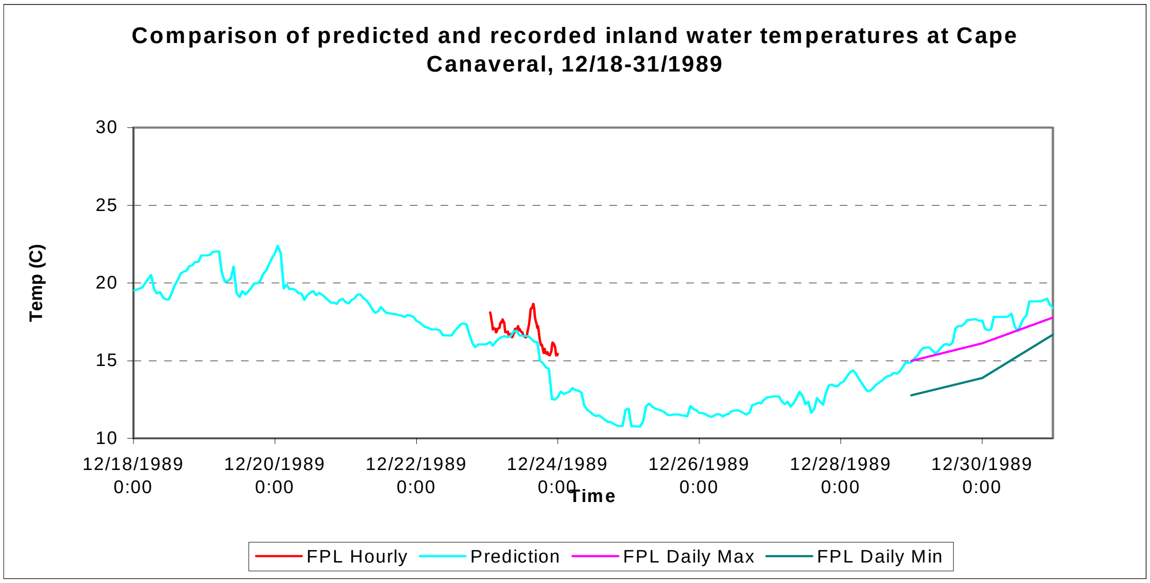


Figure 2-4 Comparison of December 1989 water temperatures measured by FPL at the Cape Canaveral power plant with predicted water temperatures

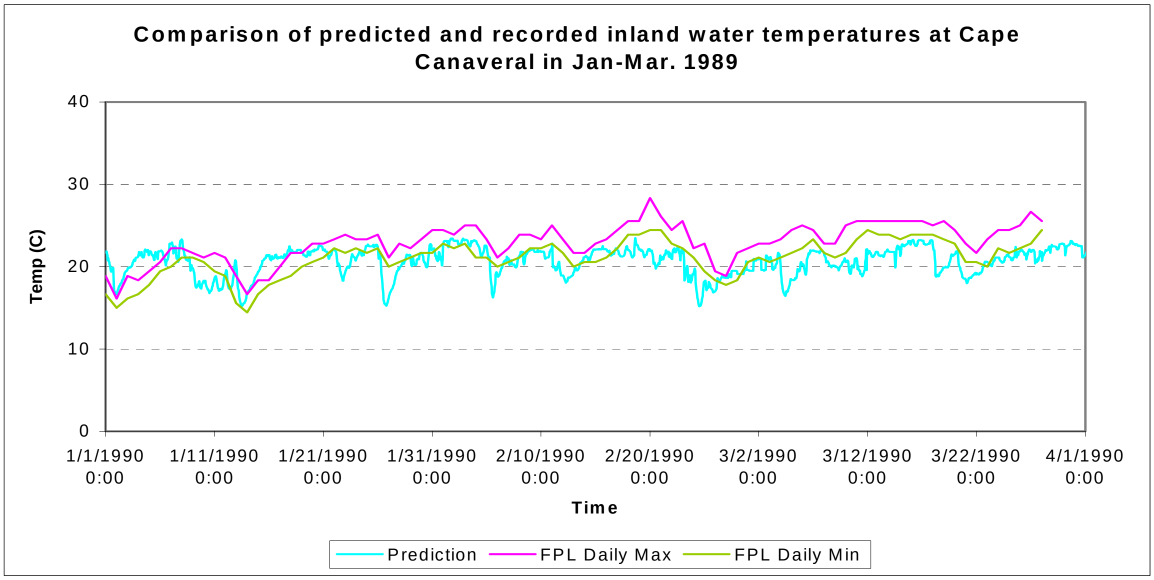


Figure 2-5 Comparison of Jan-Mar. 1990 water temperatures measured by FPL at the Cape Canaveral power plant with predicted water temperatures

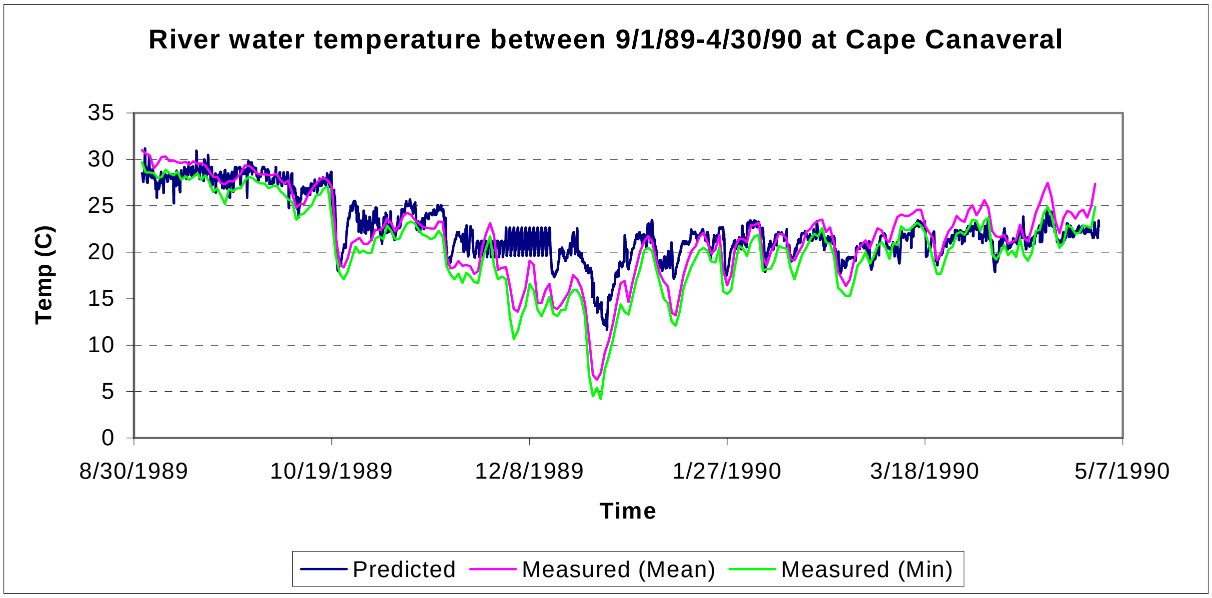


Figure 2-6 Comparison of predicted water temperatures for the Indian River with the measured daily minimum and mean temperatures in Banana Creek provided by the U.S. Geological Survey, Sirenia Project.

than the measured minimum temperatures between 29 and 31 December. Figure 2-5, which illustrates the predicted water temperatures and the measured minimum and maximum temperatures at the Cape Canaveral power plant between 29 December and 31 March, shows that the predicted temperatures for this site consistently fell within or very close to the bounds of the measured water temperatures throughout early 1990.

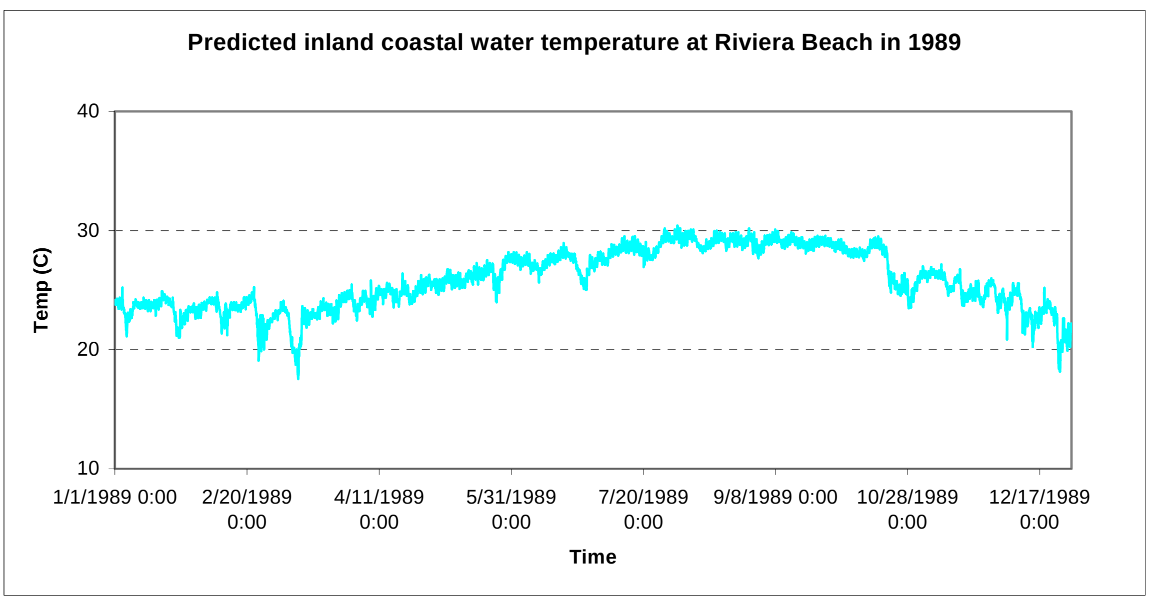


Figure 2-7 Predicted ambient water temperatures at the Riviera power plant in 1989.

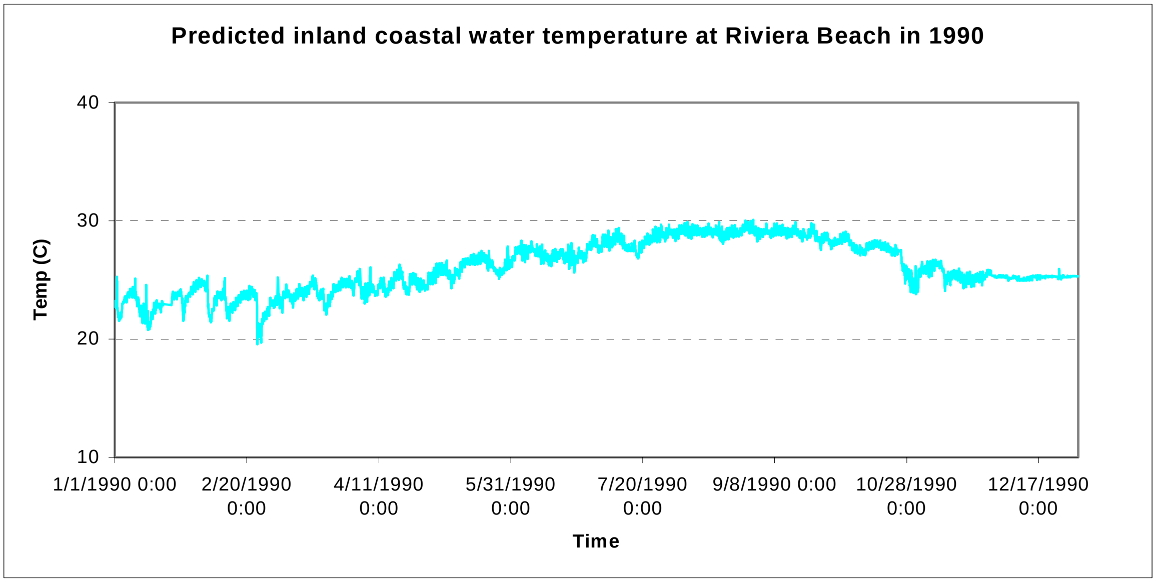


Figure 2-8 Predicted ambient water temperature at the Riviera power plant in 1990

As this report was being finalized, a more complete set of water temperature data for the Cape Canaveral area was located for the years 1989 and 1990. The Sirenia Project in the U.S. Geological Survey's Office of Biological Services provided minimum and maximum daily water temperatures for a site located about one mile upstream from the Indian River on the northern Banana River near the Route 3 bridge. Those data were compared with the predicted temperatures, as shown Figure 2-3. The comparison revealed that the predicted temperatures closely tracked the daily trends of the measured data, but that in December 1989 and January 1990, the measured temperatures were significantly cooler than the predicted temperatures. The lowest measured temperature occurred on 26 December 1989 when the water temperature reached a low of 4.2ºC, a high of 10.6ºC, and had a mean of 7.0ºC, compared to a minimum predicted temperature for that day of 12.2ºC and a maximum predicted temperature of 14.6ºC. It is possible that the winter water temperatures in this creek are colder than those in the Indian River due to the shall dead end nature of the Creek.

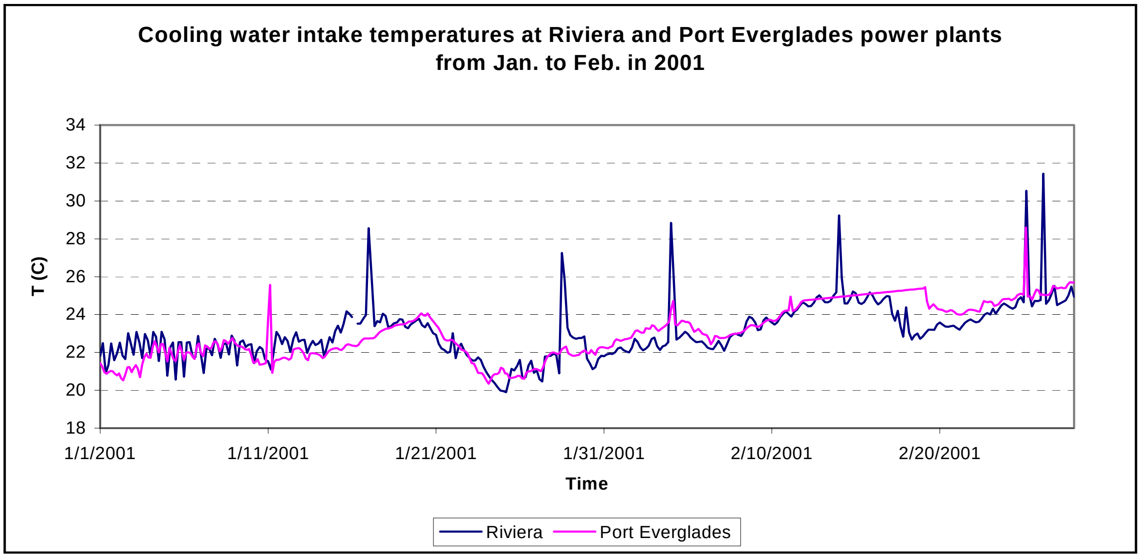
Water Temperatures at the Riviera Power Plant

Using Eq. (1) and the same regression coefficients developed to calibrate the model, the ocean air and water temperatures for 1989 and 1990 at the Lake Worth ocean pier were used to predict hourly inland waters at the Riviera Power Plant. Figures 2-7 and 2-8 shows the predicted water temperatures at this site for 1989 and 1990, respectively. Unfortunately, no measured water temperature data for 1989-1990 was available for this site for comparison purposes.

Inland Water Temperatures near Miami

Because ocean air and ocean water temperature data before 1994 were not available from the NODC monitoring station for Miami, it was not possible to use the regression equation to predict inland water temperature for Miami. However, measured water temperatures were available from FP&L for more recent years at both the Riviera and Port Everglades power plants. A comparison of data on intake water temperatures at the two power plants during the winter months in 2001 (Figure 2-9), 2002 (Figure 2-10), and 2003 (Figure 2-11) reveals that the water temperatures at the Riviera plant were very close to those at Port Everglades plant except in December in 2002 when water temperatures at the former plant were about 5 degrees Celsius cooler than those at the Port Everglades plant.

Because the present project seeks to provide required heating during the coldest periods, the predicted inland water temperatures for 1989 and 1990 at the Riviera Beach power plant were selected for use in analyzing heating requirements at the southern site in the Miami area, but modifies them to increase the temperature estimates by 2 degrees Celsius. Figure 2-12 shows the inland water temperatures used for analyses of a southern refuge basin in the Miami area in 1989.



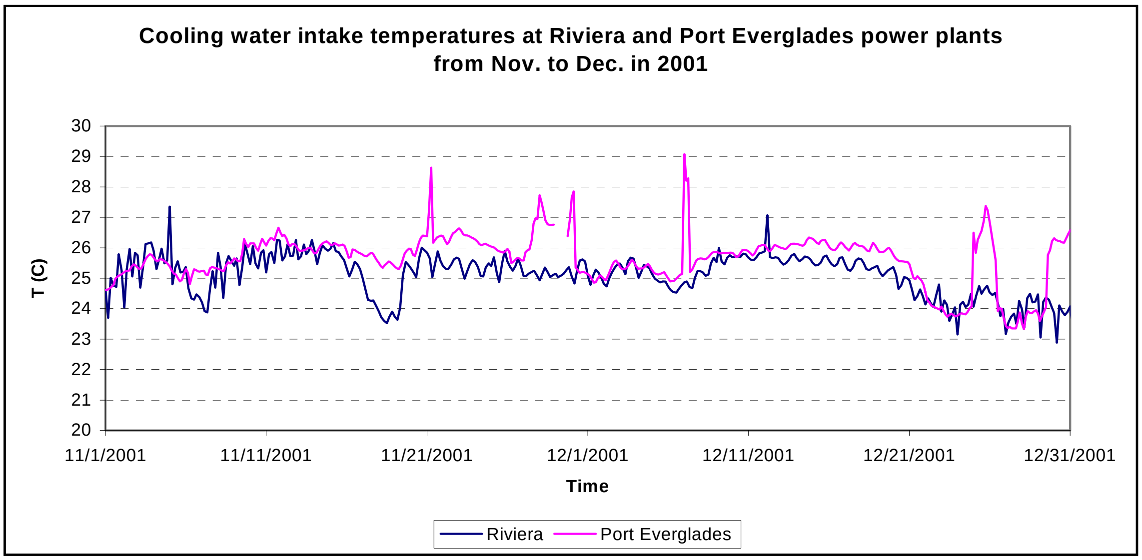
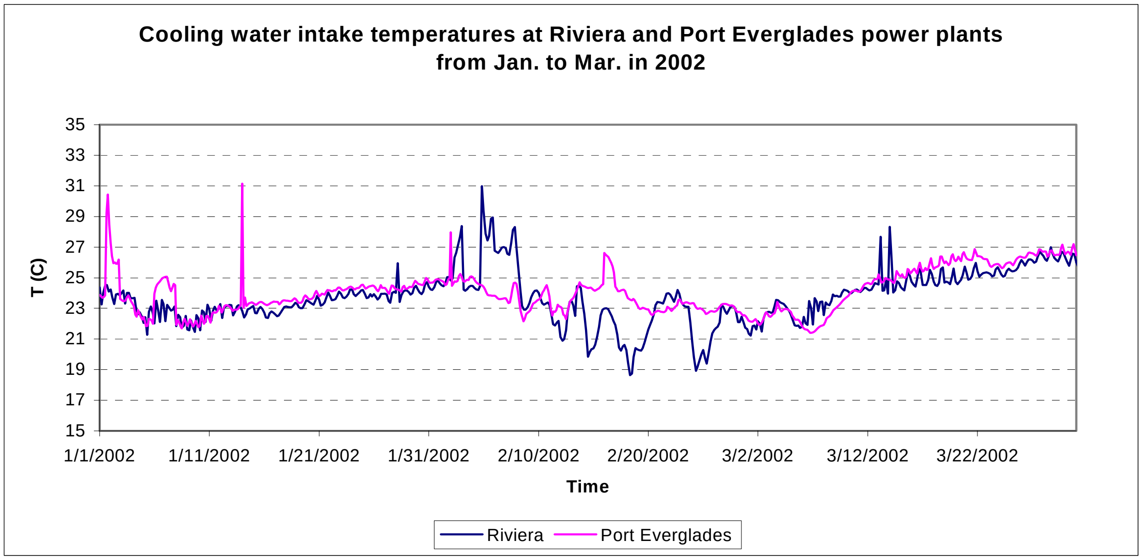


Figure 2-9 Comparison of ambient water temperatures measured by FPL at cooling water intakes for the Riviera and Port Everglades power plant in 2001



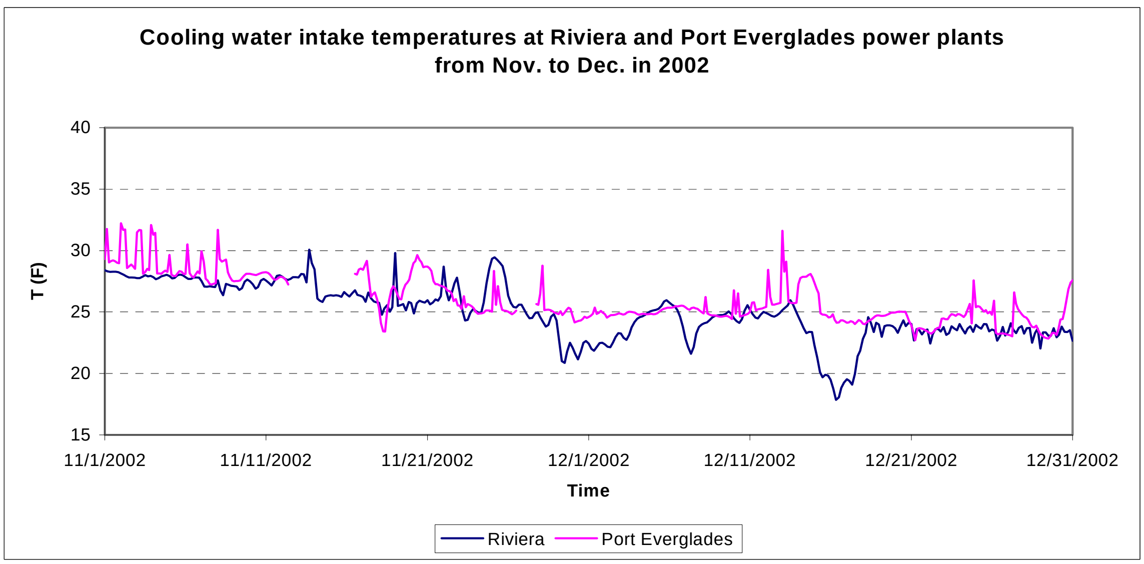


Figure 2-10 Comparison of ambient water temperatures measured by FPL at cooling water intakes for the Riviera and Port Everglades power plant in 2002

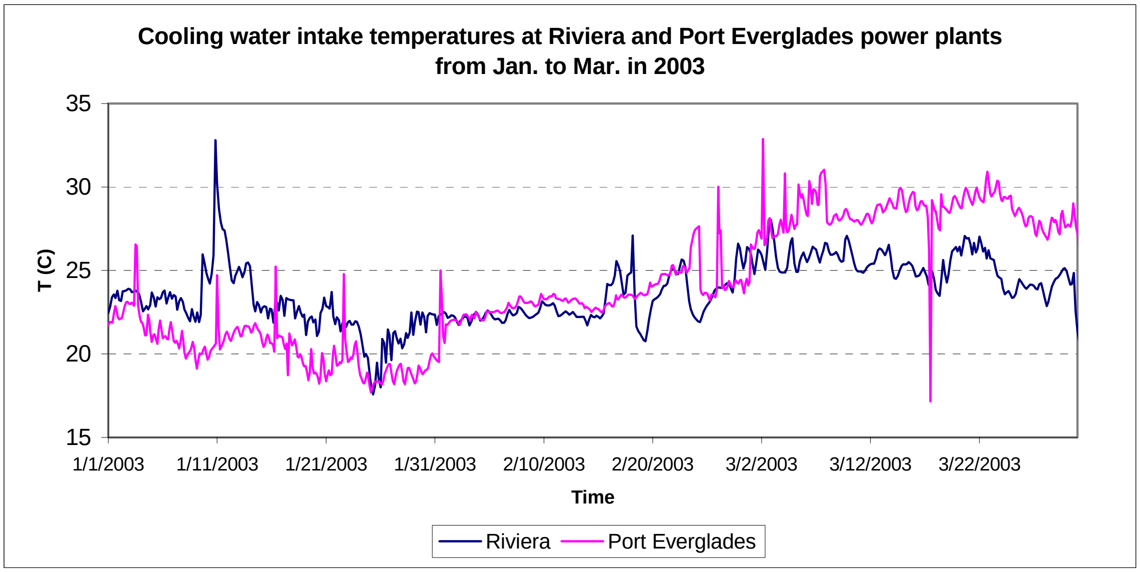


Figure 2-11 Comparison of ambient water temperatures measured by FPL at cooling water intakes for the Riviera and Port Everglades power plant in 2003

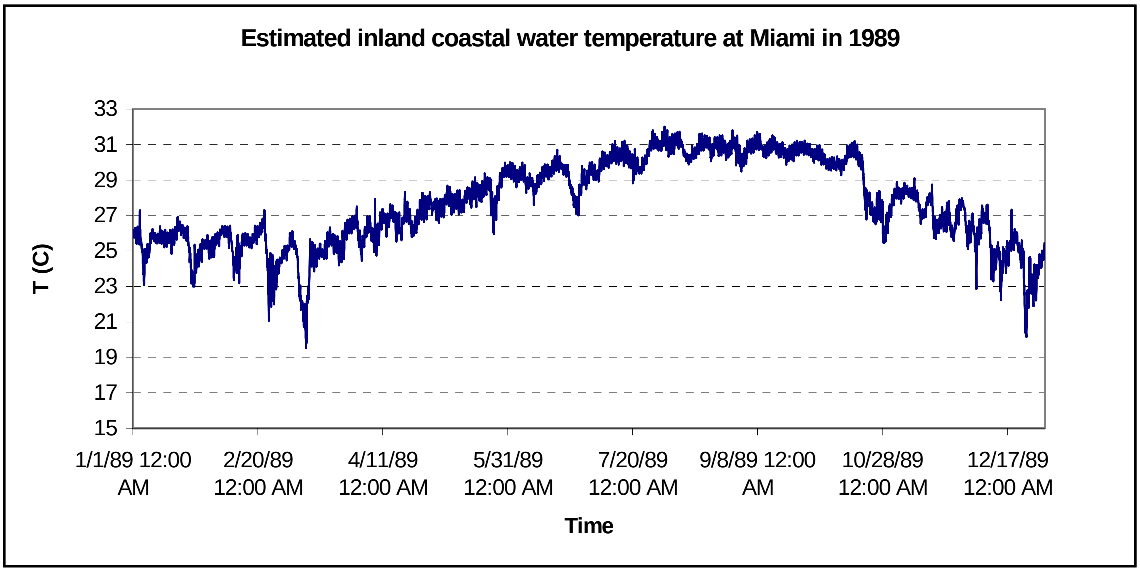


Figure 2-12 Estimated inland water temperatures for Miami in 1989

Task 3 Simulation benchmarking and validation

The objective of this task was to use an appropriate model to calculate how much heat would be required to maintain a minimum water temperature of 22 °C in the two different warm-water refuge configurations at each of the three hypothetical sites using data collected in Task 2. Although there are several models available to calculate heat losses from swimming pools, the model used for the present project also must account for tidal impact. Before the model can be used with high level of confidence, the model should be validated to compare predicted results with measured temperature data.

This section describes the mathematical formulas used to model heat losses and the required solar collector performance for the various manatee refuges considered. The section also describes the exercise to validate the model against measured pool data in Cocoa Beach.

The model considers heat transfer across the following boundaries:

- heat from solar radiation entering the refuge embayment,
- heat transfer due to convection at the water surface through air movement;
- heat exchange between the water surface and sky temperatures due to night sky radiation,
- heat exchange between the ground and water within the refuge area,
- heat exchange due to tidal effects, and
- heat exchange between reheat water and the water in the refuge.

3.1 Heat losses in manatee refuges

Sources of heat loss and gain for manatee refuges include conduction from refuge walls and ground, radiation between the water surface and sky, evaporation between the water and ambient air, solar heat gain from solar radiation, rain, and tide.

Although rain is a factor in calculation of heat losses, it is not considered in the present study, Firstly, the weather data do not detail rain information. Secondly, Cromer[5] assumed 0.1°F temperature drop with light rain, 0.2°F with moderate rain, and 0.3°F with heavy rain, respectively. The maximum temperature drop of 0.3°F is not significant to affect refuge water temperatures. Thirdly, low precipitation rates in winter are not sufficient to significantly cool a water body of the size and volume envisioned. Therefore, the rain impact is not included in refuge heat loss and gain.

<u>Conduction</u>

Conduction heat loss from surrounding walls and ground may be written as:

$$Q_{cond} = UA(T_{soil} - T_w) \qquad \textbf{(2)}$$

where

Q_{cond} = Heat conduction loss from surrounding walls and ground [W]

U = Overall heat transmission coefficient [W/m^2.K]
A = Surface area [m^2]
T_w = Refuge water temperature [^{o}C]
T_{soil} = Soil temperature [^{o}C]

There are two types of conduction loss: wall conduction loss and ground conduction loss from the bottom of refuges. The U value is assumed to be 0.57 W/m^2.K [5]. The average wall temperature is assumed to be a third of ground temperature and two thirds of ambient temperature. It should be pointed out that conduction loss is minor compared to other major sources of heat loss. The sensitivity study in the next section will demonstrate this conclusion.

Solar Radiation

Solar radiation gain from global and diffuse horizontal radiation is

$$Q_{solar} = \alpha_w A_w q_{solar} \quad \textbf{(3)}$$

where
Q_{solar} = Heat gain from solar radiation [W]
α_w = Refuge water absorptivity [dimensionless]
q_{solar} = Global and diffuse solar heat flux [W/m^2]

The absorptivity of water is assumed to be 0.75[5].

Night Sky Radiation

Radiation loss between refuge water surface and sky temperature[5] may be written as

$$Q_{rad} = \varepsilon_w \sigma A_w \left(T_{sky}{}^4 - T^4{}_w\right) \quad \textbf{(4)}$$

where
Q_{rad} = Total radiation loss due to sky temperature [W]
ϵ_w = Emissivity of refuge water surface, assume 0.95[5]
σ = Stefan-Boltzmann constant [5.67×10^{-8} W/m^2.K^4]
A = Water surface area [m^2]
T_w = Water surface temperature [K]
T_{sky} = Sky temperature [K]

The clear sky emissivity may be a function of ambient dew point and hour of a day[6]

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5 Cromer, C. 1982, "Chapter 4: Sizing Guide for Solar Pool Heating Systems," Solar Water and Pool Heating Manual, Vol. II, Florida Solar Energy Center, FSEC-IN-22-82, Cocoa, FL

6 ASTM, 1999, "Standard Practice for Estimation of Heat Gain or Loss through Ceilings under Attics Containing Radiant Barriers by Use of a Computer Program," ASTM C 1340-99, American Society for Testing and Materials

$$\varepsilon_{sky,clear} = 0.711 + 0.56 * (T_d / 100) + 0.73 * (T_d / 100)^2 + 0.13 * \cos(2\pi * hour / 24) \quad \textbf{(5)}$$

where

T_d = Dew point temperature [^{o}C]

hour = The hour of a day [1-24]

The sky emissivity may be a function of sky cloud cover

$$\varepsilon_{sky} = \varepsilon_{sky,clear} + (1.0 - \varepsilon_{sky,clear}) * C_c / 10.0 * 0.784 \quad \textbf{(6)}$$

where

C_c = Cloud cover used in NCDC weather data [0-10]

The sky temperature may be expressed as a function of sky emissivity:

$$T_{sky} = T_{air} * (\varepsilon_{sky})^{0.25} \quad \textbf{(7)}$$

<u>Convection</u>

The algorithm to predict hourly convection loss at water surface is

$$Q_{conv} = hA_w(T_{amb} - T_w) \quad \textbf{(8)}$$

where

Q_{conv} = Convective loss [W]

h = Heat transfer coefficient [W/m^2.K]

A_w = Water surface area [m^2]

T_w = Water surface temperature [K]

T_{amb} = Ambient air temperature [K]

<u>Evaporation</u>

The equation used to predict hourly evaporation loss from the refuge water surface is

$$Q_{evap} = h_m * A_w * \lambda * \left(w_{amb} - w_w\right) \quad \textbf{(9)}$$

where

Q_{evap} = Evaporation loss [W]

A_w = Refuge water surface area [m^2]

h_m = Mass transfer coefficient [kg/m^2.s]

w_w = Water surface saturated humidity ratio [kg/kg]

w_{amb} = Ambient air humidity ratio [kg/kg]

λ = Latent heat [J/kg]

The mass transfer coefficient, h_m, can be obtained from heat transfer coefficient based on Lewis relation[7]

$$\frac{h}{h_m C_p} \approx 1 \qquad \textbf{(10)}$$

where

h = Heat transfer coefficient [W/m^2.K]
C_p = Air specific heat [J/kg.K]

<u>Tide</u>

Heat transfer from tides and water circulation through a refuge is determined by the inland coastal temperature and volume change rate. The equation used to predict hourly tidal loss from the refuge is

$$Q_{tide} = \dot{m} C_{p,water} * (T_{river} - T_w) \qquad \textbf{(11)}$$

where

Q_{tide} = Tidal heat loss [W] m
$\dot{m}$ = Tidal water flow rate [kg/s]
$C_{p,water}$ = Water specific heat [J/kg.K]
T_{river} = River water temperature [^{o}C]
T_w = Refuge water temperature [^{o}C]

Two types of tidal water flow rates are used in the present study: constant and variable. The constant tidal flow rate is based on the daily water volume turn over rate, varying from 0.5 to 5 volume change per day. This range of volume change rate was selected at project kickoff meeting in January, 2004 at FSEC. The hourly flow rate is equally distributed based on the daily turn over rate.

The variable tidal flow rate is based on tidal height and tidal flow direction. The tidal heat loss occurs only during a rising tide (from river to refuge), while ebb tides (from refuge to river) cause no heat losses within the refuge itself. Unlike a 24-hour solar day, a lunar day lasts 24 hours and 50 minutes, because the moon revolves around the Earth in the same direction as the Earth's rotation. Therefore, it takes the Earth an extra 50 minutes to “catch up” to the moon. Since the Earth rotates through two tidal “bulges” every lunar day, Florida experiences two high and two low tides every 24 hours and 50 minutes. High tides occur 12 hours and 25 minutes apart, taking 6.2 hours for the water at the shore to go from high to low, and about 6.2 hours to go from low to high. In addition, high and low tidal time varies with locations. Therefore, the three locations used in the present study have different high and low tidal time and heights.

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7 ASHRAE, 1997, ASHRAE Handbook of Fundamentals, p. 5.11, Eq. (50)

WXTide32, a *free* Windows tide and current prediction program, was used to predict tide times and water levels[8]. A detailed description of the program is given in Appendix B. Unfortunately, hourly simulations are used in the present study. Since the tidal cycle did not match the solar daily cycle, we had to modify the tidal cycle data to fit the solar cycle. The following approach was used to meet the hourly simulation requirements.

- The time and height of high and low tide at each cycle were obtained for each cycle in the three locations in 1989 and 1990, using WXTide32;
- The tidal shape at each cycle was assumed to be a sine curve, so that continuous tidal curves were generated in the three locations in both years;
- Hourly tidal height was calculated based on the continuous curves. It should be noted that although the points at the lowest tide and highest tide may not be obtained due to an hourly interval, the best approach is to meet the hourly simulation requirements;
- An hourly tide input file was created which included time, tidal height, and height difference between previous and current hour; and
- Tidal energy loss was calculated based only on the incoming flow of the rising tide, because outgoing flows are not a source of heat losses within the refuges.

The predicted mass flow rate is expressed as

$$\dot{m} = \rho_{water} * \Delta h * A_w / 3600 \qquad \textbf{(12)}$$

where

$\dot{m}$	= Tidal water flow rate [kg/s]
ρ_{water}	= Water density [1000 kg/m^3]
Δh	= Height difference in an hour [m/h]
A_w	= Refuge surface area [m^2]

The tidal curves are presented in Appendix B for all three locations in 1989.

