**Workpaper WPSCGNRWH150309A**

**Revision 0**

**Southern California Gas Company**

**Customer Programs Department**

**Pool Cover**

Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| Revision No. | Date | **Description** | **Author** |
| - | 11/08/2012 | Savings calculation report in attachment –C | Stu Knoke (ICF) |
| 0 | 03/9/2015 | Developed new gas (and water) savings using the Pool Cover and Pool Heater Energy Analysis excel tool. The savings for four different pool categories were recorded for all 16 weather zones of CA. | Raad Bashar (SCG) / Joseph Pan (SCG) |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

# 

Measure Summary Table A

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Measure ID | Measure Name | Program Application Type  (RE, NC, ROB, ER, etc) | EUL/RUL  (yr) | CZ | Building Type | Building Vintage | Unit  Definition | NTG  IMC | NTG Savings | Program  Delivery  Method  (CustIncent, PreReb, DirInstall, etc) | Gross  Realization Rate (GRR) | % Eligible for TOU AC  Adjustment |
| RctPlc001 | Pool Cover (Colleges/ Schools) | ROB/NC | 5 | 6 | ECC, EUn | Any | Area-ft2 | 0.60 | 0.60 | PreRebDown | 1.0 | n/a |
| RctPlc002 | Pool Cover (City Parks/ Recreations) | ROB/NC | 5 | 6 | CRe | Any | Area-ft2 | 0.60 | 0.60 | PreRebDown | 1.0 | n/a |
| RctPlc003 | Pool Cover (MF Residence) | ROB/NC | 5 | 6 | MFm | Any | Area-ft2 | 0.60 | 0.60 | PreRebDown | 1.0 | n/a |
| RctPlc004 | Pool Cover (Private/ Health Club) | ROB/NC | 5 | 6 | Fhc | Any | Area-ft2 | 0.60 | 0.60 | PreRebDown | 1.0 | n/a |
|  |  |  |  |  |  |  |  |  |  |  |  |  |

Measure Summary Table B

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Measure ID | Measure Name | 1st Baseline | | | | | 2nd Baseline | | | | |
| Gas  Savings (Therms) | User Entered kW Savings per unit (kW/unit) | Gross Unit Annual Electricity Savings (kWh/unit) | Measure Electric End Use Shape (Load Shape) | Incremental  Measure Cost ($/unit) | Gas  Savings (Therms) | User Entered kW Savings per unit (kW/unit) | Gross Unit Annual Electricity Savings (kWh/unit) | Measure Electric End Use Shape (Load Shape) | Incremental  Measure Cost ($/unit) |
| RctPlc001 | Pool Cover | 0.88 | 0 | 0 | n/a | $1.19 | n/a | n/a | n/a | n/a | n/a |
| RctPlc002 | Pool Cover | 0.61 | 0 | 0 | n/a | $1.19 | n/a | n/a | n/a | n/a | n/a |
| RctPlc003 | Pool Cover | 0.65 | 0 | 0 | n/a | $1.19 | n/a | n/a | n/a | n/a | n/a |
| RctPlc004 | Pool Cover | 0.64 | 0 | 0 | n/a | $1.19 | n/a | n/a | n/a | n/a | n/a |
|  |  |  |  |  |  |  |  |  |  |  |  |

Note: Complete Measure Summary Table is in the attachment.

# Table of Contents

[Revision History ii](#_Toc414363883)

[Measure Summary Table A iii](#_Toc414363884)

[Measure Summary Table B iii](#_Toc414363885)

[List of Figures v](#_Toc414363886)

[List of Tables v](#_Toc414363887)

[SECTION 1 - General Measure & Baseline Data 1](#_Toc414363888)

[1.01 Measure & Delivery Description 1](#_Toc414363889)

[1.02 DEER Differences Analysis 2](#_Toc414363890)

[1.03 Code Analysis 3](#_Toc414363891)

[1.04 Measure Effective Useful Life 3](#_Toc414363892)

[1.05 Net-to-Gross Ratios for Different Program Strategies 3](#_Toc414363893)

[1.06 Gross Realization Rate 4](#_Toc414363894)

[1.07 Gross Savings and INstallation Adjustment (GSIA) 4](#_Toc414363895)

[1.08 Time-of-Use Adjustment Factor 4](#_Toc414363896)

[1.09 EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information 4](#_Toc414363897)

[SECTION 2 - Energy Savings & Demand Reduction Calculations 5](#_Toc414363898)

[2.01 Load Shapes 5](#_Toc414363899)

[2.02 Energy Savings 5](#_Toc414363900)

[2.03 Methodology Overview 5](#_Toc414363901)

[2.04 Swimming Pool Characteristics 5](#_Toc414363902)

[2.05 Weather Data 7](#_Toc414363903)

[2.06 Energy Savings Calculation 9](#_Toc414363904)

[2.07 Savings Results 23](#_Toc414363905)

[SECTION 3 - Base Case & Measure Costs 24](#_Toc414363906)

[3.01 Base Case Cost 24](#_Toc414363907)

[3.02 Gross Measure Cost 24](#_Toc414363908)

[3.03 Incremental Measure Cost 24](#_Toc414363909)

[Attachments 25](#_Toc414363910)

[References 26](#_Toc414363911)

List of Figures

[Figure 1 - Types of Pool Covers 2](#_Toc414363912)

[Figure 2 - California Building Climate Zones 8](#_Toc414363913)

List of Tables

[Table 1 - DEER Difference Summary 3](#_Toc414363914)

[Table 2 - Code Summary 3](#_Toc414363915)

[Table 3 - Effective Useful Life 3](#_Toc414363916)

[Table 4 - Swimming Pool Parameters 6](#_Toc414363917)

[Table 5 - California Weather Stations Sorted by Climate Zone 8](#_Toc414363918)

[Table 6 - California Weather Stations Sorted by Climate Zone 10](#_Toc414363919)

[Table 7 - Pool Cover Radiation Properties 13](#_Toc414363920)

[Table 8 - Indoor Pools Space Conditions 22](#_Toc414363921)

[Table 9 - Physical Constants 22](#_Toc414363922)

1. General Measure & Baseline Data

Measure & Delivery Description

* + 1. Measure Description

Pool covers are protection and insulation products that lie on a swimming pool’s surface and thereby slow the heat loss and the evaporation rate, which in turn also reduces heat loss. If the pool is heated by a natural gas pool heater, the reduction in heat loss leads to a reduction in gas consumption. The pool cover is either manually or automatically pulled onto the pool or removed from the pool.

