How big would a solar thermal installation on Evergreen's Campus Recreation Center (CRC) **roof need to be, in order to heat the swimming pool?**

DRAFT - 1 Sept. 2015 - E.J. Zita, Tim Smith, Jimmy Hadley

Outline: The CRC[1] has two indoor pools, an Olympic-sized pool, 25 yards by 25 m, and a diving pool 9 x 12 m, with a total area of about 680 m^2. The CRC's flat roof area is approximately 1670 m^2. Student research teams[2] recommend unglazed flat panels for pool water heating.

A. We estimate the power required for pool heating in two ways:

1. by calculating the rate of heat loss from first principles, and
2. by comparing with published heat loss from similar pools (see Appendix A2)

B. Then we estimate the area of solar thermal panels required to provide this heating power:

1. by calculating the water heating production capacity from unglazed flat panels at Olympia's latitude, and

2. by comparing with solar-thermally heated pools elsewhere.

C. Finally, we estimate the costs, benefits, and opportunities of solar-thermal pool heating at Evergreen:

1. How much would solar-thermal pool heating cost?

2. How much power, expense, and carbon could solar-thermal pool heating save?

3. What resources are available for installing solar-thermal pool heating at Evergreen?

4. What other costs or complications should be considered?

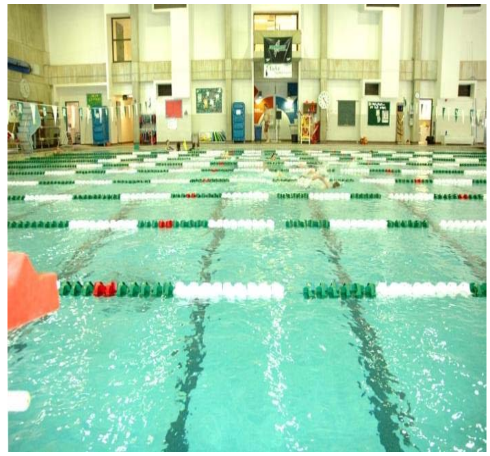
Solar heating peaks in summer. Does heat loss peak in winter months, when it is cold outside? Calculate intersection of curves to find months when solar thermal heating of pool makes sense.

Glazed panels suffer less heat loss, and may contribute to shower water heating even in winter. How much?

Installing both glazed and unglazed solar heating on CRC enables Evergreen to compare and evaluate both systems as part of our Campus Learning Laboratory. This can serve as a pilot project to inform future solar thermal installations in Washington State.

5. What other benefits could be capitalized on?

[1] CRC website reference
[2] R.Matthew Smith and Kramer Fry in Energy Systems & Climate Change, 2014; Tim Smith and Jimmy Hadley, SURF, summer 2015



A1. First, we estimate the power required for pool heating by calculating the rate of heat loss from first principles.

The rate of heat loss is $q = L\,G$ (1)

where L is water's latent heat of vaporization, and G is the rate of water lost to evaporation.

We can calculate the evaporation rate[3] of our pool from $G = \Theta A[(x_s - x)/3600]$ (2)

$\Theta = (25 + 19v)$ *kg/m²·hr* accounts for the effect of the airspeed (v) at the water's surface,
A = surface area of the pool (680 m^2).
x_s = humidity of saturated air (in *kg H_2O/kg of air*) at the same temperature as the water surface
x = relative humidity in the air at the water surface (in *kg H_2O/kg of air*),
and 3600 converts seconds to hours.

We assume that the water and the air are in thermal equilibrium at 25°C, and the airspeed at the surface is about 1 *mph* (0.5 *m/s)*. We measure and calculate the humidities, and both techniques yield $(x_s - x) = 0.01$ (see Appendix 1). Then we find an evaporation rate of

$$G = (25 + 19 \times 0.5)\left[\frac{kg}{m^2 hr}\right] 680\left[m^2\right]\left(\frac{0.01}{3600\, {}^{s}\!/_{hr}}\right) = \mathbf{0.065}\,\frac{kg}{s}$$

The pool loses about 0.065 *kg/s* of water while it is heated to 25°C and uncovered, with breezes due to swimming and diving . This loss rate varies more strongly with surface air speed than with temperature; we estimate that it could increase a factor of three if air speeds doubles (Appendix 2).

[3] Equation is from www.engineeringtoolbox.com/evaporation-water-surface-d_690.html

Now we can find the power required to hold the pool at a steady temperature, using the basic thermodynamic equation $Q = m L$: the heat Q required to evaporate a mass m of water depends on the latent heat of evaporation, L = 2260 *Joules/g* = 2260 *kJ / kg*.

