CHAPTER 5

METHODS FOR SIZING FOR THE COLLECTOR ARRAY

INTRODUCTION

An understanding of solar collector characteristics, performance testing methods and ratings will assist system designers to make the most effective use possible of solar hardware

In Florida solar collectors used for swimming pool heating often are large, unglazed, uninsulated areas of relatively inexpensive black materials contain passages through which pool water may be forced When these areas are exposed to sunshine, they become warmer than the pool water A circulation pump forces the pool water through the collector passages where it is warmed a few degrees The heat collection areas often are made of durable plastic materials that incorporate inhibitors which make them resistant to ultraviolet attack. Sometimes the plastic is in panel form, sometimes in pipe form Metal decks with tubular passages also are used to collect the sun's energy, as are black patio squares with fluid passages Because of their low cost, these types of solar pool heating collectors by far outnumber arrays of more expensive, glazed, conventionally boxed and insulated flat-plate collectors But they, too, are used for swimming pool and spa heating As the sizing calculations in this chapter bring out, glazed, insulated collectors exhibit better thermal performance during cold windy weather.

FACTORS AFFECTING SOLAR POOL HEATER PERFORMANCE

5.1.1 Cold Weather

The cold-weather performance of unglazed solar collectors operating under windy conditions has fallen short of what would have been expected from their performance equations or FSEC low-temperature ratings is not surprising; those ratings are based on the daytime average round Florida temperature rather than on the daytime average winter temperature when pool heaters are most often used

5.1.2 Temperature and Insolation Corrections

Correction factors which may be used to modify reported measures of thermal performance of glazed collectors to accurately reflect their performance under winter temperature and insolation conditions in Florida are contained in Figures A.1 through A.6, Appendix A. Correction factors for unglazed collectors are shown in Figures A.8 through A.13 These cover the range of temperatures and insolation rates indicated in Table 5.1, which also shows the conditions for which the modification factors may be used.

Table 5.1
Matrix of Temperature/Insolation Conditions for which Corrective Factors are Derived in Chapter 5

t_{inlet} = 95

Average Air Temp. (°F)	$\Delta t = t_{inlet} - t_{air}$ (°F)	Insolation rate (Btu/ft² day) 1000	1200	1400	1600	1800	2000
40	55	x	x	x	x	x	x
50	45	x	x	x	x	x	x
60	35	x	x	x	x	x	x
70	25	x	x	x	x	x	x
81	14	x	x	x	x	x	x
90	5	x	x	x	x	x	x

The methodology used to develop Figures A.1 through A.13 is described in the Appendix A

5.1.3 Wind Speed

Equally important to collector performance evaluation is the fact that the ASHRAE test procedure used to develop thermal performance equations and ratings for unglazed collectors is carried out at wind speeds of than three mph over the collector surface Unglazed collector performance suffers badly when the collector is exposed to cold winds but the reported low-temperature ratings give no hint of that fact

(A third factor reducing the solar contribution of an array of either glazed or unglazed collectors is the loss inherent to system functioning That system loss is made up of heat losses in connecting piping, losses in absorbed radiation resulting from the sun's motion both daily and seasonally, other than optimum controller set points, and other factors discussed in Section 5.7.)

5.1.4 Wind Speed Corrections

Glazed-collector performance ratings that have been corrected for temperature and insolation require no additional modification for normally encountered wind speeds

However, in the case of unglazed collectors those ratings must be further modified to reflect their response to winds speeds of 5 mph or more. Figure 3 is a nomograph which may be used to make such modifications. The methodology used to develop that nomograph is presented in Appendix B.