Governing equation

The general governing equation to calculate refuge heat losses may be written as:

$$\rho C_p V \frac{dT_w}{dt} = Q_{cond} + Q_{solar} + Q_{rad} + Q_{conv} + Q_{evap} + Q_{tide} + Q_{heat} \qquad \textbf{(13)}$$

where

ρ	= Water density [1000 kg/m^3]
C^p	= Water specific heat [4180 J/kg.K]
V	= Refuge volume [m^3]
T_w	= Refuge water temperature [K]
t	= Time [s]
Q_{heat}	= Heating energy [W], either from ideal heating or solar collectors

Other nomenclatures are defined earlier.

8 http://www.wxtide32.com/

3.2 Selection of simulation program

Initially, we planned to use the FSEC 3.0 program to simulate refuge water temperatures for the present project. The FSEC program, developed by the Florida Solar Energy Center[9], is a general building simulation program, which provides detailed simulations for a whole building. It simulates energy, moisture, multizone airflows and air distribution systems simultaneously. Its capabilities are listed as follows:

- Zone thermal balance
- Zone moisture balance
- Zone contaminant balance, including radon
- Heat and moisture transfer in building envelope
- Multi-zone airflow, including air distribution system
- Zone and air distribution system pressures
- HVAC system models
- Duct system heat and moisture exchange
- Radon transport in soil and slab

The wall heat transfer model in the FSEC program uses either the finite element method or conduction transfer function (CTF). Users have a choice of selecting either a detailed or simplified moisture model to simulate moisture transfer in buildings. The program can perform 1-D, 2-D and 3-D thermal simulations. The other main reason selecting the FSEC 3.0 program was that it could be modified to simulate complicated physical phenomenon, such as manatee refuge thermal performance in 2-D or 3-D. Although other software, such as FLUENT (a CFD commercial software), can also perform this work, it is not easy to modify these programs to simulate evaporation loss or tidal impact.

Although we planned to use the FSEC 3.0 program to perform 2-D simulations, it became apparent that water temperatures did not change very much, after analyzing the 2-D simulation results. After looking at other literature and available pool calculation software, it was decided to use a lumped water temperature approach that assumes the refuge water temperature is homogeously distributed. Since there was a little difference of temperature between lumped and 2-D approach, we concluded the lumped approach would be accurate enough for the present study. Also, because the main interest was calculating how many solar collectors would be needed, the slight difference in refuge temperatures in the two approaches would likely have a little impact on solar collector selection.

Finally, because the refuge volume varies with variable tide, the 2-D simulation cannot change volume, due to fixed mesh. The lumped approach allowed us to vary the refuge volume.

3.3 Solar collectors

9 Florida Solar Energy Center, 1992, "FSEC 3.0: Florida Software for Enervironmetal Computation," Version 3.0, FSEC-GP-47-92

There are three main types of solar collectors commonly used: unglazed, glazed, and evacuated. The thermal performance of solar collectors is dependent on both efficiency and tilt. Therefore, two equations were required to calculate solar collector performance in different locations: an incident angle modifier and collector efficiency. The performance curves in three types of solar collectors are provided by Florida Solar Energy Center through performance testing based on ASHRAE Standard 93-1998. In accordance with Florida Law (§ 377.705, F.S.), the Florida Solar Energy Center is charged to "develop and promulgate standards for solar energy systems manufactured or sold in the state based on the best currently available information. . ." and "establish criteria for testing performance of solar energy systems. . .".

The performance of unglazed solar collector may be written as:

Incident angel modifier:

$$K_{\tau\alpha} = 1.0 - 0.02 * \left(\frac{1}{\cos\theta} - 1 \right) \tag{14}$$

where

$K_{\tau\alpha}$ = Incident angle modifier [dimensionless]

θ = Angel between the normal of the collector and solar direct normal

The efficiency equation is

$$\eta = 82.8 - 1336 * \frac{T_i - T_a}{I} - 10126 * \left(\frac{T_i - T_a}{I} \right)^2 \tag{15}$$

where

η = Efficiency of solar collector [%]

T_i = Inlet water temperature of solar collector [^oC]

T_a = Ambient temperature [^oC]

I = Solar radiation received on solar collector surface, including direct and diffuse solar radiation [W/m^2]

The performance of glazed solar collector may be written as:

Incident angel modifier:

$$K_{\tau\alpha} = 1.0 - 0.15 * \left(\frac{1}{\cos\theta} - 1 \right) \tag{16}$$

The efficiency equation is

$$\eta = 67.4 - 486 * \frac{T_i - T_a}{I} - 1669 * \left(\frac{T_i - T_a}{I} \right)^2 \tag{17}$$

The performance of evacuated solar collector may be written as:

Incident angel modifier:

$$K_{\tau\alpha} = 1.0 - 0.08 * \left(\frac{1}{\cos\theta} - 1 \right) \quad \textbf{(18)}$$

The efficiency equation is

$$\eta = 57.1 - 269 * \frac{T_i - T_a}{I} - 503 * \left(\frac{T_i - T_a}{I} \right)^2 \quad \textbf{(19)}$$

Figure 3-1 illustrates the efficiencies of three different types of solar collectors. When $(T_i-T_a)/I$ is small, the unglazed solar collector has the highest efficiency. Therefore, the unglazed solar collector works the best when the inlet water temperature is much larger than the ambient temperature, When $(T_i-T_a)/I$ is between 0.02 and 0.04, the glazed solar collector performs the best. When the inlet water temperature is slightly larger than the ambient air temperature, the evacuated solar collector works the best.

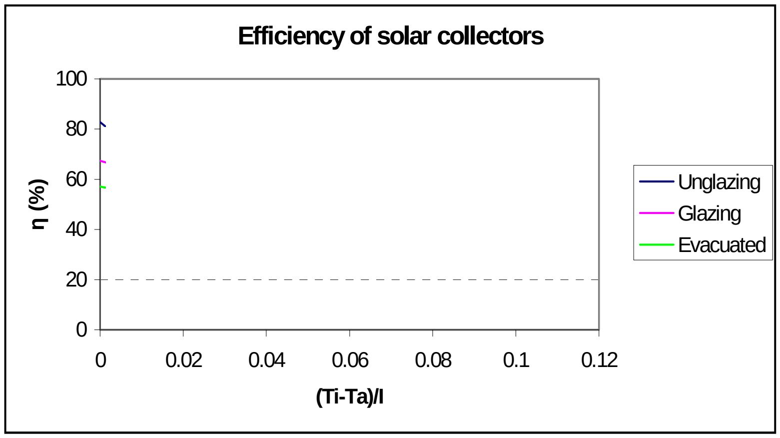

Figure 3-1 Efficiencies of different solar collectors

In addition to the efficiency, which was measured at direct normal tilt, the solar collector position is also important to determine how much solar radiation can be absorbed. In general, a tilt angle equal to the latitude has the best performance annually. However, the purpose in the present study requires best performance in winter. After performing simulations using three different types of solar collectors in the three locations in Dec. 1989 and Jan. 1990 with different inlet water temperatures from 10°C to 20°C, a south facing tilt angle at 50° was found to have the best performance in all three locations. Figures 3-2 and 3-3 show solar collector performance at the three locations with different tilt angles. Therefore, a 50° tilt angle facing south was used in simulations to calculate how many solar collectors would be needed in each scenario.

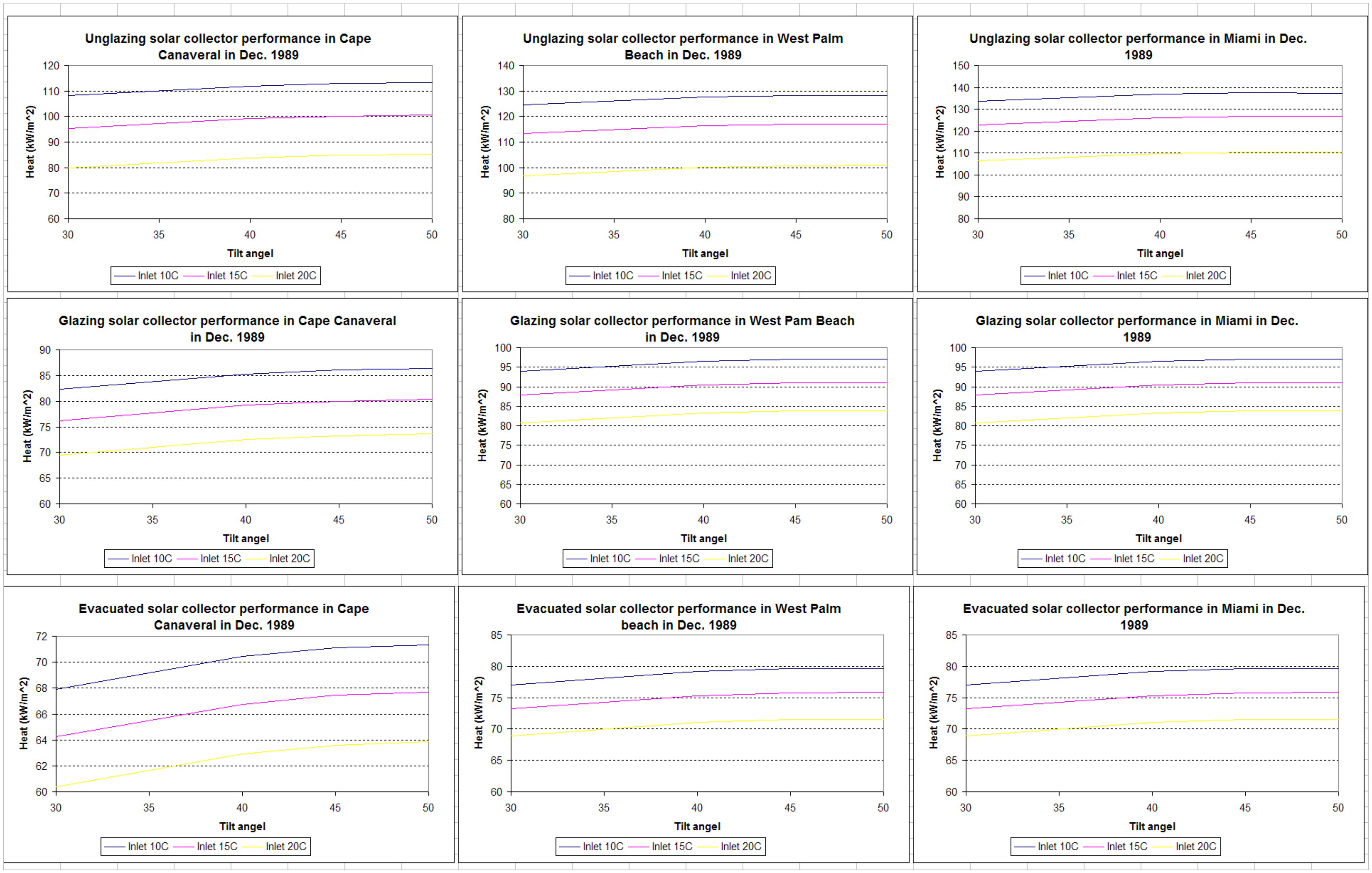

Figure 3-2 Solar collector perfoamce with three types in three locations in Dec. 1989.

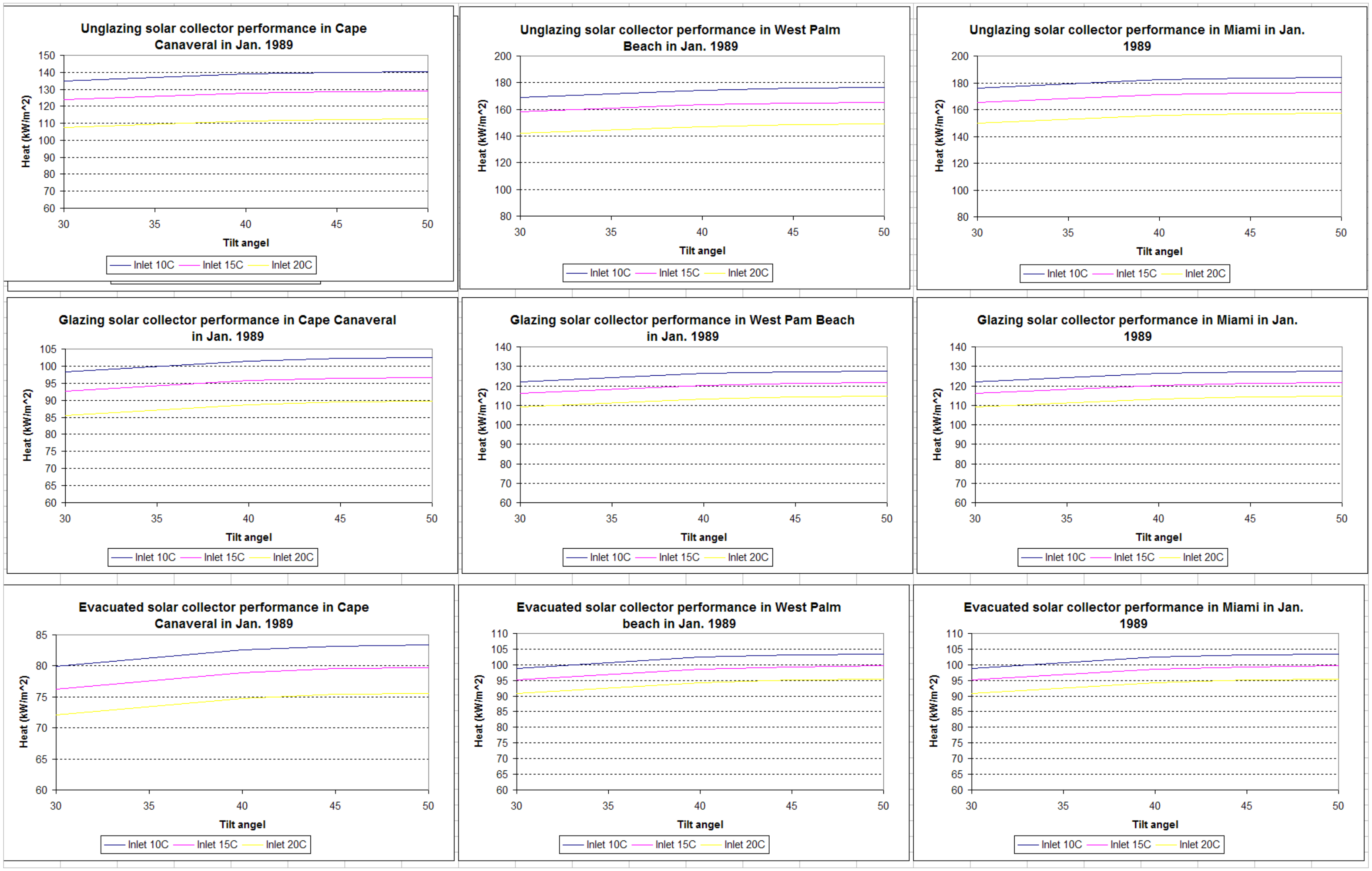

Figure 3-3 Solar collector perfoamce with three types in three locations in Jan. 1990.

3.4 Model Validation

Although the above equations are well known to calculate heat losses, the model had to be validated against measured data to be used with high confidence.

A swimming pool in Cocoa Beach was measured during 1990-1991. The swimming pool was 40 ft long and 20 ft wide with an average depth of 4.5 ft. The maximum depth was 6 ft. The pool was heated by a heat pump with COP 3.33. The temperature was maintained at 83^{o}F (28.3^{o}C). The measured data recorded in every 15 minutes consisted of

- Air temperature
- Ground temperature
- Pool water temperature
- Air relative humidity
- Horizontal solar radiation
- The amount of heat provided by a heat pump
- Heat pump power use

The required cloudy cover used to calculate sky temperatures was not measured. Cloudy cover values obtained from Daytona Beach weather in 1990 were used to calculate the sky temperature for the validation. Figure 3-4 compares the measured and predicted pool temperatures for the period of Dec. 11-14, 1990. Because the measure data agreed closely with the predicted water temperatures, we concluded the model could be used to predict refuge water temperature with high level of confidence.

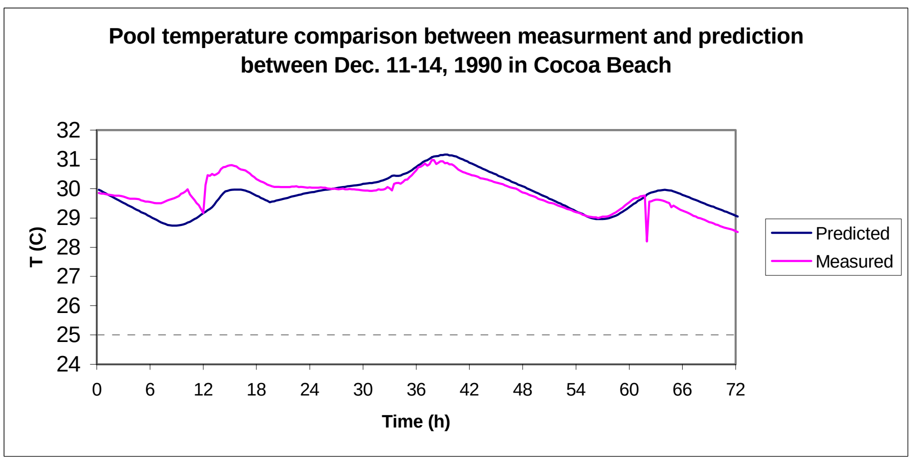

Figure 3-4 Pool temperature comparison between measurement and prediction on Dec. 11-14, 1990 in Cocoa Beach

It should be pointed out that the pool thermal performance does not include tidal or water exchange impacts, which are important for refuge water temperature prediction. Since the tidal loss is well documented, the results in the present study can be used to provide valuable information on how much solar collectors are needed to provide 95% and 99% heating energy.

Task 4 Sensitivity study

The objective of this task was to conduct a sensitivity analysis of refuge heating energy requirements to determine which parameters have the greatest effect on refuge water heating requirements at given the location and environmental conditions at each of the three possible sites.

4.1 A list of parameters

The parameters used in the simulations are annual average ground temperature, multiplier of evaporation rate, refuge depth, and volume change rate per day due to tide. Justification of parameters is as follows:

- Average ground temperature
  Although year-round average ground temperatures are known to be 74°F in Miami and West Palm Beach, and 72°F in Cape Canaveral in a typical year, seasonal and hourly ground temperature data were unavailable. Therefore, to estimate the minimum ground temperature for the coldest year, we assumed an annual average ground temperature 2°F below the typical year, and used a formula to calculate hourly ground temperatures based on that assumption.
- Multiplier of evaporation rate
  The default multiplier is 1.0. We assumed that a refuge cover may be used to reduce evaporation heat loss, as well as convective loss. Multipliers of 0.0 and 0.5 will were used to simulate the effect of different refuge cover configurations. For example, a refuge cover could be used to cover a whole refuge with a small air space between the cover and refuge water surface. This condition was assumed to multiplier at 0.0. For manatee to breath, the cover should be 1m above the surface at high tide. That condition was assumed to be multiplier at 0.5.
- Refuge depth
  We assumed a refuge depth of at least 6 ft deep at low tide. In order to consider possible buffering effects on heat loss due to increased volume, an average depth of at least 9 ft was also examined.
- Tidal impact/water volume turn over rate (TOR)
  As mentioned earlier, two types of tidal impact were considered: constant tidal rate and variable tidal rate based on real tidal conditions. The constant tidal rate was equal to the mass flow rate at each hour based on daily volume change rate. As noted above, it was decided to consider water turn over rates of 0.5 to 5 times per day to prevent water quality problems and account for tidal exchange of water within the refuge. This parameter allows consideration of variable mass flow rates based on changes in tide or other steps to increase water circulation. Tidal heat loss within the refuge occurs only during the incoming tide when cool adjacent water mixes with warm refuge water.

Table 4-1 lists the parameters used in the sensitivity analysis with constant tidal rate:

Table 4-1: Case description with a constant tidal rate

Case	Desc	Description
1	Base	All the multipliers are set to 1.0, with 1 volume change rate per day with 6 ft deep at mean low tide
2	No cond	Assume no thermal conduction losses from refuge walls and ground
3	No solar	Assume no solar radiation absorbed by refuges
4	No sky	Assume no night sky radiation heat transfer
5	No conv	Assume no convective heat transfer between ambient and refuge water surfaces
6	No evap	Assume no evaporation loss from refuge surfaces
7	No turn over rate	Assume tidal impact to be zero
8	No solar, evap, sky, conv	Assume no solar radiation, no evaporation, no sky radiation, and no convective heat transfer (equivalent to adding a refuge cover)
9	No evap, sky, conv	Assume no evaporation, no sky radiation, and no convection (equivalent to adding a transparent refuge cover to make solar radiation pass through)
10	½ daily turn over rate (TOR)	Assume 0.5 water volume changes per day
11	2 daily TOR	Assume 2.0 water volume changes per day
12	5 daily TOR	Assume 5.0 water volume changes per day
13	No evap+1/2 TOR	Assume no evaporation and 0.5 volume change rate per day
14	No solar, evap, sky, conv + ½ TOR	Assume no solar radiation, no evaporation, no sky radiation, no convective heat transfer with 50% tidal heat losses, and 0.5 volume change rate per day
15	½ TOR & evap	Assume no evaporation, and 0.5 volume change rate per day
16	½ TOR + Low ground temperature (LT)	Assume 0.5 volume change rate per day, and ground temperature with 2°C below annual average
17	Base + LT	Assume same conditions as base case (Case 1), except for ground temperature with 2°C below annual average
18	2 TOR + LT	Assume 2 volume change rate per day, and ground temperature with 2°C below annual average
19	No evap + ½ TOR +LT	Assume no evaporation loss, 0.5 volume change rate per day, and ground temperature with 2°C below annual average
20	½ evap & tide + LT	Assume 50% evaporation loss, 1 volume change rate per day, and ground temperature with 2°C below annual average
21	9 ft deep	Same conditions as the base case, except for a refuge with 9 ft deep water
22	Case 8 + 9 ft deep	Same conditions as Case 8, except for a refuge with 9 ft deep water
23	Case 9 + 9 ft deep	Same conditions as Case 9, except for a refuge with 9 ft deep water
24	Opaque cover with 1m high	Assume the opaque cover is 1m high over the refuge surface. The condition is equivalent to no solar, no night sky radiation, ½ convection, and ½ evaporation.
25	Transparent cover with 1m high	Assume the transparent cover is 1m high over the refuge surface. The condition is equivalent to ½ night sky radiation, ½ convection, and ½ evaporation.

The parameters used in the variable tidal rate are the same as those used for the constant tidal rate, except that 5 times turn over rate was not used. The main reason was that the 5 times turn over rate could leave refuge water level too shallow, so that manatees may not survive. The secondary reason was that the high turn over rate could be non realistic. For the cases of the variable tidal rate, the tidal values did not represent volume turn over rate. Instead, values represented multipliers based on tidal height. Therefore, the total case number is 25 with constant tidal rate, while 24 with variable tidal rate.

Although simulation was run for the period between Jan. 1, 1989 and April 30, 1990, simulation results are reported only for the one year from May 1, 1989 to April 30, 1990. For stochastic reason, the initial months of a model run are not useful for prediction purposes.

The simulation procedure involved the following steps:

- Calculating required heating energy to maintain an hourly refuge temperature of 22°C (i.e., ideal heating);
- Calculating heat output from three different types of solar collectors in a unit area;
- Determining refuge energy requirement for Dec. 1989;
- Calculating the heat energy to maintain refuge water temperatures of 22°C at 95% and 99% of the time in Dec. 1989;
- Calculating solar collector size necessary to ensure heat output in Dec. 1989 met the 95% and 99% heating requirement; and
- Based on solar collector sizes for the three different types, recalculating refuge water temperatures assuming temperatures would be maintained at 22°C only for 95% and 99% of the time.

4.2 Heating requirements

We first calculated the heat required to maintain refuge water temperatures at 22°C at all times in a whole year with an ideal heater. The results were then used to calculate how many solar panels would be needed to meet those heat requirement. Appendix C provides the results. It shows the required heating energy for what was considered to be the coldest year, month, peak day, peak hour. The results also provide a basis for determining the importance of different parameters on heat losses for the three locations and two types of refuges, and two volume turn over rate assumptions. The heating energy listed in the peak hour would be used to calculate sizes of gas fired burners as a backup heater. A percentage of heating energy lost or gained relative to the based case (i.e, Case 1 on Table 4-1) was used to evaluate the importance of individual parameters (see Table 4-2) during the period of Dec. 1989. It should be pointed out that each location and type of refuge has its own base case. The absolute values are presented in Appendix C. The fist two columns list the case number and a brief description of the case, respectively. The next six columns provide percent changes in three locations and two types of refuge. A positive sign indicates heating requirements are less than the base case, and a negative sign indicates more heat is required than the base case to maintain a 22°C temperature.

Although the amount of heating energy needed to warm a small refuge is much less than a large refuge in the same location, the proportional difference is very small within one percent. That is, a refuge twice the volume will require almost exactly twice the amount of heat. Therefore, the present results can be used to predict the heating energy needs for any size of refuge.

Conduction loss was found to be very small compared to other losses. It was less than 1% in Cape Canaveral, and less than 2% for small refuges in West Palm Beach and Miami, as shown in Case 2. Therefore, heat loss through the sides and bottom of the refuge are likely negligible.

As shown in Case 3, direct solar radiation contributed 21% of the heating energy required to maintain temperatures of 22ºC under the base case scenario in Cape Canaveral, 55% in West Palm Beach, and 64% in Miami, respectively. Since more heating energy is needed without solar radiation, the signs shown on Table 4-2 are negative for this parameter. In general, the more south a refuge is located, the less heating energy is used. It should be pointed out that although solar radiations in three locations from weather data are very close, the percent contribution of solar radiation in three locations are different. The main reason is that required heating energy of the base case in Miami is lower than Cape Canaveral. That is why the percent changes in Miami are larger than Cape Canaveral.

Heat loss from sky radiation exchange was about 7% in Cape Canaveral, 15% in West Palm Beach, and 18% in Miami, respectively, as shown in Case 4. Although heat loss from sky radiation is larger than conduction loss, it is still small compared to losses from convection, evaporation, and tide.

Heat loss from convective heat transfer to air at the refuge water surface was about 25% in Cape Canaveral, 53% in West Palm Beach, and 61% in Miami, respectively, as shown in Case 5. In general, annual convection heat loss should be less than that estimated on Table 4-1; however, because Dec 1989 was very cold, the amount of convective heat loss was significant.

Heat loss from evaporation was about 29% in Cape Canaveral, 59% in West Palm Beach, and 61% in Miami, respectively, as shown in Case 6. Although Dec. 1989 was cold, heat loss due to evaporation was still larger than convective heat loss and was the second largest contributor to the total heat loss.

Heat loss from tides and water turn over was about 58% in Cape Canaveral, -5% in West Palm Beach, and -28% in Miami, respectively, as shown in Case 7. The highest heat loss in Cape Canaveral is from tidal heat loss, due to the cold inland water temperatures in Dec. 1989. However, the inland coastal water temperatures in West Palm Beach and Miami were warm enough to contribute heat to the refuges under the base case scenario as reflected by the negative numbers for those cases in Table 4-2.

As shown in Case 8, an opaque refuge cover may significantly reduce heat losses from solar radiation, evaporation, sky radiation, and convection. Heat loss reduction was estimated at 41% in Cape Canaveral, 81% in West Palm Beach, and 89% in Miami, respectively using this approach. Although solar heating is still required in West Palm Beach and Miami, the amount of requirement would be much less with a refuge cover. It should be pointed out that the opaque refuge cover is about 1-2 ft above the refuge surface. It may not have enough air space for manatees to breath.

If a transparent cover was available that could allow solar radiation pass through the cover, while eliminating heat loss due to sky radiation, convection and evaporation, heat requirements could be reduced by about 60% in Cape Canaveral, 96% in West Palm Beach, and 100% in Miami, respectively, as shown in Case 9. If so, solar collectors may not be needed at all in West Palm Beach and Miami.

Cases 10, 11, and 12 examine the impact of tide and water turn over rate. When the volume change rate per day is reduced to 0.5 from the based case 1.0 (Case 10 in Table 4-2), energy use in Cape Canaveral is reduced 29%, while energy use is only reduced 1% in West Palm Beach and less than 1% in Miami. However, when the volume change rate per day is double from 1.0 to 2.0 (Case 11), more heating energy is needed: 58% in Cape Canaveral, 11% in West Palm Beach, and 8% in Miami. When the volume turn over rate is increased to 5.0 times per day, the impact on heating energy needs is much larger: 234% in Cape Canaveral, 69% in West Palm Beach, and 55% in Miami. Although 5.0 change rate is unlikely to occur naturally due to tides, artificial means of increasing circulation through the refuge may be needed to address water quality problems.

Cases 13, 14, and 15 repeat Cases 6, 8, and 9, assuming a 0.5 volume change rate per day. Because of the lower turn over rate, a greater reduction in heating requirements is expected in all the three locations.

Cases 16 through 20 assume low ground temperature. Since heat energy loss to the ground is only about 1%, the impact on required heating energy appears to be negligible.

The increased volume of 9 ft deep refuges require more heating energy: 29% in Cape Canaveral, 0.4% in West Palm Beach, and 8% in Miami, respectively, as shown in Case 21. The value of using deep refuge as a buffer against heat loss in cold period appears to unnecessary and costly.

If an opaque refuge cover is used over a deep refuge (Case 22), heat loss is reduced to 11% in Cape Canaveral, 71% in West Palm Beach, and 60% in Miami. If a transparent cover is used (Case 23), heat loss reduction is greater: 31% in Cape Canaveral, 90% in West Palm Beach, and 87% in Miami.

The above cases using refuge covers assumed that the refuge cover is about 1-2 ft above the water surface, it may not have enough air space for manatees to breath. Cases 24 and 25 assumed the refuge cover is 1 meter high over the refuge water surface, so that manatees have enough air space to breath. If an 1m high opaque cover is used (Case 24) by assuming no solar radiation and night sky radiation, 50% reduction of convection and evaporation compared to the base case, heat loss is reduced to 13% in Cape Canaveral, 34% in West Palm Beach, and 24% in Miami. If an 1m high transparent cover is used (Case 25) by assuming night sky radiation, 50% reduction of night sky radiation, convection and evaporation compared to the base case, heat loss reduction is greater: 30% in Cape Canaveral, 61% in West Palm Beach, and 58% in Miami.

From the above analysis, the biggest impact on heating energy use is from tides and water volume turn over rates. Evaporation loss is the second most important source loss, while convective heat loss to air is the third most important. Other sources are comparatively unimportant. Increasing refuge volume using deep refuges requires more heat with little benefit in terms of heat conservation in cold period. Using refuge covers does reduce heat losses.

Table 4-2: Percent change of heating energy use in Dec. 1989 with constant tide

Case	Percent change	Cape Canaveral		West Palm Beach		Miami	
		Small refuge	Large refuge	Small refuge	Large refuge	Small refuge	Large refuge
		Dec (%)	Dec (%)	Dec (%)	Dec (%)	Dec (%)	Dec (%)
2	No cond	0.77	0.50	1.39	0.85	1.71	1.06
3	No solar	-21.53	-21.59	-55.11	-55.36	-64.66	-64.93
4	No sky	7.22	7.24	15.31	15.36	18.12	18.20
5	No conv	25.14	25.21	53.53	53.70	61.12	61.36
6	No evap	28.84	28.91	58.54	58.67	60.87	61.04
7	No TOR	57.62	57.78	-4.96	-4.89	-28.81	-28.52
8	No solar, evap, sky, conv	40.59	40.70	80.45	80.68	88.96	89.26
9	No evap, sky, conv	59.60	59.71	95.97	96.08	100.00	100.00
10	½ TOR	28.93	29.01	1.10	1.16	0.20	0.32
11	2 TOR	-58.03	-58.19	-11.28	-11.44	-7.51	-7.67
12	5 TOR	-233.58	-234.24	-68.92	-69.48	-54.75	-55.33
13	No evap+1/2 TOR	57.49	57.65	70.24	70.47	70.12	70.40
14	No solar, evap, sky, conv + ½ TOR	69.96	70.15	91.27	91.54	98.86	99.12
15	½ TOR & evap	43.39	43.51	41.19	41.39	41.68	41.92
16	½ TOR + LT	28.77	28.87	0.67	0.76	-0.29	-0.13
17	Base + LT	-0.16	-0.15	-0.36	-0.33	-0.37	-0.34
18	2 TOR + LT	-58.19	-58.34	-11.54	-11.67	-7.76	-7.91
19	No evap + ½ TOR +LT	57.35	57.51	70.03	70.27	69.90	70.20
20	½ evap & TOR + LT	43.24	43.37	40.86	41.09	41.34	41.61
21	9 ft Deep	-29.10	-29.04	0.40	0.57	-7.85	-7.79
22	Case 8 + 9ft	11.03	11.19	70.82	71.15	59.95	60.31
23	Case 9 + 9ft	31.58	31.79	90.08	90.35	87.01	87.30
24	Opaque cover with 1m high	13.30	13.34	33.56	33.69	24.09	24.17
25	Trans cover with 1m high	30.60	30.68	61.47	61.62	57.52	57.71

Table 4-3 lists the percentage change in required heating energy in Dec. 1989 compared to the base case in the three locations and two types of refuges with variable tide. As noted above, the effect of tides on heating energy use occurs only between low tide and high tide, when cold water from adjacent water bodies enter the refuge. The percent change trend is very similar to the above cases with a constant tide. The most affected parameter was heat loss due to evaporation, which increased nearly 50% from the constant tide condition.

Table 4-3: Percent change of heating energy use in Dec. 1989 with variable tide

Case	NCDC Real tide (89-90)	Cape Canaveral		West Palm Beach		Miami	
	Percent change	Small refuge	Large refuge	Small refuge	Large refuge	Small refuge	Large refuge
1	Base	Dec (%)	Dec (%)	Dec (%)	Dec (%)	Dec (%)	Dec (%)
2	No cond	1.33	0.80	2.06	1.25	2.57	1.60
3	No solar	-30.23	-30.39	-79.20	-79.83	-115.95	-117.01
4	No sky	10.21	10.27	19.19	19.29	22.55	22.68
5	No conv	35.83	36.02	63.22	63.58	63.52	63.90
6	No evap	40.93	41.14	74.53	74.81	73.43	73.70
7	No TOR	39.42	39.59	-8.86	-8.92	1.22	1.41
8	No solar, evap, sky, conv	58.79	59.10	94.68	95.09	91.86	92.41
9	No evap, sky, conv	81.54	81.81	100.00	100.00	100.00	100.00
10	½ TOR	29.50	29.64	-5.65	-5.68	1.92	2.09
11	2 TOR	-119.74	-120.34	-6.62	-6.87	-33.91	-34.56
12	No evap+1/2 TOR	71.89	72.26	82.60	82.91	88.35	88.89
13	No solar, evap, sky, conv + ½ TOR	88.74	89.20	100.00	100.00	100.00	100.00
14	½ TOR & evap	50.16	50.41	46.88	47.27	56.51	56.99
15	½ TOR + LT	29.27	29.43	-6.26	-6.23	1.04	1.29
16	Base + LT	-0.23	-0.21	-0.53	-0.48	-0.66	-0.59
17	2 TOR + LT	-119.98	-120.56	-6.92	-7.14	-34.24	-34.86
18	No evap + ½ TOR +LT	71.66	72.05	82.40	82.72	88.04	88.62
19	½ evap & TOR + LT	49.93	50.20	46.34	46.78	55.95	56.48
20	9 ft Deep	-0.07	0.13	5.35	5.71	9.25	9.66
21	Case 8 + 9 ft	58.48	58.99	95.68	96.29	93.58	94.41
22	Case 9 + 9 ft	82.06	82.50	100.00	100.00	100.00	100.00
23	Opaque cover with 1m high	19.60	19.71	31.72	31.96	20.55	20.79
24	Trans cover with 1m high	43.45	43.68	76.38	76.69	77.05	77.34

4.3 Solar collector requirements

Based on the results of heating requirements needed to maintain refuges at 22ºC 100% of the time, we calculated size of solar collector array needed to provide those heating requirements 95% and 99% of the time in Dec. 1989. The main reason to select a monthly heat requirement, instead of the peak day, is that the solar collector size will need to be larger when the peak day is cloudy, than when it is clear. Monthly energy needs more closely match average cloud cover conditions. It should be pointed out that, the refuge water temperature may be above 22ºC during day time when the solar system is working, but below 22ºC at night when solar heat is not available. Since manatees can survive at low temperatures in a short period, this constraint appears acceptable.