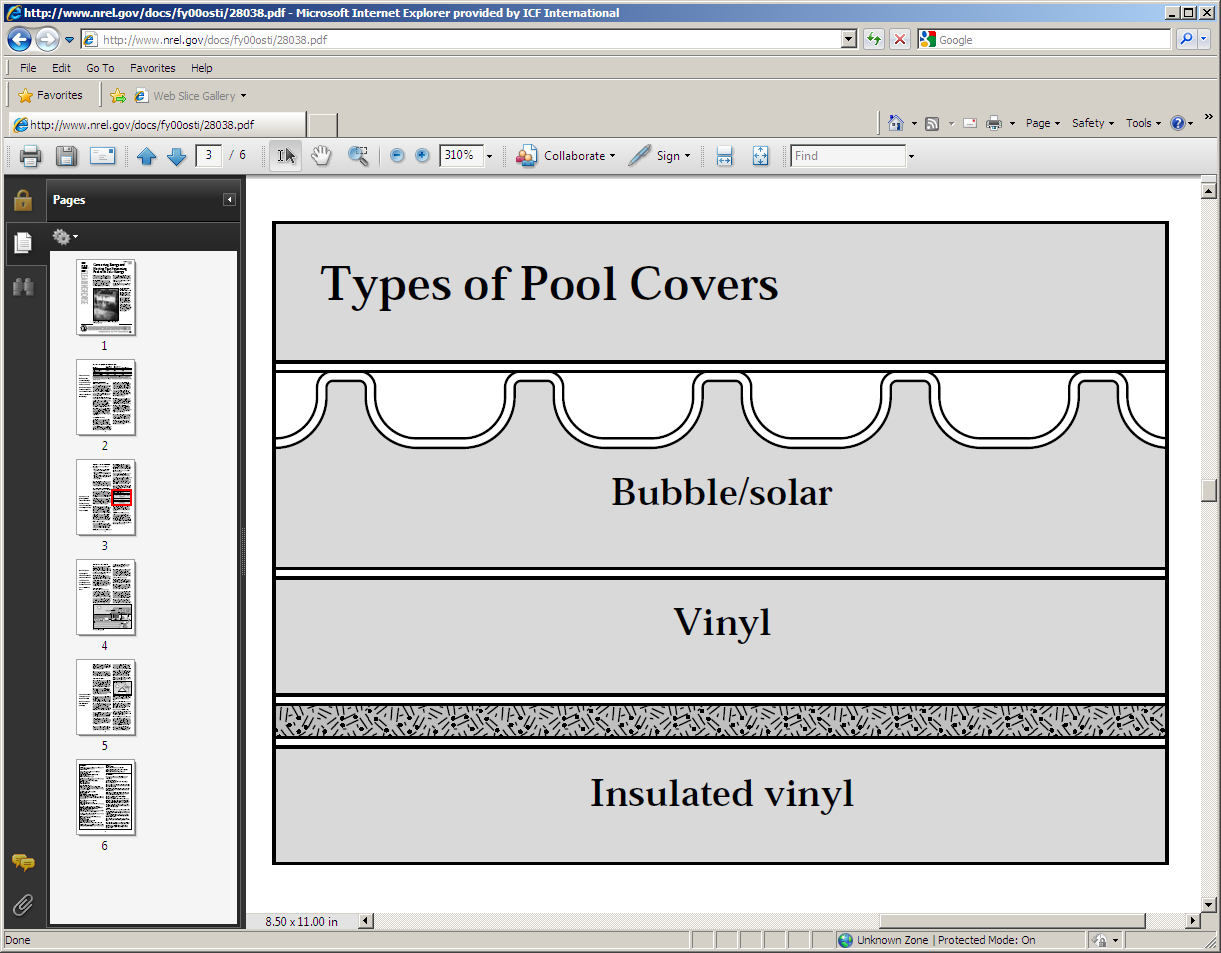
* + - * 1. Figure 1 illustrates the three basic types of pool covers: bubble/solar, vinyl, and insulated vinyl.

Polyethylene floating pool covers (solar blankets) are made from a highly buoyant, air-filled bubble material that provides insulation and prevents heat loss through evaporation. When left on in sunlight, a solar cover will add as much as 10 degrees to an unheated pool. They lay on top of the pool without tie-downs or anchors to hold them in place; therefore removing a solar cover is as easy as pulling it off and storing it. Solar covers are often rolled-up on a large reel and wheeled out of the way.

Soft vinyl pool covers are stretched over the pool to keep out debris and prevent heat loss through evaporation, but they provide little insulating value.

Insulated floating pool covers have woven, high-density, UV stabilized polyethylene fabric outer layers and cross-linked polyethylene foam sandwiched between the outer layers. Outdoor pools need weighted edges to help prevent wind lift. Stainless steel storage reels are specifically designed for easy removal and storage of insulated floating pool covers. All-welded reels are constructed of stainless steel tubing, and have two hand wheels for ease of handling. Double and triple reels come with casters.

* + - * 1. Evaporation is one of the main forms of heat loss from heated swimming pools and spas. Pool covers prevent pool water evaporation and associated heat loss from exposed pool surfaces with a layer on the pool surface. Since the primary mode of heat loss from a heated pool is by evaporation, reducing the evaporation will significantly reduce the heat loss. Pool covers will lower the air humidity over indoor pools as well, thereby reducing the latent cooling load of the air conditioning system.
        2. A secondary benefit is a reduction in the pool water lost through evaporation and a reduction in debris in the pool.



1. Types of Pool Covers[[1]](#endnote-1)
   * 1. Market Applicability
        1. The target markets for these measures are schools/colleges (educational institutions), city (municipal) recreational centers, home owner associations (e.g., condominiums with common pools), private/health clubs, and multi-family residences (apartment buildings). Typical NAICS codes include 61 and 71-72.
        2. This measure applies to outdoor and indoor heated swimming pools that do not already have pool cover or have old and degraded ones that are unusable.
     2. Terms & Conditions
        1. This measure is for commercial pools based on the following:
           1. Replace on Burn-Out type for existing pools that currently do not have a cover or the pool cover has reached the end of its useful life.
           2. New Construction option for new pools with proposed cover higher than code baseline.
        2. The pools must be heated with natural gas.
        3. The pool cover may be manually or automatically extended when the pool closes and retracted when the pool opens each day.
        4. Pool covers must have a manufacturer’s warranty of 5 years of greater to qualify for a rebate.
        5. Larger pools must have a storage reel system to store and use the pool cover.
        6. Rebate is based on the square footage of the pool.
        7. These measures are only applicable to commercial pool applications in the Energy Efficiency Rebate Program and the Multi-Family Residential Program.
     3. Delivery Method
        1. The preferred delivery method for pool covers is a downstream prescriptive rebate offered to the gas customer purchasing the new cover.
        2. However, a midstream point-of-sale rebate or an upstream manufacturer rebate strategy may also be implemented.
     4. Qualifying Efficiency

Pool covers must cover at least 95% of the pool water surface area.

DEER Differences Analysis

* + 1. There is no DEER measure similar to the pool covers for outdoor (or indoor) pools, as shown in Table 1.
    2. There was an outdoor pool cover workpaper targeting school pool facilities developed by a third party contractor, and the measure was input into DEER. However, this workpaper is designed to target more general multi-family, school and commercial markets including indoor and outdoor pools.

1. DEER Difference Summary

|  |  |
| --- | --- |
| DEER Difference Summary Table | |
| Modified DEER Methodology | No |
| Scaled DEER Measure | No |
| DEER Building Prototypes Used | No |
| Deviation from DEER | DEER does not contain this type of measure |
| DEER Version | IOU Workpaper |
| DEER Run ID and Measure Name | N/A |

Code Analysis

* + 1. The California Title 24 standard also requires that pool and spa heating systems with gas heaters for outdoor use must use a pool cover (Table 2). The pool cover must be fitted and installed during the final inspection. However, these pool cover requirements do not apply for maintenance or repairs of existing pool heating or filtration systems.
    2. Other than the above, no federal, state, or regional codes were identified that impact the assumptions and methodologies used to quantify demand reduction and energy savings for pool covers.

1. Code Summary

|  |  |  |
| --- | --- | --- |
| Code | Applicable Code Reference | Effective Dates |
| Title 24 (2013) | Section 110.4 | 1992-present |
| Title 20 (2010) | N/A |  |
|  |  |  |

Measure Effective Useful Life

* + 1. The effective useful life (EUL) of commercial pool covers is 5 years, based on the DEER measure ID (Table 3). Vendors typically provide 3 year full and 2 year pro-rated warranty for pool cover.

1. Effective Useful Life

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| MeasureID | EUL ID | EUL Yrs | RUL Yrs | Description |

IOU workpaper OutD-PoolCover 5 1.7 Outdoor pool cover

Net-to-Gross Ratios for Different Program Strategies

* + 1. The default NTG ratio for gas measures is 60%

Gross Realization Rate

* + 1. 100% (GRR) was approved for deemed measures.

Gross Savings and INstallation Adjustment (GSIA)

* + 1. N/A

Time-of-Use Adjustment Factor

* + 1. The Time-of-Use Adjustment Factor does not apply to the gas savings that are being claimed through this program.

EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information

* + 1. A study done by the Pacific Northwest National Laboratory (PNNL) on a swimming pool facility in the State of Idaho[[2]](#endnote-2) provided some information that were useful for this workpaper.
    2. The PNNL staff analyzed several major energy-conservation and retrofit options that included different types of pool covers. Both vinyl and insulated pool covers were examined.
    3. The study provided the estimated gas consumption when using these covers in indoor and outdoor pools.

1. Energy Savings & Demand Reduction Calculations

Load Shapes

* + 1. Load shapes are not applicable to gas measures, because the price of gas is not dependent on time-of-use.

Energy Savings

The energy saving for pool cover is calculated from the difference in energy consumption between an existing vinyl pool cover to a proposed insulated pool cover.

* + 1. Baseline pool cover is researched to be a vinyl pool cover. Because vinyl pool tends to have a R-value significantly less than 1, the baseline R-value is set as the default value of 0.1 based on the DOE’s Energy Smart Pools Software Manual on page 9.
    2. The proposed pool cover is based on research of products with the vendors in the market. The cover must have 1/8" thick (L), high-density polyethylene foam of thermal conductivity (K) Factor 0.25 BTU/sq. ft.-Hr-°F/inch (ASTM D2326). The new pool cover must cover at least 95% of the pool with a minimum R-value of 0.5 ft2-hr-F/Btu (R=L/K).
    3. As reference in B. above, R-value of 0.5 is the thermal resistance of the cover itself.
    4. The total thermal resistance (approximately 2.0) used in the calculation consists of conductive and convective modes of heat transfers.

Methodology Overview

The annual gas energy savings calculations are based on a pool heat transfer model developed for swimming pools in California to ascertain the benefits of using pool cover at various types of swimming pools in the California climate zones.

Annual gas energy consumption is calculated for baseline conditions and measure conditions to determine the energy savings.

The climate zone is determined from the pool location in California, and the incident solar radiation is determined at a centrally located airport weather station within each climate zone.

The energy savings calculation approach is based on an hourly Excel spreadsheet for one calendar year. The pool heat transfer model was compared to two other swimming pool energy savings calculation methods[[3]](#endnote-3),[[4]](#endnote-4).

Swimming Pool Characteristics

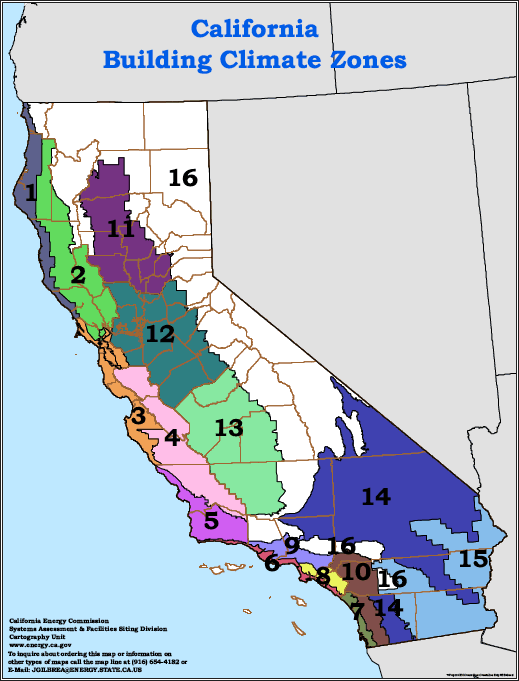
* + 1. Typical swimming pool characteristics are listed in Table 1 by pool type.
       1. The area, Apool, is the pool water area exposed to the air (when a pool cover is not covering the pool).
       2. The average depth, dpool, is the pool volume divided by the pool surface area.
       3. The annual pool operating schedule is described with an annual opening day, followed by a winter schedule, a summer schedule, and an annual closing day. Between annual opening and closing days, the schedule is defined by winter and summer pool opening and closing times. It assumed that the pool is covered and unused during the hours the pool is closed; and it is uncovered and actively used during the hours the pool is open.
       4. The wind shielding factor, FW, is used to adjust the airport wind speed to the poolside wind speed for calculating heat loss and evaporation rate. The wind shielding factor accounts for fences, buildings, and hedges which screen the pool from the wind.
          1. A pool surrounded by a wide flat open area, especially in the direction of the prevailing wind, has a wind shielding factor of 0%.
          2. A pool that is totally protected from the wind has a wind shielding factor of 100%.
          3. The wind shielding factor is assumed to be constant all year.
          4. The wind shielding factor is used to calculate the wind speed ratio, which is the ratio of the poolside wind speed to the wind speed measured at the local airport weather station. For a poolside anemometer about 1 foot above the pool and an airport weather station anemometer at 10 meters above the ground, the maximum wind speed ratio (i.e., at 0% wind shielding factor) is estimated to be 0.6. The wind speed ratio is zero at 100% wind shielding factor.
       5. The solar shading factor, FS, is used to account for anything that shades the pool from the sun as it arcs across the sky. The solar shading factor is the average percentage of the pool that is shaded from the sun.
          1. A pool fully exposed to the sun has a solar shading factor of 0%.
          2. A fully shaded pool has a solar shading factor of 100% (e.g., a large awning or a tall building to the south might provide this shade).
          3. The solar shading factor is assumed to be constant all year.
       6. The pool activity factor, Fa, is used to adjust the evaporation rate based on the level of activity supported in the pool[[5]](#endnote-5).
          1. A value for pool activity factor is recommended when the user selects the pool type.
          2. During the hours when the pool is uncovered and unoccupied, the typical pool activity factor for an unoccupied pool of 0.5 is applied.
       7. The Pool Location (indoor/outdoor) was introduced to satisfy the large number of indoor pools that operate throughout the year. The Indoor pool will maintain higher room “space” temperature and higher relative humidity than the outdoor conditions specifically in winter.
       8. The conditions stated in points 1 thru 6 are for the Outdoor Pool. Indoor pool will have those same conditions except for:
          1. Indoor pool may have extended hours of operation based on the type of facility
          2. Indoor pool is totally protected from the wind and has a wind shielding factor of 100%.
          3. Indoor pool has a solar shading factor of 100%
       9. The indoor pool space condition is important for calculating the evaporation losses in particular and for the convection and radiation heat losses to a lesser degree. The indoor conditions are monitored by:
          1. Room indoor temperature in degree (F)
          2. Room relative humidity (%)
       10. The Indoor pool calculated gas savings is based ONLY on the pool water heating and does not include any HVAC energy saving (gas or electric).

1. Swimming Pool Parameters

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Pool Type** | **Area (sq. ft.)** | **Average depth (ft)** | **Solar Shading Factor** (FS) | **Wind Shielding Factor** (FW) | **Typical Activity Factor (Fa)** | **Winter Schedule** | **Summer Schedule** |
| Schools/Colleges | 1,000 | 6 | 0% | 30% | 1.0 | 8AM-4PM | 6AM-10PM |
| City Recreation Centers | 1,000 | 6 | 0% | 0% | 1.0 | 5AM–9PM | 5AM–9PM |
| MF Residential | 1,000 | 6 | 30% | 40% | 0.65 | 10AM-8PM | 10AM-8PM |
| Private/Health Club | 1,000 | 6 | 20% | 30% | 1.0 | 6AM-10PM | 6AM-10PM |
| Homeowners Association (HOA) | 1,000 | 6 | 0% | 20% | 0.65 | 8AM–10PM | 8AM–10PM |

Weather Data

* + 1. The heat transfer model uses hourly weather data. Weather data for one of the 16 climate zones of California shown in Figure 2 are used[[6]](#endnote-6). Climate zone weather data is based on the typical meteorological year (TMY) data derived from the 1961-1990 and 1991-2005 National Solar Radiation Data Base (NSRDB) archives.



