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Wind Issues in Solar Thermal Performance Ratings

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WIND ISSUES IN SOLAR THEMAL PERFORMANCE RATINGS

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ABSTRACT

The U.S. Solar Rating and Certification Corporation (SRCC) issues ratings for the thermal performance of solar collectors and solar water heaters (SWH). A bias favoring unglazed collectors currently exists because unglazed collectors have been tested under ASHRAE96 which specifies low wind during testing, whereas glazed collectors are tested under ASHRAE93 which specifies high winds. Wind is mostly negligible for glazed collectors, but it significantly affects unglazed collector efficiency. This bias didn't matter until ~2007 when unglazed SWH began to directly compete against glazed SWH under SRCC/OG300. It is suggested here that wind bias be mitigated by using a calibrated collector model to derive a wind correction to the measured efficiency curve. The resulting models depend explicitly on wind velocity, and could provide unbiased ratings. For unglazed collectors, the forced convection correlation has to be fit to wind-dependent collector data. The calculated rating increase for glazed systems is small, depending on collector insulation levels. The corresponding decrease for typical unglazed systems is ~20%, depending on unglazed collector type and wind coupling.

1. INTRODUCTION

The U.S. Solar Rating and Certification Corporation (SRCC) produces test results and performance ratings for collectors and systems. Manufacturers, suppliers, consumers, incentive organizations, analysts and researchers all use these data. It is essential that ratings be *unbiased*, applying test and rating conditions uniformly. Collectors are tested under consensus test standards, yielding parameters for use in established models. Up to ~2007, SRCC tests were done under ASHRAE93 (1) for glazed collectors, and ASHRAE96 (2) for unglazed collectors. ASHRAE93 specifies that wind speed be between 5-10 mph for valid data, and ASHRAE96 specifies that wind must be below 3 mph. The resulting parameters for optical gain and thermal loss *implicitly* incorporate these divergent wind speed ranges, but have no *explicit* wind dependence. These parameters are then used in wind-independent collector models to generate ratings under rating conditions specified by SRCC. Thus, unglazed collectors are implicitly rated at low wind speed and glazed collectors at high wind speed. The goal of this work is mitigate this wind bias in SRCC rating calculations.

Inconsistent assumptions about wind were not a significant issue as long as the unglazed and glazed systems had no real market overlap. Unglazed collectors were used only in solar pool systems (SPS). Similarly, glazed collectors were used almost entirely in SWH or combi-systems. Although glazed collectors were occasionally used in SPS, there isn't an active SPS rating and the wind bias was of small consequence. Peace and harmony reigned. However, unglazed SWH began to enter the U.S. market in 2007, competing directly against glazed systems. So, using the collector parameters as obtained from the U.S. standards, an artificial advantage is given to unglazed systems over directly-competing glazed ones, a situation to be rectified. In this work, a correction to measured efficiency is proposed, based upon calibrating the wind dependent forced convection correlations in collector models.

SRCC is currently transitioning to use of ISO9806 (3) for collector testing. For glazed collectors, this standard is substantially identical to ASHRAE93. For unglazed collectors, ISO9806 improves on ASHRAE96 substantially by characterizing losses explicitly as a function of the wind velocity. With indoor testing (used for all unglazed data here), collector curves are determined at 3 wind speeds, and the wind dependence of the gain and loss parameters is fit with a linear function. It also treats the IR exchange with the surface as mostly part of the optics, rather than as part of the loss coefficient (the latter is more applicable for glazed systems with IR-opaque glazings). Unglazed collectors tested under ISO9806 can thus be rated at any wind speed chosen for rating (currently set at 3 mph for SRCC). The 12 year re-test requirement in SRCC suggests that ~12 years from now wind bias will be resolved by universal reporting under ISO9806. This paper considers what to do about wind bias in SRCC thermal performance ratings until that time.

In section 2, modeling is laid out for glazed and unglazed collectors. In section 3, the models are calibrated/validated against collector test data. In Section 4, the impact on ratings is estimated. In section 5, the relationship between TMY weather and typical urban site weather is examined.