The solar collector size determination is based on the assumption that the heating energy generated by solar collector in Dec. 1989 must maintain a temperature of 22ºC 95% of time. Appendix D provides solar collector sizes for the three locations, two types of refuges, and two types of water volume change. A dimensionless parameter is used in this section to discuss solar collector requirements. The parameter is defined as a ratio of solar collector size to refuge water surface area, called the solar collector ratio.

Table 4-4 presents the solar collector ratio assuming a constant tide in three locations and two refuges. The first two columns identify case number and a brief scenario description consistent with the previous tables. The third and fourth columns show the solar collector ratios in Cape Canaveral with small and large refuges, respectively. The fifth and sixth columns provide these ratios for West Palm Beach and the last two columns show the ratios for Miami.

Table 4-4: Ratio of required solar collector size to refuge surface area with a constant tide

Case	Desc	Cape Canaveral		West Palm Beach		Miami	
		Small refuge	Large refuge	Small refuge	Large refuge	Small refuge	Large refuge
1	Base	3.99	3.98	0.78	0.78	0.53	0.53
2	No cond	3.96	3.96	0.77	0.77	0.52	0.52
3	No solar	4.83	4.82	1.21	1.21	0.87	0.87
4	No sky	3.71	3.70	0.66	0.66	0.44	0.44
5	No conv	2.99	2.98	0.36	0.36	0.28	0.27
6	No evap	2.85	2.84	0.32	0.32	0.24	0.24
7	No TOR	1.70	1.69	0.82	0.82	0.45	0.44
8	No solar, evap, sky, conv	2.37	2.36	0.15	0.15	0.14	0.14
9	No evap, sky, conv	1.62	1.61	0.03	0.03	0.03	0.02
10	½ TOR	2.84	2.83	0.78	0.77	0.48	0.47
11	2 TOR	6.29	6.28	0.87	0.87	0.66	0.66
12	5 TOR	13.11	13.10	1.32	1.32	1.12	1.12
13	No evap+1/2 TOR	1.70	1.69	0.23	0.23	0.15	0.15
14	No solar, evap, sky, conv + ½ TOR	1.20	1.19	0.07	0.07	0.06	0.06
15	½ TOR & evap	2.27	2.26	0.46	0.46	0.29	0.29
16	½ TOR + LT	2.85	2.84	0.78	0.77	0.48	0.47
17	Base + LT	4.00	3.99	0.79	0.78	0.53	0.53
18	2 TOR + LT	6.29	6.28	0.87	0.87	0.66	0.66
19	No evap + ½ TOR +LT	1.71	1.70	0.24	0.23	0.15	0.15
20	½ evap & TOR + LT	2.27	2.26	0.46	0.46	0.29	0.29
21	9 ft Deep	5.16	5.14	0.78	0.78	0.57	0.57
22	Case 8 + 9ft	3.55	3.54	0.23	0.23	0.21	0.21
23	Case 9 + 9ft	2.74	2.72	0.08	0.08	0.07	0.07
24	Opaque cover with 1m high	3.46	3.44	0.52	0.52	0.40	0.40
25	Trans cover with 1m high	2.78	2.77	0.30	0.30	0.22	0.22

As shown in the first 7 cases on Table 4-2, solar collector ratios for Cape Canaveral are significantly higher than those for West Palm Beach and Miami, and the ratio difference between West Palm Beach and Miami is relatively small. In addition, the ratios between small and large refuges in all the cases are almost identical. That means the solar collector size is proportional to the refuge size. If a different size of refuge will be used, the solar collector size can be easily calculation based on the linear relationship. Under the base case scenario, the ratios of small and large refuges is 4 for Cape Canaveral. 0.78 for West Palm Beach and 0.35 for Miami. When an opaque cover is used for the small refuge (Case 8), the solar collector ratio is reduced by nearly 50% in Cape Canaveral, by 82% in West Palm Beach, and by 90% in Miami. When a transparent cover is used for the small refuge (Case 9), the solar collector ratio is reduced by 60% in Cape Canaveral, and almost equal to 0 in both West Palm Beach and Miami, meaning little or no solar collectors may be needed at those two sites. In general, this reflects the warmer weather and inland coastal water temperature at the two southern sites. When a small refuge is 9 ft deep in Case 21, the solar collector ratio increases to 5.2 from 4 in Cape Canaveral, to 0.6 from 0.35 in Miami, and remains the same in West Palm Beach. Therefore, there is no benefit to increase refuge depth with constant tide. The highest demand of solar collector occurs in 5 volume change rate per day in Case 12. The solar collector ratio for the small refuge is 13 in Cape Canaveral, 1.3 in West Palm Beach and 0.5 in Miami. When a refuge cover is 1m high above the refuge water surface, the required ratio for Cape Canaveral is 84% with an opaque cover and 70% with a transparent cover, compared to the base case. Although the 1m high cover can reduce collector size, it may not be as effective as Cases 8 and 9. The refuges at Cape Canaveral would require the largest solar panel array of any site considered in this study. Assuming the required area of an individual solar panel is 4' x 15', the amount of land required for the solar collecting array would be about 0.3 ac for a small refuge and 1.5 ac for a large refuge.

It should be pointed out that the solar collector ratios are almost the same for both small and large refuges in West Palm Beach and Miami.

Table 4-5: Ratio of required solar collector size to refuge surface area with a variable tide

		Cape Canaveral		West Palm Beach		Miami	
Case	Desc	Small refuge	Large refuge	Small refuge	Large refuge	Small refuge	Large refuge
1	Base	2.80	2.79	0.74	0.74	0.43	0.42
2	No cond	2.76	2.76	0.73	0.73	0.42	0.42
3	No solar	3.64	3.62	1.33	1.32	0.92	0.92
4	No sky	2.51	2.50	0.60	0.59	0.33	0.33
5	No conv	1.80	1.78	0.27	0.27	0.16	0.15
6	No evap	1.65	1.64	0.19	0.19	0.11	0.11
7	No TOR	1.70	1.68	0.81	0.80	0.42	0.42
8	No solar, evap, sky, conv	1.15	1.14	0.04	0.04	0.03	0.03
9	No evap, sky, conv	0.52	0.51	0.00	0.00	0.00	0.00
10	½ TOR	1.98	1.96	0.78	0.78	0.42	0.41
11	2 TOR	6.12	6.11	0.79	0.79	0.57	0.57
12	No evap+1/2 TOR	0.79	0.77	0.13	0.13	0.05	0.05
13	No solar, evap, sky, conv + ½ TOR	0.32	0.30	0.00	0.00	0.00	0.00
14	½ TOR & evap	1.40	1.38	0.39	0.39	0.19	0.18
15	½ TOR + LT	1.98	1.97	0.79	0.78	0.42	0.42
16	Base + LT	2.81	2.79	0.75	0.74	0.43	0.43
17	2 TOR + LT	6.13	6.11	0.79	0.79	0.57	0.57
18	No evap + ½ TOR +LT	0.79	0.78	0.13	0.13	0.05	0.05
19	½ evap & TOR + LT	1.40	1.39	0.40	0.39	0.19	0.18
20	9 ft Deep	2.80	2.78	0.70	0.69	0.39	0.38
21	Case 8 + 9 ft	1.16	1.14	0.03	0.03	0.03	0.02
22	Case 9 + 9 ft	0.50	0.49	0.00	0.00	0.00	0.00
23	Opaque cover with 1m high	2.25	2.23	0.51	0.50	0.34	0.34
24	Trans cover with 1m high	1.58	1.57	0.18	0.17	0.10	0.10

Table 4-5 provides the solar collector ratio with a variable tide in three locations and two refuges in the same format as Table 4-4. Compared to the constant tide scenarios, the base case with a variable tide requires in Cape Canaveral reduces solar collector ratio from 4 to 2.8 for the both small and large refuges, while reductions were from 0.8 to 0.7 in West Palm Beach, and from 0.5 to 0.4 in Miami, due to warmer water in southern Florida. When an opaque cover is used (Case 8), reductions of the solar collector ratio were from 2.4 to 1.2 in Cape Canaveral, from 0.15 to 0.04 in West Palm Beach, from 0.14 to 0.03 in Miami. When transparent covers are used, the reduction is from 1.6 to 0.5 in Cape Canaveral, and there is almost no need of solar collector in West Palm Beach and Miami. If an opaque cover is 1m high over the water surface (Case 23), the ratio is 2.3 for Cape Canaveral, 0.5 for West Palm Beach, and 0.3 for Miami. If a transparent cover is used (Case 24), the reductions are much higher than the case (23) with an opaque cover.

As noted above measured temperature data uncovered as the report was being finalized showed that ambient river water temperatures in Cape Canaveral could be up to 8ºC cooler than those used in this study to predict heating requirements. Based on a preliminary assessment of this new data, it appeared that the added heating requirements for refuges at Cape Canaveral could be met by increasing the capacity of the backup water heating system by 60%. If a solar heated refuge was to be tested or built in the Cape Canaveral area, the heating requirements will need to be reexamined.

Task 5 Economic analysis of solar water heating systems

The objective of this task was to review available solar collector technology to identify and estimate the cost and life span of an effective, reliable solar water heating system capable of providing 95-99 % of the heat required to maintain the refuge embayments at 22 °C during the coldest winter periods. It also sought to identify and estimate the cost and life span of a cost-effective back up oil or gas burner system to provide such additional heat as may be needed during atypically cold or cloudy winter periods.

There are two options to heat refuges using solar water heating systems. The first option is to pump refuge water through the solar water heating system, and then release it back to the refuge. The advantage is that there is no need for a heat exchanger. The disadvantages are 1) the need for filters to block any dirt and debris; 2) the corrosion effect of salt water on the pipes and solar panel conduits, so that cost is expected to increase; and 3) life span of the solar system will be reduced compared to fresh water solar systems.

The second option is to use a close water circulation system with a heat exchanger, placed inside the refuge. The heat exchanger would need an efficiency of about 90-95%. The advantage is that fresh water could be used to carry heat inside the solar water heating system reducing the need for special anti-corrosion materials. The disadvantage is the heat exchanger reduces the heating efficiency. However, the efficiency reduction could be compensated for by increasing the flow rates through a solar system. We recommend this option. The following economic analysis is based on this option.

5.1 Solar collector types and cost

There are five types of solar collectors available in the market (Table 5-1 from Goswami et al[8]).

Table 5-1: Solar collector types and associated installed costs

Collector type	Potential outlet temperature		Approximated cost of solar panel ($\$/ft^2$)
	(°C)	(°F)	
Unglazed plastic	27-32	80-90	≤12
Glazing flat plate	49-60	120-140	25
Evacuated tube	93-121	200-250	35
Evacuated CPC	121-177	250-350	35
Parabolic trough	232-371	450-700	25-30

A brief description for each collector type is presented below (available from the DOE web site)[10]:

Unglazed collectors
Unglazed solar collectors are generally used in swimming pool heating systems, and rely on a liquid flat-plate collector technology. They pump water through pool's existing filtration system to the solar collectors, where it is heated and then transferred back into the pool. Because solar pool collectors operate just slightly warmer than the surrounding air temperature, these systems typically use inexpensive, unglazed low-temperature collectors made from specially formulated plastic materials. Glazed (glass-covered) solar collectors usually are not used in pool-heating applications, except for indoor pools, hot tubs, or spas in colder climates. In some cases, unglazed copper or copper-aluminum solar collectors are used.

Glazed flat panel collectors
Flat-plate collectors are the most common solar collectors used for residential water-heating and space-heating installations. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-colored absorber plate. These collectors heat either liquid or air to temperatures less than 180°F.

Evacuated tube collectors
Evacuated-tube collectors are typically more efficient at higher temperatures than flat-plate collectors. In an evacuated-tube collector, sunlight enters through the outer glass tube and strikes the absorber, where the energy is converted to heat. The heat is transferred to the liquid flowing through the absorber. The collector consists of rows of parallel transparent glass tubes, each of which contains an absorber covered with a selective coating. The absorber typically has a fin-tube design (the fins increase the absorber surface and the heat-transfer rate), although cylindrical absorbers also are used.

Evacuated CPC collectors
Compound parabolic concentrating collectors (CPCCs) use mirrored surfaces to concentrate the sun's energy on a receiver, similar to parabolic-trough collectors. CPCCs achieve moderate concentration and moderately high temperatures, but unlike parabolic-trough collectors, they can collect both direct and diffuse sunlight and do not require an automated sun-tracking system. CPCCs are being investigated for use in commercial applications requiring higher temperatures.

Parabolic-trough collectors
Parabolic-trough collectors use trough-shaped reflectors that concentrate sunlight on a tube running along the reflector's focal line, achieving much higher temperatures than flat-plate or evacuated-tube collectors. They usually include a mechanical control system, called a tracker, that keeps the trough reflector pointed at the sun throughout the day. Parabolic-trough collectors can provide hot water and steam, and are generally used for commercial and industrial purposes.

10 http://www..eere.energy.gov/solar/sh_basics.html

Although there are other types of solar collectors, the most possible candidates for the present project are unglazed swimming pool collector, glazed flat panel collector, and evacuated solar collectors. Based on information from manufacturers, the estimated panel costs for these three types of collectors are provided below. The cost of 4'x10' Unglazed swimming pool collectors are $130/panel in small quantities and 10% less ($117/panel) in large quantities. The cost for 4'x10' glazing flat panels is $474/panel in large quantifies. The cost for 4.65'x6.63' evacuated panels is $2,184.

Based on these estimated costs, the cost can be normalized by a unit area. Using installed costs provided by Goswami et. al.[9], the total costs based on types of solar collectors are listed in Table 5-2:

Table 5-2: Estimated normalized cost of solar collectors

Type	Panel ($/ft^2)	Installed ($/ft^2)	Total ($/ft^2)
Unglazed collector	2.925	12.0	14.93
Glazed flat panel	11.85	25.0	36.85
Evacuated panel	70.85	35.0	105.85

5.2 Water pump requirement

The heat transfer from solar collectors to refuges is achieved by flowing water, driven by water pumps. Therefore, the cost of the water pump and electricity to run it should be included in economic analysis. Since each solar collector has its own recommended water flow rate, water pump requirements are based on the number of solar collector panels and collector types. The following table lists recommended flow rates based for the different collector types.

Table 5-3: Recommended flow rate

Collector type	Size	Recommended flow rate
Unglazed pool panel	4.44 m^2 (3.653m x 1.216 m)	0.252 l/s (4.0 gpm)
Glazed flat panel	4.44 m^2 (3.653m x 1.216 m)	0.0757 l/s (1.2 gpm)
Evacuated panel	2.85 m^2 (2.020m x 1.417m)	0.05 l/s (0.8 gpm)

Although a large flow rate is required for a large scale solar water heating system as would be needed for both small and large refuges, it may not need a single large water pump. Instead, a commonly used centrifugal water pump is recommended for two main reasons. First, solar collectors perform most efficiently in series of 3 - 4 panels each. For larger series, the inlet temperature at the last collector may be too high with low efficiency. Therefore, a series of small pumps for each series of linked collectors is preferable. Second, when a single large pump is used, it is hard to maintain the proper pressure across multiple parallel connections. Thus, a series of medium range water pumps from 1 hp to 5 hp is recommended for the present project.

The connection of water pumps should be serial and parallel combination as shown in Figure 5-3.

Figure 5-1 plots the costs of water pumps of different sizes, based on power consumption under standard test conditions. The real power consumption varies with pressure head loss and flow rate. The costs are from two pump manufacturers: Price and Myers. The cost of pumps is proportional to the pump power.

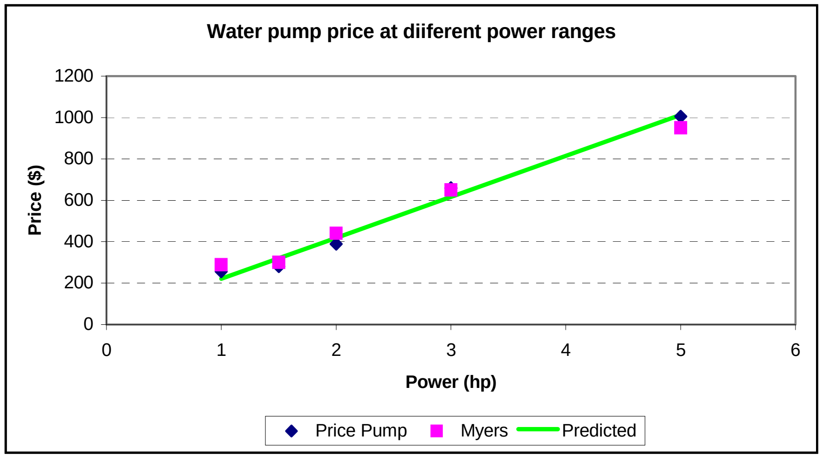

Figure 5-1 water pump costs vs. water pump power

Figure 5-2 shows pump flow rates at different power consumption. In general, the flow rate is dependent on pressure head loss and discharge pressure. The head loss and discharge pressure needed for the present project are conservatively estimated to be 10ft and 30 psi respectively.

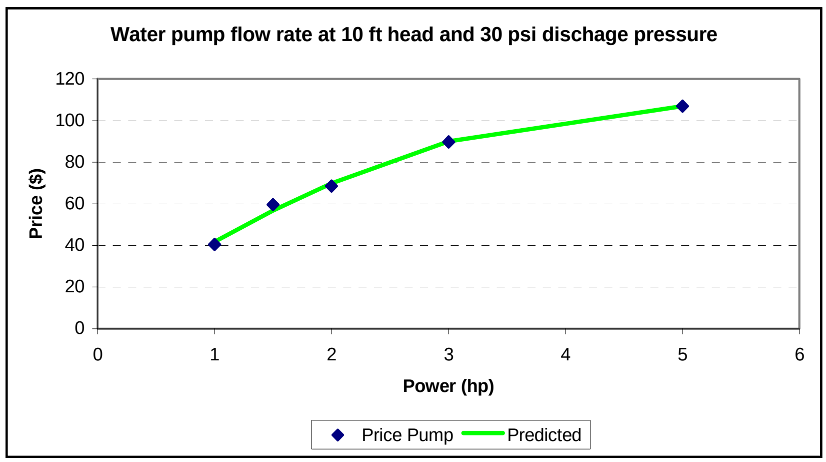

Figure 5-2 Water pump flow rates vs. water pump power

A heat exchanger is also required to deliver heat to the refuges from the solar water heating system. Since manufacturer's data on these performance and cost were not available, we assumed efficiency of 0.9 and did not attempt to estimate their cost. In general, water-to-water heat exchangers are built to customer's needs. It is unlikely that costs from manufacturers can be estimated without providing detailed requirements, such as flow rate, pressure drop, and surface area, which are beyond the scope of this study.

5.3 Gas fired boiler requirements

The proposed solar systems maintain refuge water temperature of 22°C 95-99% of the time without hot water storage systems. Too may cloudy days in cold winter may cause the refuge temperature to be below 22°C a long time, especially for the Cape Canaveral site. It is essential to provide additional heating with a backup gas fired boiler.

The costs of boiler and installation may be obtained from RS Means[11]. Figure 5-3 plots the equipment, installation and total costs for boilers in different capacities, which are selected in the range for the proposed backup systems. A predicted cost is also plotted in the same figure. The predicted formula using the least square approach may be written as:

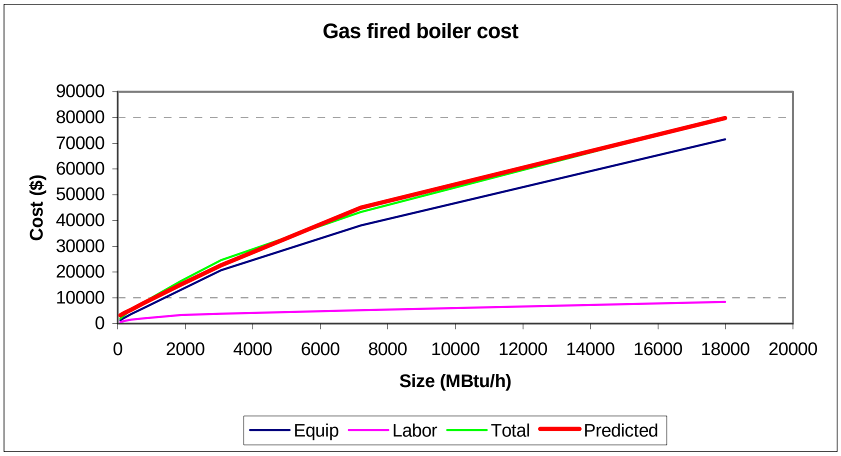

Figure 5-3 Estimated and predicted costs for gas fired boilers.

$$TotalCost = 2722.672 + 6.944638 * Cap - 0.0001481 * Cap^2 \quad \textbf{(20)}$$

where

TotalCost = Total boiler cost, including equipment and installation [$]
Cap = Boiler capacity [MBtu/h]

The value of r^2 (coefficient of determination) for Eq. (20) is 0.9978. The boiler total cost is used as a part of initial investment for the proposed solar system.

The boiler efficiency is assumed to be 80%, which is the required minimum efficiency for large boilers[12]. The current natural gas price is $1.10 per MMBtu[13]. The boiler efficiency is used to calculate how much natural gas is needed, and the gas price is used as a part of annual cost (O&M) for the proposed solar system.

The energy use in the coldest hour listed in the last column in Tables C-1 through C-12 would be used to calculate capacities of backup gas fired boilers. The initial cost of gas boilers can be predicted using Eq. (20). The energy use in the coldest month in the fourth column in the same tables would be used to calculate how much gas is needed to provide additional heat to the refuges.

It should be pointed out that the backup gas heating system is required in Cape Canaveral, and is unnecessary in West Palm Beach and Miami. The detailed discussion is provided in Section 5.6.4.

11 RS Means, 1997, "Building Construction Cost Data," 55th Annual Edition, Kingston, MA

12 New Building Institute, "Gas Boilers Guideline," Nov. 1998, Fair Oaks, CA

13 http://tonto.eia.doe.gov/oog/info/ngw/ngupdate.asp

As noted above, as this report was being finalized, measured water temperature data was found indicating water temperatures during the winter of 1989-90 were colder than predicted. If water temperatures also were colder than predicted for West Palm Beach, a backup water heating system also may be prudent for this area as well. Further efforts to find water temperature data for the winter of 1989-90 should be undertaken for West Palm Beach to help determine the accuracy of predicted water temperatures for this area.

5.4 Life cycle cost analysis for refuge solar systems

After estimating initial cost of solar water heating system components and annual cost as operation and maintenance (O&M) cost, such as power consumption and annual operation and maintenance cost, it is possible to estimate solar heating system costs over the expected life-span of the systems based in 2004 dollars. The present values using the life cycle cost method are used to compare which system is the most economic system. It should be noted that these estimates do not include costs for land, a heat exchanger, environmental assessments, etc.

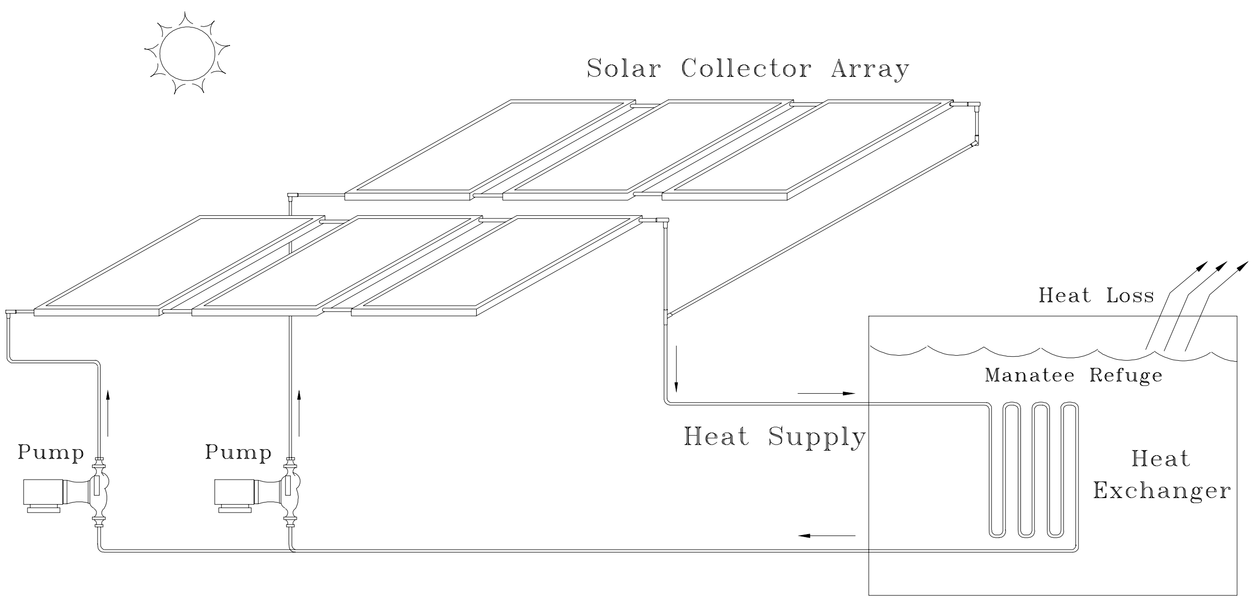

Figure 5-4 Schematic of solar collector system

A Schematic solar collector system for a manatee refuge is shown in Figure 5-4. Each water pump pumps water through a separate series of linked solar panels. Each pump has an outlet to be connected by a manifold to deliver hot water to a heat exchanger to provide heat for the refuges. A partial estimation of costs for such a system is provided below. Costs in this analysis do not include land, heat exchangers, and construction of the refuge embayment.

5.4.1 Initial cost

The following assumptions are used to calculate the initial costs for solar collectors and water pumps:

Solar collector
Based on required solar panel areas and total cost of each solar panel (labor+material) listed in Table 5-2, the initial investment for solar panels can be calculated for the three solar collector types, three locations, two types of refuges, and two types of water change rate impact (constant and variable turn over rate).

Water pump
The installation cost of water pump and pipes are assumed to be 20% of the water pump cost. A 5 hp water pump was used for water pump cost calculation. The number of 5 hp water pumps is dependent on the total water flow rate at each scenario.

The initial cost consists mainly of solar collectors, water pumps and backup gas boilers. Unglazed solar collectors are the least expensive, but require the higher water flow rate. The cost of pumps, however, is low relatively to solar collectors. For the base case, the initial cost of solar collectors for a small refuge in Cape Canaveral is $149,091 for unglazed, $402,016 for glazed, and $1,309,454 for evacuated, respectively. The initial cost for water pumps is $9,360 for unglazed, $3,072 for glazed, and $3,584 for evacuated, respectively. The initial cost for backup gas boilers is $10,456, and is independent of solar collector types . The total initial cost with solar collectors, water pumps and gas boilers is $168,907 for unglazed, $415,544 for glazed, and $1,323,495 for evacuated, respectively.

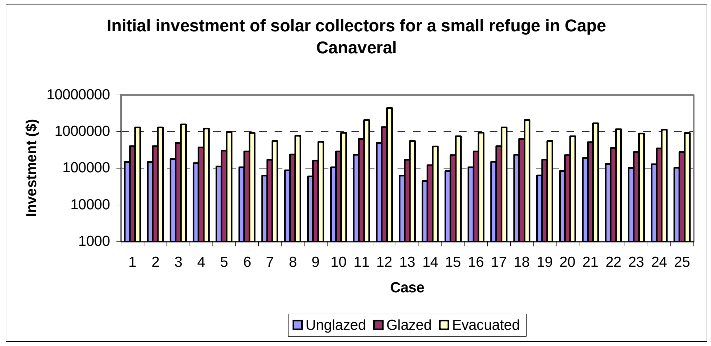

Figure 5-5 Initial cost of solar collectors for a small refuge in Cape Canaveral with constant tide

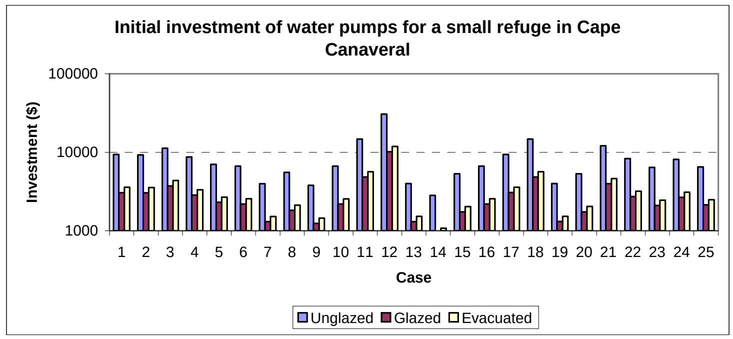

Figure 5-6 Initial cost of water pumps for a small refuge in Cape Canaveral with constant tide

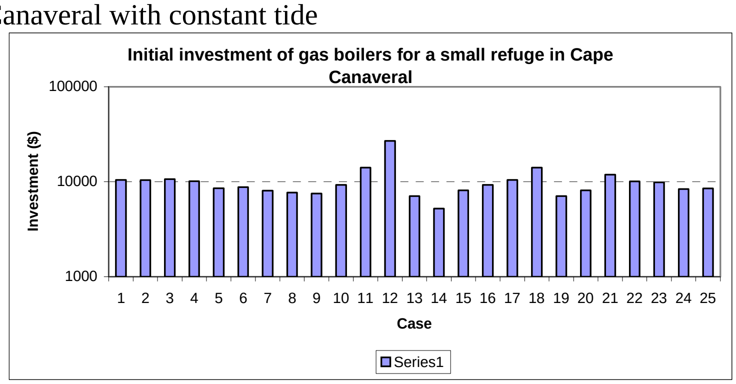

Figure 5-7 Initial cost of gas boilers for a small refuge in Cape Canaveral with constant tide

Figures 5-4 through 5-7 estimate initial costs of solar collectors, water pumps, backup gas boilers, and the total initial costs at different scenarios considered in Task 4 for a small refuge at Cape Canaveral.

For comparison, it should be noted that Goswami et. al.[8] estimated the cost at about $130,000 for a large refuge in West Palm Beach based on a target water temperature of 20°C. The present study estimated the initial cost at about $207,119 for the base case to maintain the refuge water temperature at 22°C with additional costs of water pumps and backup gas boilers.

All initial investment estimates for the different scenarios and locations are provided in detail in Appendix F.

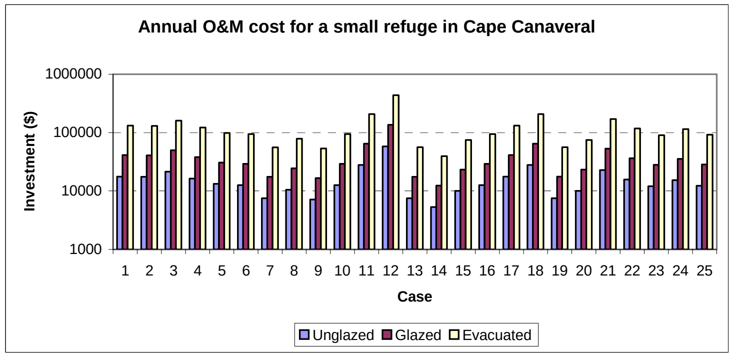

Figure 5-9 Annual O&M cost for a small refuge in Cape Canaveral with a constant tide.

5.4.2 Annual operating and maintenance cost

The assumptions used to estimate annual operating and maintenance (O&M) costs for the collector systems were:

- Electricity: $0.08/kWh
- Pump efficiency: 0.9
- Collector operation and maintenance costs: 10% of the collector initial cost
- Natural gas: $1.1/MMBtu
- Gas boiler efficiency: 80%

Based on these assumptions, annual operating and maintenance costs were calculated and are also provided in detail in Appendix G.

The annual O&M costs depend mainly on required water pump power consumption, which in turn is dependent on the required flow rates in each case, location, solar collector type and daily water volume change rate type. The O&M cost from backup gas boiler is natural gas cost, a small portion of the total O&M cost.
In the base case for a small refuge in Cape Canaveral, the annual cost is $18,019 for unglazed, $41,465 for glazed, and $132,357 for evacuated, respectively.

The O&M costs of backup gas systems assumed to be zero in West Palm Beach and Miami, because there is no need to use the additional heating systems..

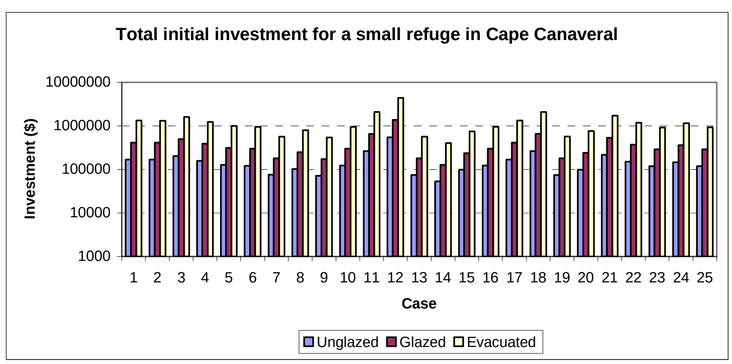

Figure 5-8 Total initial cost for a small refuge in Cape Canaveral with a constant tide

5.4.3 Lifetime project cost

The lifetime cost is presented as present value (PV) using life cycle cost analysis. The present value is defined as the time-equivalent value of past, present or future cash flows as of the beginning of the base year[14]. In order to calculate present values, product life span and discount rate were used. It is assumed that the life of the solar collectors and water pumps is 20 years, and discount rate is 6%. Although backup gas boilers would be used a few weeks in a year, the lifetime was also assumed to be 20 year conservatively.

In addition, refuge cover cost was provided by a manufacturer at $2,000 for a manual cover and $6,000 for an automatic cover for a small refuge (50'x50') . The cost of a transparent cover is assumed to be 50% more. For a manual transparent cover the cost was estimated at $3,000, and for an automatic transparent cover, it was estimated at $7,000. Since there is no cost estimate to cover a large refuge, we assumed a linear relationship. Thus, the cost of a cover for a large refuge is estimated to be 6 times higher than a small refuge cover, or $12,000 for an opaque manual cover and $36,000 for an opaque automatic cover. The estimated cost for a transparent manual and automatic covers over a large refuge area is $18,000 and $42,000, respectively.

We included the cost for an opaque manual cover in estimates for Cases 8, 13, 14, 19, 22, and 24 with a constant tide, and 8, 12, 13, 18, 21, 22, and 23 with a variable tide. The cost of a transparent cover was included in Cases 9, 23, and 25 with a constant tide, and Cases 9, 22, and 24 with a variable tide.

The formula used to calculate present values as a lifetime cost estimate indicator is:

$$PV = I + M\,\frac{(1+i)^n - 1}{i(1+i)^n} \qquad \textbf{(21)}$$

where

PV	= Present value as lifetime cost [$]
I	= Initial cost [$]
M	= O&M annual cost [$]
n	= life span [20 years]
I	= Discount rate [0=1]

Figures 5-10 though 5-15 plot the present values for the 25 cases with a constant tide. The first case is the base case. Each of six figures presents one location and one type of refuge. Figures 5-16 through 5-21 show present values with 23 cases with variable tide. In the same manner, the first case is also the base case. Each plot presents the lifetime costs for one location and one refuge size.

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14 NIST, 1995, NIST Handbook 135

The lifetime costs in different scenarios are provided in detail in Appendix G.

