CHAPTER 2

DETERMINING THE POOL OR SPA HEATING LOAD

INTRODUCTION

Because the magnitude of the heating load forms the basis for subsequent sizing decisions it is important to determine that load as accurately as possible

When converting from conventional heating to solar heating of a pool historical energy consumption records (if available) may be used to estimate future heating requirements. When designing a solar pool heating system for a new pool, it is often possible to use energy consumption data from a nearby pool as a basis for estimating the energy requirement of the proposed installation Energy consumption may differ significantly between pools, but if they are similarly situated, sized, exposed to sunlight and protected from the wind, this is usually not the case

2.1 CONVERTING FROM CONVENTIONAL FUELS

2.1.1 Electric Resistance Pool Heaters

Electric resistance pool heaters usually operate with an efficiency approaching 100% If they have been metered separately the energy consumption may be calculated by using the following formula

Btu/time period = 3413 x kWh/time period

2.1.2 Oil- and Gas-Fired Pool Heaters

Gas- and oil-fired pool heaters more often operate at 50-75% fuel conversion efficiency in field service than the 80±% efficiency they exhibit in laboratory tests FSEC recommends the use of a 70% conversion factor unless a substantial body of field data supports higher claims The aver- energy content of commonly used liquid and gaseous fuels is given in Table 2

Table 2.1
Energy Content of Oil and Gas

Fuel	Energy Content
LPG (Propane)	92,000 Btu/gal
Natural gas	100,000 Btu/therm
Light home heating oil	140,000 Btu/gal

following formula may be used to calculate the energy furnished by gas- and oil-fired heaters

Btu/time period = 0.7 x Btu content/unit x units/time period

2.1.3 Steam-Fired Heat Exchangers

If steam from a central boiler and a heat exchanger have been used to heat a pool or spa, sufficient data may exist to calculate the pool heat- load from the manufacturer's data on the heat exchanger effectiveness and steam quality and consumption data If such is not the case, weather data may be used to estimate the heat losses from the pool during the heating season

2.1.4 Heat Pump Water Heaters

Dedicated heat pumps (also called heat pump water heaters) are manu- factured specifically for swimming pool and spa heating Coefficients of performance (COP of 4 to 8 are claimed by several of their manufactures

If the energy input of such units is separately monitored, the following formula may be used to calculate their thermal output

Btu/time period = kWh/time period x 3413 x COP

2.2 CALCULATING HEAT LOSSES FROM SWIMMING POOLS AND SPAS*

In the absence of reliable, historical, energy-consumption data, it may be convenient to calculate the heat losses which may be expected to occur from a pool under various monthly weather conditions These losses then may be equated to the pool's average energy requirement for a given increment of time Past records of monthly average air temperatures, humidities, and pool temperatures may yield sufficiently accurate results for some purposes For other purposes, it may be necessary to make calculations based on daily weather data and sum them to arrive at monthly totals Weather data for eight Florida cities is contained in Appendix E Because the calculation procedure required is somewhat tedious, tables containing loss factors for six Florida cities and several pool configurations have been developed and are presented in Appendix "G". Appropriate monthly values may be multiplied by pool areas and to arrive at total monthly losses

2.2.1 Heat Losses from Pools and Spas

Heat Losses from a swimming pool or spa may be attributed to four mechanisms

1) Conduction through the pool walls.
2) Convection from the pool surface

*Adapted from "Solar Heating for Swimming Pools", published by the Environmental Information Center, Winter Park, FL.