5.1.5 Methods for Estimating Wind Speed at Specific Locations

Graphs, tables and formulas that may be used to convert published wind speed data to that which may be expected on top of or adjacent to specific building is given in Appendix C

5.2 SOLAR COLLECTOR TESTING PROCEDURES

An understanding of collector testing and rating procedures enable solar pool heater designers and installers to better understand the reasons for the wind speed corrections They will be reviewed before corrective measures are presented

5.2.1 Glazed Collectors

At present the ASHRAE 93-77 performance test for glazed solar collectors may be conducted at any wind speed below 10 mph Wind speeds occurring in field installations over the collector surface are close enough to that figure so that test-generated performance graphs predict actual collector output with reasonable accuracy. Additionally, the low temperature performance of even those collectors with only a single cover is seriously impaired by moderate increases in wind speed

5.2.2 Unglazed Collectors

The generally accepted procedure (in America) for testing unglazed, low temperature collectors -- ASHRAE 96-80 -- requires that the test be conducted at wind speeds below 3 mph In this case, serious problems arise when efforts are made to correlate test results with actual field performance of unglazed collectors under cool, windy conditions Cool winds blowing over an unglazed collector surface substantially increase the convective losses which occur from that surface during periods when pool heating is desired The test results do not reflect this fact

5.2.3 Collector Performance Graphs

Both ASHRAE test procedures result in the generation of performance graphs such as Figure 5.1 Performance of typical pool heating collectors is shown in that figure Efficiency, defined as the amount of energy collected divided by the total amount of solar energy striking the collector surface, is displayed on the vertical axis of Figure 5.1. (One of the goals in selecting solar collectors is to obtain the highest efficiency at the least cost.) The horizontal axis shows the fluid parameter, which includes three variables Collector inlet temperature (t_i), air temperature (t_a), and hourly quantity of solar radiation striking each square foot of area (I). If we plot the fluid parameter, $\frac{t_i - t_a}{I}$