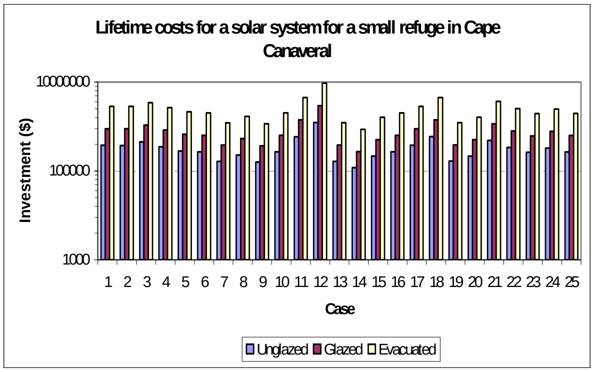


Figure 5-10 Estimated lifetime costs for a solar heating system for a small refuge in Cape Canaveral with a constant tide

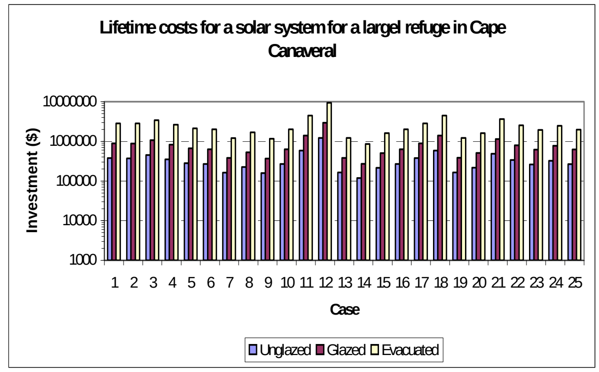


Figure 5-11 Estimated lifetime costs for a solar heating system for a large refuge in Cape Canaveral with a constant tide

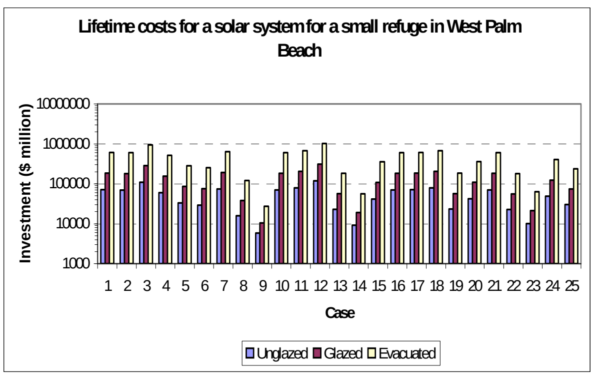


Figure 5-12 Estimated lifetime costs for a solar heating system for a small refuge in West Palm Beach with a constant tide

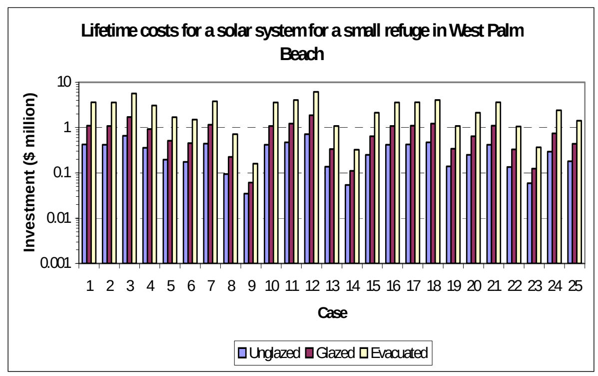


Figure 5-13 Estimated lifetime costs for a solar heating system for a large refuge in West Palm Beach with a constant tide

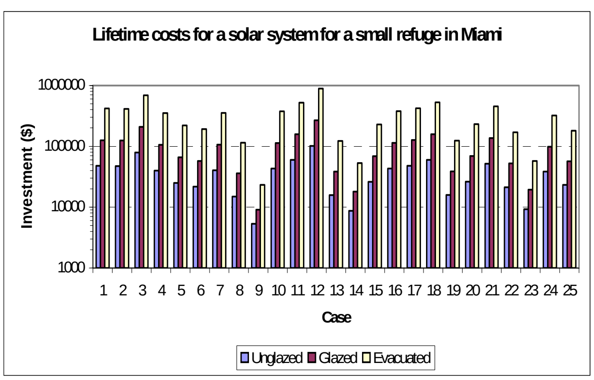


Figure 5-14 Estimated lifetime costs for a solar heating system for a small refuge in Miami with a constant tide

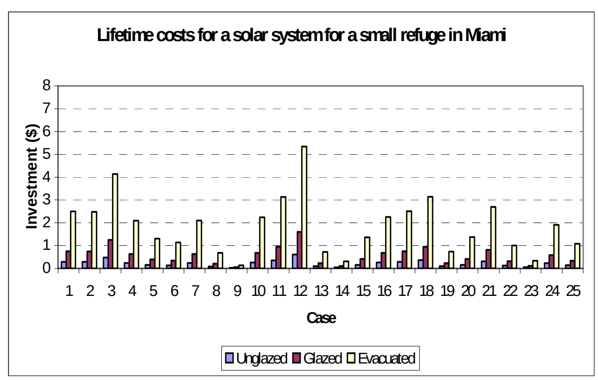


Figure 5-15 Estimated lifetime costs for a solar heating system for a large refuge in Miami with a constant tide

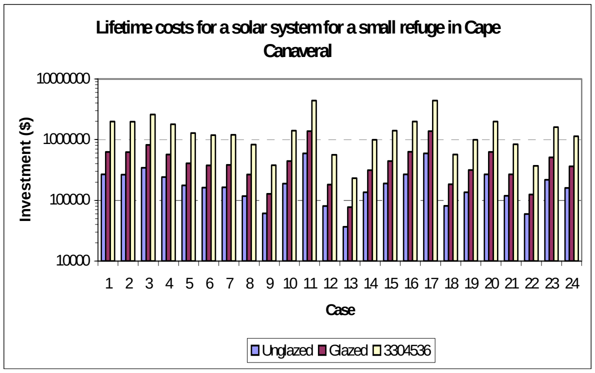


Figure 5-16 Estimated lifetime costs for a solar heating system for a small refuge in Cape Canaveral with a variable tide

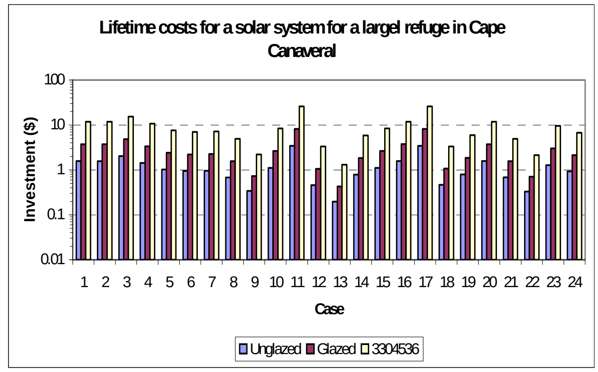


Figure 5-17 Estimated lifetime costs for a solar heating system for a large refuge in Cape Canaveral with a variable tide

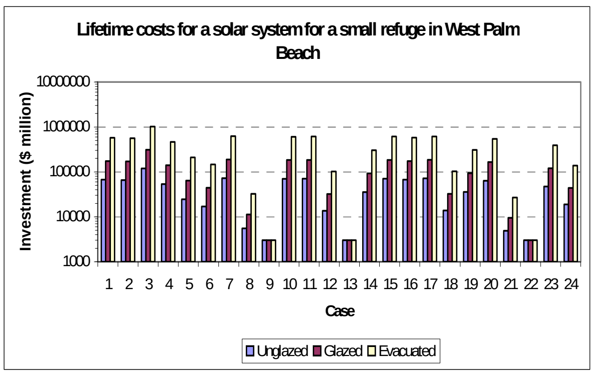


Figure 5-18 Estimated lifetime costs for a solar heating system for a small refuge in West Palm Beach with a variable tide

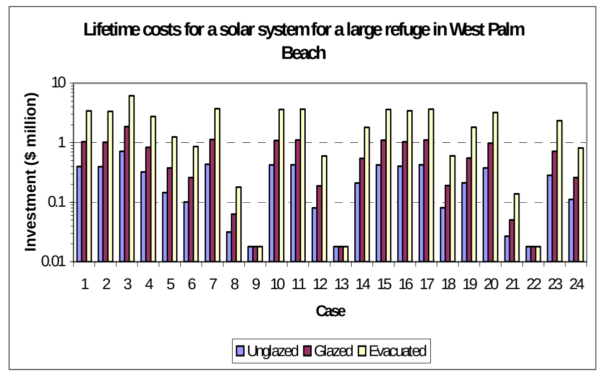


Figure 5-19 Estimated lifetime costs for a solar heating system for a large refuge in West Palm Beach with a variable tide

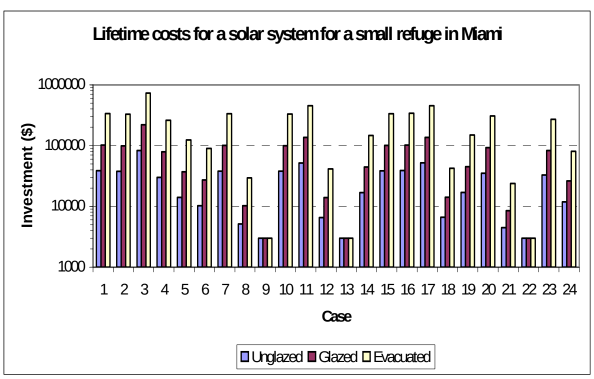


Figure 5-20 Estimated lifetime costs for a solar heating system for a small refuge in Miami with a variable tide

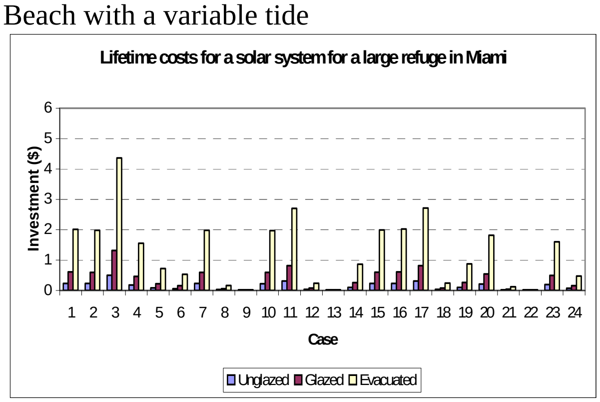


Figure 5-21 Estimated lifetime costs for a solar heating system for a large refuge in Miami with a variable tide

5.5 Results analysis

The previous section presents the lifetime cost estimates for solar system powered manatee refuges under different scenarios at three locations, two sizes of refuges, two types of tidal impact, and three types of solar collectors. Based on this information, we assessed which case appeared most economical for both small and large refuges in three locations.

Because unglazed solar collectors are the least expensive among three types of collectors and will provide a sufficient heat source, they recommended for use in heating refuges in all three locations.

Because several simulations were used mainly for analyzing sensitivity of potential heat loss sources (e.g., no solar radiation and no conduction) and other cases seem unlikely aor unnecessary (e.g., 0.5 and 5 volume change rate per day), we concentrated on Cases 1 (the base case), Case 8 (an opaque refuge cover), Case 9 (a transparent refuge cover), Case 24 (an opaque cover with 1 m high), and Case 25 (a transparent cover with 1 m high) to determine the most feasible and economical solar water heating system. Although it seems unlikely the entire area of a large refuge could be covered, we still considered this possibility for comparison purposes.

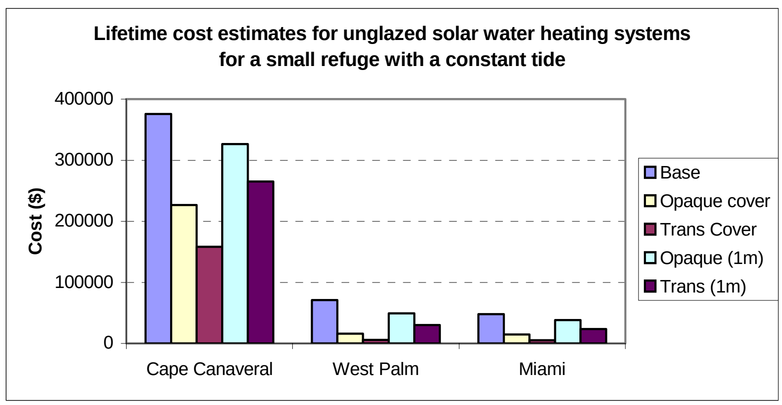


Figure 5-22 20-year cost estimates for unglazed solar water heating systems for a small refuge with a constant tide in three locations

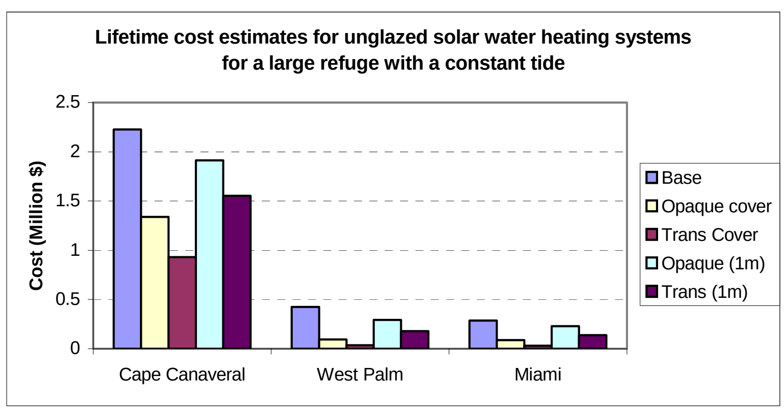


Figure 5-23 20-year cost estimates for unglazed solar water heating systems for a large refuge with a constant tide in three locations

Figure 5-22 shows the estimated lifetime costs for these five cases in the three locations for a small refuge with a constant tide and volume change rate per day. The base case selected here is mainly used for comparison. However, it does provide information on the costs if a recommended cover is not used. Compared to the based case, use of an opaque refuge cover could reduce refuge system costs 40% in Cape Canaveral, 78% in West Palm Beach, and 69% in Miami, respectively. By using a transparent refuge cover, the costs could be reduced 58% in Cape Canaveral, 92% in West Palm Beach, and 89% in Miami, respectively. When an opaque refuge cover is 1m high over the refuge surface, reductions of lifetime costs are 13% in Cape Canaveral, 30% in West Palm Beach, and 20% in Miami, respectively. If a transparent cover with 1m high is used, the costs could be reduced to 29% in Cape Canaveral, 57% in West Palm Beach, and 51% in Miami, respectively.

Figure 5-23 provides estimates of lifetime costs at the three locations for a large refuge with a constant tide. Proportionally, cost savings for using an opaque or transparent covers are almost identical to the estimated savings for a small refuge.

Figure 5-24 provides the same analysis for small refuges with a variable tide, rather than a constant tide, because from a point of view in solar panels needed with a variable tide, costs are significantly lower and proportional savings using covers are greater. Compared to the base case, cost savings for a small refuge with an opaque cover are 56% in Cape Canaveral, 92% in West Palm Beach, and 87% in Miami, respectively. The savings using a transparent refuge cover are 77%in Cape Canaveral, 96% in West Palm Beach, and 92% in Miami, respectively. When an opaque refuge cover is 1m high over the refuge surface, reductions of lifetime costs are 18% in Cape Canaveral, 29% in West Palm Beach, and 15% in Miami, respectively. If a transparent cover with 1m high is used, the costs could be reduced to 41% in Cape Canaveral, 72% in West Palm Beach, and 69% in Miami, respectively. As above, cost savings with covers are similar for large refuges (Figure 5-25)

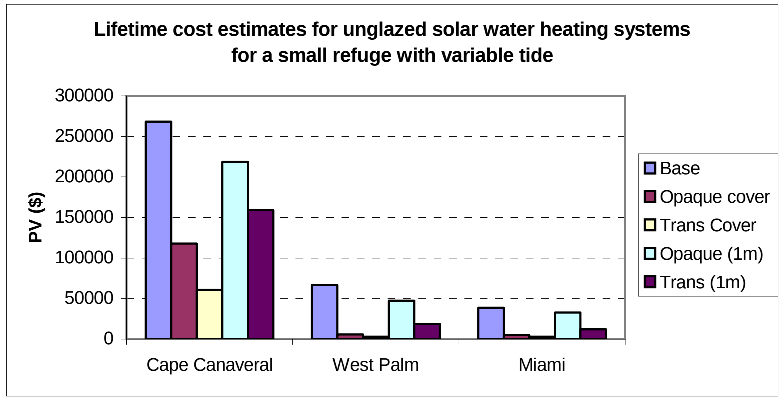


Figure 5-24 20-year cost estimates for unglazed solar water heating systems for a small refuge with a variable tide in three locations

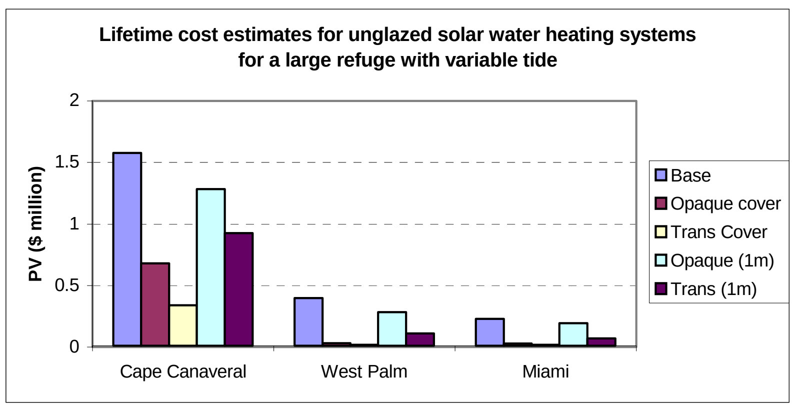


Figure 5-25 20-year cost estimates for unglazed solar water heating systems for a large refuge with a variable tide in three locations

5.6 Discussion

This section discuss issues related to tidal impact, photovoltaic system, backup gas heating system, solar collector type, which are not covered in the previous sections.

5.6.1 Tidal selection

This sensitivity analysis calculates heat loss calculation due to tides and water turn over rates assuming they are either constant or variable. The purpose using a constant tide (i.e., volume exchange rates) is to facilitate hourly heating loss calculations with equally hourly volume change rates. Although this does not account for natural flow rate changes due to tides, a constant flow may be required artificially to meet water quality standards if tidal exchange volumes are not sufficient to do so. For this analysis, we assume natural tides with supplemental pumping sufficient to allow and complete change in water volume per day will achieve necessary water quality levels. On the other hand, natural water volume change rates defined as a variable tide in the present study do reflect reality. Therefore, variable tide calculation is used to finalize solar water heating system selection, while constant tide calculation is used for supplemental information.

5.6.2 Photovoltaic system

Although a photovoltaic system could be used to provide electricity to drive water pumps, it is not economical and not recommended for several reasons:

- The estimated cost of a photovoltaic system for a small refuge in Cape Canaveral is $80,000.
- Estimated electricity costs using photovoltaic systems are currently about $0.3-0.4/kWh in Florida, compared to $0.08/kWh for electricity provided by local utility companies.
- The selected refuge locations are located in areas easily connected to the utility grid.
- Photovoltaic systems generate DC electricity, while water pumps need AC electricity. The cost of equipment to convert DC to AC currently would add yo the total cost.

5.6.3 Backup gas heating system

We also considered whether a backup gas heating system would be required and its possible cost. To assess this need, we examined the predicted refuge water temperature for the period of two winter months in the three locations assuming a constant tide.

Figures 5-27 and 5-28 show hourly predicted water temperature using three different solar systems for a small refuge in Cape Canaveral in Dec. 1989 and Jan. 1990, respectively. When a solar water heating system was used to heat a small refuge in Cape Canaveral, there are about 8 days in Dec. 1989, when the refuge water temperature is below 22^{o}C. The minimum water temperature during the period is 14^{o}C. Although manatees may survive in a short period at temperature of 17^{o}C, but decline to 14^{o}C could cause cold stress-related death during a cold winter. Therefore, a backup gas heating appears desirable and necessary in Cape Canaveral.

Figures 5-29 to 5-32 show hourly predicted water temperature using three different solar systems for small refuges in West Palm Beach in Dec. 1989 and Jan. 1990, respectively. There are about 6 days in Dec. 1989, when the refuge water temperatures are below 22^{o}C. The minimum water temperatures during the period is 17^{o}C, reached for less tan two days at these sites. It suggests that a backup system at both sites may be unnecessary.

backup gas heating system.

Figures 5-28 and 5-29 show hourly predicted water temperature using three different solar systems and one ideal heating system for a small refuge in Miami in Dec. 1989 and Jan. 1990, respectively. There are about 5 days in Dec. 1989, when the refuge water temperature is below 22^{o}C. The minimum water temperature during the period is 17^{o}C. It also should have no problems for manatees to survive without a backup gas heating system.

Based on simulation results, a backup gas heating system is recommended for Cape Canaveral, but not for sites in West Palm Beach and Miami. It should be noted that if a cover is used in the refuges, the need for a gas heating system would be even less.

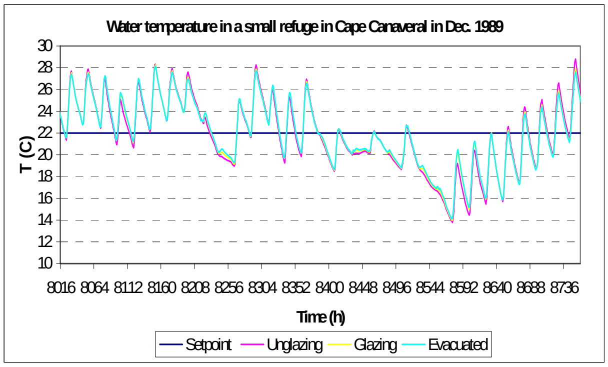


Figure 5-26 Predicted water temperature for a small refuge in Cape Canaveral in Dec. 1989

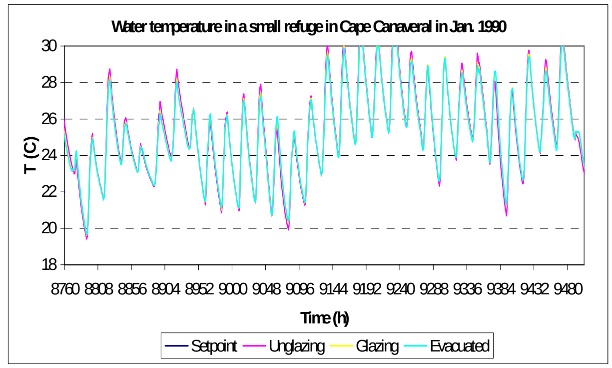


Figure 5-27 Predicted water temperature for a small refuge in Cape Canaveral in Jan. 1990

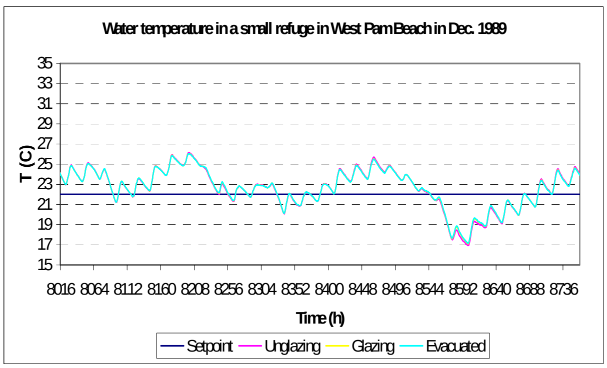


Figure 5-28 Predicted water temperature for a small refuge in West Palm Beach in Dec. 1989

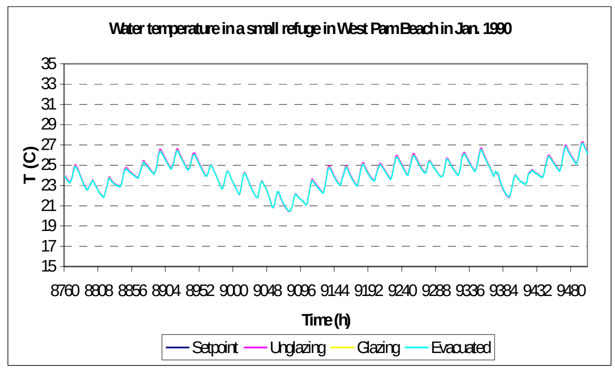


Figure 5-29 Predicted water temperature for a small refuge in West Palm Beach in Jan. 1990

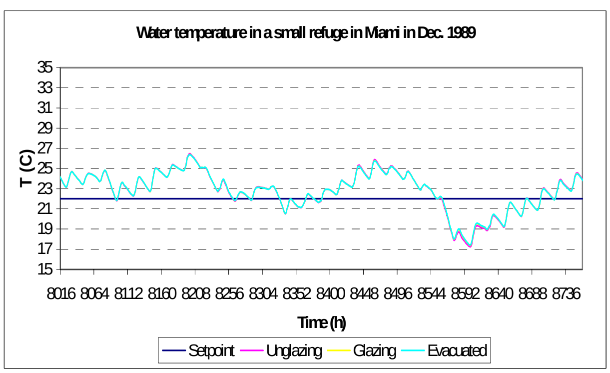


Figure 5-30 Predicted water temperature for a small refuge in Miami in Dec. 1989

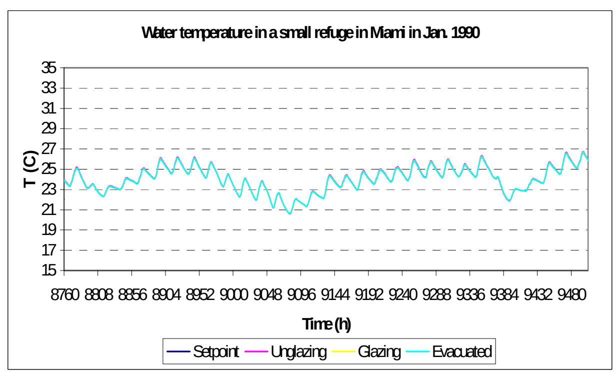


Figure 5-31 Predicted water temperature for a small refuge in Miami in Jan. 1990

5.5.4 Solar collector type

Although Meyer et. al.[15] suggested that thermal heating by means of parabolic trough solar collectors offered the most feasible solution, Goswami, et. al.[8] concluded reasonably that unglazed solar collectors could provide warm water for manatee refuges and cost-effective. We concluded that unglazed solar collector systems are the most cost-effective approach for providing enough heat for manatees to survive in cold winter in Cape Canaveral, West Palm Beach and Miami. We also found that installing transparent refuge covers with 1 m high above the refuge surface could significantly reduce the necessary number of solar panels and thus the cost of the solar collector systems.

15 Meyer, S., L. Leonardi, J. Strate, and T. Lurtz, "Design of a Sustainable Thermal Refuge for Manatees," University of Florida, Dept. of Environmental Sciences, Winner of the FWEA 2001 Student Design Competition, March 2001

Task 6 Conclusions and Recommendations

The objective of this study was to assess the feasibility and cost of using solar collector systems to warm water manatee refuges that would remain at temperatures of 22ºC or higher year round at three locations along Florida east coast. Based on the above assessment, we reached following conclusions:

- Solar collector systems can be used to create warm-water refuges and able to sustain manatees through winter months at Cape Canaveral, West Palm Beach and Miami.
- The largest source of heat loss will be due to tidal and water turn over rates within the refuges. For a small refuge (i.e., 50ft x 50 ft), the number of unglazed solar panels needed to maintain a temperature of 22ºC increases from 209 for 1 complete turn over per day to 686 for 5 complete turn over per day assuming a constant circulation rate. For a large refuge (i.e., 150ft x 100 ft), the number of unglazed solar panels increases from 1250 for 1 complete turn over per day to 4111 for 5 complete turn over per day with a constant circulation rate.
- Unglazed solar collectors are the best choice for the refuge water heating system, because of their ability to produce warm water to the refuges and their lowest cost relative to the other three types of collector examined in the present study. Although the unglazed collector may provide low outlet water temperature, the amount of heat provided by the unglazed collector is enough to meet the requirements.
- The use of refuge cover above the refuge surface would significantly reduce heat losses and system costs. A solar water heating system may not be needed in West Palm Beach and Miami, if a transparent refuge cover could be used.
- Deep refuge requires more heating energy to maintain warm temperatures and provide little benefit for buffering heat loss during cold periods.
- A control system is needed in the solar heating system to control the system operation.
- A photovoltaic system would not be a cost effective means of providing electricity to drive water pumps.
- The opaque and transparent covers over the refuge surface with 1m high could significantly reduce the number of solar panels, compared to the base case.
- A backup gas heating system is recommended for Cape Canaveral, but not may not be needed for sites in West Palm Beach and Miami. If a cover is used in the refuges, it requires much less capacity of a gas heating system.
- For the base case at Cape Canaveral, the amount of land needed for the solar array is about 0.3 acres for a small refuge and 1.5 acres for a large.

The estimated costs for an unglazed solar collector water heating system with a variable tide are provided in Table 6-1. In addition, the numbers of unglazed solar panels at different scenarios are also provided.

Table 6-1: Estimated costs for possible scenarios in three locations

Case	Cost	Cape Canaveral		West Palm Beach		Miami	
		Small refuge	Large refuge	Small refuge	Large refuge	Small refuge	Large refuge
Base	Initial cost ($)	123271	713613	29261	174997	16965	100798
	Annual cost ($)	12381	73888	3263	19505	1891	11235
	Lifetime cost ($ Million)	0.268	1.578	0.067	0.399	0.039	0.230
	# Panel	146	874	39	231	22	133
Opaque cover	Initial cost ($)	56217	314365	1560	8600	1383	7660
	Annual cost ($)	5104	30232	174	959	154	854
	Lifetime cost ($ Million)	0.118	0.680	0.006	0.032	0.005	0.029
	# Panel	60	358	2	11	2	10
Trans cover	Initial cost ($)	30939	163780	0	0	0	0
	Annual cost ($)	2287	13448	0	0	0	0
	Lifetime cost ($ Million)	0.061	0.339	0.003	0.018	0.003	0.018
	# Panel	27	159	0	0	0	0
Opaque cover at 1 m high	Initial cost ($)	100397	578166	19986	119118	13483	79864
	Annual cost ($)	9945	59268	2229	13277	1503	8902
	Lifetime cost ($ Million)	0.219	1.284	0.048	0.283	0.033	0.194
	# Panel	118	701	26	157	18	105
Trans cover at 1 m high	Initial cost ($)	74153	420532	6911	40784	3891	22817
	Annual cost ($)	7005	41633	771	4546	434	2543
	Lifetime cost ($ Million)	0.159	0.926	0.019	0.111	0.012	0.070
	# Panel	83	493	9	54	5	30

It should be pointed out that although we propose to use a refuge cover for refuges with the lowest cost, the costs in the base case with variable tide are also provided for future design reference.

Recommendations

To further investigate the development of a solar heated thermal refuge for manatees, it is recommended that a proposed site be identified in order to provide a basis for developing a detailed assessment of refuge design and costs parameters. If further consideration is to be given to a site in the Cape Canaveral area, water heating requirements as analyzed in this report, should be reexamined in light of the hourly water temperature data for the winter of 1989-90 in the Banana River that came to light at the end of this study.

The following study will be needed to provide accurate cost estimation for possible solar water heating systems during design stage:

- Detailed design of heat exchanger
- Land cost
- Permit cost
- Water piping cost (The estimation of pipe system is included in economical analysis).

A monitoring system in the refuge is recommended.

Appendix A: Ocean Air and Ocean Water Temperatures Used to Predict Inland Coastal Water temperatures at the Cape Canaveral and Rivera Power Plants

This appendix provides detailed comparison of inland coastal water temperatures between measurement and prediction in Cape Canaveral and Riviera Beach in 2001, 2002 and 2003. The inland coastal water temperature prediction is assumed to be a bi-quadratic function of ocean air and water temperatures, obtained from National Oceanic Data Center (NODC). The equation is presented as Eq. (1) in the Task 2 section. The measured inland coastal water temperatures at the Cape Canaveral and Riviera power plants are provided by FPL. It should be pointed out that the FPL measured data are not a full year. Therefore, statistical analysis is performed based on the FPL data we received.

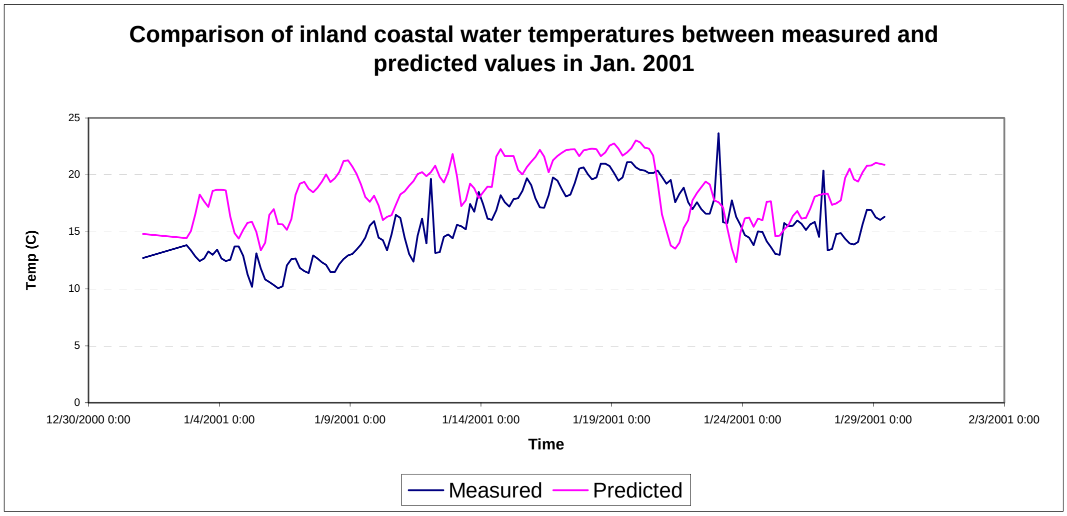
By performing linear regression, the values of coefficient of determination (r^2) are listed in the following table. The coefficient of determination is defined as an indicator to compare estimated and actual y-values, and ranged in value from 0 to 1.0. If it is 1.0, there is a perfect correlation in the sample. It means that there is no difference between the estimated y-value and the actual y-value. At the other extreme, if the coefficient of determination is 0, the regression equation is not helpful in predicting a y-value. The y-value used in the present study is inland coastal water temperature.

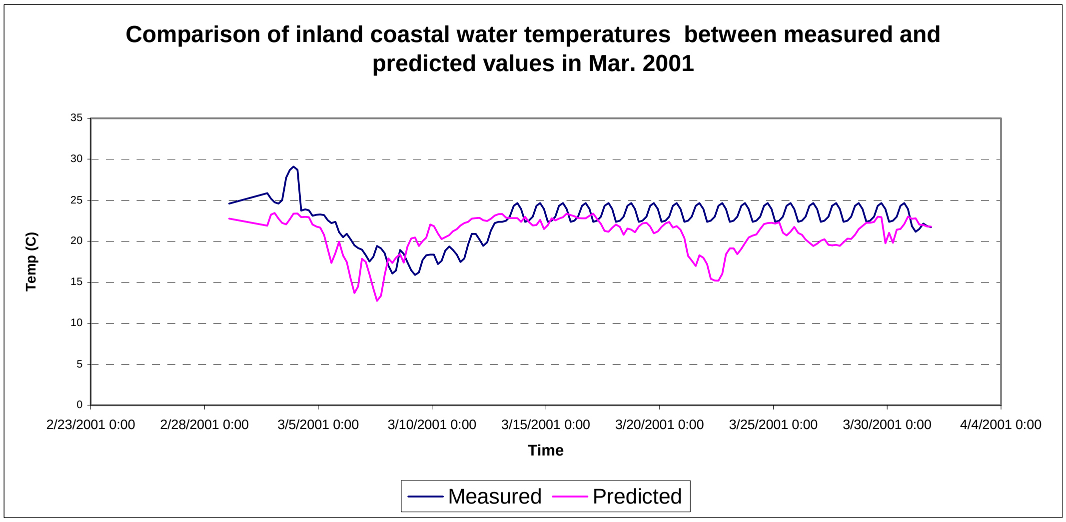
Table A-1 presents coefficients of determination for inland coastal regression at Cape Canaveral and riviera power plants in 2001 and 2002. Since ocean measurement station is 20 mile away from the shore of Cape Canaveral, the values of r^2 is less than 0.5, 0.49 in 2001 and 0.45 in 2002. The regression is much better in Riviera Beach with 0.72 in 2001 and 0.65 9n 2002, because the measured station is located near the pier in Riviera. In general, both regression equation represent inland coastal water temperatures well.