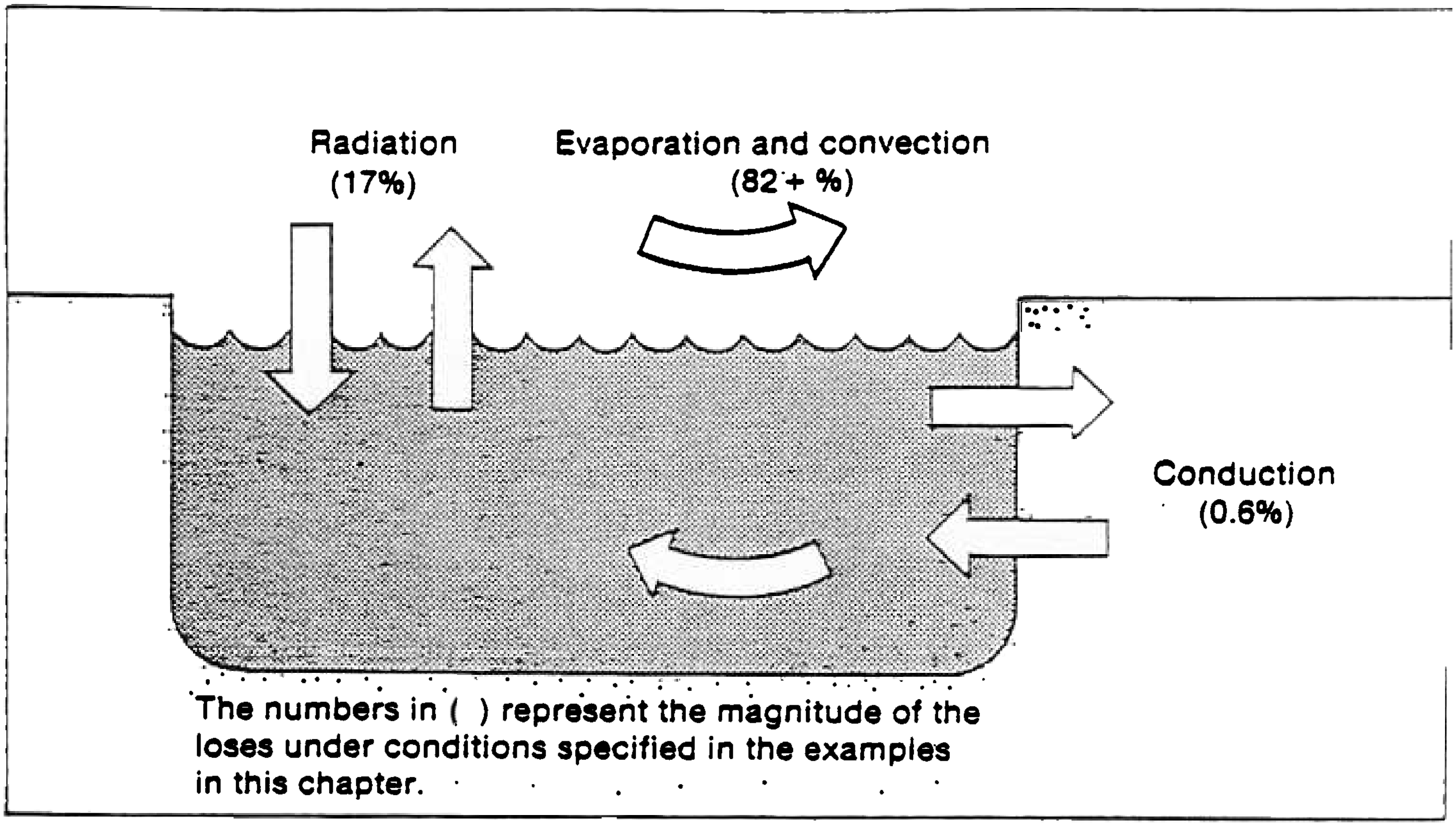

Figure 2.1

Pool Heat Loss Mechanisms

3) Reradiation from the pool surface

4) Evaporation from the pool surface Figure 2.1 shows the loss mechanisms and relative magnitudes for swimming pools

2.2.1.1 <u>Conduction Losses</u> -- Because most soils are poor conductors of heat, losses through the bottoms and sides of below-grade pools are usually small enough to ignore. However, if pools are situated where cold groundwater flows past them, the following formula and heat transfer coefficients may be used to estimate the losses The same formula may be used to estimate wall losses from above-ground pools

$Q_c = U \times A \times \Delta t$

where

Q_c is the conductive loss in Btu/hr,

U is the overall conductive heat transfer coefficient in Btu/ft^2/hr (per °F), and

A is the pool wall area in square feet (plus the area of the pool bottom in the case of below-grade pools)

For below-grade pools:

Δt is the pool temperature minus ground water temperature

For above-ground pools:

Δt is the pool temperature minus air temperature

Below Grade Pools: Even under conditions of rapid groundwater flow, the soil close to the pool shell will rise in temperature as it absorbs heat from the pool This reduces the temperature difference (Δt) Because it is difficult to evaluate this reduction from individual situations, the following U values for both concrete and fiberglass walls have been modified using experimental data developed by ASHRAE engineers for uninsulated cement basement floors The U values are for use with actual pool and groundwater temperature differences

U = 0.1 for 4-in concrete pool walls with a 1-in. marble-cement waterproof inner lining, and

U = 0.1 for ½-in (nominal) fiberglass-reinforced plastic pool walls

The two values are, for our purposes, the same. This is because the main resistance to heat flow is not in the wall, but is in the soil surrounding it

EXAMPLE A 30' x 45' concrete pool with an average depth of 5 feet is located at a canal-front motel in a Florida coastal city The motel manager wants to maintain the pool to 80°F during November when the groundwater is 70°F Calculate the conductive losses.

$$Q = 0.1 \times [(30' \times 5' \times 2) + (45' \times 5' \times 2) + (30' \times 45')]$$
$$\times (80° - 70°) = 2100 \text{ Btu/hr}$$

(b) Above-ground Pools: If the bottoms of such pools rest firmly on the ground, heat loss through them may be ignored. However, losses through the walls of above-ground pools may be large enough to require consideration. The following overall coefficients include the insulating effect of the static air film at interface of the air and support wall

For vinyl pool liners supported by uninsulated, corrugated metal shells:

U = 2 for 0-mph wind speeds,

U = 4 for 7-mph wind speeds, and

U = 6 for 15-mph wind speeds.

If an inch of foam insulation is applied to the outside of the supporting shell, U = 0.1. For vinyl pool liners supported by 1-in thick wood walls, U = 0.8 (7 mph average wind speed). For above-ground ½-in fiberglass-plastic walls supported by an open framework of wood or metal tubing, U = 1.9 (7-mph average wind speed).

EXAMPLE: A round, above-ground pool, 4 feet deep and 18 feet in diameter, is subjected to 65°F winds blowing a 7 mph. If the pool temperature is 80°F and it is supported by an uninsulated corrugated metal wall how much heat is lost through the wall each hour? (π = 3.14, and losses through the pool bottom may be ignored.)

$Q = 4 \times 4' (3.14 \times 18') \times (80° - 65°)$

$= 13{,}565$ Btu/hr

A little data interpretation is called for here. About one half of the pool wall is protected from the 7-mph wind, so the loss coefficent is nearer to 2 on the leeward side of the pool. Therefore, the actual losses are closer to 10,000 Btu than 14,000 Btu

The actual loss may be less than the higher calculated value, however, the example indicates that insulating the walls of this above-ground pool may be well worth the cost if the pool is to be heated

2.2.1.2 Convection Losses. The convection losses may be evaluated using the formula

$$= h_{cv} \; A \; \Delta t$$

where:

is the convective heat loss in Btu/hr,

is the convective transfer coefficent in Btu/ft²/hr (per °F)

1 + .3 x wind speed (mph)

A is the pool area in ft^2, and

Δt is the temperature difference between the pool and the air.

It is important to understand that the rate of convective transfer varies with both the temperature difference and the wind speed, and is dependent on a series of resistances to heat transfer Any heat which escapes from the pool by convection must pass through a thin but static liquid film at the pool surface It then must pass through a thin but static layer of air in contact with the liquid surface. It next passes through a boundary layer of eddy currents in the air, and finally is taken up by the main airstream where it is carried away from the pool by either natural or forced convection The transmission of heat through the thin fluid layers themselves is by conduction

The thickness of the static air layer affects the rate of heat loss and varies greatly with wind speed Not only is this complex process difficult to quantify but there are additional barriers to accurate analysis

Convection, radiation and evaporation occur simultaneously across the air to water interface The evaporation process reduces the temperature of the liquid surface because it draws virtually all of the 1050 Btu/lb of water required for the phase change from the pool water, not the air above it. The convective process cools the liquid surface if the air is cooler than the surface and warms it if the air is warmer than the surface