The rate of heat loss depends on the rate of evaporation: $\frac{dQ}{dt} = L\frac{dm}{dt}$, and the evaporation rate is $G = \frac{dm}{dt}$, therefore the minimum power required to keep the pool temperature steady is $q = \frac{dQ}{dt} = L\frac{dm}{dt} = LG,$ as we claimed in (1).

$$q = LG = 2260\frac{kJ}{kg} \times 0.065\frac{kg}{s} = 147\frac{kJ}{s} \approx \mathbf{150\,kW}$$

We can find the pool's annual energy requirement in kW.hr by converting units:

$$q = 150\,kW\left|\frac{24\,hr}{day}\right|\frac{365\,days}{year}\left| = \mathbf{1.3 \times 10^6}\,\frac{kW \cdot hr}{year}\right.$$

If the pool's surface air speed doubled, to 2 miles per hour, these power requirements triple. Since the CRC pool has a heat recovery exchanger, we will assume that our original power estimate q is close to the actual requirement.

B1. Next, we estimate the area of solar thermal panels required to provide this heating power, by calculating the water heating production capacity from unglazed flat panels at Olympia's latitude.

Olympia's average horizontal solar insolation[4] through the year is 3.3 kWh/m^2 per day.

3.3 kWh/m^2 day * 365 days/year = 1200 kWh/m^2 per year.

Since we need 1.3x10^6 kWh/year for the swimming pool, our minimum array size for year-round operation would be:

1.3x10^6 kWh/year * 1200 kWh/m^2 year = 1080 m^2 of solar thermal panels

A more conservative estimate considers that most solar thermal panels are about 80% efficient and Olympia gets about 1000 hours of sunshine per year, yielding an annual insolation of

1000 W/m^2 * 1000 hours/year * 0.8 = 800 kWh/m^2 year

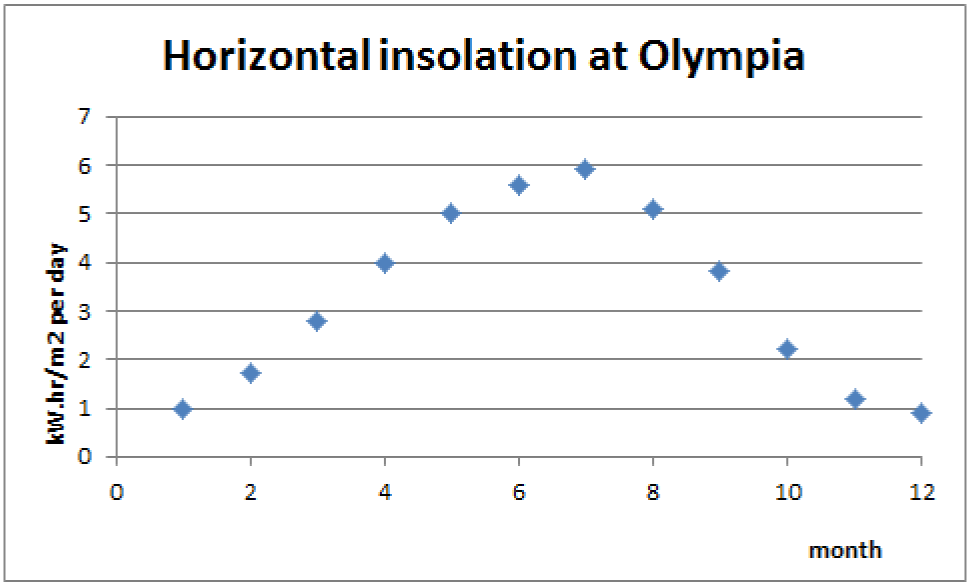
Since we need 1.3x10^6 kWh/year for the pool, our maximum array size would be:

1.3x10^6 kWh/year *700 kWh/m^2 year = 1860 m^2 of solar thermal panels

Assuming year-round pool heating, we would need 1080-1860 m^2 of solar thermal panels.