1. California Building Climate Zones
   * 1. Table 5 lists a centrally located weather station in each climate zone (used to determine the latitude for incident solar heating of the pool), along with a few other weather stations in each climate zone.
2. California Weather Stations Sorted by Climate Zone

|  |  |  |
| --- | --- | --- |
| **Climate Zone** | **Centrally Located  Weather Station** | **Other Weather Stations** |
| 1 | Arcata Airport | Crescent City FAA |
| 2 | Ukiah Municipal Airport | Napa Co. Airport, Santa Rosa (AWOS) |
| 3 | San Francisco Int’l | Hayward Air Term, Monterey NAF, Oakland Metropolitan, Salinas Municipal |
| 4 | San Jose Intl Airport | Mountain View Moffat |
| 5 | Lompoc (AWOS) | Paso Robles Munic, San Luis Co Rgnl, Santa Maria Public |
| 6 | Los Angeles Int’l | Camarillo (AWOS), Long Beach Daugherty, Oxnard Airport, Point Mugu NAF, Santa Barbara Muni, Santa Monica Muni |
| 7 | San Diego Lindbergh | Camp Pendleton MC, Carlsbad/ Palomar, Chula Vista Brown, San Diego Miramar, San Diego North Is, San Diego/ Montgomery |
| 8 | Santa Ana John Wayne | Fullerton Municipal, Jack Northrop Fld |
| 9 | Burbank-Glendale | Chino Airport, Van Nuys Airport |
| 10 | Riverside Municipal | March AFB |
| 11 | Redding Municipal | Beale AFB, Red Bluff Muni, Redding Muni, Yuba County |
| 12 | Sacramento Metropolitan | Concord, Livermore Muni, Merced/Macready Fld, Modesto City-County, Sacramento Executive, Sacramento Metro, Stockton Metro, Travis AFB |
| 13 | Bakersfield Meadow | Fresno, Fresno Yosemite, Lemoore Reeves, Porterville (AWOS), Visalia Muni (AWOS) |
| 14 | Palmdale Airport | China Lake NAF, Daggett Barstow, Edwards AFB, Lancaster Gen. Wm. Fox, Palmdale Airport, Sandberg, Twentynine Palms |
| 15 | Palm Springs Int’l | Blythe Riverside, Imperial, Needles Airport, Palm Springs Thermal |
| 16 | Truckee-Tahoe | Alturas, Bishop Airport, Blue Canyon AP, Montague Siskiyou, South Lake Tahoe |

Energy Savings Calculation

* + 1. In general, the hourly change in the average pool water temperature is equal to the sum of the heat transferred into the pool each hour, divided by the specific heat of the pool.

 *Eqn-1*

* + - 1. *Tpool* is hourly change in pool temperature, F
      2. *qin* is heat added to the pool via each heat transfer mechanism, Btu/hr
      3. *w* is the density of water, lb/ft3
      4. Cw is the specific heat of water, Btu/lb-F
      5. *Apool* is the area of pool, ft2
      6. *dpool* is the average pool depth, ft
    1. The pool energy savings calculation accounts for the following heat transfer mechanisms:
       1. Natural gas fired pool heater to maintain the pool water temperature
       2. Solar direct radiative heating of the pool surface (reduced by shading and atmospheric clearness factor, which includes haze and cloud cover)
       3. Evaporative cooling from the pool surface (with and without pool cover; with and without swimmers present)
       4. Radiation heat transfer from the pool surface to the sky
       5. Convection heat transfer from the pool surface to the air (free convection under calm conditions, forced convection when windy)
       6. Conduction heat transfer from the pool water to the piping and the soil
       7. Heating the makeup water needed to replace pool water lost by evaporation.

Table 6 lists the average ground temperature, which is used to calculate heat loss to the soil beneath the pool and the energy required to heat the make-up water, and the lowest monthly average air temperature.

1. California Weather Stations Sorted by Climate Zone

|  |  |  |  |
| --- | --- | --- | --- |
| **Climate Zone** | **Centrally Located  Weather Station** | **Ground Temperature** | **Lowest Monthly  Average Temperature** |
| 1 | Arcata Airport | 54 ºF | 49 ºF |
| 2 | Ukiah Municipal Airport | 57 ºF | 45 ºF |
| 3 | San Francisco Int’l | 57 ºF | 50 ºF |
| 4 | San Jose Intl Airport | 59 ºF | 49 ºF |
| 5 | Lompoc (AWOS) | 58 ºF | 52 ºF |
| 6 | Los Angeles Int’l | 61 ºF | 56 ºF |
| 7 | San Diego Lindbergh | 62 ºF | 57 ºF |
| 8 | Santa Ana John Wayne | 63 ºF | 55 ºF |
| 9 | Burbank-Glendale | 64 ºF | 55 ºF |
| 10 | Riverside Municipal | 64 ºF | 53 ºF |
| 11 | Redding Municipal | 61 ºF | 45 ºF |
| 12 | Sacramento Metropolitan | 59 ºF | 45 ºF |
| 13 | Bakersfield Meadow | 64 ºF | 47 ºF |
| 14 | Palmdale Airport | 61 ºF | 43 ºF |
| 15 | Palm Springs Int’l | 73 ºF | 56 ºF |
| 16 | Truckee-Tahoe | 50 ºF | 37 ºF |

* + 1. Solar direct radiative heating of the pool surface
       1. Daytime short-radiation solar heating is impacted by latitude, the atmosphere’s clearness number, shading, and reflection off the water surface. The global horizontal solar irradiation is taken from the weather data files for each climate zone10. The clearness number is modeled using a constant factor of one for all of California, as specified in ASHRAE Handbook[[7]](#endnote-7).
       2. Incoming solar radiation can be obscured by physical objects (such as trees, walls, and buildings) and atmospheric clearness. Shading due to trees, walls, and buildings is included as the solar shading factor. The recommended solar shading factor for each pool type is listed in Table 4.
       3. The fraction of the solar irradiation that is reflected off the pool surface, the reflectance, depends upon the angle of incidence of the sunlight on the pool surface, which in turn depends on numerous parameters[[8]](#endnote-8).
          1. The solar declination results from the tilt of the earth’s axis of rotation relative to its orbit around the sun13.

 *Eqn-2*

** is the solar declination, degrees north of the equator

*D* is the day of the year

* + - * 1. The next parameter is the time since the vernal equinox, described as an angle13.

 *Eqn-3*

*B* is the time before or after the vernal equinox, expressed in degrees

*D* is the day of the year

* + - * 1. The equation of time describes the difference between clock time and solar time, as measured by the angle that the sun across the sky compared to the stars13.

 *Eqn-4*

*ET* is the equation of time, minutes

*B* is the time before or after the vernal equinox, expressed in degrees

* + - * 1. The hour angle is an angular measure of time relative to local noon each day, when the sun is due south in the sky13.

 *Eqn-5*

*ω* is the hour angle, degrees

*H* is the hour of the day, local standard time

*ET* is the equation of time, minutes

*LS* is the standard meridian for the local time zone, (-120º for California)

*L* is the longitude of the centrally located weather station in the climate zone, (~-120º for California)

* + - * 1. The zenith angle is the angle between the zenith (straight up) and the sun13.

  *Eqn-6*

*Z* is the zenith angle, degrees from the zenith

** is the solar declination, degrees north of the equator

ϕ is the latitude of the centrally located weather station in the time zone, (~36º for California)

*ω* is the hour angle, degrees

* + - * 1. The refraction angle of the sunlight underwater is given by Snell’s Law[[9]](#endnote-9). For this calculation, the pool surface is assumed to be smooth and horizontal.