2. COLLECTOR MODELING

The collector models are based on the linear form of the familiar Hottel-Willier-Bliss efficiency equation (4):

$$\eta = F_r(\tau\alpha)_n - F_rU_l(T_{inlet} - T_{amb})/I_{net} \qquad (1)$$

The linear form based upon inlet temperature is used here because that form results from ISO9806 testing for unglazed. The heat removal factor F_r is calculated as in (4):

$$F_r = F`*F``, F`` = \xi*(1-\exp(-1/\xi)), \xi = m_{dot}c_p/(A_{coll}*U_l*F`) \qquad (2)$$

F` is the collector efficiency factor, which incorporates most of the collector geometry and physics, as in (4). Notice that F_r depends on U_l. Since U_l depends on wind speed, the gain term $F_r(\tau\alpha)_n$ will vary with wind, even though the optical parameters are constants. The total loss coefficient is the sum of top, back and edge coefficients acting in parallel.

2.1 Glazed Collectors

These methods have been embodied in a useful numerical model CoDePro (5). This software was used here for glazed collectors. Outputs from CoDePro include efficiency equations, simulating efficiency with increasing inlet temperature (as in testing). Unglazed collectors and glazed collectors with 1 or 2 glazings are modeled. The user also sets test weather, which includes the wind velocity. Thermal losses are handled with correlations and 1-D relations. Top-cover losses are computed using a correlation for natural convection in a tilted cavity, net radiation method for infrared radiation (IR) exchange, forced convection on the top surface, and infrared radiation exchange to a black-body sky temperature as in (6). Side and back losses are 1-D conduction relations, with neglect of interior/exterior film coefficients and radiation transfer at the surfaces. Temperature dependence of the insulation conductivity is neglected, which will lead to under-predicting the convex curvature in the efficiency plot at values of ΔT/I. Thermal shorts (e.g., piping) are also ignored.

In this paper, CoDePro as supplied (5) has been modified to include the effect of the inner and outer film coefficients and radiation on the side and back surfaces U_{back} and U_{edge}:

$$U_{surf} = [(h_{nat\text{-}conv,inner}+h_{rad})^{-1}+t_i/k_{ins,i}+(h_{wind}+h_{rad})^{-1}]^{-1} \qquad (3)$$

As can be seen, radiation is combined with the convection coefficient on both inner and outer surfaces. As in (5), the radiation exchange and film coefficients can be reasonably neglected with a well-insulated collector; however, we wanted to treat the case of poor insulation in the collector. In Fig. 1, the variation due to wind is shown for a non-selective collector with low insulation (no side insulation and 1 cm of back insulation, as might be done to minimize overheating). The effect is small except at larger values of ΔT/I, but the effect is sufficiently large to give a small boost in ratings to such collectors when wind is lowered to 3 mph.

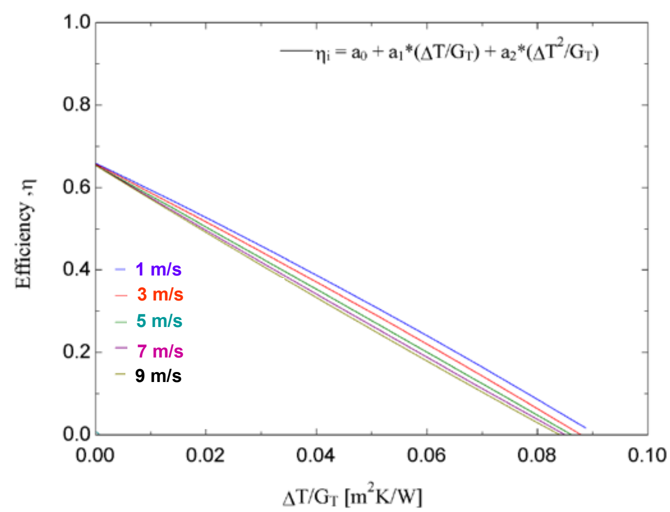

Fig. 1. Efficiency vs. ΔT/I for a glazed non-selective with low insulation, for wind from 1 m/s to 9 m/s.

2.2 Unglazed collectors

The unglazed collector is modeled as fully-wetted, as in Fig. 2. In this case, F’ simplifies to:

$$F` = (1/U_{top})/[\ 1/U_{top} + t_{wall}/k_{ins,top} + 1/h_{channel}\ ] \qquad (4)$$

The unit is assumed mounted flat on the roof with no gap between collector and support. The U value out the back was modeled as in Fig. 2. This configuration is considered similar to the test configuration, and appropriate to assume when matching test data. Other backings will induce some change in U_l.