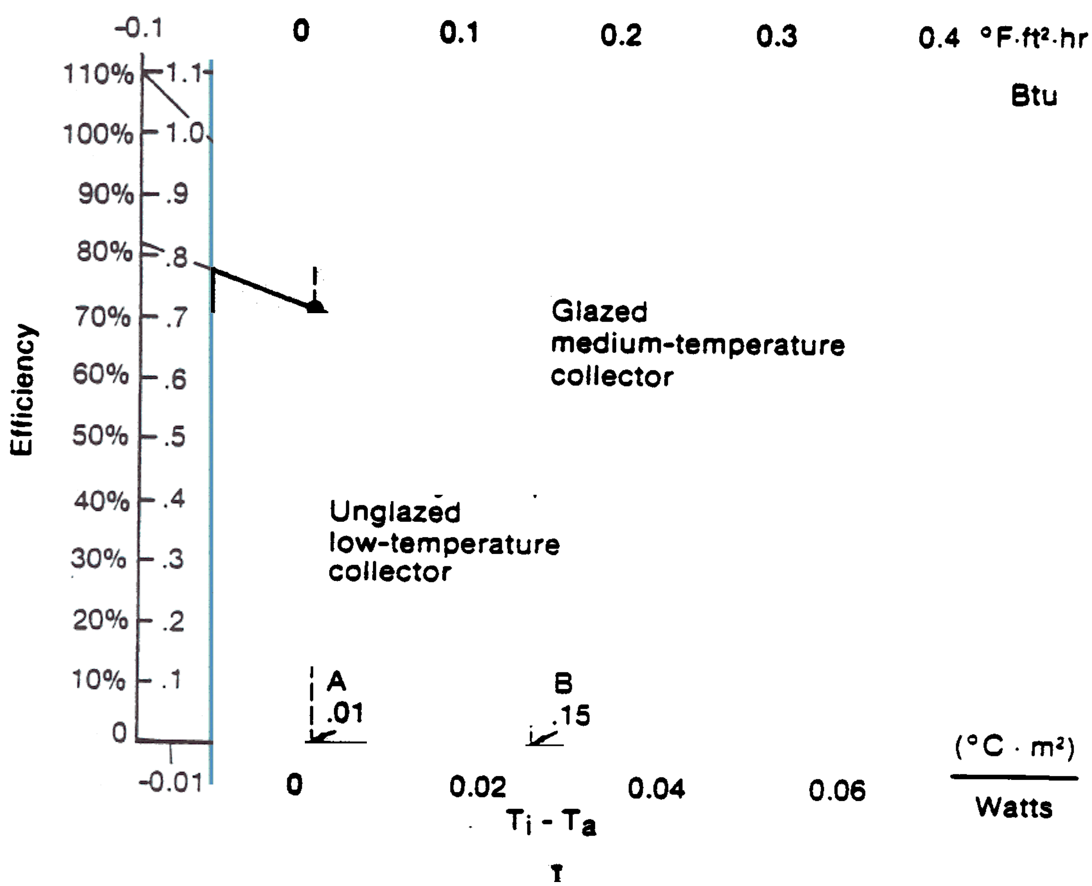

Figure 5.1

Collector Efficiency

on the horizontal axis and the collector efficiency on the vertical axis, the graphs turn out to be smooth curves which are nearly straight lines

Efficiency decreases as the fluid parameter increases for both types of collectors. Factors that reduce collector efficiency are: decreases in air temperature decreases in solar radiation and increases in pool tempera- (which is equal to the collector inlet temperature) When using graphs like those in Figure 5.1, care must be exercised because the horizontal axis is sometimes labeled in metric units, sometimes in English engineering units. Both are shown in Figure 5.1

The following two examples are marked in Figure 5.1:

	Case A	Case B
Pool Temperature	78°F	80°F
Air Temperature	75°F	65°F
Solar Radiation	300 Btu/ft^2-hr (sunny)	100 Btu/ft^2-hr (cloudy)
Fluid Parameter	$\frac{78-75°F}{300\ Btu/ft^2\text{-}hr} = 0.01$	$\frac{80-65°F}{100\ Btu/ft^2\text{-}hr} = 0.15$
Low Temp. Collector Efficiency	83%	48%
Medium Temp. Collector Efficiency	70%	60%

Case A represents conditions on a relatively warm, sunny day In situation, a typical low-temperature collector is more efficient than a typical medium-temperature collector and will capture more energy per square foot. During a cool, cloudy period such as that represented by Case B, the situation is reversed and the medium-temperature collector is the more efficient. (During windy, cold weather, the glazed collector is affected only slightly but the unglazed collector may actually cool any pool water flowing through it.)

In pool heating applications, air temperature sometimes exceeds pool water temperature, and energy can be captured directly from the air as well as the sun's rays. For these situations the fluid parameter is negative, and efficiencies greater than 100 percent may result. Figure 5.1 been exaggerated to show this. The steep slope of unglazed collector curve indicates that it gains efficiency rapidly as its negative fluid parameter increase Conversely, it loses efficiency rapidly as its positive fluid parameter increases.

5.2.4 Weather Conditions During the Pool Heating Season

An examination of the temperature and insolation data for the Florida cities displayed in Appendix E reveals that often, during winter months either or both do not conform to the Florida standard daily totals in Table Because collector output is dependent upon the fluid parameter which includes both the air temperature and insolation rate, some method of modifying a collector's low-temperature rating to bring it into correspondence with non standard temperatures and insolation rates is called for if an accurate estimate of their cold weather performance is required As previously indicated table 5.1 shows a matrix of temperatures and insolation rates for which correction factors have been developed. Those correction factors are presented in the form of nomographs for both glazed and unglazed collectors in Appendix A and the methodology by which they were developed is summarized in that appendix.

Table 5.2
Insolation and Ambient Temperature
for Standard Florida Day

I Watts/m²	Fraction of Daily Insolation	Total I Btu/ft²hr	t_a Temp, °C	Fraction of Mean Daytime Temperature	t_a Temp, °F
50	.01	16	24	.93	75
151	.03	48	25	.95	77
252	.05	80	25	.95	77
353	.07	112	26	.98	79
454	.09	144	27	1.00	81
555	.11	176	27	1.00	81
656	.13	208	28	1.01	82
757	.15	240	29	1.04	84
858	.17	272	29	1.04	84
959	.19	304	30	1.06	86
5,045 W·hr/m²		1,600 Btu/ft²	27 (AVG)		81 (AVG)

5.2.5 Weather Data for Use with Figures A.1 to A.13

Appendix contains weather data that includes average temperatures insolation rates for each month. Add 5°F to the average monthly temperature to bring it into correspondence with the average temperature during collecto operation (four hours before to four hours after solar noon). The sample problem in Appendix D demonstrates the use of the nomographs contained in Appendix A for the rerating of both glazed and unglazed collectors to bring their predicted low-temperature performance into accord with weather conditions for winter months in Daytona Beach