It is probably more realistic to heat the pool with unglazed flat panels only in the sunniest months of April-September, when the solar panels will lose less heat to cold wet winter weather. The average daily insolation in the summer is 4.9 kW.hr/m^2, which yields 715 kW hr/m^2 over half a year. For this period, the pool requires ½ of 1.3×10^6 kWh = 0.65×10^6 kWh. Assuming 80% efficiency, the size of the solar thermal array would need to be

$$0.65 \times 10^6 \text{ kWh} * 715 \text{ kW hr/m}^2 = \mathbf{910\ m^2}.$$

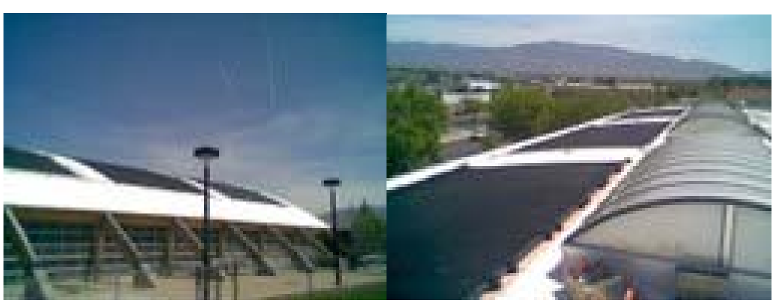


This may be an overestimate of the required solar thermal panel area because:

- We included winter heating in the required power - summer heating needs are likely to be lower
- The estimated air velocity is high according to our measurements, discussed below.

B2. Consider the sizes and costs of solar-thermal unglazed flat-panel systems used to heat other Olympic-sized pools. These are city pools in Albuquerque, NM[4]:

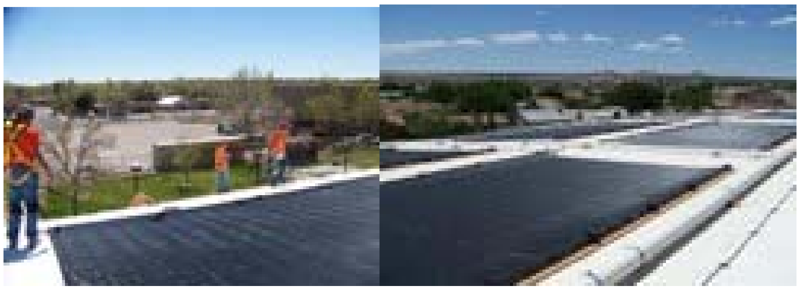
Highland Pool:



[4] Example from www.cabq.gov/municipaldevelopment/renewable-energy/solar-projects/solar-thermal-water-heater-at-city-pools

Highland Pool Capacity: 300,000 gallons
Pool Area: 675 m^2
96 Solar collector panels for a total of 450 m^2
Output: 3,734,400 BTU/Day and a 7.5 Hp water booster pump

West Mesa Pool:



West Mesa Pool Capacity: 300,000 gallons
Pool Area: 675 m^2
136 Solar collector panels for a total of 660 m^2
Output: 5,290,400 BTU/Day and a 7.5 HP water booster pump

Valley Pool:

Valley Pool Capacity: 250,000 gallons
Pool Area: 635 m^2
88 Solar collector panels for a total of 320 m^2
Output: 3,423,200 BTU/Day and a 7.5 HP water booster pump.
Annual avoided cost for natural gas and electricity: $104,184
Annual reduction in CO2 equivalents: 252,132 pounds of CO2
Budget: $418,516
Funding Source: 1% for Energy Conservation Set-aside for Capital Improvements
Payback: 4.4 years

Our calculated solar-thermal unglazed flat-panel system is comparable to those used to heat other Olympic-sized pools.

C. Finally, we estimate the costs, benefits, and opportunities of solar-thermal pool heating at Evergreen. We will assume a solar-thermal system size of 910 m^2 on the CRC roof for our following cost-benefit analysis, with April-Sept. heating only.

1. How much would solar-thermal pool heating cost[5]? Solar thermal systems cost approximately $5100 per 90 m^2, including solar thermal collectors, hardware and data analysis system . This does not include installation costs and a water tank for the heater water.

   Our 910 m^2 solar thermal pool heating system would cost about $52,000 plus installation.

2. We can now calculate the annual cost savings, assuming a heating cost of 3.4c per kW.hr (our present cost with natural gas). Recall that CRC pool heating requires approximately 1.3 million kW.hr per year. We conservatively assume that solar thermal panels could supply full heating only in May-August, and partial heating in April and September, resulting in 542,000 kW.hr in power savings.

$(542{,}000\ kWh) \times (\$0.034/kWh) = \$18{,}400$ per summer

According to the college engineer Rich Davis, the boilers are estimated to produce around two million btuh. Converting these to kWh, we get the following savings if the boilers were turned off in the summer.

$(1{,}752{,}000\ kWh) \times (\$0.034\ /kWh)$= $59,000 a summer

The potential savings from solar thermal heating of the pool in one year of operation are comparable to the cost of the system itself.

If the College turned off the boilers, we may need additional investments such as on-demand heaters for domestic hot water around campus.