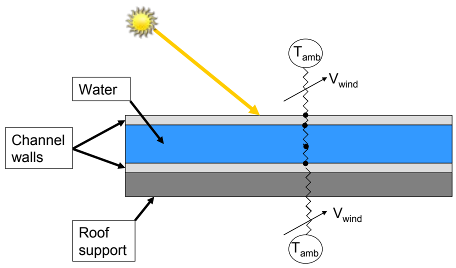

Fig. 2. Simple fully-wetted model for an unglazed collector.

The efficiency equation used for unglazed differs from that for a glazed collector in two significant ways. First, the incident radiation I_{net} includes both short-wave solar (I_{sun}) and net sky infrared radiation from a blackbody at ambient temperature (I_{netIR}):

$$I_{net} = I_{sun} - \varepsilon/\alpha I_{netIR} \quad (4)$$

The value of ε/α is usually close to 1.0, also assumed here. I_{netIR} is characterized and modeled as in (6), in which effective sky temperature and net fluxes are correlations based mainly on dew point temperature. Maximum values for I_{netIR} are around 0.1 kW/m^2, ~ 10% of the maximum I_{sun}. The second difference is that the loss coefficient and optical gain are taken as linear in wind velocity (3,7):

$$F_r (\tau\alpha)_n = A_o – A_{wind}v_{wind}; \text{ and } F_rU_l = B_o + B_{wind}v_{wind} \quad (5)$$

v_{wind} is taken to as the *local wind*, defined in (3) as measured 20 cm above the collector and averaged over the collector area. In section 5 we will consider what value to take for v_{wind} when using typical meteorological year (TMY) wind data. A spreadsheet model for the unglazed collector was developed and used in this work.

2.3. Uncertainty in the forced convection models

The forced convection coefficient correlation with wind velocity is the key component of the unglazed collector model. Figs. 3-4 show the forced convection film coefficient as a function of wind for 8 models available in the literature (4,7,8), for two size scales. The first four correlations (filled symbols) are non-dimensional laboratory correlations with steady, well-developed wind incident on the surface. These correlations are of the form $h = Nu(Re)k_{air}/L_{scale}$. The laminar correlation is the lowest, and doesn't apply except at very low wind speed. The next four correlations are empirical forms, linear in v_{wind} except for the Sharples correlation of the form $h=K\sqrt{v_{wind}}$. Infrared is believed not implicitly present except in the McAdams correlation. The last 2 correlations are the term $B_{wind}v_{wind}$ and U_{total} from tested collector in (4) (in figure legends, U_{total} = "Harrison C,D", "Harrison D" = $B_{wind}v_{wind}$). h_{wind} from the empirical correlations is significantly larger than from the non-dimensional ones for the collector scale (Fig. 4a); there is a range of 2-4X in values. Still, these correlations are too small compared to the measured loss. The dimensional correlations were done on small plates outdoors, with size ~.5m X .5m. Fig 4 compares the correlations when L_{scale} = .5m in the dimensionless, indicating reduced disagreement when length scales are matched, as in (8).

The large variation between the convection models shows that h_{wind} should be considered uncertain to factor of 2 or so. Coupled with the fact that the convective top losses dominate unglazed collector losses, we conclude that *unglazed performance cannot be predicted without appeal to wind-dependent test data.* On the other hand, it is also clear that these correlations are all mostly linear over the range of interest, including the power law forms. It is therefore reasonable to expect that any of these models will predict wind effects well when *fit* to the wind dependence in collector data, as in ISO9806.

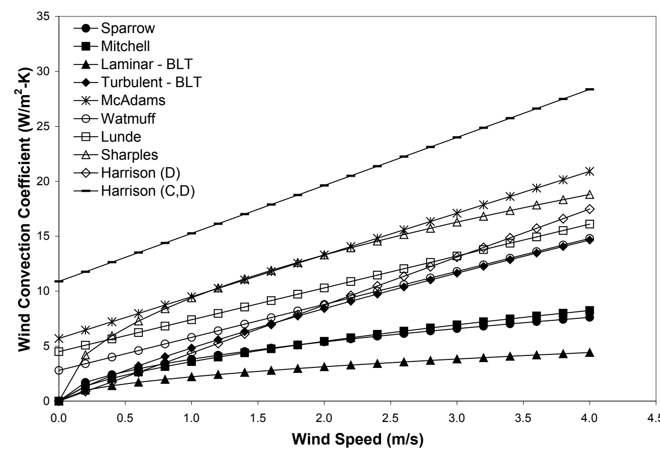

Fig. 3. h_{wind} vs. v_{wind} for 8 literature correlations, with L = 2 m. The loss coefficients for a collector in (7) is also plotted.