  *Eqn-7*

*R* is the refraction angle in the water, degrees from the straight down

*na* is the index of refraction in air, 1.0003

*nw* is the index of refraction in water, 1.33

** is the zenith angle, degrees from the zenith

* + - * 1. The parallel component of the reflection of unpolarized sunlight off the water surface is given by14:

  *Eqn-8*

*r||* represents the parallel component of reflection of unpolarized radiation sunlight off the water surface

*R* is the refraction angle in the water, degrees from the straight down

** is the zenith angle, degrees from the zenith

* + - * 1. The perpendicular component of the reflection of unpolarized sunlight off the water surface is given by14:

  *Eqn-9*

*r⊥* represents the perpendicular component of reflection of unpolarized radiation sunlight off the water surface

*R* is the refraction angle in the water, degrees from the straight down

** is the zenith angle, degrees from the zenith

* + - * 1. And finally, the reflectance of the sunlight off the water can be calculated using the following approximate expression14:

  *Eqn-10*

*ρ* is the reflectance of the sunlight off the water surface, non-dimensional

*r||* represents the parallel component of reflection of unpolarized radiation sunlight off the water surface

*r⊥* represents the perpendicular component of reflection of unpolarized radiation sunlight off the water surface

*μ* is the extinction coefficient of the solar irradiation in water (averaged across the solar spectrum), roughly 0.06 per foot[[10]](#endnote-10)

*dpool* is the average pool depth, ft

*R* is the refraction angle in the water, degrees from the straight down

* + - 1. The solar direct radiative heating of the pool is therefore given by:

 *Eqn-11*

* + - * 1. *qsolar* is the solar direct radiative heating of the pool, Btu/hr
        2. *C* = 0.317 is the conversion factor from W/m2 to Btu/hr-ft2
        3. *I* is the global horizontal solar radiation taken from the weather data files for each climate zone for each hour of the year, W/m2
        4. *Apool* is the area of pool, ft2
        5. *FS* is the solar shading factor, non-dimensional
        6. *ρ* is the reflectance of the sunlight off the water surface, non-dimensional

The pool cover reduces the effect of solar direct heating. A portion of the solar direct radiation is reflected away by the pool cover, a portion is absorbed by the pool cover itself, and a portion is transmitted through the pool cover into the water below. Table 7 lists the typical portions reflected, transmitted, and absorbed by the pool cover types included in this pool heat transfer model. The pool cover significantly raises the temperature of the top surface of the pool cover, and the heat is conducted through the pool cover down to the water. Radiative heat transfer to the sky and convective heat transfer to the air are also affected by the temperature of the top surface of the pool cover. Since the thermal mass of the pool cover is negligible compared to the pool water, the solar direct radiative heating of the pool with a cover is the sum of the heat transmitted and absorbed by the pool cover (only the reflected portion is lost). The solar direct radiative heating of the pool with a cover is therefore given by:

 *Eqn-12*

*qsolar* is the solar direct radiative heating of the pool, Btu/hr

*C* = 0.317 is the conversion factor from W/m2 to Btu/hr-ft2

*I* is the global horizontal solar radiation taken from the weather data files for each climate zone for each hour of the year, W/m2

*Apool* is the area of pool, ft2

*FS* is the solar shading factor, non-dimensional

*r* is the reflectance of the sunlight off the pool cover, non-dimensional

1. Pool Cover Radiation Properties

|  |  |  |  |
| --- | --- | --- | --- |
| **Pool Cover Type** | **Reflectance** | **Transmittance** | **Absorptance** |
| Insulated | 50% | 0% | 50% |
| Vinyl | 40% | 30% | 30% |

* + - 1. In this analysis, the thermodynamic control volume for swimming pool includes the water and the pool cover. Therefore, the total solar direct radiative heating is the same for no pool cover, a partial cover, or a full cover if the cover is only used during the night hours when there is no solar heat gain.
    1. Evaporative cooling from the pool surface (with and without pool cover; with and without swimmers present)
       1. The pool water provides the latent heat required to evaporate the water, thereby cooling the pool water.
       2. Whenever the saturation vapor pressure of the air is lower than the saturation vapor pressure of the pool water, the pool will lose water by evaporation to the air. Since the pool water provides the latent heat required to evaporate the water, the resulting heat loss cools the pool water. Conversely, on sufficiently hot and humid days, the moisture in the air will condense on the pool surface and heat the pool water.
       3. The ASHRAE Handbook[[11]](#endnote-11) gives a crude estimate of the total heat loss via convection, radiation, and evaporation (= 10.5 x Area x ΔT). The pool cover heat transfer model calculates and adds the individual components of heat transfer instead.
       4. An older ASHRAE Handbook[[12]](#endnote-12) gave an equation for the evaporation rate that relies on the saturation vapor pressure difference between the pool and the air, as well as wind speed:

 *Eqn-12*

* + - * 1. *W* is evaporation rate, lb/hr-ft2
        2. *V* is air velocity over water surface, mph
        3. *Pw* is saturation vapor pressure at the water temperature, in. Hg
        4. *Pa* is saturation vapor pressure at the air dewpoint, in. Hg
        5. *Y* is latent heat of vaporization at pool temperature, Btu/lb
        6. *Fa* is typical activity factor (see Table 4)
      1. Smith, Lof, and Jones[[13]](#endnote-13) updated the coefficients in the ASHRAE equation based on field tests which measured the evaporation rates and total energy loads from an unoccupied, heated outdoor pool in Fort Collins, Colorado similar to the large outdoor pools considered in this workpaper. Pool and air temperatures, humidity, thermal radiation, wind speed, and water loss due to evaporation were measured over 21 test periods ranging from 1.1 to 16.2 hours during August and September of 1992. Data were analyzed and compared to commonly used evaporation rate equations. They concluded that “the rate of evaporation from an inactive outdoor swimming pool is 16-28% lower than that predicted by the ASHRAE equation.” They recommended simply adjusting the coefficients in the ASHRAE equation:

 *Eqn-13*

*W* is evaporation rate, lb/hr-ft2

*V* is air velocity over water surface, mph

*Pw* is saturation vapor pressure at the water temperature, in. Hg

*Pa* is saturation vapor pressure at the air dewpoint, in. Hg

*Y* is latent heat of vaporization at pool temperature, Btu/lb

*Fa* is typical activity factor (see Table 4)

* + - 1. Saturation vapor pressure equations[[14]](#endnote-14) were used to convert the dew point and dry bulb temperature from the weather data, given by the following equation.

 *Eqn-14*

* + - * 1. *pws* is saturation pressure, psia
        2. *T* is absolute temperature, °R = °F + 459.67
        3. *C8* = −1.044 039 7 E+04
        4. *C9* = −1.129 465 0 E+01
        5. *C10* = −2.702 235 5 E−02
        6. *C11* = 1.289 036 0 E−05
        7. *C12* = −2.478 068 1 E−09
        8. *C13* = 6.545 967 3 E+00
      1. The evaporation rate with swimmers disturbing the pool surface and splashing water droplets into the air will be higher than for a calm pool. The ASHRAE Handbook9 uses a typical activity factor, Fa, to represent the relative evaporation rates of various types of pools, as listed in Table 4 above.
      2. Since the Smith, Lof, and Jones evaporation rate equation uses a wind speed at the pool side, a method to convert weather station wind speeds to poolside wind speeds was needed. The wind speed for evaporative cooling in the tests described in Smith, Lof, and Jones is measured close to the pool surface, while the wind speed at a weather station is typically reported for a height of 10 meters above level ground. The poolside data collected at a workout club in a coastal southern California climate[[15]](#endnote-15) and an HOA pool in the southern California desert climate[[16]](#endnote-16) were used to determine a wind shielding factor of 0.33, representing the annual average ratio of the poolside wind speed to the weather station wind speed. The actual wind shielding factor at any moment in time will vary from pool to pool due to the actual wind screening around the pool, the local topography, and the direction of the wind. Even the annual average ratio is likely to be different for each pool due to its predominant wind direction and the local topography as well as the physical wind screens immediately around the pool. The wind shielding factor, FW, recommended for each pool type is listed in Table 1. In the model, the weather station wind speed is multiplied times the wind shielding factor to derive a wind speed at the pool’s edge for use in calculating the evaporation rate and the convection heat transfer.
      3. In addition to increasing the evaporation rate and the convection heat transfer, excessive wind speed at the pool’s surface may disturb the pool cover. For safety reasons, pool covers are retracted when poolside wind speeds are expected to exceed 8 mph. Without a good wind screen, the pool cover is likely to be retracted most of the time at many sites. Fortunately, most swimming pools are encircled with high hedges, fences, walls, and buildings to screen the occupants from the wind. Since most pools have good wind screens, the poolside wind speed is much lower than the wind speed measured at a nearby weather station. The same wind shielding factor that was used to calculate the evaporation rate and the convection heat transfer was used to determine whether the pool cover needs to be retracted due to high winds.
      4. The pool cover obviously reduces the evaporation rate, but it also has an effect on heat transfer by radiation, convection, or conduction. The pool cover effectiveness is assumed to be 100% with regard to evaporation. The pool cover is effective only when the pool is covered, and it is assumed the pool is covered whenever the pool is closed and the wind speed is less than the maximum safe wind speed for the pool to be covered; otherwise, the pool cover effectiveness is assumed to be zero. With the pool cover effectiveness term, the evaporation rate with a pool cover is therefore:

 *Eqn-15*

* + - * 1. *W* is evaporation rate, lb/hr-ft2
        2. *V* is air velocity over water surface, mph
        3. *Pw* is saturation vapor pressure at the water temperature, in. Hg
        4. *Pa* is saturation vapor pressure at the air dewpoint, in. Hg
        5. *Fa* is typical activity factor (see Table 3)
        6. *ηPC* is the pool cover effectiveness, %
        7. *Y* is latent heat of vaporization at pool temperature, Btu/lb
      1. The air velocity over the water surface is calculated from the weather file wind speed as follows:

 *Eqn-16*

* + - * 1. *V* is air velocity over water surface, mph
        2. *FW* is wind shielding factor, non-dimensional
        3. *VW* is the hourly wind speed taken from the climate zone’s typical weather file, mph
      1. As the pool water evaporates, it cools the pool water at the rate of:

 *Eqn-17*

* + - * 1. *qevaporation* is the evaporative heat loss from the pool, Btu/hr
        2. *Y* is the latent heat of vaporization at pool temperature, Btu/lb
        3. *Apool* is the area of pool, square feet
        4. *W* is evaporation rate, lb/hr-ft2
      1. When the pool cover is extended, evaporation and evaporative heat loss are assumed to be negligible. When the pool surface is partially covered, evaporation and evaporative heat loss are proportional to the uncovered water surface area.
    1. Heating the makeup water
       1. As the pool water evaporates, it is replaced by make-up water heated by the pool heater. The evaporative mass loss of the pool is calculated each hour, and that value is assumed equal to the pool makeup water flow from the water supply. The pool heater must heat the makeup water from its supply temperature to the pool temperature. This is a small term. There are differences between the climate zones in the local water supply temperature – it is assumed to be equal to the ground temperature, which in turn is assumed equal to the annual average air temperature in each climate zone. The heat required is given by

 *Eqn-18*

* + - * 1. *qmakeupwater* is the heat delivered to the makeup water, Btu/hr
        2. *W* is evaporation rate, lb/hr-ft2
        3. *Cw* is specific heat of water, (Btu/lb-F)
        4. *Apool* is the area of pool, square feet
        5. *Tpool* is the pool water temperature, F
        6. *Tmakeupwater* is makeup water temperature, F
      1. When the pool cover is extended, heating the makeup water is assumed to be negligible. When the pool surface is partially covered, the energy used to heat the makeup water is proportional to the uncovered water surface area.
    1. Radiative cooling and heating
       1. Long-wavelength radiative cooling from the pool surface occurs when the sky temperature is lower than the pool temperature; and radiative heating occurs when the sky temperature is higher than the pool temperature. Smith, Lof, and Jones18 provided an equation for radiative cooling based on the sky temperature, which in turn is based on the weather station dew point and dry bulb temperatures.

**** *Eqn-19*

* + - * 1. *qsky* is the radiation heat transfer from the sky into the pool, Btu/hr
        2. *hrunc* is the radiative heat transfer coefficient based on pool temperature, Btu/ft2-hr-R
        3. *Aunc* is the uncovered pool surface area, square feet
        4. *Tsky*is the sky temperature, F
        5. *Tpool* is the pool temperature, F
        6. *hrcov* is the radiative heat transfer coefficient based on the cover temperature, Btu/ft2-hr-R
        7. *Acover* is the pool surface area covered by the pool cover, square feet
        8. *Tcover* is the temperature of the top surface of the pool cover, F
      1. A linearized radiation coefficient is given by Bliss[[17]](#endnote-17).

 *Eqn-20*

* + - * 1. *hr* is the radiative heat transfer coefficient, Btu/ft2-hr-R
        2. *ε* is emissivity coefficient of pool water, 0.9, non-dimensional
        3. *σ* is Stefan-Boltzmann constant, 0.000000001714 Btu/ft2-hr-R4
        4. *Tsurface* is the pool temperature where the pool is uncovered and the temperature of the top surface of the pool cover, where the pool is covered, F
        5. *Tsky*is the sky temperature, F
      1. The sky temperature is given by Bliss as:

**** *Eqn-21*

* + - * 1. *Tsky*is the sky temperature, F
        2. *Tair* is dry bulb temperature of the air, F
        3. *Tdp* is dew point temperature of the air, F
      1. The pool cover reduces but does not eliminate radiative cooling (or heating). The temperature of the top of the pool cover, Tcover, balances the heat transfer up through the pool cover with the heat transfer from the pool cover to its surroundings. If the pool cover has no insulating value, then the pool cover temperature is equal to the pool water temperature. Otherwise, the pool cover temperature is calculated after the convection heat transfer is known (see next section).
    1. Convective cooling (or heating if the air temperature is higher than the pool temperature) from the pool surface is the greater of free convection and forced convection. The transition wind speed depends on the temperature difference between the pool or cover top surface, and the air.
       1. At low wind speeds, the pool and/or the cover is cooled by free convection[[18]](#endnote-18). At higher wind speeds, forced convection dominates[[19]](#endnote-19). The heat transfer mechanism (free or forced) with the greater heat transfer is used. The same wind shielding factor as above was used to calculate the wind speed across the pool surface for convective cooling. The convection heat transfer is given by the following equation:

 *Eqn-22*

* + - * 1. *qconv* is the convection heat transfer into the pool, Btu/hr
        2. *hcunc* is the convection heat transfer coefficient based on the pool temperature, Btu/ft2-hr-R
        3. *Aunc* is the uncovered pool surface area, square feet
        4. *Tair*is the dry bulb air temperature, F
        5. *Tpool* is the pool temperature, F
        6. *hccov* is the convection heat transfer coefficient based on the cover temperature, Btu/ft2-hr-R
        7. *Acov* is the pool surface area covered by the pool cover, square feet
        8. *Tcover* is the temperature of the top surface of the pool cover, F
      1. The convection heat transfer coefficient is given by

 *Eqn-23*

* + - * 1. *hc* is the uncovered or covered convection heat transfer coefficient, as appropriate, Btu/ft2-hr-R
        2. *Nu* is the uncovered or covered Nusselt number, as appropriate, non-dimensional
        3. *kair* is the thermal conductivity of air, Btu/ft-hr-F
        4. *L* is the characteristic length of the pool surface, ft

The Nusselt number for **free convection** from a horizontal flat surface is given by one of the following three equations, as appropriate23:

 (104<*Ra*<107 – laminar plume – *Tsurf* > *Tair*) *Eqn-25*

(107<*Ra*<1011 – turbulent plume – *Tsurf* > *Tair*) *Eqn-26*

 (105<*Ra*<1010 – down flow – *Tsurf* < *Tair*) *Eqn-27*

*Nu* is the uncovered or covered Nusselt number, as appropriate, non-dimensional

*Ra* is the Rayleigh number

The Rayleigh number for a horizontal flat surface is given by

 *Eqn-28*

*Ra* is the Rayleigh number

*g* is the acceleration due to gravity, ft/hr2

*β* is volumetric thermal expansion coefficient of air, 1/R

*Lfree* is the characteristic length of the pool surface for free convection, ft

*ν*is kinematic viscosity of air, ft2/hr

*α*is thermal diffusivity of air, ft2/hr

*Tsurf* is the pool temperature or the temperature of the top surface of the cover, as appropriate, F

*Tair*is the dry bulb air temperature, F

For **free convection** heat transfer from the surface of the pool, the characteristic length *Lfree* is given by the following equation23:

 *Eqn-29*

*Lfree* is the characteristic length of the pool surface for free convection, ft

*Apool* is the surface area of the pool, sq. ft.