3. What resources are available for installing solar-thermal pool heating at Evergreen?

In-house funds may be required for a significant portion of this investment. The Clean Energy Committee is a potential partner in this project. Department of Commerce may provide some funds if we decide to apply for the Higher Education Efficiency grant. Non-state matching funds may be necessary for the Department of Commerce grant. Alumni fundraising may be a possibility, as the cost of this project is relatively low, and the benefits are relatively high. There may also be additional grants available for this project.

4. What other costs or complications should be considered?

   Since Phase 1 of the CRC has a roof in good condition, we do not expect loading to be a problem. Installation is the main cost not accounted for yet. We estimate another $50,000, bringing the

[5] http://shop.solardirect.com/product_info.php?cPath=21_34_38_50&products_id=81

project total to around $100,000. Installation of infrastructure for domestic hot water to the whole campus is another issue to consider, if boilers are to be turned off in summer.

5. What other benefits could be capitalized on?

The solar-thermal CRC roof study is already part of Evergreen's Campus Learning Laboratory, and it offers continuing opportunities for student research.

If a premium control system is installed with the solar thermal panels students and facilities would have access to data and a greater ability to care for panels.

A control system also offers the potential for greater energy use reductions across campus.

Appendix 1: Humidity definitions, calculations, and measurements

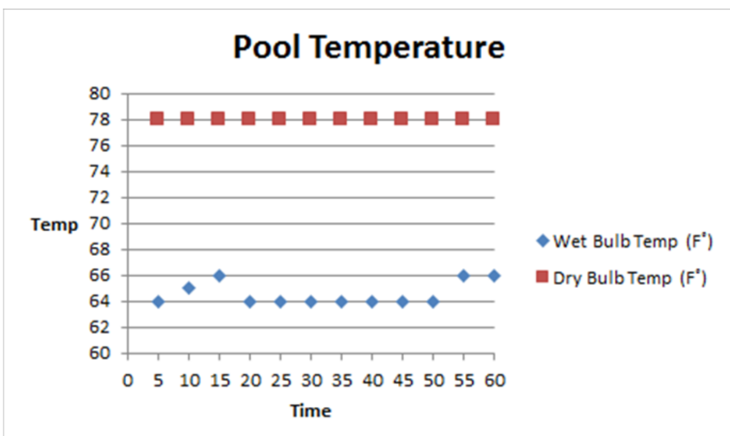
The humidity ratios defined below contribute to the evaporation rate of water in the pool. The greater the humidity of saturated air (the greater the difference x_s - x), the faster the water evaporates, and the faster the pool loses heat.

x_s = humidity of saturated air (kg H_2O/kg of Air) at the same temperature as the water surface
x = relative humidity in the air at the water surface (kg H_2O/kg of Air)

We can calculate these humidities at the surface of the pool if we know the temperature of the water and the air. For the humidity of saturated air (x_s), we use well known data[6] of temperature and vapor pressure to find a humidity of .02 kg H_2O/ kg Air.

For the relative humidity (x), we refer to the Mollier Diagram[7] and get a value of .0098 kg H_2O/ kg Air.

We also measured these quantities using a wet bulb dry bulb thermometer. The amount of error on the temperature readings was $\pm$1degree.The relative humidity was determined to be around 50%, this confirmed our estimate.