CORRECTION FACTORS FOR WIND SPEED

Wind Speed Correction Not Required for Glazed Collectors

After low-temperature performance ratings for glazed collectors have been adjusted for winter temperature and insolation conditions, they do not require further correction for the wind speeds normally encountered at Florida locations. The reasons for this have been stated in Section 5.1.4

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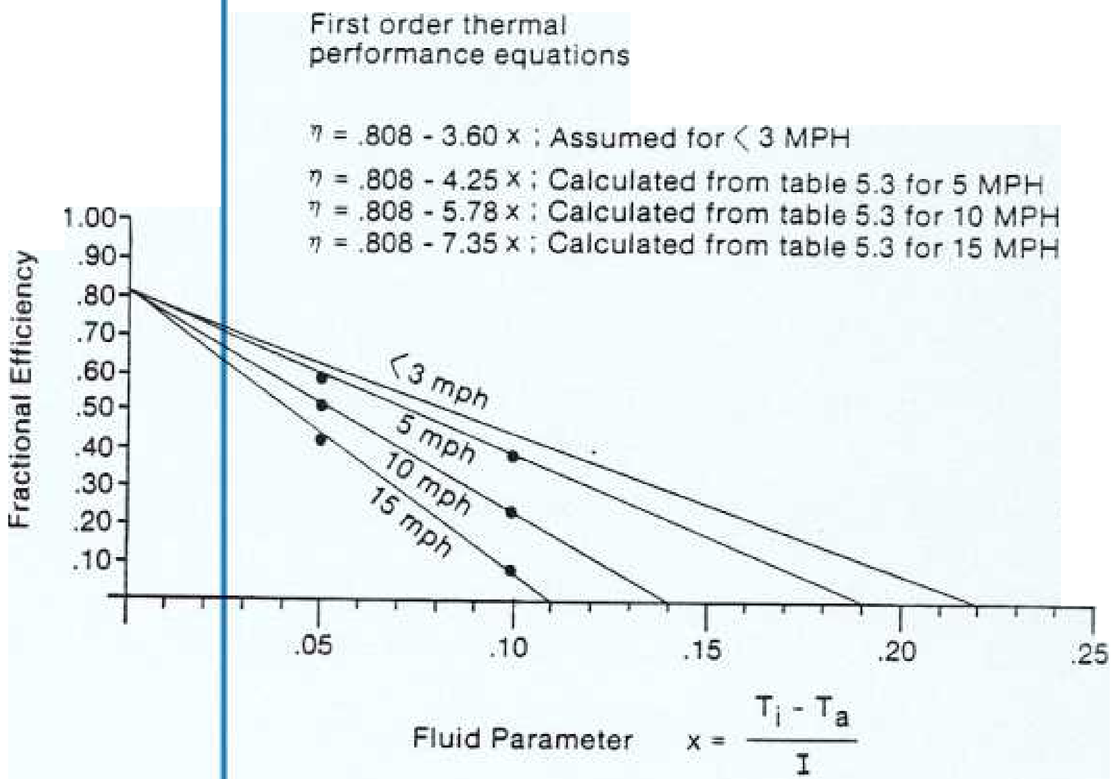

Figure 5.2

Modified Performance Graphs and Equations

(for unglazed collectors)

The equations appearing in Figure 5.2 have been used to generate a nomograph which is presented in Figure 5.3. It may be used to correct low temperature ratings for <u>unglazed</u> collectors for the effect of wind speed. The appropriate rating may be entered on the left vertical axis and the rating as corrected for windspeed read from the horizontal axis. If temperature and insolation corrections are required, they should be made first (using Figures A.1 to A.6). The low temperature rating as corrected from Figures A.1 to A.6 may then be entered on the left vertical axis of Figure 5.3 and corrected for the effect of wind speed