*Ppool* is the pool perimeter, ft

* + - 1. For convenience, the pool perimeter is approximated from the pool area:

 *Eqn-25*

* + - * 1. *Ppool* is the pool perimeter, ft
        2. *Apool* is the surface area of the pool, sq. ft.

The Nusselt number for **forced convection** across a horizontal flat surface is given by24

(Re<5x105 - laminar flow regime) *Eqn-31*

(Re>5x105 - mixed and turbulent flow regime) *Eqn-32*

*Nu* is the uncovered or covered Nusselt number, as appropriate, non-dimensional

*Re* is the Reynolds number, non-dimensional

*Pr* is the Prandtl number, non-dimensional

The Reynolds number for forced convection over the pool is given by

  *Eqn-33*

*Re* is the Reynolds number, non-dimensional

*V* is wind speed, ft/hr

*Lforced* is the characteristic length of the pool surface for forced convection, ft

** is the kinematic viscosity of air, ft2/hr

For **forced convection** heat transfer from the surface of the pool, the characteristic length *L* is given by the following equation:

 *Eqn-34*

*Lforced* is the characteristic length of the pool surface for forced convection, ft

*Apool* is the surface area of the pool, sq. ft.

*Ppool* is the pool perimeter, ft

* + - 1. The Prandtl number for air is given by

 *Eqn-32*

*Pr* is the Prandtl number, non-dimensional

*Cp* is the specific heat capacity of air, Btu/lb-F

*μ* is the dynamic viscosity of air, lb/ft-hr

*kair* is the thermal conductivity of air, Btu/hr-ft-F

* + - 1. Convective heating or cooling is reduced by the pool cover, but not eliminated. The temperature of the top of the pool cover is adjusted to balance the heat transfer up through the pool cover with the heat transfer from the pool cover to its surroundings. Radiative heating, conductive heating, and solar direct radiative heating all contribute to the pool cover temperature, as well as the insulating value of the pool cover. If the pool cover has no insulating value, then the pool cover temperature is equal to the pool water temperature. Otherwise,

**** *Eqn-33*

* + - * 1. *Tcover*is the temperature of the top of the pool cover, F
        2. *Tpool* is the pool water temperature, F
        3. *Rcover*is the insulating value of the pool cover, hr-ft2-F/Btu
        4. *hrcov* is the radiative heat transfer coefficient based on the cover temperature, Btu/ft2-hr-R
        5. *Tsky*is the sky temperature, F
        6. *hccov* is the convection heat transfer coefficient based on the cover temperature, Btu/ft2-hr-R
        7. *Tair* is dry bulb temperature of the air, F
        8. C = 0.317 is the conversion factor from W/m2 to Btu/hr-ft2
        9. *I* is the global horizontal solar radiation taken from the weather data files for each climate zone for each hour of the year, W/m2
        10. *FS* is the solar shading factor, non-dimensional
    1. Conduction heat transfer to the piping and the soil
       1. An estimate was made for conduction heat transfer from the soil to the pool[[20]](#endnote-20), although this is a small (usually cooling) term. There is a difference between the climate zones in the ground temperature. The average dry bulb temperature from the 30-year weather data files for each climate zone is an accurate estimate for the ground temperature, since the ground temperature is equal to the long-term average of the air temperature. The conduction heat transfer is given by the following equation:

 *Eqn-34*

* + - * 1. *qground* is the conduction heat transfer from the ground into the pool, Btu/hr
        2. *Uground* is the overall heat transfer coefficient, Btu/hr-ft2
        3. *Apool* is the area of pool, square feet
        4. *Tgroundwater* is the ground temperature
        5. *Tpool* is the pool temperature
      1. The overall heat transfer coefficient from the pool to the ground is given by

 *Eqn-35*

* + - * 1. *Uground* is the overall heat transfer coefficient, Btu/hr-ft2
        2. *kground* is the thermal conductivity of the ground, Btu/hr-ft-F
        3. *dgroundwater* is the depth to the water table (assumed to be 16 feet), ft
        4. *dpool* is the average pool depth, ft
        5. *Ppool* is the pool perimeter, ft
        6. Apool is the surface area of the pool, square feet
    1. Indoor pool heating losses
       1. The same heating losses and calculations will be used in the indoor pool cover case, with the following exceptions:
          1. The outdoor air temperatures and relative humidity for each weather zone will be replaced by the indoor conditions of the pool.
          2. For the same indoor conditions, similar savings was obtained for different weather zones. Yet, for different pool operating schedules, more savings were achieved in using the pool cover for longer hours.
          3. Detailed analysis are shown in Attachment B..
       2. The saturation vapor pressure Pa used in the evaporation formula (*Eqn-15*) was calculated at the indoor air dewpoint temperature using Eqn-36. *A simple approximation for the conversion between the dew point, temperature and relative humidity. “This approach is accurate to within about ±1 °C as long as the relative humidity is above 50%”[[21]](#endnote-21).*

 T_{dp:f}\approx T_{f}-\frac{9}{25}(100-R\!H); *Eqn-36*

* + - * 1. *Tdp:f* is the indoor dew point temperature, °F
        2. *Tf* is indoor dry-bulb temperature, °F
        3. *RH* is indoor relative humidity*.*
      1. The default values used in the indoor swimming pools are shown in Table 8.

1. Indoor Pools Space Conditions

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Name** | **Default Value** | **Comment** |
| Pool water temperature, default | *Tpool* | 80°F | Standard heating pool temp |
| Indoor air dry bulb temperature setpoint | *Tair* | 82°F | 2°F higher than water temp |
| Indoor air relative humidity setpoint | *Rh%* | 60% | 10% above average |

* + 1. Physical Constants Used to Calculate Energy Savings:
       1. Table 9 lists the physical constants used to calculate energy savings, and the properties of water and air, evaluated at a representative pool temperature of 80 F.

1. Physical Constants

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Name** | **Default Value** | **Comment** |
| Density, water (lb/ft3) | *ρw* | 62.2 | at 80 F |
| Specific heat, water (Btu/lb-F) | *Cw* | 1 | at 80 F |
| Latent heat of water (Btu/lb) | *Y* | 1049 | at 80 F |
| Index of refraction, water | *nw* | 1.33 |  |
| Extinction coefficient, sunlight in water (1/ft) | ** | 0.06 |  |
| Gravity (ft/hr2) | *g* | 417,312,000 |  |
| Thermal conductivity, air (Btu/hr-ft-F) | *kair* | 0.0150 | at 80 F |
| Density, air (lb/ft3) | *ρa* | 0.074 | at 80 F |
| Specific heat, air (Btu/lb-F) | *Cp* | 0.24 | at 80 F |
| Thermal diffusivity, air (ft2/hr) | ** | 0.84 | at 80 F |
| Coefficient of thermal expansion, air (1/F) | *β* | 0.00185 | at 80 F |
| Viscosity, air (lb/ft-hr) | *μ* | 0.045 | at 80 F |
| Kinematic viscosity, air (ft2/hr) | ** | 0.61 | at 80 F |
| Index of refraction, air | *na* | 1.0003 |  |
| Stefan-Boltzman constant (Btu/hr-ft2/R4) | *σ* | 1.714E-09 |  |
| Time Zone |  | -8 (Pacific) | For solar heating |
| Ground reflectance |  | 0.1 | For solar heating |
| Constants used in water saturation pressure equation | C8 | -10440.397 |  |
| C9 | -11.29465 |  |
| C10 | -0.027022355 |  |
| C11 | 1.28904E-05 |  |
| C12 | -2.48E-09 |  |
| C13 | 6.5459673 |  |
| Emissivity of water | *ε* | 0.9 | For radiative heat transfer |
| Thermal conductivity for dry, packed soil (Btu/hr-ft-F) | *kground* | 0.037 | For conductive heat transfer |
| Maximum poolside wind speed for pool cover (mph) | *Vmax* | 8 |  |

Savings Results

* + 1. The energy savings are analyzed by performing a sensitivity analysis[[22]](#endnote-22) using the default values and variations of parameters in Table 4. For detailed analysis, please refer to Attachment B.
    2. Please refer to Attachment A for complete result of pool cover savings in all 16 climate zones and different building types.