Table A-1: Coefficients of determination of inland coastal water temperature regression

Location	**Year**	**r^2**
Cape Canaveral	2001	0.49
Cape Canaveral	2002	0.45
Riviera	2001	0.72
Riviera	2002	0.65

Ocean air and ocean water temperatures collected for the years 2001 and 2002 at two National Ocean Data Center monitoring stations were used to predict inland coastal water temperatures at the Cape Canaveral and Riviera power plants during those years. These data were collected from an ocean buoy 20 miles east of Cape Canaveral and a station on ocean pier in Lake Worth. Figures A-1 and A-2 include the ocean air and water temperature data used in this study from the offshore Cape Canaveral NODC monitoring. Figures A-3 and A-4, show the same data used from the ocean pier in Lake Worth.





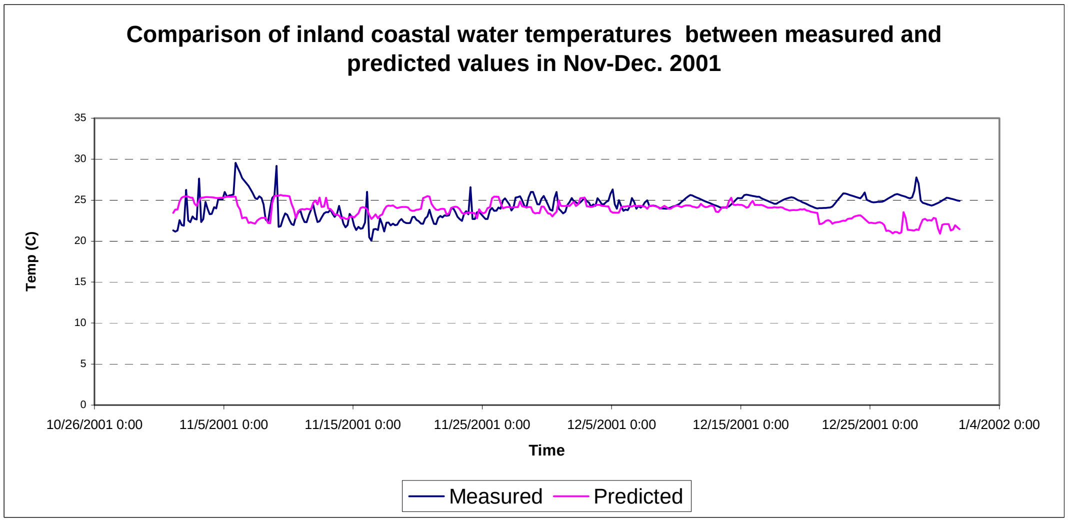
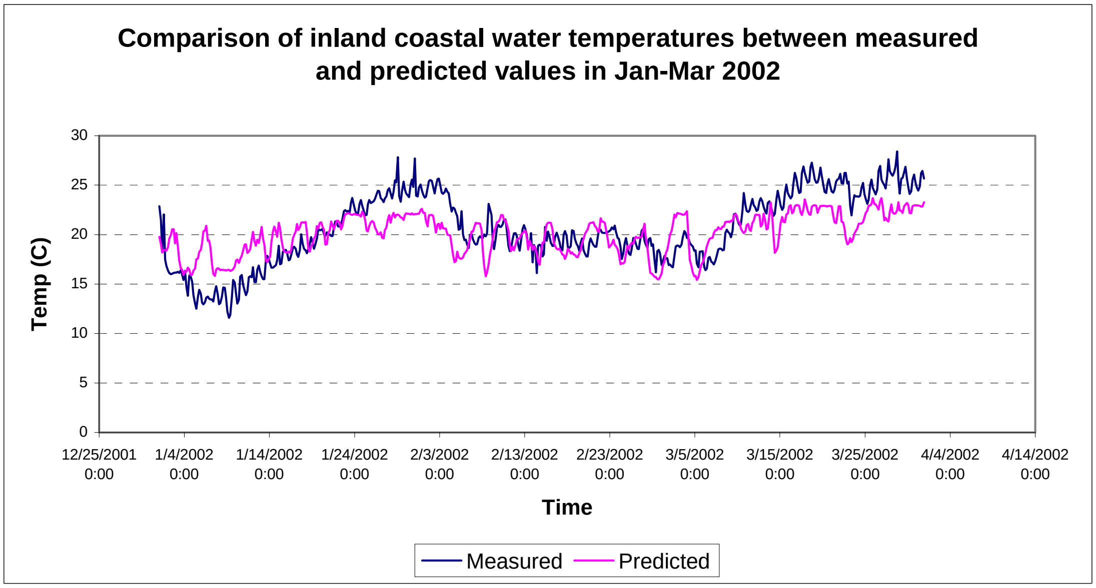


Figure A-1 Comparison of inland coastal water temperatures between measurement and prediction in Cape Canaveral in 2001.



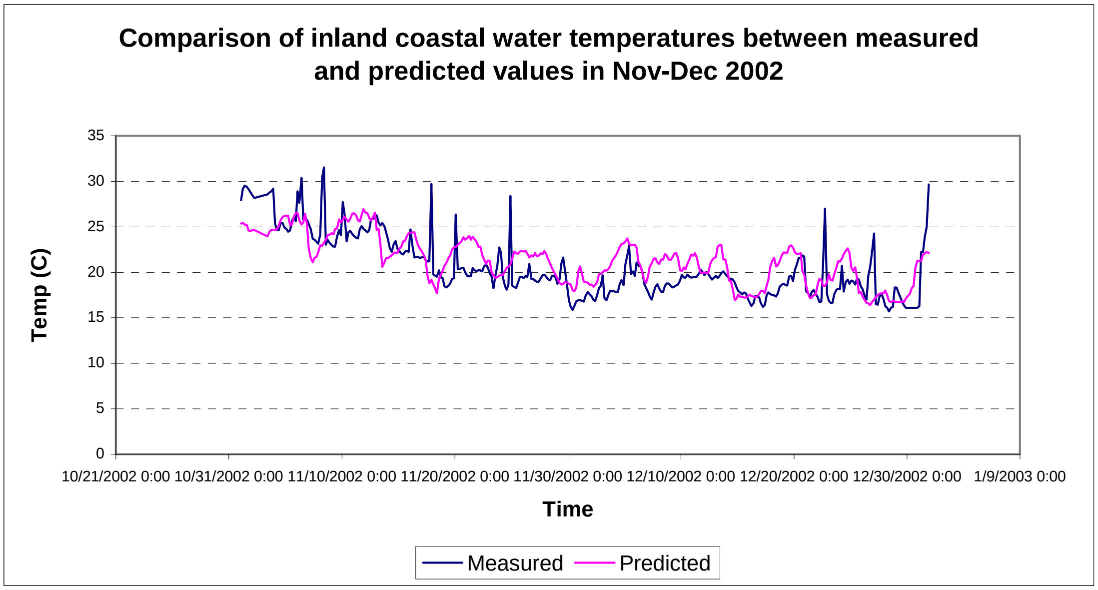


Figure A-2 Comparison of inland coastal water temperatures between measurement and prediction in Cape Canaveral in 2002

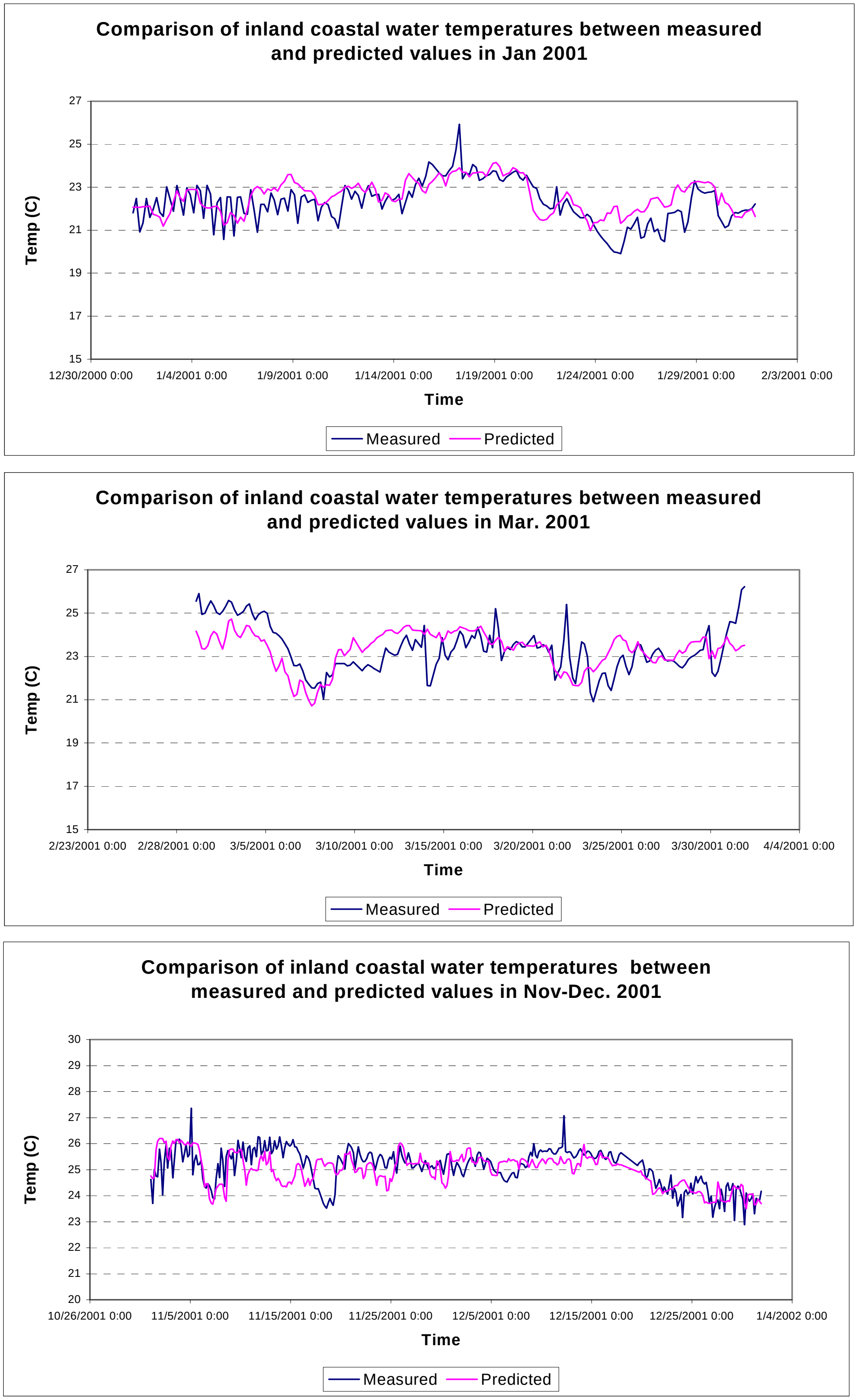
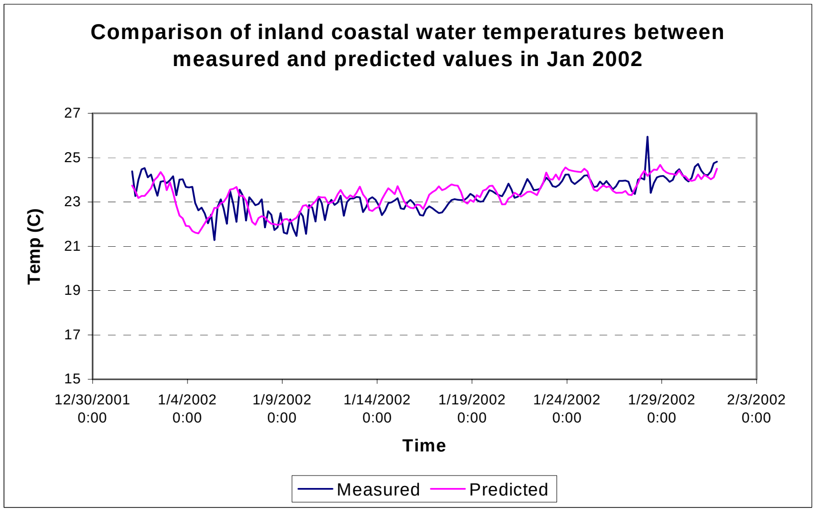
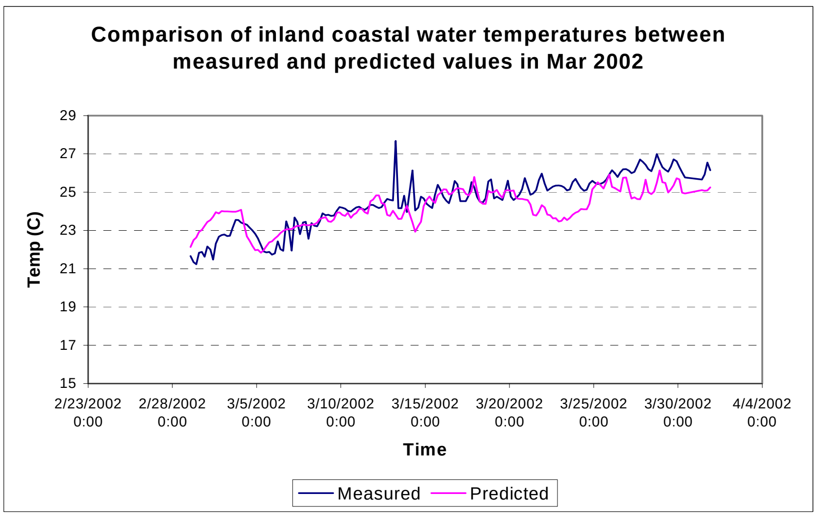


Figure A-3 Comparison of inland coastal water temperatures between measurement and prediction in Riviera in 2001





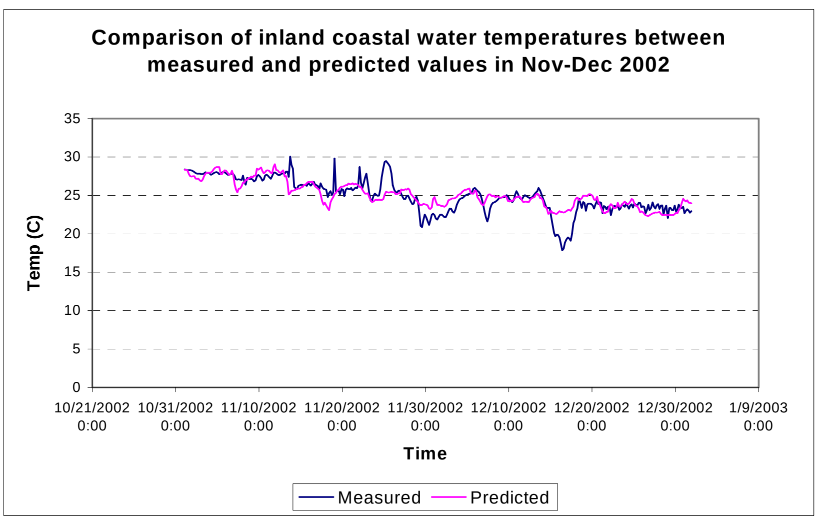


Figure A-4 Comparison of inland coastal water temperatures between measurement and prediction in Riviera in 2002

Appendix B: Tidal calculation software and hourly prediction

This appendix provide a brief description of the software: WXTide32, and calculated hourly tidal height with time in three locations in 1989 and 1990.

B-1 WXTide32 software

WXTide32, a *free* Windows tide and current prediction program, was used to predict tide time and water levels[16]. The program is able to perform following predictions:

- Predicts tides from 1970 through 2037.
- 8,800 tide level stations worldwide including 44 in England, Ireland and Scotland.
- 100 tidal current stations (all in North America).
- User station manager to easily add custom tide and current secondary stations.
- Text outputs: daily tide list, monthly calendar, incremental tide.
- Graphic modes: tide clock, realtime graph, scrolling graph, overview.
- Each mode has separate display options and window settings.
- Designed for interactive use but can also be used from other programs.
- Worldwide timezone support, solar/lunar events, cursor, recent stations.
- Tested on Windows 9x, NT4, 2000, ME, XP.
- Self-contained, nothing else needed.
- Context sensitive help and all "**C**" source code included.
- WXTide32 is based on the UNIX program XTide version 1.6.2 written by Dave Flater.

B-2 Tidal height

The methodology to calculate hourly tidal height and height difference between previous and current hour in 1989 and 1990 has been described in Section 3.2. This section show hourly tidal height graphically in three locations in 1989.

Figures B-1 through B-3 plot predicted hourly tidal history in Cape Canaveral, West Palm Beach and Miami, respectively. Each figure has two sub-figures. The first sub figure shows tidal history in 1989 to provide a picture in a long period. The second sub figure shows the tidal history between Nov. 1989 and Dec. 1989 to provide tidal trend in detail in a short period.

16 http://www.wxtide32.com/

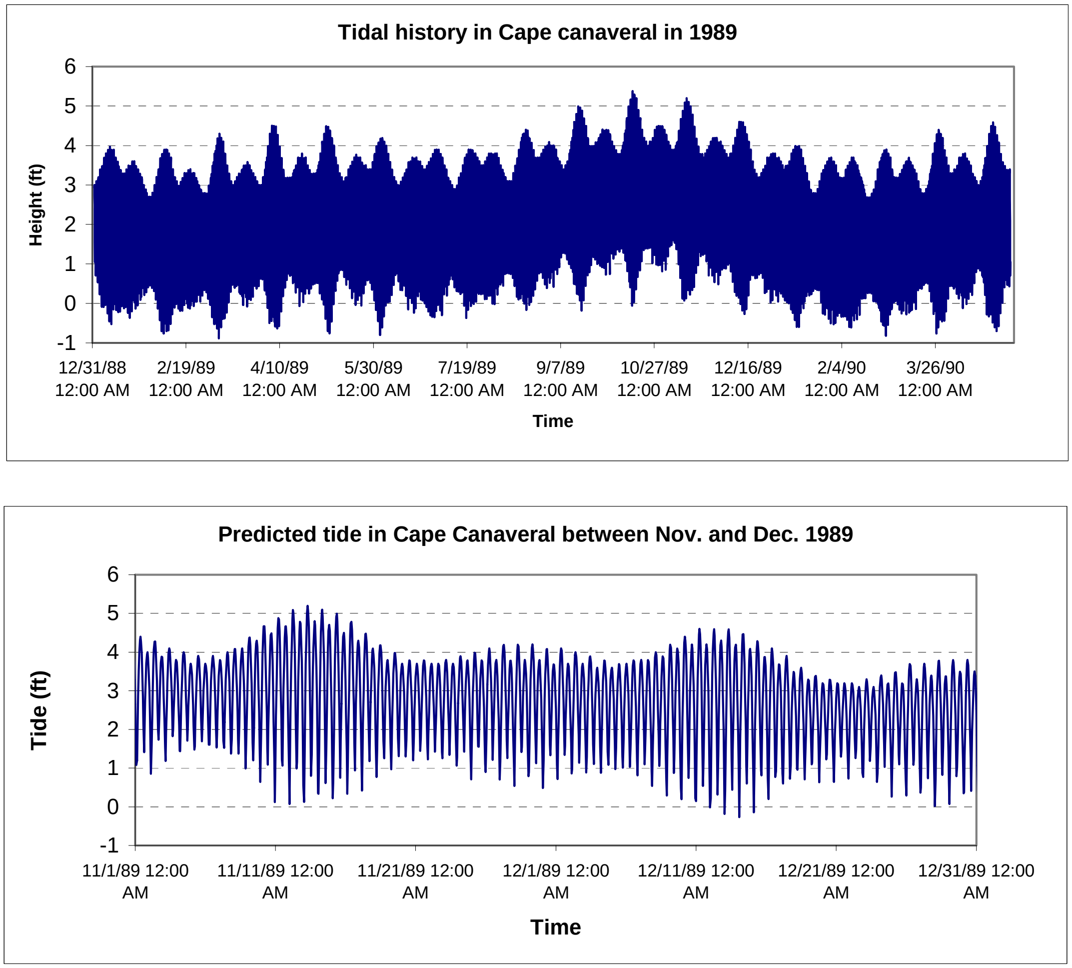


Figure B-1 Predicted hourly tidal history in Capa Canaveral

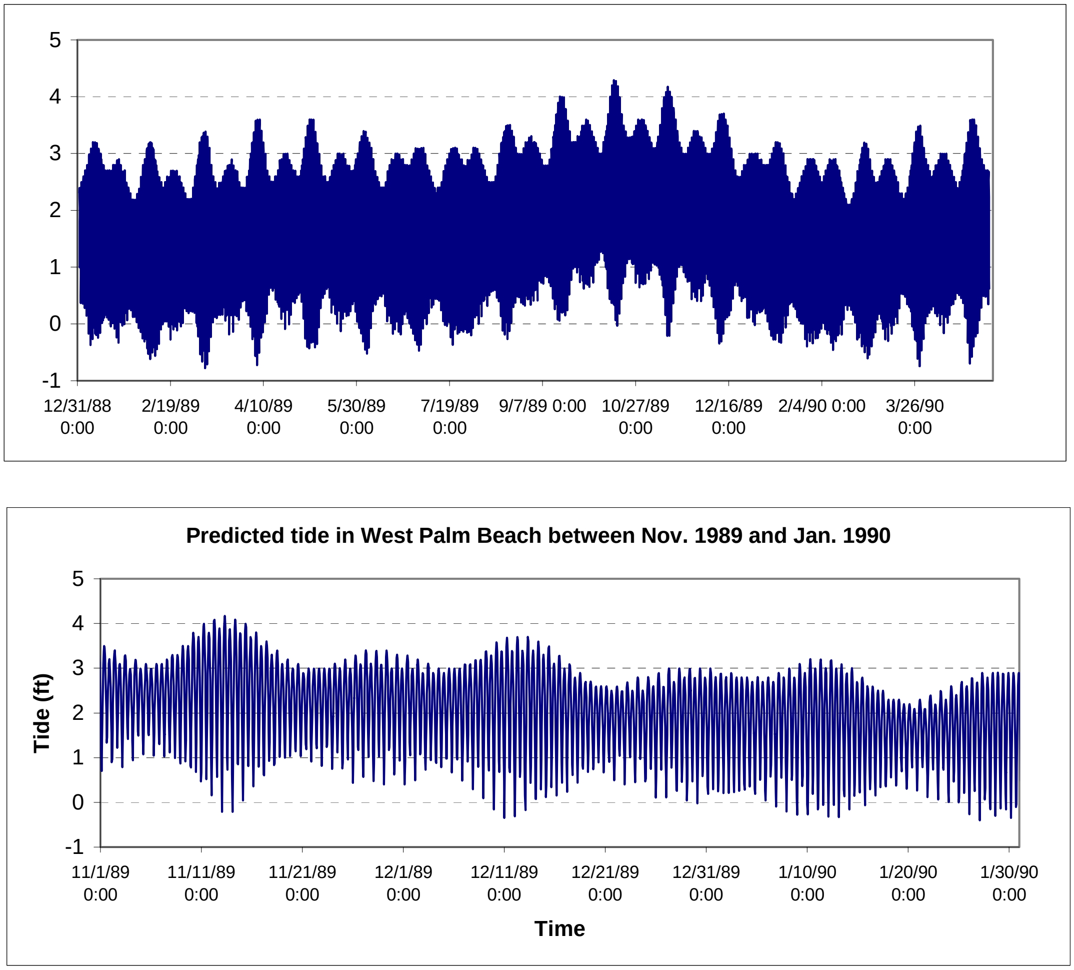
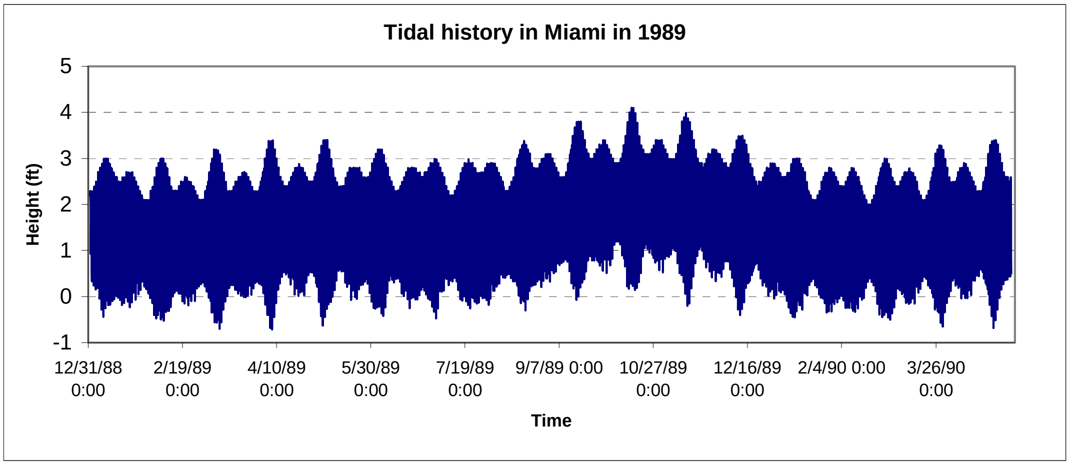


Figure B-2 Predicted hourly tidal history in West Palm Beach



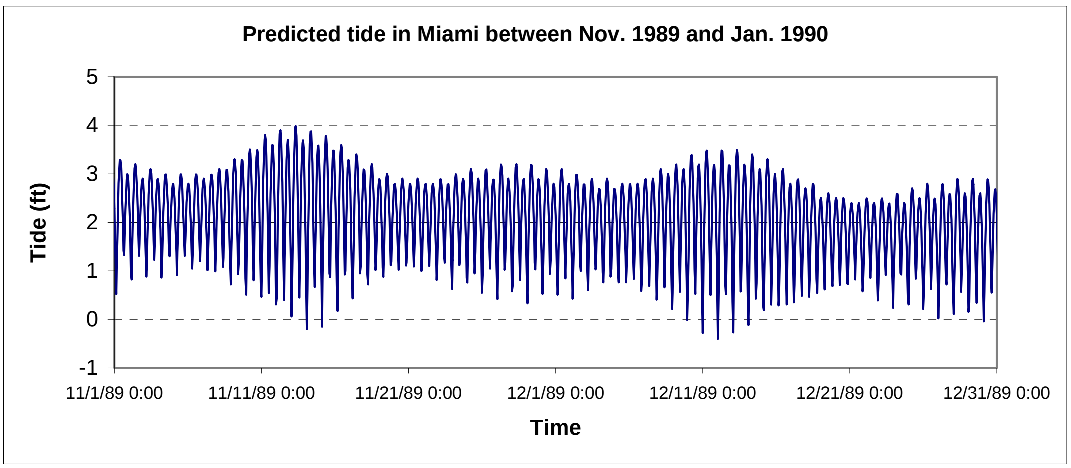


Figure B-3 Predicted hourly tidal history in Miami

Appendix C: Heating energy requirements

This appendix provides heating energy required to maintain refuge temperatures at 22°C 100% of the time in two types of refuges at three different locations with constant and variable water turn over rates. This means that the heating equipment turns on when the refuge temperature is below setpoint.

The twelve tables follow the same format for two types of refuges at three different locations assuming two different water turn over (tidal) impact. The first column identifies the case number. The second column is a brief description of the case. The third column provides estimates of annual heating energy required in kWh from May 1, 1989 to April 30, 1990. The fourth column provides estimates of monthly heating energy required in Dec. 1989, the coldest month in the study period. The last two columns provide estimates of heating energy required for the coldest day and the coldest hour in the coldest day in Dec. 1989. All the units of heating energy use are kWh.

Table C-1: Heating energy required in Cape Canaveral for a small refuge with a constant tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	169097.4	76377.8	6539.5	334.53
2	No cond	166923.1	75787.7	6503.8	332.86
3	No solar	272147.8	92824.2	7304.6	344.84
4	No sky	151636.4	70860.4	6196.9	320.16
5	No conv	123374.2	57173.9	4919.7	249.97
6	No evap	100348.9	54352.2	5080.9	260.18
7	No TOR	56145.2	32368.3	3395.8	228.66
8	No solar, evap, sky, conv	113862.1	45376.3	4467.9	213.35
9	No evap, sky, conv	48570.9	30856.8	3723.7	205.84
10	½ TOR	112595.9	54279.3	4794.5	281.59
11	2 TOR	281735.4	120699.7	10164.8	496.36
12	5 TOR	622722.9	254780.1	23489.8	1109.76
13	No evap+1/2 TOR	49020.5	32465.5	3335.9	185.4
14	No solar, evap, sky, conv + ½ TOR	56257.9	22947.1	2247.1	107.01
15	½ TOR & evap	78303.1	43234.6	4065.2	233.06
16	½ TOR + LT	113053.6	54400.4	4798.6	281.76
17	Base + LT	169569.2	76499.8	6543.6	334.7
18	2 TOR + LT	282242.4	120824.3	10168.8	496.53
19	No evap + ½ TOR +LT	49311.9	32577.3	3340	185.57
20	½ evap & TOR + LT	78683.4	43350.1	4069.3	233.23
21	9 ft Deep	220600	98605.3	8297.7	396.01
22	Case 8 + 9ft	170065.5	67951.4	6697	319.82
23	Case 9 + 9ft	93110.5	52260	5952.8	308.55
24	1m Opaque cover	180500	66218.2	5338.8	242.65
25	1m Trans cover	103298.8	53006.6	4723.4	248.87

Table C-2: Heating energy required in Cape Canaveral for a large refuge with a constant tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	1011041	456990.4	39144.9	2003.55
2	No cond	1001539	454726.1	39023	1997.16
3	No solar	1629018	555667	43735.6	2065.05
4	No sky	906335.1	423888.6	37089.2	1917.31
5	No conv	736809.4	341771.2	29460.9	1496.48
6	No evap	598949.6	324854.3	30393.3	1557.77
7	No TOR	333803	192930.2	20296.7	1368.35
8	No solar, evap, sky, conv	679589.4	271014.4	26750.1	1279.24
9	No evap, sky, conv	289055.3	184120	22284.8	1231.7
10	½ TOR	672069.4	324398.8	28675	1685.95
11	2 TOR	1686759	722920.3	60931.2	2974.82
12	5 TOR	3732681	1527425	140881.3	6655.21
13	No evap+1/2 TOR	291483.3	193539.8	19923.4	1108.17
14	No solar, evap, sky, conv + ½ TOR	333923.5	136423.4	13425.1	641.18
15	½ TOR & evap	466690.3	258140.3	24299.2	1394.74
16	½ TOR + LT	674597.8	325067.2	28697.5	1686.89
17	Base + LT	1013646	457663.8	39167.4	2004.49
18	2 TOR + LT	1689556	723608.3	60953.7	2975.76
19	No evap + ½ TOR +LT	293053.4	194156.5	19945.9	1109.11
20	½ evap & TOR + LT	468789.1	258778.2	24321.7	1395.68
21	9 ft Deep	1318251	589713.7	49647.9	2369.72
22	Case 8 + 9ft	1015032	405843.6	40095.9	1917.61
23	Case 9 + 9ft	554381	311728.4	35630.5	1846.29
24	1m Opaque cover	1079239	396031.5	31975.1	1452.59
25	1m Trans cover	616590.9	316777.1	28283	1489.86

Table C-3: Heating energy required in West Palm Beach for a small refuge with a constant tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	26743.9	17407.7	4596.9	300.54
2	No cond	26235.6	17165.7	4568.7	299.25
3	No solar	51699.7	27001.1	5382.1	300.54
4	No sky	22358.2	14742	4267.3	285.8
5	No conv	13554.9	8089.1	2696.3	180.75
6	No evap	8332.7	7217	2989.4	209.79
7	No TOR	24700.1	18271.8	3080.6	226.56
8	No solar, evap, sky, conv	4924	3402.4	1504.9	92.75
9	No evap, sky, conv	702	702	625.9	85.02
10	½ TOR	25122.8	17216.1	3838.8	263.55
11	2 TOR	30969.3	19371.4	6113.1	374.51
12	5 TOR	47399.9	29404.8	10661.8	596.45
13	No evap+1/2 TOR	5381.3	5180.7	2231.3	172.8
14	No solar, evap, sky, conv + ½ TOR	1942.8	1519	759.4	46.83
15	½ TOR & evap	12752.7	10237.3	3035	218.17
16	½ TOR + LT	25279.8	17291.8	3842.8	263.72
17	Base + LT	26870.4	17470.5	4600.9	300.71
18	2 TOR + LT	31066.7	19416	6117.2	374.68
19	No evap + ½ TOR +LT	5425	5217.1	2235.4	172.97
20	½ evap & TOR + LT	12842.7	10295.1	3039.1	218.34
21	9 ft Deep	26083.8	17337.4	5366.2	338.05
22	Case 8 + 9ft	7324.8	5079.6	2250.3	138.91
23	Case 9 + 9ft	1727.7	1727.7	1229.6	127.31
24	1m Opaque cover	20158.5	11565.1	3298.5	180.53
25	1m Trans cover	8817.5	6707.1	2678	187.9

Table C-4: Heating energy required in West Palm Beach for a large refuge with a constant tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	159599	103877.1	27503.2	1799.56
2	No cond	157413.8	102993.9	27412.4	1795.5
3	No solar	309148.1	161384.4	32214.5	1799.56
4	No sky	133342.4	87924.9	25526	1711.14
5	No conv	80633.5	48092.7	16099.4	1080.85
6	No evap	49509.9	42928.8	17858.2	1255.09
7	No TOR	146982.5	108958.9	18405.7	1355.7
8	No solar, evap, sky, conv	29060.2	20073.9	8983.3	554.92
9	No evap, sky, conv	4073.4	4073.4	3739.5	508.24
10	½ TOR	149763.8	102674	22954.4	1577.63
11	2 TOR	185086	115757.2	36600.6	2243.43
12	5 TOR	283807.8	176055.9	63892.9	3575.03
13	No evap+1/2 TOR	31823.2	30676.9	13309.8	1033.16
14	No solar, evap, sky, conv + ½ TOR	11177	8787.1	4531.9	279.35
15	½ TOR & evap	75782.8	60878.5	18132	1305.39
16	½ TOR + LT	150627.8	103091.5	22977	1578.57
17	Base + LT	160296.1	104223.3	27525.7	1800.5
18	2 TOR + LT	185623.9	116003.2	36623.1	2244.37
19	No evap + ½ TOR +LT	32064.8	30878.1	13332.3	1034.1
20	½ evap & TOR + LT	76279.5	61197.5	18154.5	1306.33
21	9 ft Deep	155367.5	103290	32080	2022.81
22	Case 8 + 9ft	43224.3	29966.7	13443.5	831.07
23	Case 9 + 9ft	10020.6	10020.6	7341.1	761.06
24	1m Opaque cover	120148.9	68886	19713	1079.54
25	1m Trans cover	52385.3	39868.2	15990.2	1123.76

Table C-5: Heating energy required in Miami for a small refuge with a constant tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	17872.3	12636.2	4258.3	286.13
2	No cond	17471.6	12441.9	4231.8	284.89
3	No solar	38709.2	20895.5	5098.9	293.61
4	No sky	14562.3	10575.6	3947.2	271.65
5	No conv	9605.3	6604.8	2537.3	176.38
6	No evap	6301.4	5743.7	2734.3	200.27
7	No TOR	12565.8	10654.3	2742.3	216.28
8	No solar, evap, sky, conv	4908	3390.3	1501.4	92.73
9	No evap, sky, conv	611	611	642.5	84.97
10	½ TOR	15109.3	11347.8	3500.1	249.68
11	2 TOR	23729.7	15791.9	5774.5	360.93
12	5 TOR	41651.4	26912.2	10323.2	585.33
13	No evap+1/2 TOR	3645.2	3645.2	1979.4	162.87
14	No solar, evap, sky, conv + ½ TOR	1926.6	1507.4	758.3	46.8
15	½ TOR & evap	7774.3	6908.5	2738.4	205.8
16	½ TOR + LT	15217.1	11409.8	3504.2	249.85
17	Base + LT	17971.1	12686.2	4262.3	286.3
18	2 TOR + LT	23809.5	15827	5778.6	361.1
19	No evap + ½ TOR +LT	3667.8	3667.8	1983.4	163.04
20	½ evap & TOR + LT	7832.2	6945	2742.5	205.97
21	9 ft Deep	18916.9	13627.6	5026.7	324.03
22	Case 8 + 9ft	7300.9	5061.4	2245.1	138.88
23	Case 9 + 9ft	1641.6	1641.6	1233.3	127.24
24	1m Opaque cover	16015.8	9592.5	3165.3	173.85
25	1m Trans cover	6454	5367.5	2480.2	181.09