It should be remembered that under conditions of moderately high wind speed, low humidity, and low air temperature, the surface of the pool will be cooled by both evaporation of water and convection. This will have a tendency to reduce the temperature difference between the pool surface and the wind sweeping over it Theoretically the pool surface can be cooled to the wet-bulb temperature of the air (Practically, because of the large quantity of heat available to the pool surface from the pool itself this will almost never occur.) However, under windy, low temperature low humidity conditions you may wish to utilize a compromise pool surface temperature mid-way between measured pool temperature and wet-bulb temperature of the air or apply a correction factor as suggested on Page 2-14 The wet-bulb temperature may be read from Figure 2.2

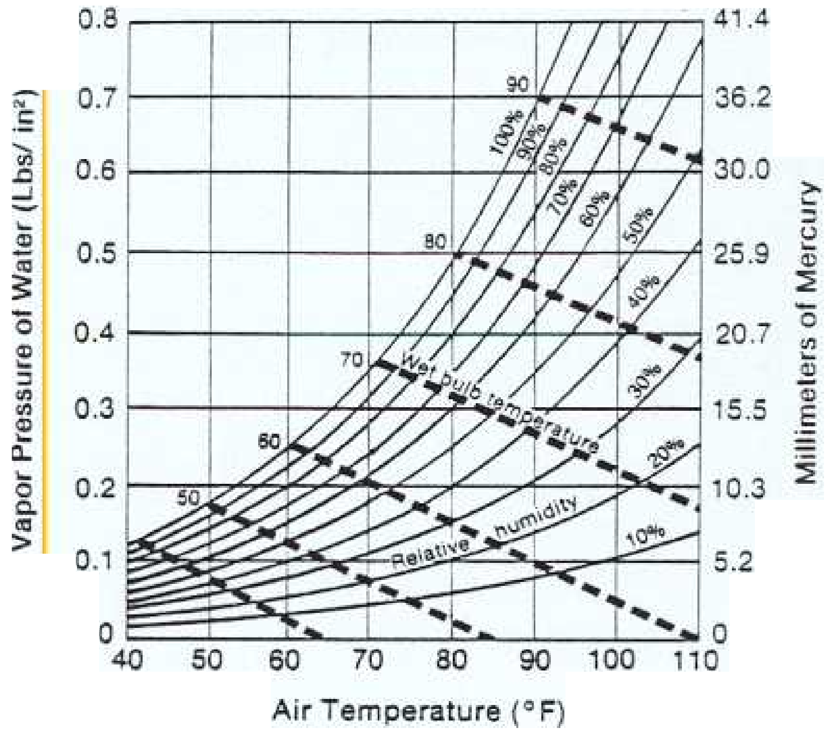

Figure 2.2

Psychrometric Chart

EXAMPLE: Th| 80°F, 30' x 45' pool described in the first example is exposed to a |6-mph 65°F north wind at 50% relative humidity It is protected by m|otel buildings on the north and surrounded by a 6 ft privacy fence. These reduce the effective wind speed at the pool surface to 4 mph. Ca|culate the convective heat loss in Btu/hr. Ignore surface temperature de|ression because of evaporation.

[1 4(.3)] x (30' x 45') x (80° - 65°) = 44,550 Btu/hr

2.2.1.3 <u>Radiati|n Losses</u>. The following formula is sometimes used to evaluate losses |through radiation from a warm pool to a cool sky;

$$Q_R = 0\ \ 73\ A\varepsilon\left[\left(\frac{t_w}{100}\right)^4 - \left(\frac{t_{sky}}{100}\right)^4\right]$$

where

Q_R is the radiation loss in Btu/hr

A is the exposed surface area of the pool in ft²,

ε is the emissivity of pool water (≅ 0.90

t_w is the pool temperature in °Rankine (°F + 460°)

Without introduction of serious error, the value for t_w may be assumed to be th pool temperature. Some judgment is called for in estimating t_{sky}. For example, on a very cloudy night the clouds may be only 10°F below the temperature of the air; the pool radiates to those clouds On a very clear night, because the pool radiates both to the clear atmosphere and to outer space, the effective sky temperature may be as much as 80°F below air temperature