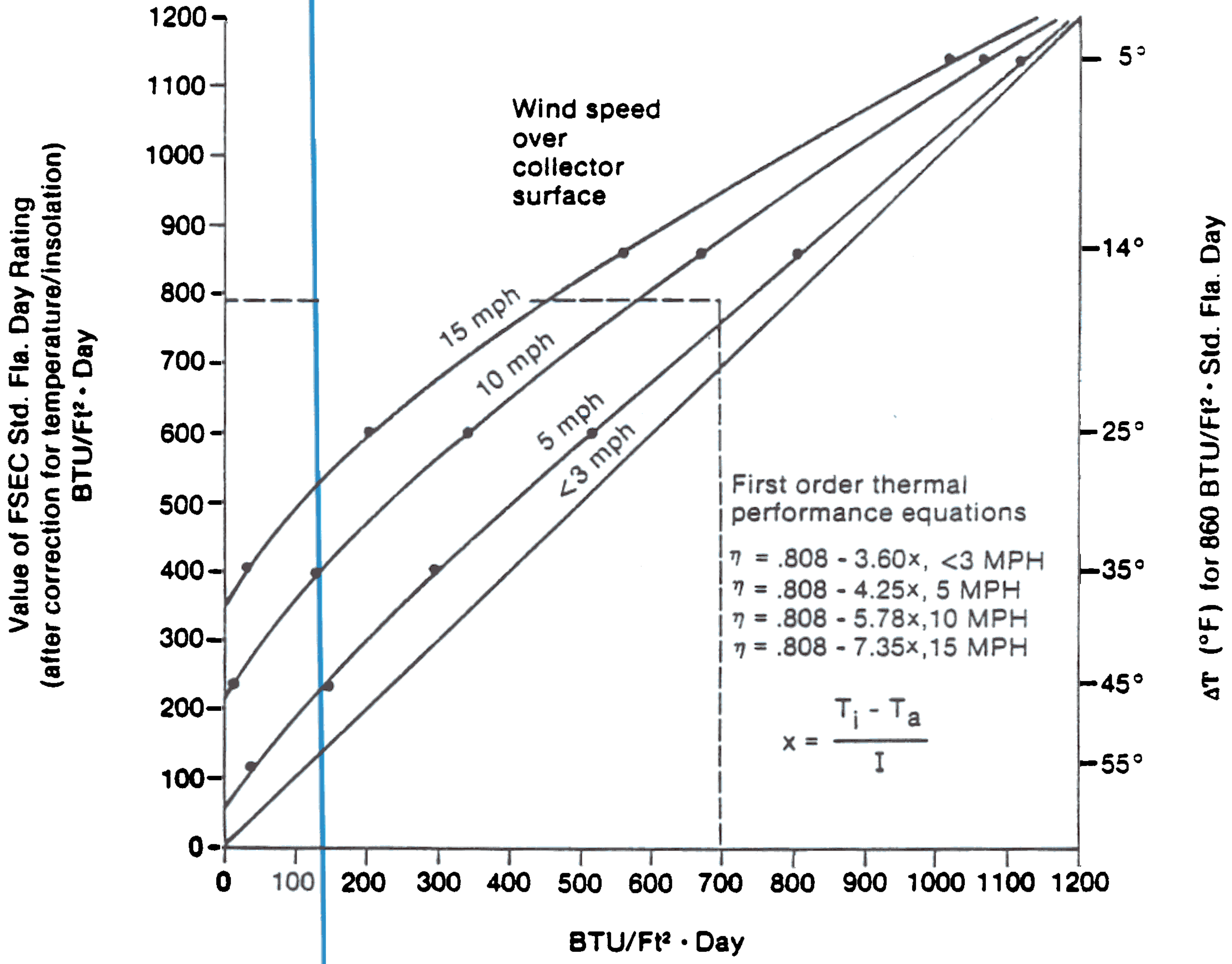

Figure 5.3

Wind Speed Correction Factors for Unglazed Collectors

5.3.2.1 Calculator Programs

If a programmable calculator with adequate memory and functional capacity is available the reader may program it to reevaluate the FSEC standard day rating of any collector for specific conditions of insolation pool and ambient temperatures and wind speed simultaneously. This is a far more accurate method of predicting collector output than the nomograph method if operating conditions differ substantially from 1600 Btu/ft^2·day and $t_i - t_a$ 14°F It is also far more accurate when the first order thermal performance equations differ from $808 - 3.60 \frac{t_i - t_a}{I}$ (unglazed)

and $.67 - 1.03 \frac{t_i - t_a}{I}$ (glazed)

Programs for several popular Hewlett/Packard and Texas Instruments calculators are contained in Appendix F.