Table C-6: Heating energy required in Miami for a large refuge with a constant tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	106574	75383.7	25477.3	1713.29
2	No cond	104829.4	74651.6	25390.7	1709.34
3	No solar	231416.1	124879.6	30520.9	1758.15
4	No sky	86802.4	63058.2	23610.7	1626.42
5	No conv	57147.8	39298.1	15151.5	1054.78
6	No evap	37399.4	34155.5	16333.3	1198.15
7	No TOR	74626.6	63363.3	16381.9	1294.2
8	No solar, evap, sky, conv	29020.4	20043.7	8980.6	554.86
9	No evap, sky, conv	3539.2	3539.2	3840	508.13
10	½ TOR	89952.1	67602.4	20928.6	1494.56
11	2 TOR	141809	94397.6	34574.8	2162.09
12	5 TOR	249405	161153.1	61867.1	3508.49
13	No evap+1/2 TOR	21599.1	21599.1	11804.7	973.75
14	No solar, evap, sky, conv + ½ TOR	11136.7	8758.4	4529.3	279.3
15	½ TOR & evap	46166.9	41097.9	16358.4	1231.32
16	½ TOR + LT	90544.3	67944.9	20951.1	1495.5
17	Base + LT	107119.1	75659.8	25499.8	1714.23
18	2 TOR + LT	142248.6	94590.4	34597.3	2163.03
19	No evap + ½ TOR +LT	21723	21723	11826.9	974.69
20	½ evap & TOR + LT	46486.5	41299.2	16380.9	1232.26
21	9 ft Deep	112761.8	81259.6	30052.1	1938.95
22	Case 8 + 9ft	43164.6	29921.2	13439.6	830.99
23	Case 9 + 9ft	9573	9573	7368.5	760.88
24	1m Opaque cover	95459.7	57166.8	18919.4	1039.6
25	1m Trans cover	38281.5	31883.5	14809.4	1083.03

Table C-7: Heating energy required in Cape Canaveral for a small refuge with a variable tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	110493.7	53400.1	4434.5	411.94
2	No cond	108050.3	52689.9	4390.1	410.55
3	No solar	217795.3	69545.2	5199.6	411.94
4	No sky	94138.5	47945.8	4091.9	399.71
5	No conv	66461.1	34267.3	2585.2	375.63
6	No evap	48214.9	31544.4	2975.9	381.53
7	No TOR	54452.8	32351.8	3401.4	228.92
8	No solar, evap, sky, conv	56015	22005.1	2369.3	332.99
9	No evap, sky, conv	12733.3	9858	1650.1	332.99
10	½ TOR	67681.3	37646.4	3595.9	231.7
11	2 TOR	282952.3	117339.8	10195.3	1406.65
12	No evap+1/2 TOR	17220.9	15012.1	2148.1	158.81
13	No solar, evap, sky, conv + ½ TOR	15349.6	6012.9	614.4	84.33
14	½ TOR & evap	38408.2	26615.1	2872	192.95
15	½ TOR + LT	68125.4	37769.2	3600.1	231.87
16	Base + LT	110959.7	53523.1	4438.7	412.11
17	2 TOR + LT	283478.8	117467.4	10199.6	1406.82
18	No evap + ½ TOR +LT	17384.8	15133.3	2152.3	158.99
19	½ evap & TOR + LT	38704.3	26736.2	2876.2	193.13
20	9 ft Deep	106445.1	53436.8	4447.7	412.36
21	Case 8 + 9 ft	55739.7	22170.3	2376.9	333.41
22	Case 9 + 9 ft	11988.7	9582.6	1657	333.41
23	1m Opaque cover	123274.9	42934.5	3138.8	366.35
24	1m Trans cover	49897.3	30195.2	2556.7	372.46

Table C-8: Heating energy required in Cape Canaveral for a large refuge with a variable tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	658413.6	318676.6	26484.3	2468.21
2	No cond	648301.6	316139.7	26340.6	2463.28
3	No solar	1301589	415532.2	31074.9	2468.21
4	No sky	560386.4	285955.2	24428.5	2394.83
5	No conv	394467.9	203888.5	15439.5	2250.37
6	No evap	286150.3	187565.1	17732.7	2285.74
7	No TOR	322844.5	192510.7	20310.7	1369
8	No solar, evap, sky, conv	331353.3	130333.2	14144.4	1994.52
9	No evap, sky, conv	74618.7	57967.4	9829.8	1994.52
10	½ TOR	401774.8	224218.2	21475.2	1385.65
11	2 TOR	1692632	702185.8	61094	8436.73
12	No evap+1/2 TOR	101187.7	88400.1	12788.6	947.68
13	No solar, evap, sky, conv + ½ TOR	87492.7	34422.5	3617.7	502.43
14	½ TOR & evap	227241.8	158035.9	17131.9	1153.19
15	½ TOR + LT	404175	224881.9	21498.1	1386.6
16	Base + LT	660923.7	319336.8	26507.2	2469.16
17	2 TOR + LT	1695452	702867.4	61117.1	8437.68
18	No evap + ½ TOR +LT	102075.9	89054.7	12811.5	948.64
19	½ evap & TOR + LT	228828.9	158688.9	17154.8	1154.14
20	9 ft Deep	632417	318259.6	26517.4	2469.26
21	Case 8 + 9 ft	327949.6	130685.3	14163.3	1995.57
22	Case 9 + 9 ft	69408.7	55772.7	9845.3	1995.57
23	1m Opaque cover	734561.1	255869	18710.3	2194.67
24	1m Trans cover	295893.6	179462.9	15261.4	2231.36

Table C-9: Heating energy required in West Palm Beach for a small refuge with a variable tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	22945.8	16449.9	3550.1	230.67
2	No cond	22336.5	16110.6	3516.2	229.02
3	No solar	66249.3	29477.4	4335.3	234.41
4	No sky	18246.4	13293.6	3220.6	218.15
5	No conv	9397.3	6049.7	1649.3	186.32
6	No evap	4253.2	4190.1	1942.6	182.05
7	No TOR	22984	17907.6	3086.2	226.82
8	No solar, evap, sky, conv	1155	875.1	780.1	138.74
9	No evap, sky, conv	0	0	0	1
10	½ TOR	22685	17379.1	3202.2	226.9
11	2 TOR	28541	17538.1	4941.2	633.9
12	No evap+1/2 TOR	2862.1	2862.1	1530.4	136.15
13	No solar, evap, sky, conv + ½ TOR	0	0	209.1	35.51
14	½ TOR & evap	9427.7	8739	2398.5	181.53
15	½ TOR + LT	22862	17479.2	3206.5	227.08
16	Base + LT	23100.9	16537.2	3554.3	230.85
17	2 TOR + LT	28648.3	17587.7	4945.5	634.07
18	No evap + ½ TOR +LT	2895.5	2895.5	1554.5	136.33
19	½ evap & TOR + LT	9534.5	8826.2	2402.7	181.7
20	9 ft Deep	20956.7	15570.6	3561.3	231.2
21	Case 8 + 9 ft	742.7	709.9	784.8	139.02
22	Case 9 + 9 ft	0	0	0	1
23	1m Opaque cover	21087.1	11231.6	2251.7	175.48
24	1m Trans cover	4365.4	3885.2	1630.8	179.83

Table C-10: Heating energy required in West Palm Beach for a large refuge with a variable tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	136526.6	97882.8	21202.2	1379.11
2	No cond	134019.2	96663.5	21097	1374.13
3	No solar	395913.9	176026	25913.6	1403
4	No sky	108405.7	79003.6	19225	1306.68
5	No conv	55492.7	35652.6	9797.1	1115.77
6	No evap	24956.9	24658.9	11557.2	1090.14
7	No TOR	136668.4	106609.3	18419.8	1356.35
8	No solar, evap, sky, conv	6269.6	4801.8	4642.4	830.28
9	No evap, sky, conv	0	0	0	1
10	½ TOR	134868	103438.8	19115.5	1356.55
11	2 TOR	170300.5	104606.1	29548.4	3801.49
12	No evap+1/2 TOR	16729.8	16729.8	8905.1	812.08
13	No solar, evap, sky, conv + ½ TOR	0	0	1224.4	210.8
14	½ TOR & evap	55597	51615	14293	1084.32
15	½ TOR + LT	135827.5	103980.6	19138.4	1357.51
16	Base + LT	137333.4	98355.1	21225.1	1380.07
17	2 TOR + LT	170883.3	104874.8	29571.3	3802.42
18	No evap + ½ TOR +LT	16912	16912	9037	813.04
19	½ evap & TOR + LT	56176.8	52088.6	14315.9	1085.27
20	9 ft Deep	124186.9	92290.1	21230.3	1380.43
21	Case 8 + 9 ft	3695.3	3629.8	4652.1	830.98
22	Case 9 + 9 ft	0	0	0	1
23	1m Opaque cover	125216.8	66597.2	13412	1050.7
24	1m Trans cover	25564.3	22818.7	9686.2	1076.83

Table C-11: Heating energy required in Miami for a small refuge with a variable tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	13291.7	10208.9	3201.5	276.87
2	No cond	12870.8	9947	3170.1	275.47
3	No solar	47484.9	22046.5	4042.1	276.87
4	No sky	9995.1	7907.2	2890.4	265.91
5	No conv	5009.7	3723.8	1476.6	189.46
6	No evap	2712.3	2712.3	1392.9	182.55
7	No TOR	11456.2	10084.3	2747.5	216.53
8	No solar, evap, sky, conv	1066.6	831.1	760.3	135.53
9	No evap, sky, conv	0	0	0	1
10	½ TOR	11836.5	10013.1	2860.7	231.45
11	2 TOR	20859.3	13670.4	4564.8	630.37
12	No evap+1/2 TOR	1189.6	1189.6	537.1	78.13
13	No solar, evap, sky, conv + ½ TOR	0	0	202.8	34.66
14	½ TOR & evap	4439.7	4439.7	2098	186.43
15	½ TOR + LT	11964.1	10102.7	2864.9	231.62
16	Base + LT	13393.6	10276.5	3205.7	277.04
17	2 TOR + LT	20942.2	13704	4569	630.54
18	No evap + ½ TOR +LT	1220.8	1220.8	538.7	78.3
19	½ evap & TOR + LT	4496.8	4496.8	2102.2	186.6
20	9 ft Deep	11584.7	9265	3211.8	277.33
21	Case 8 + 9 ft	660.9	655	764.9	135.78
22	Case 9 + 9 ft	0	0	0	1
23	1m Opaque cover	14661.5	8111.2	2108.5	176.36
24	1m Trans cover	2343.4	2343.4	1243.6	181.18

Table C-12: Heating energy required in Miami for a large refuge with a variable tide

Case	Desc	Year	Dec	Peak Day	Peak Hour
1	Base	78954.9	60652.3	19119.4	1657.18
2	No cond	77225	59681.9	19020.5	1652.84
3	No solar	283702.6	131621.2	24163	1657.18
4	No sky	59222.9	46895.9	17252.8	1591.45
5	No conv	29443.7	21895	8769.5	1134.84
6	No evap	15948.6	15948.6	8172.5	1093.36
7	No TOR	67753.6	59798.5	16394.5	1294.83
8	No solar, evap, sky, conv	5848.5	4604	4521.8	811.24
9	No evap, sky, conv	0	0	0	1
10	½ TOR	70113.1	59386.2	17074.2	1384.65
11	2 TOR	124479.8	81611.8	27300.2	3780.62
12	No evap+1/2 TOR	6735.8	6735.8	3183.7	464.73
13	No solar, evap, sky, conv + ½ TOR	00	1191.3205 .92		
14	½ TOR & evap	26086.5	26086.5	12498.1	1114.52
15	½ TOR + LT	70805	59871.9	17097	1385.6
16	Base + LT	79501.1	61011.7	19142.2	1658.13
17	2 TOR + LT	124930.4	81794	27323.1	3781.55
18	No evap + ½ TOR +LT	6904.2	6904.2	3192.3	465.68
19	½ evap & TOR + LT	26396.9	26396.9	12521	1115.47
20	9 ft Deep	68430.5	54790.4	19145.4	1658.35
21	Case 8 + 9 ft	3390.7	3390.7	4533.5	811.89
22	Case 9 + 9 ft	0	0	0	1
23	1m Opaque cover	86918	48044	12561.5	1056.26
24	1m Trans cover	13743.4	13743.4	7284.3	1085.18

Appendix D: Solar collector size requirements

This appendix provides solar collector sizes requirement to meet 95% of time in Dec. 1989 in three locations, two typed of refuges, and two different tidal impacts. The solar collector type consists of unglazed, glazing and evacuated collectors.

All twelve tables listed below have the same format. The first two columns show case number and a brief description. The last three columns present required solar collector sizes in three different types in units of m^2. In general, a typical solar collector size for unglazed and glazed flat panel is 4ft x10ft (3.716 m^2), while for evacuated panel is 2.2mx 1.4m (2.85 m^2). Using the required solar collector size divided by 4x10 can obtain how many panels of solar collector are needed.

Table D-1: Required solar collector size in Cape Canaveral for a small refuge with a constant tide

Small refuge in Cape Canaveral		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	927.72	1013.52	1149.28
2	No cond	920.6	1005.71	1140.42
3	No solar	1122.68	1229.55	1395.2
4	No sky	861.16	940.53	1066.43
5	No conv	695.26	759.17	860.69
6	No evap	661.28	721.86	818.33
7	No TOR	394.47	430.22	487.58
8	No solar, evap, sky, conv	551.03	602.24	682.94
9	No evap, sky, conv	375.86	410.08	464.8
10	½ TOR	660.67	720.97	817.27
11	2 TOR	1460.16	1598.69	1814.01
12	5 TOR	3044.66	3356.04	3815.42
13	No evap+1/2 TOR	395.51	431.46	489.01
14	No solar, evap, sky, conv + ½ TOR	279.38	304.91	345.63
15	½ TOR & evap	526.47	574.43	651.11
16	½ TOR + LT	662.13	722.57	819.09
17	Base + LT	929.2	1015.13	1151.11
18	2 TOR + LT	1461.65	1600.33	1815.88
19	No evap + ½ TOR +LT	396.87	432.94	490.7
20	½ evap & TOR + LT	527.87	575.96	652.84
21	9 ft Deep	1198.05	1308.74	1483.98
22	Case 8 + 9ft	825.18	901.87	1022.7
23	Case 9 + 9ft	636.18	694.32	787.05
24	1m Opaque cover	802.7	878.1	996.03
25	1m Trans cover	644.91	703.99	798.08

Table D-2: Required solar collector size in Cape Canaveral for a large refuge with a constant tide

Large refuge in Cape Canaveral		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	5550.91	6064.21	6876.5
2	No cond	5523.59	6034.26	6842.5
3	No solar	6720.72	7360.44	8352.01
4	No sky	5151.57	5626.32	6379.41
5	No conv	4156.13	4538.15	5145.02
6	No evap	3952.44	4314.45	4891.02
7	No TOR	2351.3	2564.35	2906.24
8	No solar, evap, sky, conv	3291.14	3596.98	4078.92
9	No evap, sky, conv	2242.79	2446.92	2773.45
10	½ TOR	3948.51	4308.89	4884.43
11	2 TOR	8745.6	9575.26	10864.92
12	5 TOR	18253.09	20119.77	22873.78
13	No evap+1/2 TOR	2357.58	2572.02	2915.16
14	No solar, evap, sky, conv + ½ TOR	1660.94	1812.74	2054.8
15	½ TOR & evap	3143.48	3429.77	3887.59
16	½ TOR + LT	3956.6	4317.75	4894.47
17	Base + LT	5559.04	6073.12	6886.61
18	2 TOR + LT	8753.82	9584.32	10875.22
19	No evap + ½ TOR +LT	2365.33	2580.31	2924.51
20	½ evap & TOR + LT	3151.21	3438.22	3897.18
21	9 ft Deep	7165.07	7827.03	8875.03
22	Case 8 + 9ft	4928.5	5386.49	6108.19
23	Case 9 + 9ft	3794.82	4141.64	4694.75
24	1m Opaque cover	4800.76	5251.67	5956.96
25	1m Trans cover	3854.18	4207.22	4769.49

Table D-3: Required solar collector size in West Palm Beach for a small refuge with a constant tide

Small refuge in West Palm Beach		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	182.16	212.72	246.83
2	No cond	179.67	209.79	243.41
3	No solar	282.19	329.77	382.72
4	No sky	154.34	180.19	209.06
5	No conv	84.68	98.87	114.71
6	No evap	75.48	88.17	102.32
7	No TOR	191.34	223.35	259.12
8	No solar, evap, sky, conv	35.66	41.61	48.27
9	No evap, sky, conv	7.35	8.58	9.96
10	½ TOR	180.09	210.34	244.07
11	2 TOR	202.62	236.68	274.64
12	5 TOR	306.56	358.72	416.48
13	No evap+1/2 TOR	54.26	63.34	73.48
14	No solar, evap, sky, conv + ½ TOR	15.92	18.58	21.55
15	½ TOR & evap	107.12	125.1	145.15
16	½ TOR + LT	180.97	211.31	245.18
17	Base + LT	182.81	213.49	247.71
18	2 TOR + LT	203.08	237.22	275.27
19	No evap + ½ TOR +LT	54.64	63.78	74
20	½ evap & TOR + LT	107.72	125.81	145.97
21	9 ft Deep	181.51	211.92	245.87
22	Case 8 + 9ft	53.24	62.12	72.06
23	Case 9 + 9ft	18.1	21.12	24.51
24	1m Opaque cover	121.05	141.35	164
25	1m Trans cover	70.16	81.95	95.09

Table D-4: Required solar collector size in West Palm Beach for a large refuge with a constant tide

Large refuge in West Palm Beach		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	1087.09	1269.42	1472.91
2	No cond	1078.01	1258.71	1460.45
3	No solar	1686.63	1971.04	2287.53
4	No sky	920.51	1074.68	1246.87
5	No conv	503.47	587.84	682.01
6	No evap	448.97	524.48	608.6
7	No TOR	1140.14	1331.41	1544.86
8	No solar, evap, sky, conv	210.38	245.49	284.78
9	No evap, sky, conv	42.68	49.81	57.78
10	½ TOR	1074.07	1254.45	1455.63
11	2 TOR	1210.8	1414.33	1641.17
12	5 TOR	1835.52	2147.77	2493.6
13	No evap+1/2 TOR	321.31	375.06	435.11
14	No solar, evap, sky, conv + ½ TOR	92.12	107.48	124.67
15	½ TOR & evap	637.03	743.94	863.2
16	½ TOR + LT	1078.43	1259.54	1461.54
17	Base + LT	1090.65	1273.62	1477.79
18	2 TOR + LT	1213.35	1417.32	1644.65
19	No evap + ½ TOR +LT	323.41	377.51	437.96
20	½ evap & TOR + LT	640.35	747.84	867.71
21	9 ft Deep	1081.39	1262.53	1464.81
22	Case 8 + 9ft	314.06	366.48	425.12
23	Case 9 + 9ft	104.97	122.52	142.13
24	1m Opaque cover	721	841.93	976.86
25	1m Trans cover	417.06	487.15	565.26

Table D-5: Required solar collector size in Miami for a small refuge with a constant tide

Small refuge in Miami		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	122.86	145.78	170.28
2	No cond	120.98	143.54	167.67
3	No solar	203.08	241.03	281.57
4	No sky	102.89	122.04	142.55
5	No conv	64.19	76.18	89
6	No evap	55.84	66.26	77.4
7	No TOR	103.62	122.93	143.59
8	No solar, evap, sky, conv	33.01	39.14	45.71
9	No evap, sky, conv	5.95	7.05	8.24
10	½ TOR	110.39	130.94	152.95
11	2 TOR	153.47	182.14	212.78
12	5 TOR	260.94	310.07	362.37
13	No evap+1/2 TOR	35.47	42.07	49.13
14	No solar, evap, sky, conv + ½ TOR	14.68	17.41	20.33
15	½ TOR & evap	67.19	79.71	93.11
16	½ TOR + LT	110.99	131.66	153.78
17	Base + LT	123.34	146.35	170.96
18	2 TOR + LT	153.8	182.54	213.25
19	No evap + ½ TOR +LT	35.69	42.33	49.44
20	½ evap & TOR + LT	67.54	80.13	93.6
21	9 ft Deep	132.57	157.26	183.68
22	Case 8 + 9ft	49.28	58.44	68.24
23	Case 9 + 9ft	15.98	18.95	22.13
24	1m Opaque cover	93.35	110.71	129.31
25	1m Trans cover	52.2	61.93	72.34

Table D-6: Required solar collector size in Miami for a large refuge with a constant tide

Large refuge in Miami		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	732.96	869.66	1015.87
2	No cond	725.88	861.24	1006.02
3	No solar	1213.68	1440.48	1682.78
4	No sky	613.56	727.71	849.97
5	No conv	381.95	453.3	529.53
6	No evap	332.05	394.02	460.27
7	No TOR	616.24	731.08	853.95
8	No solar, evap, sky, conv	195.17	231.41	270.25
9	No evap, sky, conv	34.46	40.86	47.72
10	½ TOR	657.63	780.07	911.15
11	2 TOR	917.37	1088.76	1271.92
12	5 TOR	1562.52	1856.74	2169.93
13	No evap+1/2 TOR	210.09	249.23	291.11
14	No solar, evap, sky, conv + ½ TOR	85.31	101.13	118.1
15	½ TOR & evap	399.7	474.2	553.89
16	½ TOR + LT	660.95	784.02	915.77
17	Base + LT	735.63	872.84	1019.59
18	2 TOR + LT	919.23	1090.97	1274.52
19	No evap + ½ TOR +LT	211.36	250.7	292.81
20	½ evap & TOR + LT	401.65	476.52	556.6
21	9 ft Deep	790.51	937.7	1095.26
22	Case 8 + 9ft	291.36	345.46	403.43
23	Case 9 + 9ft	93.18	110.5	129.05
24	1m Opaque cover	556.3	659.81	770.63
25	1m Trans cover	310.06	367.87	429.7

Table D-7: Required solar collector size in Cape Canaveral for a small refuge with a variable tide

Small refuge in Cape Canaveral		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	650.37	709.59	804.29
2	No cond	641.75	700.17	793.61
3	No solar	844.73	923.07	1046.7
4	No sky	584.04	637.18	722.19
5	No conv	417.56	455.5	516.25
6	No evap	384.34	419.28	475.2
7	No TOR	394.41	430.08	487.4
8	No solar, evap, sky, conv	268.13	292.51	331.53
9	No evap, sky, conv	120.13	131.04	148.52
10	½ TOR	458.84	500.41	567.13
11	2 TOR	1422.07	1555.94	1764.96
12	No evap+1/2 TOR	183.04	199.6	226.2
13	No solar, evap, sky, conv + ½ TOR	73.37	79.98	90.62
14	½ TOR & evap	324.47	353.85	401
15	½ TOR + LT	460.33	502.04	568.97
16	Base + LT	651.86	711.22	806.14
17	2 TOR + LT	1423.6	1557.62	1766.87
18	No evap + ½ TOR +LT	184.52	201.21	228.03
19	½ evap & TOR + LT	325.94	355.45	402.82
20	9 ft Deep	651.21	710.29	805.01
21	Case 8 + 9 ft	270.28	294.77	334.07
22	Case 9 + 9 ft	116.83	127.41	144.39
23	1m Opaque cover	522.41	570.34	646.56
24	1m Trans cover	367.95	401.37	454.9

Table D-8: Required solar collector size in Cape Canaveral for a large refuge with a variable tide

Large refuge in Cape Canaveral		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	3881.3	4234.68	4799.79
2	No cond	3850.53	4201.04	4761.63
3	No solar	5047.32	5515.36	6254.04
4	No sky	3483.03	3800.07	4307.12
5	No conv	2484.53	2710.23	3071.66
6	No evap	2285.39	2493.09	2825.61
7	No TOR	2347	2559.26	2900.32
8	No solar, evap, sky, conv	1588.1	1732.54	1963.64
9	No evap, sky, conv	706.43	770.57	873.34
10	½ TOR	2732.85	2980.44	3377.77
11	2 TOR	8510.1	9311.15	10561.93
12	No evap+1/2 TOR	1077.89	1175.41	1332.03
13	No solar, evap, sky, conv + ½ TOR	420.01	457.85	518.81
14	½ TOR & evap	1926.69	2101.1	2381.09
15	½ TOR + LT	2740.91	2989.25	3387.76
16	Base + LT	3889.3	4243.43	4809.72
17	2 TOR + LT	8518.28	9320.14	10572.14
18	No evap + ½ TOR +LT	1085.85	1184.1	1341.88
19	½ evap & TOR + LT	1934.64	2109.77	2390.92
20	9 ft Deep	3878.56	4230.42	4794.53
21	Case 8 + 9 ft	1593.19	1737.59	1969.21
22	Case 9 + 9 ft	679.97	741.54	840.38
23	1m Opaque cover	3113.34	3398.97	3853.17
24	1m Trans cover	2186.95	2385.53	2703.67

Table D-9: Required solar collector size in West Palm Beach for a small refuge with a variable tide

Small refuge in West Palm Beach		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	172.19	201.05	233.26
2	No cond	168.64	196.9	228.46
3	No solar	308.23	360.1	417.88
4	No sky	139.17	162.48	188.52
5	No conv	63.32	73.94	85.79
6	No evap	43.85	51.21	59.41
7	No TOR	187.58	218.93	253.99
8	No solar, evap, sky, conv	9.18	10.71	12.42
9	No evap, sky, conv	0	0	0
10	½ TOR	181.85	212.37	246.41
11	2 TOR	183.41	214.26	248.63
12	No evap+1/2 TOR	29.99	35	40.6
13	No solar, evap, sky, conv + ½ TOR	0	0	0
14	½ TOR & evap	91.48	106.81	123.92
15	½ TOR + LT	182.89	213.59	247.83
16	Base + LT	173.1	202.11	234.5
17	2 TOR + LT	183.93	214.87	249.33
18	No evap + ½ TOR +LT	30.35	35.41	41.08
19	½ evap & TOR + LT	92.39	107.88	125.16
20	9 ft Deep	163.06	190.34	220.83
21	Case 8 + 9 ft	7.44	8.68	10.07
22	Case 9 + 9 ft	0	0	0
23	1m Opaque cover	117.61	137.3	159.3
24	1m Trans cover	40.67	47.49	55.1

Table D-10: Required solar collector size in West Palm Beach for a large refuge with a variable tide

Large refuge in West Palm Beach		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	1024.6	1196.31	1388.01
2	No cond	1011.86	1181.42	1370.73
3	No solar	1840.62	2150.38	2495.42
4	No sky	827.12	965.65	1120.36
5	No conv	373.17	435.75	505.57
6	No evap	258.04	301.36	349.66
7	No TOR	1116.07	1303	1511.78
8	No solar, evap, sky, conv	50.35	58.74	68.13
9	No evap, sky, conv	0	0	0
10	½ TOR	1082.38	1264	1466.62
11	2 TOR	1094	1277.99	1482.96
12	No evap+1/2 TOR	175.33	204.59	237.33
13	No solar, evap, sky, conv + ½ TOR	0	0	0
14	½ TOR & evap	540.31	630.86	731.94
15	½ TOR + LT	1088.03	1270.61	1474.3
16	Base + LT	1029.53	1202.08	1394.7
17	2 TOR + LT	1096.8	1281.27	1486.77
18	No evap + ½ TOR +LT	177.24	206.82	239.92
19	½ evap & TOR + LT	545.26	636.65	738.65
20	9 ft Deep	966.52	1128.22	1308.91
21	Case 8 + 9 ft	38.06	44.4	51.5
22	Case 9 + 9 ft	0	0	0
23	1m Opaque cover	697.43	814.16	944.55
24	1m Trans cover	238.79	278.87	323.56

Table D-11: Required solar collector size in Miami for a small refuge with a variable tide

Small refuge in Miami		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	99.33	117.82	137.61
2	No cond	96.79	114.8	134.08
3	No solar	214.34	254.34	297.11
4	No sky	76.98	91.28	106.6
5	No conv	36.21	42.97	50.19
6	No evap	26.37	31.29	36.55
7	No TOR	98.11	116.37	135.92
8	No solar, evap, sky, conv	8.1	9.6	11.21
9	No evap, sky, conv	0	0	0
10	½ TOR	97.41	115.55	134.96
11	2 TOR	132.89	157.7	184.21
12	No evap+1/2 TOR	11.59	13.74	16.04
13	No solar, evap, sky, conv + ½ TOR	0	0	0
14	½ TOR & evap	43.23	51.25	59.86
15	½ TOR + LT	98.28	116.58	136.17
16	Base + LT	100	118.6	138.52
17	2 TOR + LT	133.22	158.08	184.67
18	No evap + ½ TOR +LT	11.89	14.1	16.46
19	½ evap & TOR + LT	43.78	51.91	60.63
20	9 ft Deep	90.2	106.96	124.91
21	Case 8 + 9 ft	6.38	7.56	8.83
22	Case 9 + 9 ft	0	0	0
23	1m Opaque cover	78.94	93.63	109.35
24	1m Trans cover	22.78	27.03	31.58

Table D-12: Required solar collector size in Miami for a large refuge with a variable tide

Large refuge in Miami		Unglazed	Glazing	Evacuated
Case	Desc	m^2	m^2	m^2
1	Base	590.17	699.98	817.55
2	No cond	580.74	688.79	804.48
3	No solar	1279.64	1518.47	1773.78
4	No sky	456.58	541.38	632.25
5	No conv	212.93	252.63	295.08
6	No evap	155.06	183.99	214.92
7	No TOR	581.77	690.09	806.01
8	No solar, evap, sky, conv	44.85	53.17	62.08
9	No evap, sky, conv	0	0	0
10	½ TOR	577.76	685.32	800.45
11	2 TOR	793.36	941.46	1099.76
12	No evap+1/2 TOR	65.61	77.78	90.83
13	No solar, evap, sky, conv + ½ TOR	0	0	0
14	½ TOR & evap	254	301.16	351.71
15	½ TOR + LT	582.48	690.92	806.99
16	Base + LT	593.66	704.12	822.39
17	2 TOR + LT	795.13	943.56	1102.21
18	No evap + ½ TOR +LT	67.25	79.72	93.1
19	½ evap & TOR + LT	257.01	304.74	355.89
20	9 ft Deep	533.44	632.53	738.69
21	Case 8 + 9 ft	33.04	39.16	45.72
22	Case 9 + 9 ft	0	0	0
23	1m Opaque cover	467.6	554.56	647.68
24	1m Trans cover	133.59	158.53	185.19

Appendix E: Number of solar panels and flow rate requirements

This appendix provides number of solar collector panels based on a typical size in three different types and totally required water flow rates to meet 95% of time in Dec. 1989 in three locations, two typed of refuges, and two different tidal impacts. The solar collector type consists of Unglazed, glazing and evacuated collectors.

All twelve tables listed below have the same format. The first two columns show case number and a brief description. The next three columns present required number of solar collector panels based on a typical panel size for each type of collector. The last three columns present totally required water flow rate for each type of collector.