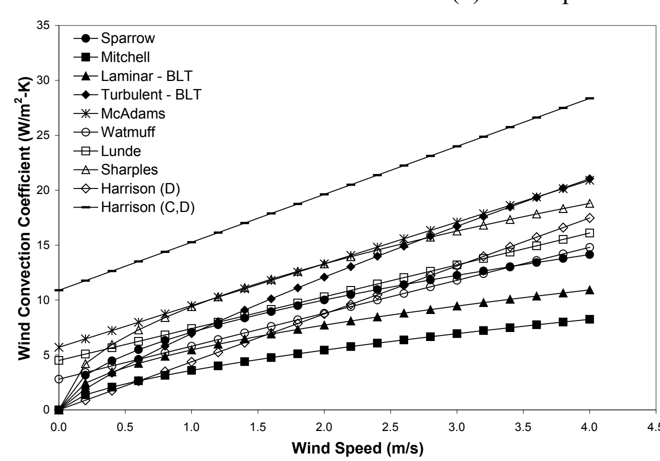

Fig. 4. h_{wind} vs. v_{wind} for 8 literature correlations, with L ~ .5 m. The loss coefficient for a collector in (7) is also plotted. The 0.5 m scale reduces the apparent discrepancies.

2.4 Other issues

The relation between real wind and indoor wind driven by fans is problematic in several ways. One issue is that laboratory fans can force wind to impinge somewhat normal to the collector, causing more turbulence and higher losses than if wind entered parallel to the surface. Real wind is extremely complex, although the roof, being much larger than the collector, might dominate in modest flows and produce developed parallel flow at the collector so that laboratory correlations would apply. It is unclear, for example if laboratory fans should be positioned so as to produce parallel flow.

Another issue is related to turbulent intensity ε_{turb}, where $\varepsilon_{turb} \equiv v_{wind,RMS}/v_{wind,avg}$. Values for ε_{turb} can range ~ .1 - .6 for real wind, whereas ε_{turb} is ~0 for laboratory wind behind correlations #1-#4. In (9), experiments were done comparing the forced convection coefficient with and without turbulence in the approaching wind. It was stated that the film coefficients were 2-4X larger with turbulence than without. This result may explain some of the systematic difference between non-dimensional lab correlations and the outdoor dimensional shown in Figs. 3-4. In the indoor data used here, ε_{turb} is set to ~0.3 by modulating the fan speed, although it is not clear this is a good, or even reasonable, representation of actual wind turbulence. To resolve the lab-vs.-reality wind issues, wind dependence in a collector tested both indoors and outdoors could be compared.

3. MODEL VALIDATION

Two fundamental factors must always be considered in considering model validation: a) limited accuracy of the model (algorithmic error); and b) limited accuracy of the inputs (input error). To calculate the total input error, it is adequate to add in quadrature the output error corresponding to the input error for each input, computed one-at-a-time. When (model+input error) overlaps (data+measurement error), the model is validated in the strict sense of that word. When inputs are not measured (as is the case here), manufacturers' estimates or typical/handbook values must be used and uncertainty is large. However, if the model algorithmic error is thought small (as here), then one should first *calibrate* the model. Note that calibration guarantees some level of agreement, and validation is only "off-fit". The calibration may change the sensitivity to some driving forces. In our case, when we change the loss coefficient to fit data, we have to decide how much of that change is to be done in the constant terms (back insulation) and how much is in the wind-dependent terms. That ratio effects the model sensitivity to wind. Here, adjustment is applied only to h_{wind}. Note that error in the wind correction term is a second order error, and not of high concern.

Only slope and intercept of the efficiency curve need be changed in the linear model to reach agreement with data. However, including all inputs, the model in (5) has 42 parameters, related to a collector test. It is suggested that parameter adjustment be limited to a few key parameters with the largest uncertainty. τ_{glaz}, α_{abs} adjust optical gain without causing change in slope. With the formulation used here, any changes causing change in loss will interact with the gain through its change on F_r. The most uncertain loss-related parameters are k_{insul} and ε_{abs}. The adjusted parameters should be in reasonable ranges, but can become unphysical (e.g., $\alpha_{abs} > 1$) without undue alarm.