Calculation of kWh of pool with a velocity of .25 m/s instead of .5 m/s

$$G = (25 + 19(.25)) \times 680 \times (.02 - .01)/3600 = .056\ kg/s$$

$$q = 2260\ kJ/kg \times .056\ kg/s = 127kW$$

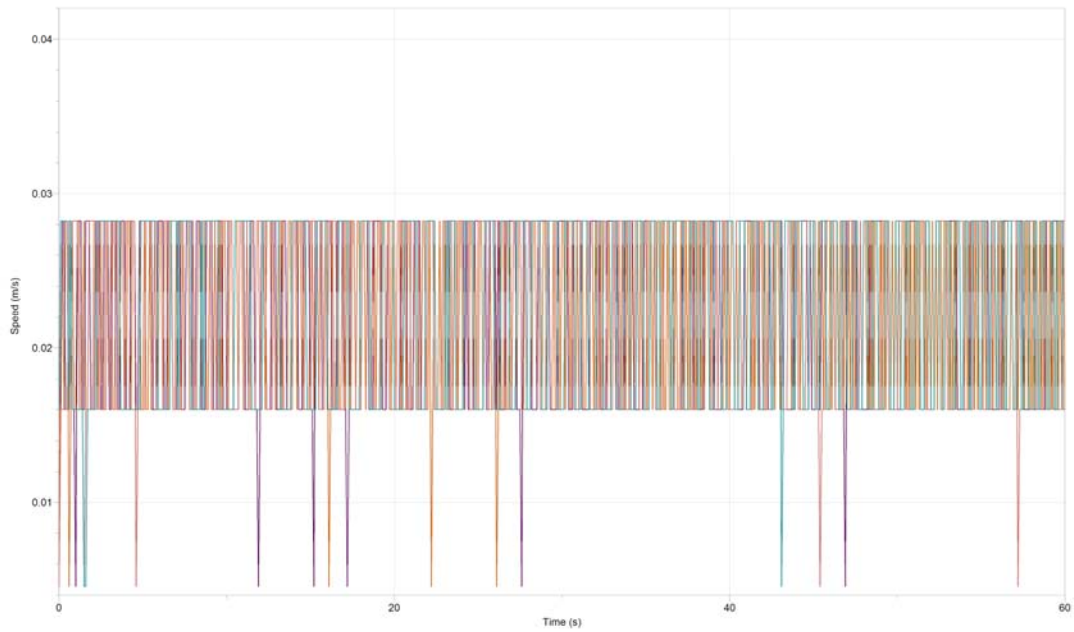
$127kW \times 24hrs/day \times 365\ days/year \times 1/2 = 556{,}000\ kWh$ every half a year

$556{,}000kWh/year \times 715\ kWh/m^2\ year = 778m^2$ Area needed to accommodate heat loss

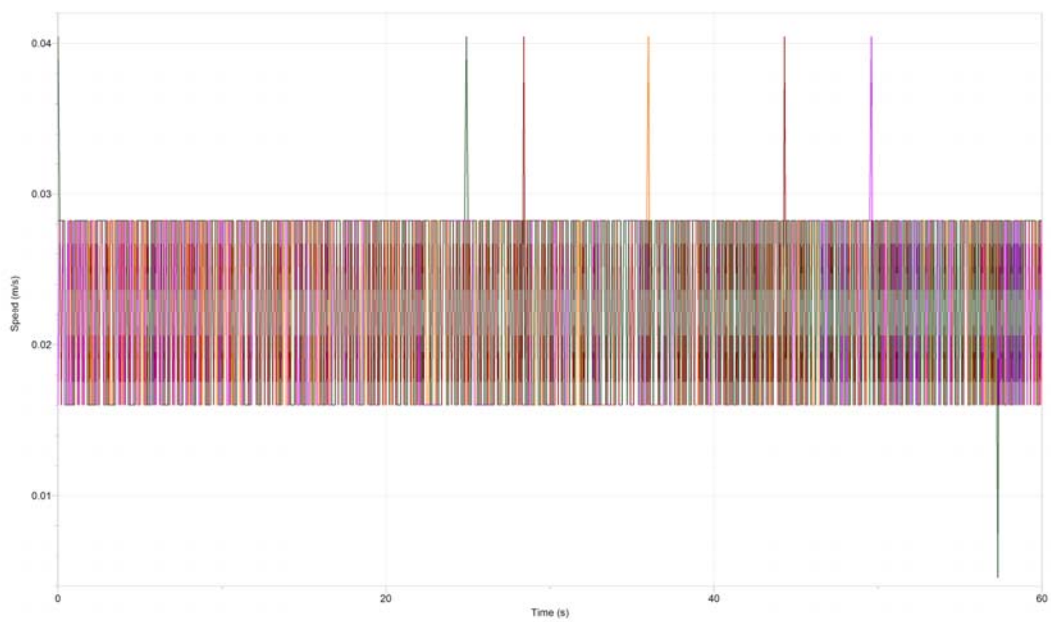
[6] Data table is available at www.engineeringtoolbox.com/humidity-ratio-air-d_686.html
[7] Diagram is available at www.engineeringtoolbox.com/psychrometric-chart-mollier-d_27.html

Pool Air Velocity measured from all sides

Lap Pool



Diving Pool



This data is well below the 0.5 m/s minimum range of the anemometer. Therefore this data can only tell us that the air velocity is below 0.5 m/s.

A2. We compare the heat loss at Evergreen's pool with published heat loss from similar pools.

Gustavus Adolphus College in St. Peter, Minnesota, published data about energy use for their pool in summer months. This pool, the same size as Evergreen's, uses $5\times10^{8}\,\frac{Joules}{day}$ = 51,000 kW.hr/year which is orders of magnitude less than Evergreen's pool. How do they operate their pool so efficiently? They probably use a pool cover, among other things. We will assume that Evergreen's CRC swimming facilities require 150 kW of power to hold the water at a steady temperature of about 25°C.