Table E-1: Number of panels and required water flow rate in Cape Canaveral for a small refuge with a constant tide

Small Refuge in Cape Canaveral		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	209	228	403	834.6	273.9	319.6
2	No cond	207	227	400	828.2	271.8	317.1
3	No solar	253	277	490	1010.0	332.3	388.0
4	No sky	194	212	374	774.7	254.2	296.5
5	No conv	157	171	302	625.5	205.2	239.3
6	No evap	149	163	287	594.9	195.1	227.6
7	No TOR	89	97	171	354.9	116.3	135.6
8	No solar, evap, sky, conv	124	136	240	495.7	162.7	189.9
9	No evap, sky, conv	85	92	163	338.1	110.8	129.2
10	½ TOR	149	162	287	594.3	194.8	227.3
11	2 TOR	329	360	636	1313.6	432.0	504.4
12	5 TOR	686	756	1339	2739.0	906.9	1061.0
13	No evap+1/2 TOR	89	97	172	355.8	116.6	136.0
14	No solar, evap, sky, conv + ½ TOR	63	69	121	251.3	82.4	96.1
15	½ TOR & evap	119	129	228	473.6	155.2	181.1
16	½ TOR + LT	149	163	287	595.7	195.3	227.8
17	Base + LT	209	229	404	835.9	274.3	320.1
18	2 TOR + LT	329	360	637	1314.9	432.5	505.0
19	No evap + ½ TOR +LT	89	98	172	357.0	117.0	136.5
20	½ evap & TOR + LT	119	130	229	474.9	155.6	181.5
21	9 ft Deep	270	295	521	1077.8	353.7	412.7
22	Case 8 + 9ft	186	203	359	742.3	243.7	284.4
23	Case 9 + 9ft	143	156	276	572.3	187.6	218.9
24	1m Opaque cover	181	198	349	722.1	237.3	277.0
25	1m Trans cover	145	159	280	580.2	190.2	221.9

Table E-2: Number of panels and required water flow rate in Cape Canaveral for a large refuge with a constant tide

Large Refuge in Cape Canaveral		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	1250	1366	2413	4993.7	1638.8	1912.2
2	No cond	1244	1359	2401	4969.1	1630.7	1902.7
3	No solar	1514	1658	2931	6046.0	1989.1	2322.5
4	No sky	1160	1267	2238	4634.4	1520.5	1774.0
5	No conv	936	1022	1805	3738.9	1226.4	1430.7
6	No evap	890	972	1716	3555.7	1165.9	1360.1
7	No TOR	530	578	1020	2115.3	693.0	808.2
8	No solar, evap, sky, conv	741	810	1431	2960.8	972.1	1134.2
9	No evap, sky, conv	505	551	973	2017.6	661.3	771.2
10	½ TOR	889	970	1714	3552.1	1164.4	1358.2
11	2 TOR	1970	2157	3812	7867.7	2587.6	3021.3
12	5 TOR	4111	4531	8026	16420.7	5437.2	6360.6
13	No evap+1/2 TOR	531	579	1023	2120.9	695.1	810.6
14	No solar, evap, sky, conv + ½ TOR	374	408	721	1494.2	489.9	571.4
15	½ TOR & evap	708	772	1364	2827.9	926.9	1081.0
16	½ TOR + LT	891	972	1717	3559.4	1166.8	1361.0
17	Base + LT	1252	1368	2416	5001.0	1641.2	1915.0
18	2 TOR + LT	1972	2159	3816	7875.0	2590.1	3024.1
19	No evap + ½ TOR +LT	533	581	1026	2127.9	697.3	813.2
20	½ evap & TOR + LT	710	774	1367	2834.9	929.1	1083.7
21	9 ft Deep	1614	1763	3114	6445.8	2115.2	2467.9
22	Case 8 + 9ft	1110	1213	2143	4433.7	1455.6	1698.5
23	Case 9 + 9ft	855	933	1647	3413.9	1119.2	1305.5
24	1m Opaque cover	1081	1183	2090	4318.8	1419.2	1656.5
25	1m Trans cover	868	948	1674	3467.3	1137.0	1326.3

Table E-3: Number of panels and required water flow rate in West Palm Beach for a small refuge with a constant tide

Small Refuge in West Palm Beach		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	41	48	87	163.9	57.5	68.6
2	No cond	40	47	85	161.6	56.7	67.7
3	No solar	64	74	134	253.9	89.1	106.4
4	No sky	35	41	73	138.8	48.7	58.1
5	No conv	19	22	40	76.2	26.7	31.9
6	No evap	17	20	36	67.9	23.8	28.5
7	No TOR	43	50	91	172.1	60.4	72.1
8	No solar, evap, sky, conv	8	9	17	32.1	11.2	13.4
9	No evap, sky, conv	2	2	3	6.6	2.3	2.8
10	½ TOR	41	47	86	162.0	56.8	67.9
11	2 TOR	46	53	96	182.3	64.0	76.4
12	5 TOR	69	81	146	275.8	96.9	115.8
13	No evap+1/2 TOR	12	14	26	48.8	17.1	20.4
14	No solar, evap, sky, conv + ½ TOR	4	4	8	14.3	5.0	6.0
15	½ TOR & evap	24	28	51	96.4	33.8	40.4
16	½ TOR + LT	41	48	86	162.8	57.1	68.2
17	Base + LT	41	48	87	164.5	57.7	68.9
18	2 TOR + LT	46	53	97	182.7	64.1	76.5
19	No evap + ½ TOR +LT	12	14	26	49.2	17.2	20.6
20	½ evap & TOR + LT	24	28	51	96.9	34.0	40.6
21	9 ft Deep	41	48	86	163.3	57.3	68.4
22	Case 8 + 9ft	12	14	25	47.9	16.8	20.0
23	Case 9 + 9ft	4	5	9	16.3	5.7	6.8
24	1m Opaque cover	27	32	58	108.9	38.2	45.6
25	1m Trans cover	16	18	33	63.1	22.1	26.4

Table E-4: Number of panels and required water flow rate in West Palm Beach for a large refuge with a constant tide

Large Refuge in West Palm Beach		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	245	286	517	978.0	343.0	409.6
2	No cond	243	283	512	969.8	340.2	406.1
3	No solar	380	444	803	1517.3	532.7	636.1
4	No sky	207	242	437	828.1	290.4	346.7
5	No conv	113	132	239	452.9	158.9	189.7
6	No evap	101	118	214	403.9	141.7	169.2
7	No TOR	257	300	542	1025.7	359.8	429.6
8	No solar, evap, sky, conv	47	55	100	189.3	66.3	79.2
9	No evap, sky, conv	10	11	20	38.4	13.5	16.1
10	½ TOR	242	283	511	966.2	339.0	404.8
11	2 TOR	273	319	576	1089.3	382.2	456.4
12	5 TOR	413	484	875	1651.3	580.4	693.4
13	No evap+1/2 TOR	72	84	153	289.1	101.4	121.0
14	No solar, evap, sky, conv + ½ TOR	21	24	44	82.9	29.0	34.7
15	½ TOR & evap	143	168	303	573.1	201.0	240.0
16	½ TOR + LT	243	284	513	970.2	340.4	406.4
17	Base + LT	246	287	519	981.2	344.2	410.9
18	2 TOR + LT	273	319	577	1091.5	383.0	457.3
19	No evap + ½ TOR +LT	73	85	154	290.9	102.0	121.8
20	½ evap & TOR + LT	144	168	304	576.1	202.1	241.3
21	9 ft Deep	244	284	514	972.8	341.2	407.3
22	Case 8 + 9ft	71	83	149	282.5	99.0	118.2
23	Case 9 + 9ft	24	28	50	94.4	33.1	39.5
24	1m Opaque cover	162	190	343	648.6	227.5	271.6
25	1m Trans cover	94	110	198	375.2	131.6	157.2

Table E-5: Number of panels and required water flow rate in Miami for a small refuge with a constant tide

Small Refuge in Miami		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	28	33	60	110.5	39.4	47.4
2	No cond	27	32	59	108.8	38.8	46.6
3	No solar	46	54	99	182.7	65.1	78.3
4	No sky	23	27	50	92.6	33.0	39.6
5	No conv	14	17	31	57.7	20.6	24.7
6	No evap	13	15	27	50.2	17.9	21.5
7	No TOR	23	28	50	93.2	33.2	39.9
8	No solar, evap, sky, conv	7	9	16	29.7	10.6	12.7
9	No evap, sky, conv	1	2	3	5.4	1.9	2.3
10	½ TOR	25	29	54	99.3	35.4	42.5
11	2 TOR	35	41	75	138.1	49.2	59.2
12	5 TOR	59	70	127	234.7	83.8	100.8
13	No evap+1/2 TOR	8	9	17	31.9	11.4	13.7
14	No solar, evap, sky, conv + ½ TOR	3	4	7	13.2	4.7	5.7
15	½ TOR & evap	15	18	33	60.4	21.5	25.9
16	½ TOR + LT	25	30	54	99.8	35.6	42.8
17	Base + LT	28	33	60	111.0	39.5	47.5
18	2 TOR + LT	35	41	75	138.4	49.3	59.3
19	No evap + ½ TOR +LT	8	10	17	32.1	11.4	13.7
20	½ evap & TOR + LT	15	18	33	60.8	21.7	26.0
21	9 ft Deep	30	35	64	119.3	42.5	51.1
22	Case 8 + 9ft	11	13	24	44.3	15.8	19.0
23	Case 9 + 9ft	4	4	8	14.4	5.1	6.2
24	1m Opaque cover	21	25	45	84.0	29.9	36.0
25	1m Trans cover	12	14	25	47.0	16.7	20.1

Table E-6: Number of panels and required water flow rate in Miami for a large refuge with a constant tide

Large Refuge in Miami		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	165	196	356	659.4	235.0	282.5
2	No cond	163	194	353	653.0	232.7	279.7
3	No solar	273	324	590	1091.8	389.3	467.9
4	No sky	138	164	298	552.0	196.7	236.4
5	No conv	86	102	186	343.6	122.5	147.2
6	No evap	75	89	161	298.7	106.5	128.0
7	No TOR	139	165	300	554.4	197.6	237.5
8	No solar, evap, sky, conv	44	52	95	175.6	62.5	75.1
9	No evap, sky, conv	8	9	17	31.0	11.0	13.3
10	½ TOR	148	176	320	591.6	210.8	253.4
11	2 TOR	207	245	446	825.3	294.2	353.7
12	5 TOR	352	418	761	1405.7	501.8	603.4
13	No evap+1/2 TOR	47	56	102	189.0	67.4	81.0
14	No solar, evap, sky, conv + ½ TOR	19	23	41	76.7	27.3	32.8
15	½ TOR & evap	90	107	194	359.6	128.1	154.0
16	½ TOR + LT	149	177	321	594.6	211.9	254.7
17	Base + LT	166	197	358	661.8	235.9	283.5
18	2 TOR + LT	207	246	447	827.0	294.8	354.4
19	No evap + ½ TOR +LT	48	56	103	190.1	67.7	81.4
20	½ evap & TOR + LT	90	107	195	361.3	128.8	154.8
21	9 ft Deep	178	211	384	711.2	253.4	304.6
22	Case 8 + 9ft	66	78	142	262.1	93.4	112.2
23	Case 9 + 9ft	21	25	45	83.8	29.9	35.9
24	1m Opaque cover	125	149	270	500.5	178.3	214.3
25	1m Trans cover	70	83	151	278.9	99.4	119.5

Table E-7: Number of panels and required water flow rate in Cape Canaveral for a small refuge with a variable tide

Small Refuge in Cape Canaveral		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	146	160	181	585.1	191.8	143.6
2	No cond	145	158	179	577.3	189.2	141.7
3	No solar	190	208	236	759.9	249.5	186.8
4	No sky	132	144	163	525.4	172.2	128.9
5	No conv	94	103	116	375.6	123.1	92.1
6	No evap	87	94	107	345.8	113.3	84.8
7	No TOR	89	97	110	354.8	116.2	87.0
8	No solar, evap, sky, conv	60	66	75	241.2	79.0	59.2
9	No evap, sky, conv	27	30	33	108.1	35.4	26.5
10	½ TOR	103	113	128	412.8	135.2	101.2
11	2 TOR	320	350	398	1279.3	420.5	315.0
12	No evap+1/2 TOR	41	45	51	164.7	53.9	40.4
13	No solar, evap, sky, conv + ½ TOR	17	18	20	66.0	21.6	16.2
14	½ TOR & evap	73	80	90	291.9	95.6	71.6
15	½ TOR + LT	104	113	128	414.1	135.7	101.6
16	Base + LT	147	160	182	586.4	192.2	143.9
17	2 TOR + LT	321	351	398	1280.7	420.9	315.4
18	No evap + ½ TOR +LT	42	45	51	166.0	54.4	40.7
19	½ evap & TOR + LT	73	80	91	293.2	96.1	71.9
20	9 ft Deep	147	160	181	585.8	191.9	143.7
21	Case 8 + 9 ft	61	66	75	243.1	79.7	59.6
22	Case 9 + 9 ft	26	29	33	105.1	34.4	25.8
23	1m Opaque cover	118	128	146	470.0	154.1	115.4
24	1m Trans cover	83	90	102	331.0	108.5	81.2

Table E-8: Number of panels and required water flow rate in Cape Canaveral for a large refuge with a variable tide

Large Refuge in Cape Canaveral		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	874	954	1081	3491.7	1144.4	856.7
2	No cond	867	946	1072	3464.0	1135.3	849.9
3	No solar	1137	1242	1409	4540.6	1490.5	1116.3
4	No sky	784	856	970	3133.4	1026.9	768.8
5	No conv	560	610	692	2235.1	732.4	548.3
6	No evap	515	562	636	2056.0	673.7	504.4
7	No TOR	529	576	653	2111.4	691.6	517.7
8	No solar, evap, sky, conv	358	390	442	1428.7	468.2	350.5
9	No evap, sky, conv	159	174	197	635.5	208.2	155.9
10	½ TOR	616	671	761	2458.5	805.4	602.9
11	2 TOR	1917	2097	2379	7655.8	2516.3	1885.2
12	No evap+1/2 TOR	243	265	300	969.7	317.6	237.8
13	No solar, evap, sky, conv + ½ TOR	95	103	117	377.8	123.7	92.6
14	½ TOR & evap	434	473	536	1733.3	567.8	425.0
15	½ TOR + LT	617	673	763	2465.8	807.8	604.7
16	Base + LT	876	956	1083	3498.9	1146.7	858.5
17	2 TOR + LT	1919	2099	2381	7663.2	2518.7	1887.1
18	No evap + ½ TOR +LT	245	267	302	976.8	320.0	239.5
19	½ evap & TOR + LT	436	475	538	1740.4	570.1	426.8
20	9 ft Deep	874	953	1080	3489.2	1143.2	855.8
21	Case 8 + 9 ft	359	391	444	1433.3	469.6	351.5
22	Case 9 + 9 ft	153	167	189	611.7	200.4	150.0
23	1m Opaque cover	701	766	868	2800.8	918.5	687.8
24	1m Trans cover	493	537	609	1967.4	644.7	482.6

Table E-9: Number of panels and required water flow rate in West Palm Beach for a small refuge with a variable tide

Small Refuge in West Palm Beach		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	39	45	82	154.9	54.3	64.9
2	No cond	38	44	80	151.7	53.2	63.5
3	No solar	69	81	147	277.3	97.3	116.2
4	No sky	31	37	66	125.2	43.9	52.4
5	No conv	14	17	30	57.0	20.0	23.9
6	No evap	10	12	21	39.4	13.8	16.5
7	No TOR	42	49	89	168.7	59.2	70.6
8	No solar, evap, sky, conv	2	2	4	8.3	2.9	3.5
9	No evap, sky, conv	0	0	0	0.0	0.0	0.0
10	½ TOR	41	48	86	163.6	57.4	68.5
11	2 TOR	41	48	87	165.0	57.9	69.1
12	No evap+1/2 TOR	7	8	14	27.0	9.5	11.3
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0.0	0.0	0.0
14	½ TOR & evap	21	24	43	82.3	28.9	34.5
15	½ TOR + LT	41	48	87	164.5	57.7	68.9
16	Base + LT	39	46	82	155.7	54.6	65.2
17	2 TOR + LT	41	48	87	165.5	58.1	69.3
18	No evap + ½ TOR +LT	7	8	14	27.3	9.6	11.4
19	½ evap & TOR + LT	21	24	44	83.1	29.2	34.8
20	9 ft Deep	37	43	77	146.7	51.4	61.4
21	Case 8 + 9 ft	2	2	4	6.7	2.3	2.8
22	Case 9 + 9 ft	0	0	0	0.0	0.0	0.0
23	1m Opaque cover	26	31	56	105.8	37.1	44.3
24	1m Trans cover	9	11	19	36.6	12.8	15.3

Table E-10: Number of panels and required water flow rate in West Palm Beach for a large refuge with a variable tide

Large Refuge in West Palm Beach		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	231	269	487	921.7	323.3	386.0
2	No cond	228	266	481	910.3	319.3	381.2
3	No solar	415	484	876	1655.8	581.1	693.9
4	No sky	186	217	393	744.1	261.0	311.5
5	No conv	84	98	177	335.7	117.8	140.6
6	No evap	58	68	123	232.1	81.4	97.2
7	No TOR	251	293	530	1004.0	352.1	420.4
8	No solar, evap, sky, conv	11	13	24	45.3	15.9	18.9
9	No evap, sky, conv	0	0	0	0.0	0.0	0.0
10	½ TOR	244	285	515	973.7	341.6	407.8
11	2 TOR	246	288	520	984.2	345.4	412.4
12	No evap+1/2 TOR	39	46	83	157.7	55.3	66.0
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0.0	0.0	0.0
14	½ TOR & evap	122	142	257	486.1	170.5	203.5
15	½ TOR + LT	245	286	517	978.8	343.4	410.0
16	Base + LT	232	271	489	926.2	324.9	387.8
17	2 TOR + LT	247	289	522	986.7	346.3	413.4
18	No evap + ½ TOR +LT	40	47	84	159.4	55.9	66.7
19	½ evap & TOR + LT	123	143	259	490.5	172.0	205.4
20	9 ft Deep	218	254	459	869.5	304.9	364.0
21	Case 8 + 9 ft	9	10	18	34.2	12.0	14.3
22	Case 9 + 9 ft	0	0	0	0.0	0.0	0.0
23	1m Opaque cover	157	183	331	627.4	220.0	262.7
24	1m Trans cover	54	63	114	214.8	75.4	90.0

Table E-11: Number of panels and required water flow rate in Miami for a small refuge with a variable tide

Small Refuge in Miami		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	22	27	48	89.4	31.8	38.3
2	No cond	22	26	47	87.1	31.0	37.3
3	No solar	48	57	104	192.8	68.7	82.6
4	No sky	17	21	37	69.3	24.7	29.6
5	No conv	8	10	18	32.6	11.6	14.0
6	No evap	6	7	13	23.7	8.5	10.2
7	No TOR	22	26	48	88.3	31.4	37.8
8	No solar, evap, sky, conv	2	2	4	7.3	2.6	3.1
9	No evap, sky, conv	0	0	0	0.0	0.0	0.0
10	½ TOR	22	26	47	87.6	31.2	37.5
11	2 TOR	30	36	65	119.5	42.6	51.2
12	No evap+1/2 TOR	3	3	6	10.4	3.7	4.5
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0.0	0.0	0.0
14	½ TOR & evap	10	12	21	38.9	13.8	16.6
15	½ TOR + LT	22	26	48	88.4	31.5	37.9
16	Base + LT	23	27	49	90.0	32.1	38.5
17	2 TOR + LT	30	36	65	119.8	42.7	51.4
18	No evap + ½ TOR +LT	3	3	6	10.7	3.8	4.6
19	½ evap & TOR + LT	10	12	21	39.4	14.0	16.9
20	9 ft Deep	20	24	44	81.1	28.9	34.7
21	Case 8 + 9 ft	1	2	3	5.7	2.0	2.5
22	Case 9 + 9 ft	0	0	0	0.0	0.0	0.0
23	1m Opaque cover	18	21	38	71.0	25.3	30.4
24	1m Trans cover	5	6	11	20.5	7.3	8.8

Table E-12: Number of panels and required water flow rate in Miami for a large refuge with a variable tide

Large Refuge in Miami		Number of panels			Flow rate (gpm)		
Case	Desc	Unglazed	Glazed	Evacuated	Unglazed	Glazed	Evacuated
1	Base	133	158	287	530.9	189.2	227.3
2	No cond	131	155	282	522.4	186.1	223.7
3	No solar	288	342	622	1151.2	410.4	493.2
4	No sky	103	122	222	410.7	146.3	175.8
5	No conv	48	57	104	191.6	68.3	82.1
6	No evap	35	41	75	139.5	49.7	59.8
7	No TOR	131	155	283	523.4	186.5	224.1
8	No solar, evap, sky, conv	10	12	22	40.3	14.4	17.3
9	No evap, sky, conv	0	0	0	0.0	0.0	0.0
10	½ TOR	130	154	281	519.8	185.2	222.6
11	2 TOR	179	212	386	713.7	254.4	305.8
12	No evap+1/2 TOR	15	18	32	59.0	21.0	25.3
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0.0	0.0	0.0
14	½ TOR & evap	57	68	123	228.5	81.4	97.8
15	½ TOR + LT	131	156	283	524.0	186.7	224.4
16	Base + LT	134	159	289	534.1	190.3	228.7
17	2 TOR + LT	179	213	387	715.3	255.0	306.5
18	No evap + ½ TOR +LT	15	18	33	60.5	21.5	25.9
19	½ evap & TOR + LT	58	69	125	231.2	82.4	99.0
20	9 ft Deep	120	142	259	479.9	170.9	205.4
21	Case 8 + 9 ft	7	9	16	29.7	10.6	12.7
22	Case 9 + 9 ft	0	0	0	0.0	0.0	0.0
23	1m Opaque cover	105	125	227	420.7	149.9	180.1
24	1m Trans cover	30	36	65	120.2	42.8	51.5

Appendix F: Initial cost of solar panels and water pumps

This appendix provides initial costs for solar collectors, water pumps, and gas fired boilers. It involves three types of solar collectors, two types of tidal impact. The initial costs of gas fired boilers are included in the Cape Canaveral site only, because they are unnecessary in both West Palm Beach and Miami.

All twelve tables listed below have the same format. The first two columns show case number and a brief description. The next three columns present initial investment for three different solar collectors. Columns 6-8 present initial costs of water pumps and associated pipe costs corresponding to the water flow requirement for each type of solar collector. Column 9 presents initial costs of backup gas boilers, including equipment and installation costs. Columns 10-12 are values of total initial cost by adding costs of collectors, water pumps and boilers together.

Table F-1: Initial costs of solar water heating systems for a small refuge in Cape Canaveral with a constant tide

Small refuge in Cape Canaveral		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	149091	402016	1309454	9360	3072	3584	10456	168907	415544	1323495
2	No cond	147946	398918	1299360	9288	3048	3557	10419	167653	412385	1313335
3	No solar	180422	487705	1589648	11327	3726	4351	10689	202438	502120	1604688
4	No sky	138394	373064	1215058	8688	2851	3326	10132	157215	386047	1228516
5	No conv	111733	301127	980644	7015	2301	2684	8538	127285	311966	991866
6	No evap	106272	286328	932380	6672	2188	2552	8771	121715	297287	943703
7	No TOR	63394	170648	555534	3980	1304	1521	8051	75424	180003	565105
8	No solar, evap, sky, conv	88554	238881	778121	5559	1825	2130	7700	101813	248405	787950
9	No evap, sky, conv	60403	162660	529579	3792	1243	1450	7527	71722	171429	538555
10	½ TOR	106174	285975	931172	6666	2185	2549	9258	122098	297419	942979
11	2 TOR	234657	634126	2066827	14732	4845	5657	14059	263448	653030	2086544
12	5 TOR	489297	1331185	4347173	30718	10171	11899	26895	546910	1368251	4385967
13	No evap+1/2 TOR	63561	171140	557163	3990	1308	1525	7056	74608	179504	565745
14	No solar, evap, sky, conv + ½ TOR	44898	120944	393800	2819	924	1078	5239	52955	127106	400117
15	½ TOR & evap	84607	227850	741855	5312	1741	2031	8151	98070	237742	752037
16	½ TOR + LT	106409	286610	933246	6680	2190	2554	9262	122351	298062	945063
17	Base + LT	149328	402655	1311540	9375	3077	3590	10460	169164	416192	1325590
18	2 TOR + LT	234897	634776	2068958	14747	4850	5663	14063	263706	653689	2088684
19	No evap + ½ TOR +LT	63780	171727	559089	4004	1312	1530	7060	74844	180100	567679
20	½ evap & TOR + LT	84832	228456	743826	5326	1746	2036	8155	98313	238357	754017
21	9 ft Deep	192534	519116	1690801	12087	3966	4628	11836	216458	534918	1707265
22	Case 8 + 9ft	132612	357730	1165233	8325	2733	3189	10124	151062	370588	1178547
23	Case 9 + 9ft	102238	275404	896741	6418	2104	2454	9870	118526	287378	909065
24	1m Opaque cover	128999	348301	1134846	8099	2661	3106	8371	145468	359333	1146323
25	1m Trans cover	103641	279240	909308	6507	2134	2489	8513	118661	289887	920310

Table F-2: Initial costs of solar water heating systems for a large refuge in Cape Canaveral with a constant tide

Large refuge in Cape Canaveral		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	892067	2405390	7834874	56004	18379	21445	43276	991347	2467045	7899595
2	No cond	887677	2393510	7796135	55728	18288	21339	43169	986574	2454967	7860643
3	No solar	1080064	2919544	9516025	67806	22308	26047	44302	1192172	2986153	9586373
4	No sky	827891	2231699	7268505	51975	17052	19895	41816	921681	2290567	7330215
5	No conv	667917	1800073	5862078	41932	13754	16045	34321	744170	1848147	5912445
6	No evap	635183	1711341	5572679	39877	13076	15253	35450	710510	1759868	5623382
7	No TOR	377869	1017158	3311281	23723	7772	9063	31918	433509	1056848	3352262
8	No solar, evap, sky, conv	528908	1426754	4647397	33205	10902	12721	30213	592325	1467869	4690330
9	No evap, sky, conv	360431	970579	3159984	22628	7416	8649	29292	412351	1007287	3197926
10	½ TOR	634551	1709136	5565170	39837	13059	15233	37771	712159	1759966	5618174
11	2 TOR	1405475	3798059	12379157	88235	29020	33883	57954	1551664	3885033	12470995
12	5 TOR	2933391	7980575	26061685	184158	60978	71334	84056	3201604	8125609	26217075
13	No evap+1/2 TOR	378878	1020200	3321444	23786	7795	9091	26864	429528	1054859	3357399
14	No solar, evap, sky, conv + ½ TOR	266924	719029	2341176	16757	5494	6408	17207	300888	741730	2364791
15	½ TOR & evap	505178	1360430	4429401	31715	10395	12124	32417	569310	1403242	4473942
16	½ TOR + LT	635851	1712650	5576609	39919	13086	15264	37788	713558	1763524	5629661
17	Base + LT	893374	2408924	7846393	56086	18406	21477	43292	992752	2470622	7911161
18	2 TOR + LT	1406796	3801653	12390893	88318	29048	33916	57967	1553081	3888667	12482775
19	No evap + ½ TOR +LT	380124	1023489	3332097	23864	7820	9120	26882	430870	1058191	3368100
20	½ evap & TOR + LT	506420	1363782	4440328	31793	10420	12154	32435	570648	1406637	4484916
21	9 ft Deep	1151473	3104618	10111938	72289	23722	27678	49192	1272954	3177531	10188807
22	Case 8 + 9ft	792042	2136570	6959485	49724	16325	19049	41821	883587	2194715	7020355
23	Case 9 + 9ft	609852	1642796	5349054	38286	12552	14641	40594	688732	1695941	5404289
24	1m Opaque cover	771513	2083093	6787178	48435	15916	18577	33504	853453	2132513	6839259
25	1m Trans cover	619392	1668808	5434211	38885	12751	14874	34198	692475	1715757	5483283

Table F-3: Initial costs of solar water heating systems for a small refuge in West Palm Beach with a constant tide

Small refuge in West Palm Beach		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	29274	84376	281231	1838	645	770	0	31112	85021	282000
2	No cond	28874	83214	277334	1813	636	759	0	30687	83850	278093
3	No solar	45350	130804	436059	2847	999	1194	0	48197	131804	437253
4	No sky	24803	71473	238197	1557	546	652	0	26361	72019	238849
5	No conv	13609	39217	130697	854	300	358	0	14463	39517	131055
6	No evap	12130	34973	116580	762	267	319	0	12892	35240	116899
7	No TOR	30750	88593	295233	1930	677	808	0	32680	89269	296041
8	No solar, evap, sky, conv	5731	16505	54997	360	126	151	0	6091	16631	55148
9	No evap, sky, conv	1181	3403	11348	74	26	31	0	1255	3429	11379
10	½ TOR	28942	83432	278086	1817	637	761	0	30759	84070	278847
11	2 TOR	32562	93880	312916	2044	717	856	0	34607	94597	313773
12	5 TOR	49266	142288	474525	3093	1087	1299	0	52359	143375	475823
13	No evap+1/2 TOR	8720	25124	83721	547	192	229	0	9267	25316	83950
14	No solar, evap, sky, conv + ½ TOR	2558	7370	24553	161	56	67	0	2719	7426	24621
15	½ TOR & evap	17215	49621	165379	1081	379	453	0	18296	50000	165832
16	½ TOR + LT	29083	83817	279351	1826	640	765	0	30909	84457	280115
17	Base + LT	29379	84682	282233	1844	647	773	0	31223	85329	283006
18	2 TOR + LT	32636	94094	313634	2049	719	858	0	34685	94813	314493
19	No evap + ½ TOR +LT	8781	25299	84313	551	193	231	0	9332	25492	84544
20	½ evap & TOR + LT	17311	49903	166314	1087	381	455	0	18398	50284	166769
21	9 ft Deep	29170	84059	280137	1831	642	767	0	31001	84701	280904
22	Case 8 + 9ft	8556	24640	82103	537	188	225	0	9093	24828	82328
23	Case 9 + 9ft	2909	8377	27926	183	64	76	0	3091	8441	28002
24	1m Opaque cover	19454	56067	186857	1221	428	511	0	20675	56495	187368
25	1m Trans cover	11275	32506	108343	708	248	297	0	11983	32754	108639

Table F-4: Initial costs of solar water heating systems for a large refuge in West Palm Beach with a constant tide

Large refuge in West Palm Beach		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	174702	503520	1678189	10968	3847	4593	0	185670	507367	1682782
2	No cond	173243	499272	1663992	10876	3815	4555	0	184119	503086	1668547
3	No solar	271052	781820	2606342	17017	5974	7134	0	288069	787793	2613476
4	No sky	147932	426275	1420646	9287	3257	3888	0	157219	429533	1424534
5	No conv	80911	233169	777061	5080	1782	2127	0	85990	234950	779188
6	No evap	72152	208037	693420	4530	1590	1898	0	76682	209626	695318
7	No TOR	183228	528108	1760166	11503	4035	4818	0	194731	532143	1764984
8	No solar, evap, sky, conv	33809	97374	324470	2123	744	888	0	35932	98118	325358
9	No evap, sky, conv	6859	19757	65833	431	151	180	0	7290	19908	66013
10	½ TOR	172610	497582	1658500	10836	3802	4540	0	183446	501384	1663040
11	2 TOR	194583	560999	1869899	12216	4286	5118	0	206799	565285	1875017
12	5 TOR	294980	851920	2841132	18519	6509	7777	0	313499	858430	2848908
13	No evap+1/2 TOR	51637	148769	495751	3242	1137	1357	0	54878	149906	497108
14	No solar, evap, sky, conv + ½ TOR	14804	42632	142045	929	326	389	0	15734	42958	142434
15	½ TOR & evap	102375	295086	983504	6427	2255	2692	0	108802	297341	986196
16	½ TOR + LT	173311	499601	1665234	10880	3817	4558	0	184191	503418	1669792
17	Base + LT	175275	505186	1683749	11004	3860	4609	0	186278	509046	1688357
18	2 TOR + LT	194993	562185	1873864	12242	4296	5129	0	207235	566480	1878993
19	No evap + ½ TOR +LT	51974	149741	498998	3263	1144	1366	0	55237	150885	500364
20	½ evap & TOR + LT	102908	296633	988642	6461	2267	2706	0	109369	298900	991348
21	9 ft Deep	173786	500787	1668960	10910	3826	4568	0	184697	504613	1673528
22	Case 8 + 9ft	50471	145366	484369	3169	1111	1326	0	53640	146476	485695
23	Case 9 + 9ft	16869	48598	161939	1059	371	443	0	17928	48969	162382
24	1m Opaque cover	115869	333954	1113004	7274	2552	3046	0	123144	336506	1116051
25	1m Trans cover	67024	193230	644040	4208	1476	1763	0	71232	194706	645803

Table F-5: Initial costs of solar water heating systems for a small refuge in Miami with a constant tide

Small refuge in Miami		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	19744	57824	194012	1240	442	531	0	20984	58266	194543
2	No cond	19442	56936	191038	1221	435	523	0	20663	57371	191561
3	No solar	32636	95605	320812	2049	730	878	0	34685	96336	321690
4	No sky	16535	48408	162417	1038	370	445	0	17573	48777	162862
5	No conv	10316	30217	101404	648	231	278	0	10963	30448	101681
6	No evap	8974	26282	88187	563	201	241	0	9537	26483	88429
7	No TOR	16652	48761	163602	1045	373	448	0	17698	49133	164050
8	No solar, evap, sky, conv	5305	15525	52081	333	119	143	0	5638	15644	52223
9	No evap, sky, conv	956	2796	9388	60	21	26	0	1016	2818	9414
10	½ TOR	17740	51938	174267	1114	397	477	0	18854	52335	174744
11	2 TOR	24664	72246	242435	1548	552	664	0	26212	72798	243099
12	5 TOR	41935	122990	412873	2633	940	1130	0	44567	123930	414003
13	No evap+1/2 TOR	5700	16687	55977	358	128	153	0	6058	16815	56130
14	No solar, evap, sky, conv + ½ TOR	2359	6906	23163	148	53	63	0	2507	6959	23227
15	½ TOR & evap	10798	31617	106087	678	242	290	0	11476	31859	106377
16	½ TOR + LT	17837	52223	175212	1120	399	480	0	18957	52622	175692
17	Base + LT	19822	58050	194787	1244	444	533	0	21066	58494	195320
18	2 TOR + LT	24717	72405	242971	1552	553	665	0	26268	72958	243636
19	No evap + ½ TOR +LT	5736	16790	56330	360	128	154	0	6096	16919	56485
20	½ evap & TOR + LT	10854	31784	106645	681	243	292	0	11536	32027	106937
21	9 ft Deep	21305	62378	209279	1338	477	573	0	22642	62854	209852
22	Case 8 + 9ft	7920	23180	77751	497	177	213	0	8417	23358	77963
23	Case 9 + 9ft	2568	7517	25214	161	57	69	0	2729	7574	25283
24	1m Opaque cover	15002	43913	147332	942	336	403	0	15944	44249	147735
25	1m Trans cover	8389	24565	82422	527	188	226	0	8916	24752	82648

Table F-6: Initial costs of solar water heating systems for a large refuge in Miami with a constant tide

Large refuge in Miami		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	117791	344954	1157451	7395	2636	3168	0	125186	347589	1160619
2	No cond	116654	341614	1146228	7323	2610	3137	0	123977	344224	1149366
3	No solar	195046	571371	1917308	12245	4366	5248	0	207291	575737	1922556
4	No sky	98603	288649	968430	6190	2205	2651	0	104793	290854	971081
5	No conv	61382	179803	603330	3854	1374	1651	0	65235	181177	604982
6	No evap	53363	156289	524418	3350	1194	1435	0	56713	157484	525853
7	No TOR	99034	289985	972964	6217	2216	2663	0	105251	292201	975628
8	No solar, evap, sky, conv	31365	91790	307915	1969	701	843	0	33334	92491	308757
9	No evap, sky, conv	5538	16207	54371	348	124	149	0	5886	16331	54520
10	½ TOR	105685	309417	1038136	6635	2364	2842	0	112320	311782	1040978
11	2 TOR	147427	431860	1449187	9255	3300	3967	0	156683	435160	1453153
12	5 TOR	251107	736482	2472352	15764	5627	6767	0	266872	742110	2479119
13	No evap+1/2 TOR	33763	98858	331682	2120	755	908	0	35882	99613	332590
14	No solar, evap, sky, conv + ½ TOR	13710	40114	134560	861	306	368	0	14571	40420	134928
15	½ TOR & evap	64234	188093	631085	4033	1437	1727	0	68267	189530	632813
16	½ TOR + LT	106219	310984	1043400	6668	2376	2856	0	112887	313360	1046256
17	Base + LT	118221	346215	1161690	7422	2645	3180	0	125642	348860	1164869
18	2 TOR + LT	147726	432737	1452149	9274	3306	3975	0	157000	436043	1456124
19	No evap + ½ TOR +LT	33967	99441	333619	2132	760	913	0	36099	100201	334532
20	½ evap & TOR + LT	64548	189013	634173	4052	1444	1736	0	68600	190457	635909
21	9 ft Deep	127040	371942	1247906	7976	2842	3416	0	135016	374784	1251321
22	Case 8 + 9ft	46823	137028	459656	2940	1047	1258	0	49763	138075	460914
23	Case 9 + 9ft	14975	43830	147036	940	335	402	0	15915	44165	147438
24	1m Opaque cover	89401	261716	878032	5613	2000	2403	0	95014	263716	880436
25	1m Trans cover	49829	145917	489587	3128	1115	1340	0	52957	147032	490927

Table F-7: Initial costs of solar water heating systems for a small refuge in Cape Canaveral with a variable tide

Small refuge in Cape Canaveral		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	104519	281461	916383	6562	2151	1610	12191	123271	295803	930185
2	No cond	103133	277725	904215	6475	2122	1589	12160	121768	292007	917964
3	No solar	135754	366139	1192578	8523	2798	2095	12191	156467	381128	1206864
4	No sky	93859	252740	822841	5892	1931	1446	11918	111670	266589	836205
5	No conv	67105	180676	588199	4213	1381	1033	11380	82697	193436	600613
6	No evap	61766	166309	541428	3878	1271	951	11512	77156	179092	553892
7	No TOR	63384	170593	555329	3979	1303	976	8057	75420	179953	564361
8	No solar, evap, sky, conv	43090	116025	377735	2705	887	664	10422	56217	127333	388821
9	No evap, sky, conv	19306	51977	169219	1212	397	297	10422	30939	62796	179938
10	½ TOR	73739	198489	646171	4629	1517	1135	8120	86488	208126	655426
11	2 TOR	228536	617169	2010941	14347	4716	3533	32642	275525	654527	2047117
12	No evap+1/2 TOR	29416	79172	257725	1847	605	453	6442	37705	86219	264620
13	No solar, evap, sky, conv + ½ TOR	11791	31724	103250	740	242	181	4709	17240	36675	108140
14	½ TOR & evap	52144	140356	456887	3274	1072	803	7230	62649	148659	464920
15	½ TOR + LT	73978	199136	648267	4644	1522	1139	8124	86747	208782	657530
16	Base + LT	104758	282108	918491	6577	2156	1614	12195	123530	296458	932300
17	2 TOR + LT	228782	617835	2013118	14363	4721	3537	32645	275790	655201	2049300
18	No evap + ½ TOR +LT	29654	79811	259810	1862	610	456	6446	37962	86867	266713
19	½ evap & TOR + LT	52381	140990	458961	3288	1077	806	7235	62904	149302	467002
20	9 ft Deep	104654	281739	917204	6570	2153	1611	12200	123424	296092	931016
21	Case 8 + 9ft	43436	116922	380629	2727	893	669	10431	56594	128246	391729
22	Case 9 + 9ft	18775	50538	164514	1179	386	289	10431	30385	61355	175234
23	1m Opaque cover	83955	226227	736671	5271	1729	1294	11172	100397	239128	749137
24	1m Trans cover	59132	159205	518299	3712	1216	911	11309	74153	171730	530519

Table F-8: Initial costs of solar water heating systems for a large refuge in Cape Canaveral with a variable tide