3.1 Glazed collectors

Glazed collector model have much less uncertainty in performance, as wind and sky-infrared radiation are blocked by the glazing and affect only the outside coefficients. In matching measured curves, the geometric parameters are set to manufacturer's data, and kept fixed. The flow rate must be set to the reported test flow rate. The wind is set to 7.5 mph, the mean of the allowed range under ASHRAE93. Adjustment to the inputs is generally needed to match data. Fig. 5 shows an example where only one parameter needed adjustment. It is usually necessary to adjust both gain and loss parameters to match data. Adjusting the loss parameters affects the gain through F_r, and iteration is usually needed. Fig. 6 shows a case where both gain/loss parameters had to be adjusted to get good agreement. The "fits" here were done visually, as opposed to least squares.

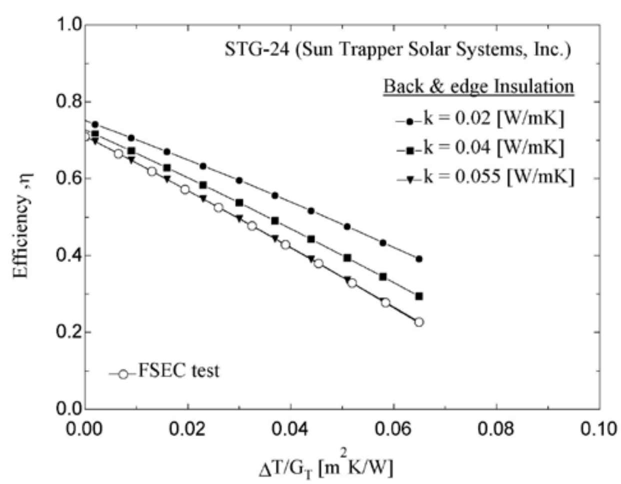

Fig. 5. Codepro models with various k values versus experimental data. It is necessary to increase the model k value to reach agreement with data. Taken from (5).

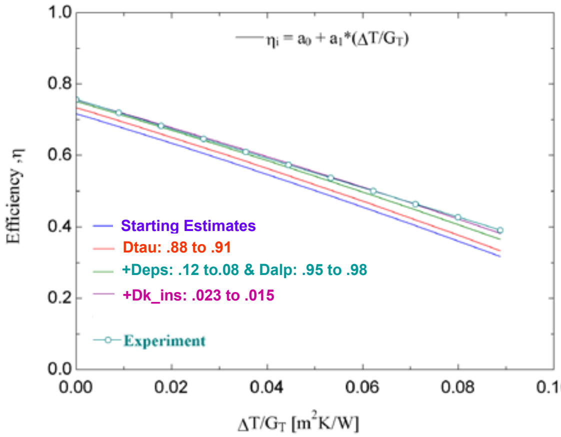

Fig. 6. Adjustment of glazed collector model input parameters to adjust efficiency curve to match SRCC data. The starting estimate is the lowest line, and the legend indicates what changes were made to the next model.

3.2 Unglazed collectors

Six data sets are available to us with wind-dependent results (7,10). Table 1 lists the parameters corresponding to Eqn. 5.

TABLE 1. UNGLAZED TEST RESULTS

Label	A_o [-]	A_{wind} [s/m]	B_o [W/m2]	B_{wind} [Ws/m^3]
#1	0.88	0.029	10.24	4.69
#2	0.92	0.028	12.16	4.63
#3	0.85	0.033	11.67	3.8
#4	0.82	0.027	9.49	4.5
#5	0.935	0.0365	11.237	5.091
#6	0.878	0.034	12.333	4.112

Note: Collector data 1-4 from (7). Collectors 5-6 from (10).

The efficiency curves of the 4 collectors in (7) are shown in Fig. 7 at the minimum and maximum wind speed allowed under ASHRAE96 (0 and 3 mph). Note the wide range (~2X) of possible results for data for a given collector from that standard. There is high potential for "noise" to occur as the wind varies in the range [0, 3 mph] during testing. It will also tend to obscure the differences between unglazed collectors, if any.