Figure 5.3 is based on an "average" unglazed performance ($\bar{\eta} = .808 - 3.60 \frac{(t_i - t_a)}{I}$; EE units) equation. The reader may wish to apply the factors in Table 5.3 to the performance equation of a particular collector in order to develop a wind speed correction nomograph for that collector It is a simple procedure which may be readily accomplished by entering ΔTs of 5, 14, 25, 35, 45 and 55°F and an insolation rate of 1600 Btu/ft²·day in any of the calculator programs contained in Appendix F.

5.3.2.2 Alternative Use of Figure 5.3

The wind speed reference curves in Figure 5.3 may be accessed in a simple, abreviated way The right-hand vertical scale represents the daily average of the difference between the collector inlet temperature and the ambient air temperature (t_i-t_a) during the solar collection period. All temperatures are in °F. The points on the wind speed reference curve were generated by applying the ten standard Florida day calculation increments Table 5.2) modified to represent ΔT values of 5, 14, 25, 35, 45 and 55°F and the first order thermal performance equations identified on Figure 5.3 If the collector under consideration has a low-temperature rating within ± approximately 100 Btu/ft²·day of 860 Btu/ft²·day, Figure 5.3 may be used to correct for ΔT's other than 14°F (standard Florida day) and/or wind speeds higher than 3 mph The process is rendered less accurate as insolation rates depart from 1600 Btu/ft²·day (in the plane of the lector) and as the slope and intercept terms of the first order thermal performance equation for the collector under study deviate from the composite equation:

$$\eta = .808 - 3.60 \frac{(t_i - t_a)}{I}.$$

To use Figure 5.3 in this alternative way:

1) Enter the right vertical axis at the desired (t_i-t_a) value
2) Move horizontally to the appropriate wind speed curve
3) Move vertically down to the horizontal scale.
4) Read the corresponding corrected rating for the "average" collector (standard Florida day uncorrected low temperature rating 860 Btu/ft²·day).
5) Use the following formula to make the ΔT/wind speed correction for the collector in question

$$\text{Btu/ft}^2\cdot\text{day}_{\text{corrected}} = \frac{\text{Btu/ft}^2\cdot\text{day}_{\text{uncorrected}}}{860} \times \text{Rating}_{\text{from horizontal scale}}$$

It should be noted that the wind speed correction factors have or no effect on the calculated performance at low positive values of the fluid parameter - that is, at high insolation rates and air temperatures near that of the pool or spa. In fact, the higher wind speeds improve heat gain from ambient air if the average collector temperature is lower than the ambient air temperature (a condition represented, as previously indicated, by a negative fluid parameter)

5.3.3 Wind Speed and Direction

An accurate estimate of the wind speed over the collector surface is required if the results of the wind speed correction process are to be reliable. In Florida most cool winds come from the north; fortunately, collectors face south and the wind speed over their surfaces is reduced by the presence of buildings and collector support structures Thus, the wind speeds over the collector surface are sometimes less than one half of those reported by the local weather bureau. (Several graphs and tables useful for estimating wind speed over the collector surface are presented in Appendix C A range of performance curves, equations or nomographs corresponding to wind speeds of 3-15 mph <u>over the collector surface</u> should be adequate for the evaluation of unglazed collector performance under cool, windy conditions. It should be noted that although increased wind speeds cause increased convective collector losses only if those winds are cooler than the collector surface, this is not true of the <u>surface of a swimming pool</u> or spa which will suffer increased evaporation losses with increased winds of almost any temperature It must also be remembered that daytime wind speeds are usually higher than nighttime wind speeds and daily averages may require adjustment to account for this increase Instructions for making this correction are contained in Appendix C