Large refuge in Cape Canaveral		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	623750	1679700	5468734	39159	12834	9608	50704	713613	1743238	5529046
2	No cond	618805	1666357	5425256	38848	12732	9532	50629	708283	1729718	5485416
3	No solar	811137	2187686	7125662	50923	16716	12519	50704	912764	2255106	7188885
4	No sky	559746	1507311	4907401	35141	11517	8622	49580	644467	1568408	4965603
5	No conv	399280	1075022	3499755	25067	8214	6149	47314	471661	1130550	3553219
6	No evap	367277	988893	3219414	23058	7556	5656	47876	438210	1044324	3272946
7	No TOR	377178	1015139	3304536	23679	7756	5806	31930	432787	1054826	3342272
8	No solar, evap, sky, conv	255218	687218	2237311	16023	5251	3931	43124	314365	735593	2284367
9	No evap, sky, conv	113528	305649	995057	7127	2335	1748	43124	163780	351109	1039930
10	½ TOR	439187	1182202	3848528	27572	9033	6762	32246	499004	1223480	3887535
11	2 TOR	1367629	3693299	12033940	85859	28220	21143	79914	1533402	3801433	12134997
12	No evap+1/2 TOR	173224	466230	1517674	10875	3562	2666	23630	207729	493422	1543970
13	No solar, evap, sky, conv + ½ TOR	67498	181608	591116	4238	1388	1039	14193	85928	197188	606347
14	½ TOR & evap	309632	833408	2712941	19439	6368	4766	27755	356825	867531	2745462
15	½ TOR + LT	440482	1185696	3859910	27653	9060	6782	32263	500399	1227019	3898955
16	Base + LT	625036	1683171	5480048	39240	12861	9628	50718	714994	1746750	5540394
17	2 TOR + LT	1368943	3696865	12045573	85942	28247	21163	79909	1534794	3805021	12146645
18	No evap + ½ TOR +LT	174503	469677	1528897	10955	3589	2686	23649	209108	496915	1555232
19	½ evap & TOR + LT	310909	836847	2724141	19519	6394	4786	27774	358202	871015	2756701
20	9 ft Deep	623310	1678010	5462741	39131	12821	9598	50720	713161	1741552	5523058
21	Case 8 + 9ft	256036	689221	2243658	16074	5266	3942	43142	315252	737629	2290742
22	Case 9 + 9ft	109276	294134	957503	6860	2247	1682	43142	159278	339524	1002328
23	1m Opaque cover	500334	1348213	4390184	31411	10301	7713	46421	578166	1404936	4444319
24	1m Trans cover	351457	946229	3080479	22064	7230	5412	47011	420532	1000469	3132902

Table F-9: Initial costs of solar water heating systems for a small refuge in West Palm Beach with a variable tide

Small refuge in West Palm Beach		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	27524	79747	265769	1737	609	727	0	29261	80356	266497
2	No cond	26956	78101	260300	1701	597	712	0	28658	78698	261013
3	No solar	49269	142835	476120	3110	1091	1303	0	52379	143926	477423
4	No sky	22246	64448	214794	1404	492	588	0	23650	64941	215382
5	No conv	10121	29329	97747	639	224	268	0	10760	29553	98014
6	No evap	7009	20313	67690	442	155	185	0	7452	20468	67875
7	No TOR	29984	86839	289388	1893	664	792	0	31876	87503	290181
8	No solar, evap, sky, conv	1467	4248	14151	93	32	39	0	1560	4281	14190
9	No evap, sky, conv	0	0	0	0	0	0	0	0	0	0
10	½ TOR	29068	84237	280752	1835	644	768	0	30903	84881	281520
11	2 TOR	29317	84987	283281	1850	649	775	0	31168	85636	284057
12	No evap+1/2 TOR	4794	13883	46258	303	106	127	0	5096	13989	46385
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0	0	0	0	0	0	0
14	½ TOR & evap	14623	42367	141191	923	324	386	0	15546	42690	141577
15	½ TOR + LT	29234	84721	282370	1845	647	773	0	31079	85369	283143
16	Base + LT	27669	80168	267182	1746	613	731	0	29416	80780	267913
17	2 TOR + LT	29400	85229	284079	1856	651	778	0	31256	85880	284857
18	No evap + ½ TOR +LT	4851	14045	46805	306	107	128	0	5158	14153	46933
19	½ evap & TOR + LT	14768	42791	142603	932	327	390	0	15700	43118	142994
20	9 ft Deep	26064	75499	251607	1645	577	689	0	27710	76076	252296
21	Case 8 + 9ft	1189	3443	11473	75	26	31	0	1264	3469	11505
22	Case 9 + 9ft	0	0	0	0	0	0	0	0	0	0
23	1m Opaque cover	18799	54461	181502	1187	416	497	0	19986	54877	181998
24	1m Trans cover	6501	18837	62779	410	144	172	0	6911	18981	62951

Table F-10: Initial costs of solar water heating systems for a large refuge in West Palm Beach with a variable tide

Large refuge in West Palm Beach		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	164660	474520	1581456	10337	3626	4329	0	174997	478146	1585785
2	No cond	162612	468614	1561768	10209	3581	4275	0	172821	472195	1566043
3	No solar	295800	852956	2843205	18570	6517	7782	0	314370	859473	2850987
4	No sky	132924	383028	1276504	8345	2927	3494	0	141268	385955	1279998
5	No conv	59971	172842	576031	3765	1321	1577	0	63736	174162	577608
6	No evap	41469	119535	398392	2603	913	1090	0	44072	120449	399482
7	No TOR	179360	516839	1722476	11260	3949	4715	0	190620	520788	1727191
8	No solar, evap, sky, conv	8092	23299	77625	508	178	212	0	8600	23477	77838
9	No evap, sky, conv	0	0	0	0	0	0	0	0	0	0
10	½ TOR	173946	501370	1671022	10920	3831	4574	0	184866	505201	1675596
11	2 TOR	175813	506919	1689639	11037	3873	4625	0	186850	510792	1694264
12	No evap+1/2 TOR	28177	81151	270407	1769	620	740	0	29946	81771	271147
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0	0	0	0	0	0	0
14	½ TOR & evap	86831	250233	833950	5451	1912	2283	0	92283	252145	836233
15	½ TOR + LT	174854	503992	1679772	10977	3851	4598	0	185831	507843	1684370
16	Base + LT	165452	476809	1589079	10387	3643	4350	0	175839	480452	1593428
17	2 TOR + LT	176263	508220	1693980	11066	3883	4637	0	187329	512103	1698617
18	No evap + ½ TOR +LT	28484	82036	273358	1788	627	748	0	30272	82663	274106
19	½ evap & TOR + LT	87627	252529	841595	5501	1930	2304	0	93128	254459	843899
20	9 ft Deep	155326	447512	1491332	9751	3419	4082	0	165077	450932	1495414
21	Case 8 + 9ft	6116	17611	58678	384	135	161	0	6500	17746	58838
22	Case 9 + 9ft	0	0	0	0	0	0	0	0	0	0
23	1m Opaque cover	112082	322939	1076191	7036	2468	2946	0	119118	325407	1079137
24	1m Trans cover	38375	110615	368654	2409	845	1009	0	40784	111460	369663

Table F-11: Initial costs of solar water heating systems for a small refuge in Miami with a variable tide

Small refuge in Miami		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	15963	46734	156789	1002	357	429	0	16965	47091	157218
2	No cond	15555	45536	152767	977	348	418	0	16531	45884	153185
3	No solar	34446	100885	338518	2163	771	927	0	36608	101656	339445
4	No sky	12371	36207	121457	777	277	332	0	13148	36483	121789
5	No conv	5819	17044	57185	365	130	157	0	6185	17174	57341
6	No evap	4238	12411	41644	266	95	114	0	4504	12506	41758
7	No TOR	15767	46159	154863	990	353	424	0	16757	46511	155287
8	No solar, evap, sky, conv	1302	3808	12772	82	29	35	0	1383	3837	12807
9	No evap, sky, conv	0	0	0	0	0	0	0	0	0	0
10	½ TOR	15654	45833	153769	983	350	421	0	16637	46184	154190
11	2 TOR	21356	62552	209883	1341	478	574	0	22697	63030	210458
12	No evap+1/2 TOR	1863	5450	18275	117	42	50	0	1980	5492	18326
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0	0	0	0	0	0	0
14	½ TOR & evap	6947	20328	68203	436	155	187	0	7383	20484	68389
15	½ TOR + LT	15794	46242	155148	992	353	425	0	16786	46595	155573
16	Base + LT	16071	47043	157825	1009	359	432	0	17080	47403	158257
17	2 TOR + LT	21409	62703	210407	1344	479	576	0	22753	63182	210983
18	No evap + ½ TOR +LT	1911	5593	18754	120	43	51	0	2031	5636	18805
19	½ evap & TOR + LT	7036	20590	69080	442	157	189	0	7477	20748	69269
20	9 ft Deep	14496	42426	142319	910	324	390	0	15406	42750	142708
21	Case 8 + 9ft	1025	2999	10061	64	23	28	0	1090	3022	10088
22	Case 9 + 9ft	0	0	0	0	0	0	0	0	0	0
23	1m Opaque cover	12686	37139	124590	796	284	341	0	13483	37422	124931
24	1m Trans cover	3661	10722	35981	230	82	98	0	3891	10803	36080

Table F-12: Initial costs of solar water heating systems for a large refuge in Miami with a variable tide

Large refuge in Miami		Initial investment of collector ($)			Initial investment of water pumps ($)			Initial cost ($)	Total initial investment ($)		
Case	Desc	Unglazed	Glazed	Evac.	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	94844	277649	931491	5954	2121	2550	0	100798	279771	934041
2	No cond	93329	273211	916600	5859	2088	2509	0	99188	275298	919109
3	No solar	205646	602306	2020991	12910	4602	5532	0	218557	606908	2026522
4	No sky	73375	214740	720366	4606	1641	1972	0	77982	216381	722338
5	No conv	34219	100207	336205	2148	766	920	0	36368	100972	337125
6	No evap	24919	72980	244873	1564	558	670	0	26484	73538	245544
7	No TOR	93494	273727	918343	5870	2091	2514	0	99364	275818	920857
8	No solar, evap, sky, conv	7208	21090	70732	452	161	194	0	7660	21251	70926
9	No evap, sky, conv	0	0	0	0	0	0	0	0	0	0
10	½ TOR	92850	271835	912008	5829	2077	2496	0	98679	273912	914505
11	2 TOR	127498	373433	1253033	8004	2853	3430	0	135502	376287	1256463
12	No evap+1/2 TOR	10544	30852	103489	662	236	283	0	11206	31087	103772
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0	0	0	0	0	0	0
14	½ TOR & evap	40819	119456	400728	2563	913	1097	0	43382	120369	401824
15	½ TOR + LT	93608	274056	919460	5877	2094	2517	0	99485	276150	921976
16	Base + LT	95405	279292	937006	5990	2134	2565	0	101395	281426	939571
17	2 TOR + LT	127783	374266	1255824	8022	2860	3437	0	135805	377126	1259262
18	No evap + ½ TOR +LT	10808	31621	106075	678	242	290	0	11486	31863	106366
19	½ evap & TOR + LT	41303	120876	405490	2593	924	1110	0	43896	121800	406600
20	9 ft Deep	85727	250895	841641	5382	1917	2304	0	91109	252812	843944
21	Case 8 + 9ft	5310	15533	52092	333	119	143	0	5643	15652	52235
22	Case 9 + 9ft	0	0	0	0	0	0	0	0	0	0
23	1m Opaque cover	75146	219968	737947	4718	1681	2020	0	79864	221649	739967
24	1m Trans cover	21469	62881	211000	1348	480	578	0	22817	63362	211577

Appendix G: Annual O&M and lifetime costs

This appendix provides annual operating and maintenance costs and lifetime costs. The annual O&M costs consist of solar collectors systems, water pumps, and backup gas boilers. The lifetime costs are presented as present values.

The twelve tables follow the same format for two types of refuges at three different locations assuming two different water turn over (tidal) impact. The first column identifies the case number. The second column is a brief description of the case. Columns 3-6 provide annual O&M costs of solar panels and water pumps for three different types of solar collectors. The six column provides O&M cost for backup gas boilers. Since there is no need of backup gas boilers in West Palm Beach and Miami, the amount of cost is 0. The last three columns provide lifetime costs using three different types of solar collectors.

Table G-1: Annual O&M and lifetime costs for a small refuge in Cape Canaveral with a constant tide

Small refuge in Cape Canaveral		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost ($)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	17661	41105	131999	358	375587	891123	2841627
2	No cond	17525	40788	130982	356	372747	884299	2819763
3	No solar	21372	49866	160244	436	452572	1079077	3447671
4	No sky	16394	38144	122484	333	349064	827376	2637207
5	No conv	13236	30789	98854	268	282174	668193	2128786
6	No evap	12589	29276	93988	255	269032	636006	2024667
7	No TOR	7509	17448	56000	152	163300	381874	1209168
8	No solar, evap, sky, conv	10490	24425	78438	213	226574	532997	1692073
9	No evap, sky, conv	7155	16631	53384	145	158453	366851	1155527
10	½ TOR	12577	29240	93867	255	269278	635720	2022543
11	2 TOR	27797	64837	208346	566	588773	1403203	4482753
12	5 TOR	57961	136109	438216	1196	1225429	2943123	9425978
13	No evap+1/2 TOR	7529	17498	56165	152	164715	383958	1213696
14	No solar, evap, sky, conv + ½ TOR	5319	12366	39697	108	118194	273179	859672
15	½ TOR & evap	10022	23297	74782	203	215353	507282	1612113
16	½ TOR + LT	12605	29305	94076	255	269856	637114	2027031
17	Base + LT	17689	41170	132209	359	376173	892526	2846138
18	2 TOR + LT	27825	64904	208561	567	589363	1404632	4487363
19	No evap + ½ TOR +LT	7555	17558	56359	153	165255	385248	1217863
20	½ evap & TOR + LT	10049	23359	74981	203	215908	508615	1616379
21	9 ft Deep	22807	53078	170441	463	483361	1149024	3667515
22	Case 8 + 9ft	15709	36577	117461	319	336898	795776	2531473
23	Case 9 + 9ft	12111	28159	90396	245	263250	616174	1951709
24	1m Opaque cover	15281	35613	114398	311	326303	773371	2464022
25	1m Trans cover	12277	28551	91663	249	265331	623221	1977525

Table G-2: Annual O&M and lifetime costs for a large refuge in Cape Canaveral with a constant tide

Large refuge in Cape Canaveral		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost (Million $)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	105672	245942	789792	2145	2.23	5.31	16.98
2	No cond	105152	244728	785887	2134	2.22	5.29	16.90
3	No solar	127941	298513	959260	2608	2.69	6.44	20.62
4	No sky	98070	228183	732700	1989	2.07	4.93	15.76
5	No conv	79120	184051	590925	1604	1.67	3.98	12.71
6	No evap	75242	174978	561752	1525	1.59	3.78	12.08
7	No TOR	44761	104001	333793	905	0.96	2.26	7.19
8	No solar, evap, sky, conv	62653	145880	468480	1272	1.34	3.17	10.09
9	No evap, sky, conv	42696	99238	318541	864	0.93	2.17	6.89
10	½ TOR	75167	174753	560995	1522	1.59	3.78	12.07
11	2 TOR	166489	388338	1247877	3393	3.50	8.38	26.82
12	5 TOR	347481	815985	2627141	7168	7.27	17.57	56.43
13	No evap+1/2 TOR	44881	104312	334817	908	0.97	2.27	7.22
14	No solar, evap, sky, conv + ½ TOR	31619	73518	236002	640	0.69	1.61	5.11
15	½ TOR & evap	59842	139099	446505	1211	1.27	3.01	9.61
16	½ TOR + LT	75321	175112	562149	1525	1.59	3.79	12.09
17	Base + LT	105827	246304	790953	2148	2.23	5.32	17.01
18	2 TOR + LT	166645	388705	1249060	3396	3.50	8.39	26.85
19	No evap + ½ TOR +LT	45028	104648	335891	911	0.97	2.28	7.24
20	½ evap & TOR + LT	59989	139442	447606	1214	1.27	3.02	9.63
21	9 ft Deep	136400	317436	1019331	2767	2.87	6.85	21.91
22	Case 8 + 9ft	93823	218457	701549	1905	1.99	4.73	15.10
23	Case 9 + 9ft	72241	167970	539210	1463	1.55	3.66	11.62
24	1m Opaque cover	91391	212989	684180	1859	1.91	4.59	14.70
25	1m Trans cover	73371	170630	547794	1487	1.55	3.69	11.78

Table G-3: Annual O&M and lifetime costs for a small refuge in West Palm Beach with a constant tide

Small refuge in West Palm Beach		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost ($)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	3468	8627	28349	0	70887	183974	607165
2	No cond	3420	8508	27957	0	69918	181440	598753
3	No solar	5372	13374	43957	0	109813	285206	941435
4	No sky	2938	7308	24011	0	60061	155840	514257
5	No conv	1612	4010	13175	0	32953	85509	282170
6	No evap	1437	3576	11752	0	29373	76255	251692
7	No TOR	3643	9058	29761	0	74459	193167	637397
8	No solar, evap, sky, conv	679	1688	5544	0	15877	37987	120737
9	No evap, sky, conv	140	348	1144	0	5860	10421	27500
10	½ TOR	3428	8531	28032	0	70081	181915	600376
11	2 TOR	3857	9599	31543	0	78849	204696	675574
12	5 TOR	5836	14548	47834	0	119297	310244	1024479
13	No evap+1/2 TOR	1033	2569	8439	0	23115	56780	182750
14	No solar, evap, sky, conv + ½ TOR	303	754	2475	0	9195	19069	56010
15	½ TOR & evap	2039	5074	16671	0	41685	108194	357048
16	½ TOR + LT	3445	8570	28160	0	70424	182754	603107
17	Base + LT	3480	8658	28450	0	71140	184640	609330
18	2 TOR + LT	3866	9621	31616	0	79028	205163	677124
19	No evap + ½ TOR +LT	1040	2587	8499	0	23263	57161	184029
20	½ evap & TOR + LT	2051	5102	16765	0	41919	108808	359065
21	9 ft Deep	3455	8595	28239	0	70634	183282	604804
22	Case 8 + 9ft	1014	2519	8276	0	22718	55725	179257
23	Case 9 + 9ft	345	857	2815	0	10044	21266	63291
24	1m Opaque cover	2304	5733	18836	0	49106	124248	405416
25	1m Trans cover	1336	3324	10921	0	30303	73875	236907

Table G-4: Annual O&M and lifetime costs for a large refuge in West Palm Beach with a constant tide

Large refuge in West Palm Beach		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost (Million $)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	20695	51483	169169	0	0.42	1.10	3.62
2	No cond	20522	51049	167738	0	0.42	1.09	3.59
3	No solar	32108	79938	262732	0	0.66	1.70	5.63
4	No sky	17524	43585	143208	0	0.36	0.93	3.07
5	No conv	9584	23841	78331	0	0.20	0.51	1.68
6	No evap	8547	21271	69900	0	0.17	0.45	1.50
7	No TOR	21705	53997	177433	0	0.44	1.15	3.80
8	No solar, evap, sky, conv	4005	9956	32708	0	0.09	0.22	0.71
9	No evap, sky, conv	812	2020	6636	0	0.03	0.06	0.16
10	½ TOR	20447	50876	167185	0	0.42	1.08	3.58
11	2 TOR	23050	57360	188495	0	0.47	1.22	4.04
12	5 TOR	34943	87106	286399	0	0.71	1.86	6.13
13	No evap+1/2 TOR	6117	15211	49974	0	0.14	0.34	1.08
14	No solar, evap, sky, conv + ½ TOR	1754	4359	14319	0	0.05	0.11	0.32
15	½ TOR & evap	12127	30172	99142	0	0.25	0.64	2.12
16	½ TOR + LT	20530	51082	167863	0	0.42	1.09	3.60
17	Base + LT	20763	51653	169730	0	0.42	1.10	3.64
18	2 TOR + LT	23098	57481	188894	0	0.47	1.23	4.05
19	No evap + ½ TOR +LT	6157	15310	50301	0	0.14	0.34	1.09
20	½ evap & TOR + LT	12190	30330	99660	0	0.25	0.65	2.13
21	9 ft Deep	20586	51204	168239	0	0.42	1.09	3.60
22	Case 8 + 9ft	5979	14863	48827	0	0.13	0.33	1.06
23	Case 9 + 9ft	1998	4969	16324	0	0.06	0.12	0.37
24	1m Opaque cover	13726	34146	112196	0	0.29	0.74	2.41
25	1m Trans cover	7940	19757	64922	0	0.18	0.44	1.41

Table G-5: Annual O&M and lifetime costs for a small refuge in Miami with a constant tide

Small refuge in Miami		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost ($)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	2339	5912	19557	0	47811	126080	418864
2	No cond	2303	5821	19258	0	47079	124142	412443
3	No solar	3866	9775	32339	0	79028	208458	692621
4	No sky	1959	4950	16372	0	40039	105548	350652
5	No conv	1222	3090	10222	0	24979	65885	218927
6	No evap	1063	2687	8890	0	21730	57306	190393
7	No TOR	1973	4986	16492	0	40323	106318	353210
8	No solar, evap, sky, conv	628	1587	5250	0	14846	35851	114440
9	No evap, sky, conv	113	286	946	0	5315	9097	23269
10	½ TOR	2101	5310	17567	0	42958	113245	376234
11	2 TOR	2922	7387	24439	0	59722	157526	523407
12	5 TOR	4967	12575	41620	0	101544	268168	891377
13	No evap+1/2 TOR	675	1706	5643	0	15803	38385	122853
14	No solar, evap, sky, conv + ½ TOR	279	706	2335	0	8713	18057	53009
15	½ TOR & evap	1279	3233	10694	0	26147	68938	229037
16	½ TOR + LT	2113	5340	17662	0	43191	113868	378276
17	Base + LT	2348	5935	19635	0	47997	126573	420536
18	2 TOR + LT	2928	7403	24493	0	59851	157872	524563
19	No evap + ½ TOR +LT	679	1717	5678	0	15889	38610	123615
20	½ evap & TOR + LT	1286	3250	10750	0	26283	69301	230242
21	9 ft Deep	2524	6378	21096	0	51589	136008	451826
22	Case 8 + 9ft	938	2370	7838	0	21177	52543	169860
23	Case 9 + 9ft	304	769	2542	0	9219	19389	57437
24	1m Opaque cover	1777	4490	14852	0	38327	97749	320083
25	1m Trans cover	994	2512	8309	0	23313	56561	180946

Table G-6: Annual O&M and lifetime costs for a large refuge in Miami with a constant tide

Large refuge in Miami		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost (Million $)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	13953	35270	116677	0	0.29	0.75	2.50
2	No cond	13818	34929	115545	0	0.28	0.74	2.47
3	No solar	23105	58421	193274	0	0.47	1.25	4.14
4	No sky	11680	29513	97622	0	0.24	0.63	2.09
5	No conv	7271	18384	60819	0	0.15	0.39	1.30
6	No evap	6321	15980	52864	0	0.13	0.34	1.13
7	No TOR	11731	29650	98079	0	0.24	0.63	2.10
8	No solar, evap, sky, conv	3715	9385	31039	0	0.09	0.21	0.68
9	No evap, sky, conv	656	1657	5481	0	0.03	0.05	0.14
10	½ TOR	12519	31637	104649	0	0.26	0.67	2.24
11	2 TOR	17464	44156	146085	0	0.36	0.94	3.13
12	5 TOR	29745	75303	249225	0	0.61	1.61	5.34
13	No evap+1/2 TOR	3999	10108	33435	0	0.09	0.23	0.73
14	No solar, evap, sky, conv + ½ TOR	1624	4101	13564	0	0.05	0.11	0.31
15	½ TOR & evap	7609	19232	63616	0	0.16	0.41	1.36
16	½ TOR + LT	12582	31797	105180	0	0.26	0.68	2.25
17	Base + LT	14004	35399	117104	0	0.29	0.75	2.51
18	2 TOR + LT	17499	44246	146383	0	0.36	0.94	3.14
19	No evap + ½ TOR +LT	4024	10167	33630	0	0.09	0.23	0.73
20	½ evap & TOR + LT	7646	19326	63928	0	0.16	0.41	1.37
21	9 ft Deep	15049	38030	125795	0	0.31	0.81	2.69
22	Case 8 + 9ft	5547	14011	46335	0	0.13	0.31	1.00
23	Case 9 + 9ft	1774	4481	14822	0	0.05	0.11	0.34
24	1m Opaque cover	10590	26760	88510	0	0.23	0.58	1.91
25	1m Trans cover	5903	14919	49353	0	0.14	0.34	1.07

Table G-7: Annual O&M and lifetime costs for a small refuge in Cape Canaveral with a variable tide

Small refuge in Cape Canaveral		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost ($)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	12381	28778	92112	251	268155	628763	1989573
2	No cond	12217	28396	90889	247	264731	620547	1963284
3	No solar	16081	37436	119874	326	344658	814263	2585551
4	No sky	11118	25842	82709	225	241776	565572	1787453
5	No conv	7949	18473	59124	161	175717	407169	1280602
6	No evap	7317	17004	54423	148	162775	375830	1179811
7	No TOR	7508	17442	55820	152	163281	381758	1206350
8	No solar, evap, sky, conv	5104	11863	37969	103	117948	266587	827502
9	No evap, sky, conv	2287	5315	17009	46	60701	127284	378564
10	½ TOR	8735	20295	64951	177	188703	442933	1402433
11	2 TOR	27072	63103	202133	551	592352	1384632	4371881
12	No evap+1/2 TOR	3485	8095	25906	70	80480	181877	564564
13	No solar, evap, sky, conv + ½ TOR	1397	3244	10378	28	36584	77204	230502
14	½ TOR & evap	6177	14351	45925	125	134930	314695	993106
15	½ TOR + LT	8763	20361	65162	177	189293	444353	1406961
16	Base + LT	12409	28845	92324	251	268745	630183	1994125
17	2 TOR + LT	27101	63171	202352	551	592958	1386095	4376580
18	No evap + ½ TOR +LT	3513	8160	26115	71	81066	183280	569068
19	½ evap & TOR + LT	6205	14416	46133	125	135512	316089	997584
20	9 ft Deep	12397	28807	92194	251	268493	629380	1991352
21	Case 8 + 9ft	5145	11955	38260	104	118803	268560	833756
22	Case 9 + 9ft	2224	5167	16536	45	59411	124139	368420
23	1m Opaque cover	9945	23131	74048	201	218777	508749	1602768
24	1m Trans cover	7005	16278	52098	142	159121	363064	1132700

Table G-8: Annual O&M and lifetime costs for a large refuge in Cape Canaveral with a variable tide

Large refuge in Cape Canaveral		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost (Million $)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	73888	171743	549698	1496	1.58	3.73	11.85
2	No cond	73302	170379	545328	1484	1.57	3.70	11.76
3	No solar	96085	223683	716247	1950	2.04	4.84	15.43
4	No sky	66306	154117	493275	1342	1.42	3.35	10.64
5	No conv	47298	109917	351783	957	1.03	2.40	7.60
6	No evap	43507	101111	323604	880	0.95	2.21	6.99
7	No TOR	44679	103794	332161	903	0.96	2.26	7.16
8	No solar, evap, sky, conv	30232	70266	224887	612	0.68	1.56	4.88
9	No evap, sky, conv	13448	31252	100020	272	0.34	0.73	2.21
10	½ TOR	52025	120876	386841	1052	1.11	2.62	8.34
11	2 TOR	162006	377627	1209610	3295	3.43	8.17	26.05
12	No evap+1/2 TOR	20520	47670	152551	415	0.46	1.06	3.31
13	No solar, evap, sky, conv + ½ TOR	7996	18569	59417	162	0.20	0.43	1.31
14	½ TOR & evap	36678	85213	272695	742	0.79	1.85	5.88
15	½ TOR + LT	52178	121233	387985	1055	1.11	2.63	8.36
16	Base + LT	74040	172098	550835	1499	1.58	3.74	11.88
17	2 TOR + LT	162161	377991	1210779	3298	3.43	8.18	26.07
18	No evap + ½ TOR +LT	20671	48023	153679	418	0.46	1.06	3.33
19	½ evap & TOR + LT	36829	85565	273821	745	0.79	1.86	5.91
20	9 ft Deep	73836	171571	549096	1494	1.58	3.73	11.84
21	Case 8 + 9ft	30329	70470	225525	613	0.68	1.56	4.90
22	Case 9 + 9ft	12944	30074	96245	262	0.33	0.71	2.13
23	1m Opaque cover	59268	137850	441286	1201	1.28	3.01	9.53
24	1m Trans cover	41633	96748	309639	842	0.93	2.14	6.71

Table G-9: Annual O&M and lifetime costs for a small refuge in West Palm with a variable tide

Small refuge in West Palm Beach		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost ($)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	3263	8154	26791	0	66689	173881	573785
2	No cond	3196	7986	26240	0	65314	170291	561978
3	No solar	5841	14604	47995	0	119377	311437	1027923
4	No sky	2637	6590	21652	0	53900	140523	463731
5	No conv	1200	2999	9853	0	24524	63948	211031
6	No evap	831	2077	6823	0	16983	44290	146140
7	No TOR	3555	8879	29172	0	72649	189344	624778
8	No solar, evap, sky, conv	174	434	1426	0	5555	11263	32551
9	No evap, sky, conv	0	0	0	0	3000	3000	3000
10	½ TOR	3446	8613	28301	0	70430	183671	606132
11	2 TOR	3476	8690	28556	0	71034	185305	611593
12	No evap+1/2 TOR	568	1419	4663	0	13615	32270	101870
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0	3000	3000	3000
14	½ TOR & evap	1734	4332	14233	0	35430	92376	304825
15	½ TOR + LT	3466	8662	28464	0	70833	184726	609625
16	Base + LT	3280	8197	26933	0	67041	174797	576835
17	2 TOR + LT	3486	8714	28637	0	71236	185833	613315
18	No evap + ½ TOR +LT	575	1436	4718	0	13754	32625	103051
19	½ evap & TOR + LT	1751	4375	14375	0	35782	93301	307875
20	9 ft Deep	3090	7720	25363	0	63153	164618	543209
21	Case 8 + 9ft	141	352	1157	0	4881	9507	26771
22	Case 9 + 9ft	0	0	0	0	3000	3000	3000
23	1m Opaque cover	2229	5568	18296	0	47550	120746	393854
24	1m Trans cover	771	1926	6328	0	18751	44072	138538

Table G-10: Annual O&M and lifetime costs for a large refuge in West Palm Beach with a variable tide

Large refuge in West Palm Beach		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost (Million $)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	19505	48518	159418	0	0.40	1.03	3.41
2	No cond	19263	47914	157434	0	0.39	1.02	3.37
3	No solar	35040	87212	286608	0	0.72	1.86	6.14
4	No sky	15746	39163	128678	0	0.32	0.84	2.76
5	No conv	7104	17672	58067	0	0.15	0.38	1.24
6	No evap	4912	12222	40160	0	0.10	0.26	0.86
7	No TOR	21246	52845	173634	0	0.43	1.13	3.72
8	No solar, evap, sky, conv	959	2382	7825	0	0.03	0.06	0.18
9	No evap, sky, conv	0	0	0	0	0.02	0.02	0.02
10	½ TOR	20605	51263	168447	0	0.42	1.09	3.61
11	2 TOR	20826	51831	170324	0	0.43	1.11	3.65
12	No evap+1/2 TOR	3338	8297	27258	0	0.08	0.19	0.60
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0	0.02	0.02	0.02
14	½ TOR & evap	10286	25585	84066	0	0.21	0.55	1.80
15	½ TOR + LT	20713	51531	169329	0	0.42	1.10	3.63
16	Base + LT	19599	48752	160187	0	0.40	1.04	3.43
17	2 TOR + LT	20880	51964	170761	0	0.43	1.11	3.66
18	No evap + ½ TOR +LT	3374	8388	27556	0	0.08	0.19	0.60
19	½ evap & TOR + LT	10380	25820	84837	0	0.21	0.55	1.82
20	9 ft Deep	18399	45757	150333	0	0.38	0.98	3.22
21	Case 8 + 9ft	725	1801	5915	0	0.03	0.05	0.14
22	Case 9 + 9ft	0	0	0	0	0.02	0.02	0.02
23	1m Opaque cover	13277	33019	108485	0	0.28	0.72	2.34
24	1m Trans cover	4546	11310	37162	0	0.11	0.26	0.81

Table G-11: Annual O&M and lifetime costs for a small refuge in Miami with a variable tide

Small refuge in Miami		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost ($)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	1891	4778	15805	0	38654	101898	338500
2	No cond	1843	4656	15400	0	37666	99286	329817
3	No solar	4080	10315	34124	0	83410	219969	730847
4	No sky	1465	3702	12243	0	29957	78945	262220
5	No conv	689	1743	5765	0	14091	37163	123460
6	No evap	502	1269	4198	0	10262	27062	89908
7	No TOR	1868	4720	15611	0	38179	100644	334343
8	No solar, evap, sky, conv	154	389	1288	0	5152	10303	29575
9	No evap, sky, conv	0	0	0	0	3000	3000	3000
10	½ TOR	1854	4686	15501	0	37907	99935	331982
11	2 TOR	2530	6396	21157	0	51714	136389	453129
12	No evap+1/2 TOR	221	557	1842	0	6510	13883	41456
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0	3000	3000	3000
14	½ TOR & evap	823	2079	6875	0	16823	44324	147247
15	½ TOR + LT	1871	4728	15640	0	38245	100826	334958
16	Base + LT	1904	4810	15910	0	38915	102573	340739
17	2 TOR + LT	2536	6411	21210	0	51842	136717	454261
18	No evap + ½ TOR +LT	226	572	1890	0	6627	14195	42489
19	½ evap & TOR + LT	833	2105	6964	0	17037	44895	149141
20	9 ft Deep	1717	4338	14346	0	35101	92506	307260
21	Case 8 + 9ft	121	307	1014	0	4483	8538	23720
22	Case 9 + 9ft	0	0	0	0	3000	3000	3000
23	1m Opaque cover	1503	3797	12559	0	32719	82977	270985
24	1m Trans cover	434	1096	3627	0	11865	26377	80682

Table G-12: Annual O&M and lifetime costs for a large refuge in Miami with a variable tide

Large refuge in Miami		O&M cost of solar panels & pumps ($)			O&M cost ($)	Present values of Lifetime cost (Million $)		
Case	Desc	Unglazed	Glazed	Evac.	boiler	Unglazed	Glazed	Evac.
1	Base	11235	28389	93899	0	0.23	0.61	2.01
2	No cond	11055	27935	92398	0	0.23	0.60	1.98
3	No solar	24360	61584	203725	0	0.50	1.31	4.36
4	No sky	8692	21956	72616	0	0.18	0.47	1.56
5	No conv	4054	10246	33891	0	0.08	0.22	0.73
6	No evap	2952	7462	24684	0	0.06	0.16	0.53
7	No TOR	11075	27988	92573	0	0.23	0.60	1.98
8	No solar, evap, sky, conv	854	2156	7130	0	0.03	0.06	0.16
9	No evap, sky, conv	0	0	0	0	0.02	0.02	0.02
10	½ TOR	10999	27794	91935	0	0.22	0.59	1.97
11	2 TOR	15103	38182	126312	0	0.31	0.81	2.71
12	No evap+1/2 TOR	1249	3154	10432	0	0.04	0.08	0.24
13	No solar, evap, sky, conv + ½ TOR	0	0	0	0	0.02	0.02	0.02
14	½ TOR & evap	4835	12214	40395	0	0.10	0.26	0.87
15	½ TOR + LT	11089	28021	92686	0	0.23	0.60	1.99
16	Base + LT	11301	28557	94455	0	0.23	0.61	2.02
17	2 TOR + LT	15137	38267	126593	0	0.31	0.82	2.71
18	No evap + ½ TOR +LT	1280	3233	10693	0	0.04	0.08	0.24
19	½ evap & TOR + LT	4893	12359	40875	0	0.10	0.26	0.88
20	9 ft Deep	10155	25653	84841	0	0.21	0.55	1.82
21	Case 8 + 9ft	629	1588	5251	0	0.02	0.05	0.12
22	Case 9 + 9ft	0	0	0	0	0.02	0.02	0.02
23	1m Opaque cover	8902	22491	74389	0	0.19	0.49	1.61
24	1m Trans cover	2543	6429	21270	0	0.07	0.16	0.47