An unglazed model can be adjusted to fit the data by adjusting h_{wind} to best match slopes; and adjusting α_{abs} to best match the y-intercepts. For 5 of the wind models, Table 2 shows the values of the parameters and value of $\delta\eta_{RMS} = \sum_i(\eta_{test} - \eta_{model})^2/N_{points}$. As expected, each of the models provided a good fit to the data ($\delta\eta_{RMS}$ < .02, which is ~ test error), with wind coefficient factors varying from 1.3 to 2.2. Fig. 8 shows the test-model comparison for collector #5 at three wind speeds, using the Watmuff wind correlation. The model is shown both before calibration (small open symbols) and after calibration (larger open symbols). The calibrated model fits the data well, with only two parameters adjusted.

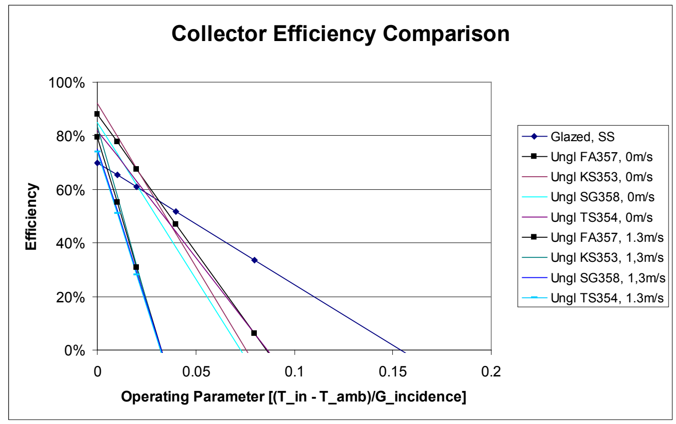

Fig. 7. Four unglazed collectors at the minimum and maximum allowed values of v_{wind} in ASHRAE96. A glazed selective-surface collector is also shown for reference.

TABLE 2. ADJUSTMENT VALUES AND FIT χ^2

Model	Wind Factor	Absorptivity	Chi-Sqrd
McAdams	1.3	0.98	0.0112
Watmuff	2.0	1.01	0.0053
Lunde	1.7	1.00	0.0108
Sharples	1.4	0.96	0.0189
BLT/Turbulent	2.2	1.00	0.0064

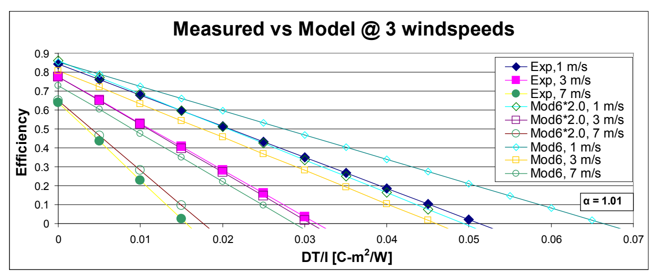

Fig. 8. Measured results (solid symbols) vs. model results (open symbols) at 3 wind speeds. The model is shown both before calibration (small open symbols) and after calibration (large open symbols).

Once the collector model has been calibrated, it can be used to produce wind-dependent corrections. Taking the measured collector curve as primary, the calibrated model is used to calculate a correction to measured collector parameters P (where P = gain or loss coefficient):

$$P(v_{wind}) = P_{test} + [P(v_{wind}) - P(v_{test})]_{calib\text{-}mod} \qquad (6)$$

In this way, data taken under ASHRAE93 and ASHRAE96 that gives constant P values can be adjusted to account for differences between the wind during test and the wind during (say) rating calculations. The wind dependence across collectors in Table 1 is rather uniform, suggesting that a single correction model is adequate. Further work is needed.

4. RATING CHANGES WITH UNIFORM WIND

There are two rating durations used by SRCC: i) *one-day ratings*: collector rating (OG100, (11)) and system rating (OG300, (12)), where the wind velocity over the collector is fixed at 3 mph over an artificial "rating day"; and 2) *annual ratings*: total system saving over a year under typical draw assumptions for TMY sites, where v_{wind} varies hourly, and $v_{wind} = F_{TMY\text{-}to\text{-}site} * v_{wind,TMY}$. Section 5 discusses $F_{TMY\text{-}to\text{-}site}$ generally. $F_{TMY\text{-}to\text{-}site} = 0.3$ is used for an urban setting.