5.4 USES FOR THE INFORMATION

The performance ratings derived by employing the above correction factors and nomographs allow designers or installers of solar commercial pool heaters to more accurately evaluate the solar contributions which may be expected from specific collectors under either specified or average monthly conditions of insolation, air temperature and/or wind speed This information will help the designer or installation contractor to offer a pool owner supportable advice as to whether to install:

1 Unglazed collectors with the expectation of using a fossil-fueled backup heater during either overcast or cold, windy weather

2 Unglazed collectors and a wind screen which will reduce but not eliminate dependence on the backup heater.

3 A more costly array of glazed collectors which will substantially reduce the dependence on the fossil-fueled heater during cold weather but will function less well than will unglazed collectors during warm weather because of higher reflection losses.

EFFECT OF BACK INSULATION ON COLLECTOR OUTPUT

The rear side of unglazed, uninsulated solar collectors will suffer additional thermal losses not accounted for in their performance ratings unless they are mounted on insulated surfaces. During testing in accordance with ASHRAE 96-80, collectors are mounted firmly against a support structure with an insulating value of approximately R-5

If a field installation is made on a support structure with a lower R value, the collectors' performance will suffer correspondingly during cool weather Airflow between the back of an uninsulated collector and its mounting substrate seriously reduces collector efficiency during cool weather

THE SPECIAL CASE OF "PIPE" COLLECTORS

It is the author's opinion that if the low temperature rating of plastic pipes used for swimming pool heating based on the projected area of the array are used to enter Figures A.1 through A.6, those nomographs may be used to rerate the pipe array's performance in the range of temperatures and insolation rates given He knows of no substantial body of data which may be used to evaluate the effect of increased wind speed on pipe collector performance Because their sides and even backs are exposed to the wind, the effect would be expected to exceed that suffered by unglazed flat plate collectors with virtually no side exposure and, when mounted against a roof, with little or no rear exposure. Because of the absence of objectively generated emperical data and uncertainties encountered in the mathematical analysis of the effect of wind speed on convective losses from arrays of pipes, no wind speed correction factors are suggested for

systems. This in no way is meant to reflect discredit on arrays of pipe used for solar swimming pool heating

SYSTEM CORRECTION FACTORS

There are several reasons why even properly operating solar pool heating systems do not deliver as much energy to the pool as would be predicted from the thermal output of their individual collectors. First, no control strategy is responsive enough to the availability of thermal energy to avoid some losses resulting from pump cycling Second, large pool heating collector arrays usually are installed in a fixed position and receive energy during much of the day at angles of incidence of more than

30° allowed during testing This reduces their thermal output below

indicated by their performance rating, the calculation of which does not include the penalty resulting from the use of an incident angle modi-

Third, during cold weather the circulation piping, which is seldom insulated, loses some energy to the surrounding ambient air (This latter loss is far less significant than the first two.) Table 5.4 suggests system correction (penalty) factors by which the predicted thermal output of the collector array may be multiplied to yield a more realistic evaluation of the deliverable energy from a solar pool heating system

Table 5.4
System Correction Factors for Florida

System Type	Collector Slope 30-40°	10-20°	0°	*
Open circulation loop	.95	.90	.85	95
Closed circulation loop (Hx effectiveness > .5)	85	.80	.75	.85

*Use this column if the FSEC low temperature rating has been modified for variations in insolation in the plane of the collector (regardless of slope angle).

To determine the system output, use the information in Table 5.4 and the following formula (Btu from collectors) x (system correction factor (deliverable Btu)

5.8 DETERMINING AND MINIMIZING WIND SPEED OVER COLLECTOR SURFACES

It is essential to accurately estimate and where possible to reduce wind speed over the surface of unglazed collectors and swimming pool or spa surfaces. This maximizes the return on the substantial investment required to install solar pool and spa heaters (or reduces fuel consumption by conventionally-fired pool heaters) Methods for estimating wind speeds at specific locations on or around several common building shapes are found in Appendix C. Appendix D applies the information from Appendix C to minimize the wind speed effect The sample problem in that appendix illustrates the use of the formulas and graphic design aids