It is difficult to select the proper sky temperature for use in this formula (unless you have access to a remote sensing infrared thermometer) Many experts agree that, on average, the sky temperature is about 20°F cooler than the ambient temperature However, on very clear cool nights, even in areas of moderately high humidity such as Cocoa Beach Florida, remote sensing infrared thermometers pointed skyward have indicated a temperature below their lower limit (-40°F), or at least 80°F below ambient air temperature While very clear nights are infrequent in Florida, they ar common in many other parts of the country

For your convenience,

$\left(\frac{t(°R)}{100}\right)^4$ (radiation parameter)

values are presented in Table 2.2

Table 2.2
Radiation Parameter vs. Temperatures (°F)

t(°F)	-20	-15	-10	-5	0	5
Value	375	392	410	429	448	468
t(°F)	10	15	20	25	30	35
Value	488	509	531	553	576	600
t(°F)	40	45	50	55	60	65
Value	625	650	677	703	731	760
t(°F)	70	75	80	85	90	95
Value	89	819	850	882	915	949
t(°F)	100					
Value	983					

EXAMPLE: The previously described 30' x 45' pool which the motel manager wishes to maintain at 80°F, is exposed to clear skies on a 55°F night. The relative humidity is 50%, the cloud cover is 10%, and the latitude is 30°N. Calculate the radiant heat loss.

Because of a 10% cloud cover, moderate nighttime temperature (55°F), and fairly high relative humidity, the sky temperature should be about 20°F below ambient air temperature. We will try several sky temperatures to see how they affect the estimated radiation loss.

If we assume the sky temperature to be 10°F below the air temperature, $t_{sky} = t_{air} - 10°F$

$$= 0.173 \times (30' \times 45') \times 0.9 \times \left[\left(\frac{80° + 460°}{100}\right)^4 - \left(\frac{45° + 460°}{100}\right)^4\right]$$

From Table 21

$$= 210\ [850 - 650] = 42{,}000 \text{ Btu/hr}$$

Assume: $t_{sky} \quad t_{air} - 20°$

= 210 [850 - 600] = 52,500 Btu/hr

Assume t_{sky} = t_{air} - 30°

= 210 [850 - 553] = 62,370 Btu/hr

Assume: t_{sky} = t_{air} - 40°

= 210 [850 - 509] = 71,610

Assume: t_{sky} = t_{air} - 50°

= 210 [850 - 468] = 80,220

2.2.1.4 Evaporation Losses The quantity of heat lost through evaporation from a pool surface usually exceeds that lost by conduction, convection, and reradiation combined A simple formula may be used to evaluate the loss:

$$= L_w \quad K_E \times \Delta P$$

where:

is the evaporative heat loss in Btu/ft²·hr

L_w is the latent heat of evaporation of water at the temperature of the pool surface ≅ 1050 Btu/lb,

is the appropriate mass transfer coefficient expressed in lb/hr·ft² (per lb/in²ΔP)

≅ 0.1 x h_{cv}; h_{cv} = 1 + .3 x wind speed (mph)*

ΔP is the partial pressure exerted by the pool surface minus the partial pressure exerted by the moisture in the air (psi)

As has been stated in the paragraph on convective losses, the pool surface temperature is between the average temperature of the entire pool and that of the air. When windy, cool, low-humidity conditions prevail,

*See Appendix C for methods of reducing the wind speed over the pool's surface.

the use of a pool surface pressure corresponding to a compromise temperature between pool temperature and wet-bulb air temperature may yield more accurate results or the correction factor on Page 2-14 may be applied.

Figure 2. should be examined to envision better the nature of evaporation from the pool surface The vertical lines represent measured air or pool temperatures. The horizontal lines represent partial pressures in psi on the left and in mm of mercury on the right. The curved lines extending upward and to the right represent relative humidity conditions The vapor pressure of the pool surface at a specific temperature is found from the intersection of a vertical line through that temperature with the 100% relative humidity curve. The wet-bulb temperature of air is represented by the lines which slope down and to the right.