We assume that the efficiency equation measured under ASHRAE93 and ASHRAE96 are taken at wind velocities at the mean of the allowed range: 1.5 mph for unglazed and 7.5 mph for glazed. The rating wind speed is taken as 3 mph, as adopted by SRCC in 2007. Using the wind dependence predicted by the calibrated models, we can predict the typical change in ratings. For purposes here, it is sufficient to estimate the change in OG100 and OG300 one-day ratings using the changes in the efficiency curves when changing wind from tested to rated value. The changes are small for well-insulated glazed (<1%), modest for low-insulation glazed (<4%), and large for unglazed (~20% except for Category C where rating is near zero). Future work will determine the rating changes by rigorous use of the models.

TABLE 3. ESIMATED RATING CHANGE DUE TO WIND CHANGE

Collector Type	OG100[1] ΔT categ.	OG300/ One-day
Insulated glazed	B[2]: ~0 C[2]: << 1%	<< 1%
Non-sel./low ins. glazed	B[2]: ~1% C[2]: ~ 4%	~3%
Unglazed/non-sel.	A[2]: ~4% B[2]: ~-24% C[2]: ~-80%	~-20%

1. Clear day ratings.
2. ΔT categories: A = -9 ºC, B = 9 ºC, C = 20 ºC.

5. ADJUSTING TMY WIND TO SITE WIND

TMY weather files are widely-used annual weather files providing hourly values for most site weather variables of interest (13). In these files, the reported wind is almost always measured at height of 10m on tall towers in clear areas like airports. However, the concomitant wind for a nearby site may be very different, as much as a factor of ten or so. For rating purposes, an urban setting would be a reasonable assumption, and the difference is large. Two models familiar from building science were examined here, the Sherman-Grimsrud model (14) and the ASHRAE model (15). The ASHRAE model has a single terrain factor, whereas the Sherman Grimsrud model assigns both a general terrain factor and a local shielding factor. The varying approaches muddy intercomparisons. The ASHRAE model is probably intended more for larger buildings, and may not be as concerned with local factors.

Both models estimate the wind adjustment factor $F_{TMY\text{-}to\text{-}site}$:

$$v_{wind,site} = F_{TMY\text{-}to\text{-}site} v_{wind,TMY} \qquad (7)$$

The model algorithms are described in Appendix A. The results of applying the models for an urban context are shown in Table 4. A value of 0.3 is recommended for urban sites, as an average taken across both models and across terrain/shielding classes appropriate to urban areas, as in Table 4. The TMY tower is assumed in Terrain 3 in the ASHRAE algorithm. There is more reduction in the Sherman-Grimsrud model than in the ASHRAE model. Yet, it has been reported that the Sherman-Grimsrud model overpredicts the affects of wind on building infiltration (17). Further work is needed.

TABLE 4. $F_{TMY\text{-}to\text{-}site}$ ADJUSTMENT FACTORS

Sherman Grimsrud			
	Building Height		
Terrain/Shielding Class[1]	**3 m**	**6 m**	**10 m**
T=IV, S=V	0.16	0.19	0.21
T=IV, S=IV	0.28	0.34	0.38
T=III, S=IV	0.38	0.44	0.49
ASHRAE Fundamentals			
	Building Height		
Terrain[1]	**3**	**6**	**10**
1: urban/city	0.30	0.38	0.45
2: rural	0.55	0.64	0.72
3: airport-like	0.84	0.93	1.00

1) See Appendix A for definitions of Terrain and Shielding.

6. CONCLUSIONS

Current SRCC ratings for both collectors and systems use test results directly from ASHRAE93 and ASHRAE96, and are biased in favor of unglazed collectors because unglazed were tested at lower wind velocities. It is suggested that this wind bias be removed by using models of the collector which include wind dependence and are calibrated to test data. Fundamental models for glazed and unglazed collectors were articulated and were calibrated against available data. The models explained data trends well. It was shown that the proposed correction in ratings is small for glazed collectors, with maximum correction of ~4% in the extreme case of poorly-insulated non-selective collectors. On the other hand, the correction is significant for an unglazed collector, of order -20% for the SRCC one-day ratings. Further test data on unglazed collectors which has explicit wind dependence is needed, to determine whether the wind correction is similar enough across all units to use a single wind correction, as proposed here.