1. Base Case & Measure Costs

Base Case Cost

* + 1. This measure is to be implemented for the following:
       1. Replace on Burn-Out (ROB) for existing pools.
       2. New Construction (NC) for new pools.
    2. The Baseline Costs are:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Description** | **Equipment Cost** | **Labor / Installation Cost** | **Maintenance / Other Cost** | **Total Measure Case Cost** |
| Pool Cover (Vinyl) | $1.05 | $0 | $0 | $1.05 |

*All costs are noted as $ per square foot*

Gross Measure Cost

* + 1. The proposed Measure Case Costs are:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Description** | **Equipment Cost** | **Labor / Installation Cost** | **Maintenance / Other Cost** | **Total Measure Case Cost** |
| Pool Cover (Insulated) | $2.24 | $0 | $0 | $2.24 |

*All costs are noted as $ per square foot*

The measure costs above are based on an estimate provided by a local vendor, (Attachment D.)

Note the cost estimate does not include a storage reel system or reel protector; additions that are included in both, baseline and measure cases.

Incremental Measure Cost

* + 1. The IMC for this measure is the Gross Measure Cost minus the Baseline Cost. Therefore the IMC for either ROB or NC is:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Description** | **Equipment Cost** | **Labor / Installation Cost** | **Maintenance / Other Cost** | **Total Measure Case Cost** |
| Pool Cover | $1.19 | $0 | $0 | $1.19 |

Attachments

*Attachment A – Savings Results for all 16 weather zones*

**

*Attachment B – Energy Savings Calculations*

**

*Attachment C – Pool Cover/Heater Tool WP.*

**

*Attachment D – Pool Cover Cost Estimate*

**

*Attachment E – Pool Cover WorkPad Measure Upload*

**

References

1. *Conserving Energy and Heating Your Swimming Pool with Solar Energy*, National Renewable Energy Laboratory, DOE/GO-102000-1077, FS104, July 2000. Accessed August 22, 2012 at <http://www.nrel.gov/docs/fy00osti/28038.pdf>. [↑](#endnote-ref-1)
2. *Payette Idaho Pool Energy conservation study, by PNNL prepared for the DOE, Section 4.1, November 2001. Accessed at* <http://www.pnl.gov/main/publications/external/technical_reports/pnnl-13740.pdf> [↑](#endnote-ref-2)
3. *Pool Energy Use Calculator*, 2011 Washington State University Extension Energy Program, Accessed June 4, 2012 at <http://www.energyexperts.org/CalculatorsTools/PoolEnergyUseCalculator.aspx>. [↑](#endnote-ref-3)
4. *Energy Smart Pools Software,* U.S. DOE, Accessed June 4, 2012 at <http://www.rlmartin.com/rspec/software.htm>. [↑](#endnote-ref-4)
5. *2011 ASHRAE Handbook – HVAC Applications*, Page 5.6, 2011. (Natatoriums) [↑](#endnote-ref-5)
6. *EnergyPlus Energy Simulation Software*: *Weather data for California Climate Zones* (Typical Meteorological Weather Data (TMY-3) for California), U. S. DOE, <http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=4_north_and_cen-tral_america_wmo_region_4/country=2_california_climate_zones/cname=California%20Climate%20Zones> [↑](#endnote-ref-6)
7. *2011 ASHRAE Handbook -- HVAC Applications*, Page 35.4, Figure 5, 2011. (Clearness Numbers) [↑](#endnote-ref-7)
8. *Estimation of Solar Radiation by Using ASHRAE Clear-Sky Model in Erzurum, Turkey*, K. Bakirci, University of Atatürk, Erzurum, Turkey. Published online Jan, 2009. [↑](#endnote-ref-8)
9. *Advances in Modeling of Ground-Source Heat Pumps Systems*, A. D. Chiasson, Oklahoma State University, December 1999. Accessed on August 27, 2012 at <http://www.hvac.okstate.edu/research/Documents/chiasson_thesis.pdf>. [↑](#endnote-ref-9)
10. *Light*, Lake Ecology Primer, Water on the Web - A National On-line Curriculum using Advanced Technologies and Real-Time Data. University of Minnesota-Duluth, Duluth, Minnesota. Accessed August 27, 2012 at <http://www.waterontheweb.org/under/lakeecology/04_light.html>. [↑](#endnote-ref-10)
11. *2011 ASHRAE Handbook – HVAC Applications*, Page 50.23-24, Eq. 22, 2011. (Swimming Pools/Health Clubs) [↑](#endnote-ref-11)
12. *2007 ASHRAE Handbook – HVAC Applications*, Page 49.22, Eq. 22, (Swimming Pool Heat Transfer), 2007. [↑](#endnote-ref-12)
13. “Measurement and Analysis of Evaporation from an Inactive Outdoor Pool”, C. C. Smith, G. Löf, and R. Jones, *Solar Energy*, Vol. 53, No. 1, pp. 3-7, Pergamon, 1994. [↑](#endnote-ref-13)
14. *2009 ASHRAE Handbook – Fundamentals*, Chap. 6, p. 2, Eq. 6, 2009. (Saturated vapor pressure equation) [↑](#endnote-ref-14)
15. *Engineering Measurement & Verification Study: HeatSavr™ Liquid Swimming Pool Cover, Workout Club Swimming Pool, Southern California Coastal Climate in Oceanside, CA 2008-2009,* Information & Energy Services, Inc., for Sempra Energy, San Diego, CA (2009). [↑](#endnote-ref-15)
16. *Engineering Measurement & Verification Study: HeatSavr™ Liquid Swimming Pool Cover, Homeowners Association (HOA) Swimming Pool, Desert Climate near Palm Springs, California, 2009*, Information & Energy Services, Inc., for Sempra Energy, Los Angeles, CA. ). [↑](#endnote-ref-16)
17. “Atmospheric Radiation near the Surface of the Ground,” R.W. Bliss, *Solar Energy*, 5(103), 1961. (Radiation Heat Transfer: the sky temperature is calculated for the radiation equation) [↑](#endnote-ref-17)
18. *2009 ASHRAE Handbook – Fundamentals*, Chap. 4, Page 4.20, Eq. T9.8. (Convection Heat Transfer: Free convection, Horizontal Plate) [↑](#endnote-ref-18)
19. *2009 ASHRAE Handbook – Fundamentals*, Chap. 4, Page 4.19, Eq. T8.11. (Convection Heat Transfer: Forced convection, Flat Plate) [↑](#endnote-ref-19)
20. “Dependence of Ground Heat Losses upon Solar Pond Size and Perimeter Insulation – Calculated and Experimental Results,” J.R. Hull, K.V. Liu, W.T. Sha, J. Kamal, and C.E. Nielsen, *Solar Energy*, 33(1): 25-33, 1984. (Conduction Heat Transfer) [↑](#endnote-ref-20)
21. *M. G. Lawrence, "The relationship between relative humidity and the dew point temperature in moist air: (A simple conversion and applications)", 2005.* Accessed at <http://climate.envsci.rutgers.edu/pdf/LawrenceRHdewpointBAMS.pdf> [↑](#endnote-ref-21)
22. *PG&E’s workpaper titled: PGECOPRO105 Commercial Pool Heaters, Rev. 1, June 15, 2012.* [↑](#endnote-ref-22)