If a horizontal line is drawn through the intersection of the 75°F air temperature line the 100% relative humidity (RH) curve, any air condition which results in a partial pressure lower than about 0.44 psi or about 22.8 mm Hg and will allow evaporation to occur from a 75°F pool. The greater the distance below that line, the more rapid the evaporation. Air that exerts the same partial pressure (for example 83°F air at 80% RH or 87°F air at 70% RH) will prevent evaporation from taking place from the pool surface Interestingly enough, air which exerts more partial pressure than 0.44 psi may lose some of its water vapor to the pool by condensation. In this fairly unusual situation the pool will gain 1050 Btu for each pound of water vapor that condenses on its surface

EXAMPLE: Calculate the evaporative heat loss (in Btu/hr) from the 80°F, 30' x 45' pool previously considered if it is exposed to 65°F air at 50%

relative humidity sweeping over the water surface at 4 mph Ignore the depression of surface temperature caused by evaporation

$$q_e = 1050 \times 19 \times 2.2\ (.50 - 15)$$

$$154\ \text{Btu/ft}^2 \cdot \text{hr}$$

$$Q_E = 154 \quad (30 \times 45) = 207{,}900\ \text{Btu/hr}$$

The values for ΔP may be read from Figure 2.2, where 0.50 psi corresponds to 100% relative humidity at 80°F, the partial pressure of the pool water, and 0.15 psi corresponds to 65°F air at 50% relative humidity

Strictly speaking, the quantity of water evaporating from an exposed surface is not a linear function of the area of that surface. W.J Humphreys documents the fact in Physics of the Air, McGraw-Hill Book Co., Inc., NY and London, 1940 However, the empirical equation used above yields results within 5% of those from an equation developed by Fitzgerald in the late 1800s and recommended by Dr Humphreys, a noted meteorological physicist

2.3 ADJUSTING THE CALCULATED VALUES

Measurements made on swimming pools in Florida have convinced several FSEC researchers that the calculated losses are about 40% higher than those that occur during typical Florida weather (if average pool and air temperatures are used in the calculations). Consequently, it is FSEC's recommendation that the calculated values be multiplied by a factor of 0.6

EXAMPLE The relationships among and totals for the previously calculated losses are

Conduction 2100 Btu/hr x 24 hrs x 0.6 = 30,240 (below-grade pool) Btu/day

Convection: 44,550 Btu/hr x 24 x 0.6 = 641,520 Btu/day

Radiation 52,500 x 24 x 0.6 = 756,000 Btu/day; $t_{sky} = t_{air}$ 20° (assumed)

Evaporation 207,900 x 24 x 0.6 = 2,993,760 Btu/day

Total Losses 4,421,520 Btu/day

Conduction = 0.6%

Convection = 15%

Radiation = 17%

Evaporation = 68%

2.4 DIRECT GAIN BY POOL SURFACE

Most swimming pools are located so as to be in direct sunlight most of the day. Under these conditions they are very effective heat collectors absorbing about 75% of the solar energy that strikes their surfaces

EXAMPLE The average insolation of the surface of the pool in the previous example during November is 1300 Btu/ft^2·day. Direct solar gain = 1300 x (30 x 45) x .75 = 1,316,250 Btu/day gain. (A screen room reduces this input by 30-40%.) Obviously, a sunny location not only increases swimming comfort but also substantially reduces pool heating costs (by nearly 1/3 during November in this example).

The previous calculations indicate that the pool cited in the example will require the addition of 4,421,520 - 1,316,250 = 3,105,270 Btu/day to maintain 80°F water temperature during average weather Cold snaps or unseasonably warm weather obviously will alter daily energy requirements

The energy requirement for November will average out at 3,105,170 Btu/day x 30 93 million Btu/mo. If natural gas costs $.51/therm, the November fuel costs will average

$$\frac{93 \times 10^6 \times \$.51}{100{,}000 \times .7 \text{ (heater efficiency)}} = \$677.57$$

if the pool is neither shaded nor enclosed by a screen room

If the pool is partially or totally shaded during a portion of the day, the direct gain should be reduced proportionately