7. NOMENCLATURE

Symbols

A	Area or constant coefficient in efficiency equation
B	Wind coefficient in collector efficiency equation
c_p	Heat capacity at constant pressure
F	Collector heat removal factor, or factor
K	Numerical factor
L	Length scale
P	Parameter
Q	Thermal energy in the tank
t	Time, or thickness of material layer
T	Temperature
U	Unit area conductance
v	Wind speed

Greek Symbols:

α	Short-wave absorptivity of the absorber
Δ	Difference
ε	Long-wave emissivity of the absorber
η	Efficiency
$\boldsymbol{\theta}$	Orientation vector (embodies both tilt and azimuth)
τ	Transmission of the glazing(s)
χ^2	Measure of deviation between model and test data

Subscripts

amb	Ambient
avg	Average
coll	Collector
dot	Denotes time derivative of the variable
env	Environment of the tank
IAM	Incidence angle modifier
l	loss
mod	Model
n	Normal to the collector plane
r	Heat removal
site	For the particular site of interest
TMY	Typical Meteorological Year
useful	Useful energy exiting the collector
wind	Wind

8. ACKNOWLEDGMENTS

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APPENDIX A: TMY TO SITE WIND TRANSLATION

Two models are described that give a direct estimate of the wind adjustment factor $F_{TMY\text{-to-site}}$, defined as

$$F_{TMY\text{-to-site}} \equiv v_{wind,site}/v_{wind,TMY} \qquad (A.1)$$

In the ASHRAE method (12),

$$F_{TMY\text{-to-site}} = (L_{TMY}/h_{TMY})^{Atmy} * (L_{site}/h_{site})^{Asite} \qquad (A.2)$$
$$= 1.59*(L_{site}/h_{site})^{Asite}$$

The two parameters L,A are based upon the terrain: i) L: meteorological boundary layer thickness; and ii) A: a power governing how the wind varies with scale height. The terrain definition, and values to use in Eqn. A.1 are given in Table A.1. The TMY site is placed in terrain class 3, at a height of 30m.

TABLE A1. TERRAIN IN ASHRAE MODEL

Class	γ	α	Description
I	0.1	1.3	ocean or other body of water with at least 5km of unrestricted expanse
II	0.15	1	flat terrain with some isolated well separated obstacles (buildings/trees)
III	0.2	0.85	rural areas with low buildings, trees, etc.
IV	0.25	0.67	urban, industrial, or forest areas
V	0.35	0.47	center of large city

In the Sherman-Grimsrud Model (13)

$$F_{TMY\text{-to-site}} = [\alpha(h/h_{met})^{\gamma}]*SC \qquad (A.3)$$

There are three parameters, α, γ, and SC, which are based upon terrain and shielding class given in Table A.2. The terrain factor is a general factor describing surroundings of order several miles, and the shielding factor is a local factor describing surrounding within a few hundred yards.

TABLE A2. TERRAIN IN SHERMAN-GRIMSRUD

Terrain Factors			
Class	**γ**	**α**	**Description**
I	0.1	1.3	ocean or other body of water with at least 5km of unrestricted expanse
II	0.15	1	flat terrain with some isolated obstacles(buildings or trees well separated)
III	0.2	0.85	rural areas with low buildings, trees, etc.
IV	0.25	0.67	urban, industrial, or forest areas
V	0.35	0.47	center of large city
Shielding factors			
Class		**SC**	**Description**
I		1	no obstructions or local shielding
II		0.88	light local shielding with few obstructions
III		0.741	moderate local shielding, some obstructions within two house heights
IV		0.571	heavy shielding, obstructions around most of the perimeter
V		0.315	very heavy shielding, large obstructions surrounding the perimeter within two house heights.

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14. ABSTRACT *(Maximum 200 Words)*
The U.S. Solar Rating and Certification Corporation (SRCC) issues ratings for the thermal performance of solar collectors and solar water heaters (SWHs). A bias favoring unglazed collectors currently exists because unglazed collectors have been tested under ASHRAE96, which specifies low wind during testing, whereas glazed collectors are tested under ASHRAE93, which specifies high winds. Wind is mostly negligible for glazed collectors, but it significantly affects unglazed collector efficiency. This bias did not matter until about 2007, when unglazed SWHs began to directly compete against glazed SWHs under SRCC/OG300. We suggest here that wind bias be mitigated by using a calibrated collector model to derive a wind correction to the measured efficiency curve. The resulting models depend explicitly on wind velocity and could provide unbiased ratings. For unglazed collectors, the forced convection correlation has to be fittted to wind-dependent collector data. The calculated rating increase for glazed systems is small, depending on collector insulation levels. The corresponding decrease for typical unglazed systems is ~20%, depending on unglazed collector type and wind coupling.

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