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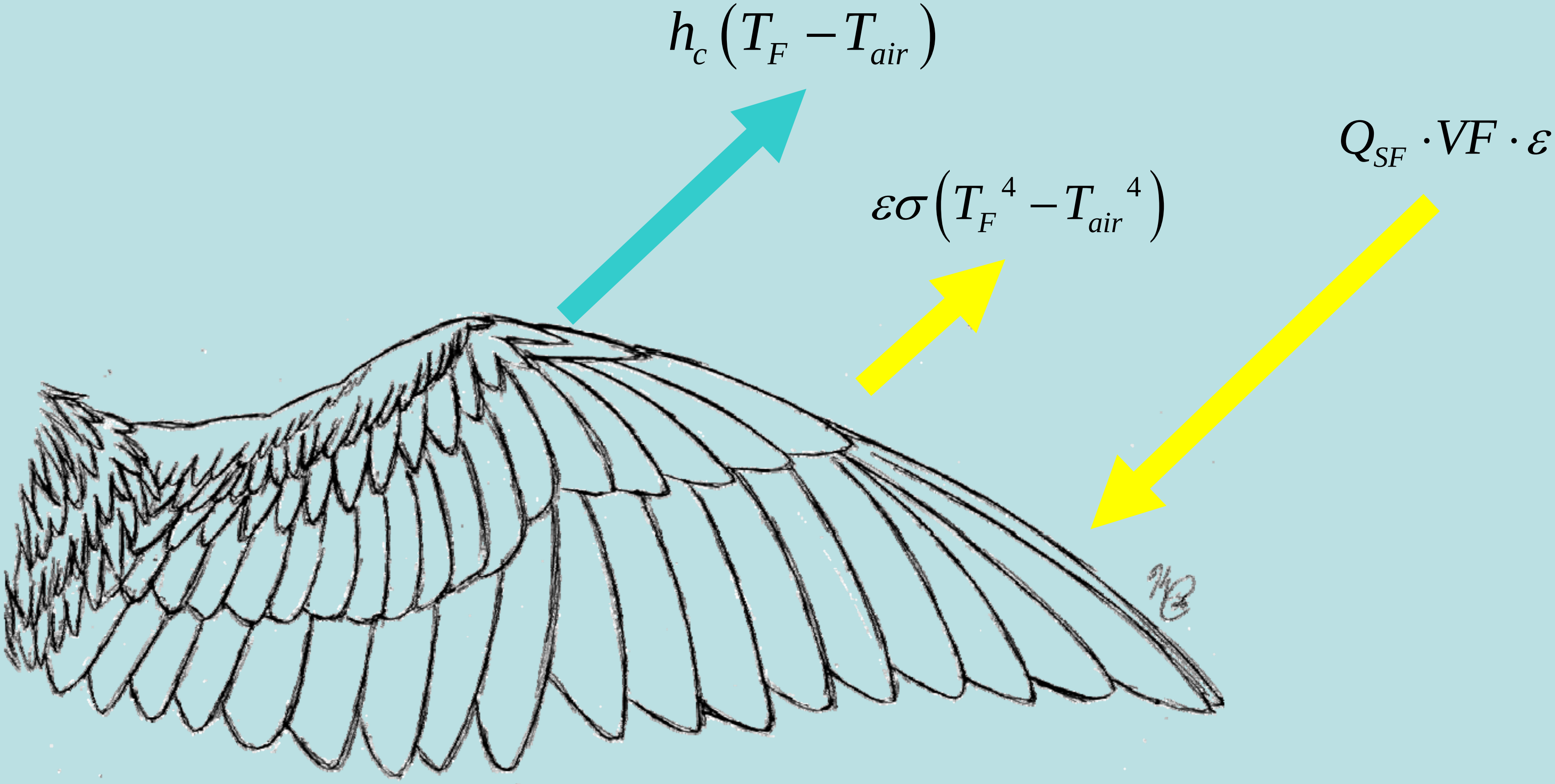
Professor of Biology, Duke University

PSA equations for heating and cooling



Solving for solar flux that heats feather to 160 C

Solar Flux = Radiant Losses + Convective Losses

$$Q_{SF} \cdot VF \cdot \varepsilon = \varepsilon\sigma\left(T_F{}^4 - T_{air}{}^4\right) + h_c\left(T_F - T_{air}\right)$$

$$Q^{MAX}{}_{SF} = \frac{\varepsilon\sigma\left(\left(160+273\right)^4 - T_{air}{}^4\right) + h_c\left(160 - T_{air}\right)}{VF \cdot \varepsilon}$$

Parameters used in the PSA

View Factor VF = 1

$$h_c = \frac{k_{air}}{L} Nu = 0.664 \frac{k_{air}}{L} \sqrt{\mathrm{Re}} \sqrt[3]{\mathrm{Pr}} \cong 28.5$$

$$T_{air} = 49C$$

$$\varepsilon = 0.95$$

$$Q^{MAX}{}_{SF} \cong 4.7 \quad \mathrm{kW/m^2}$$

Absorptivity of feathers

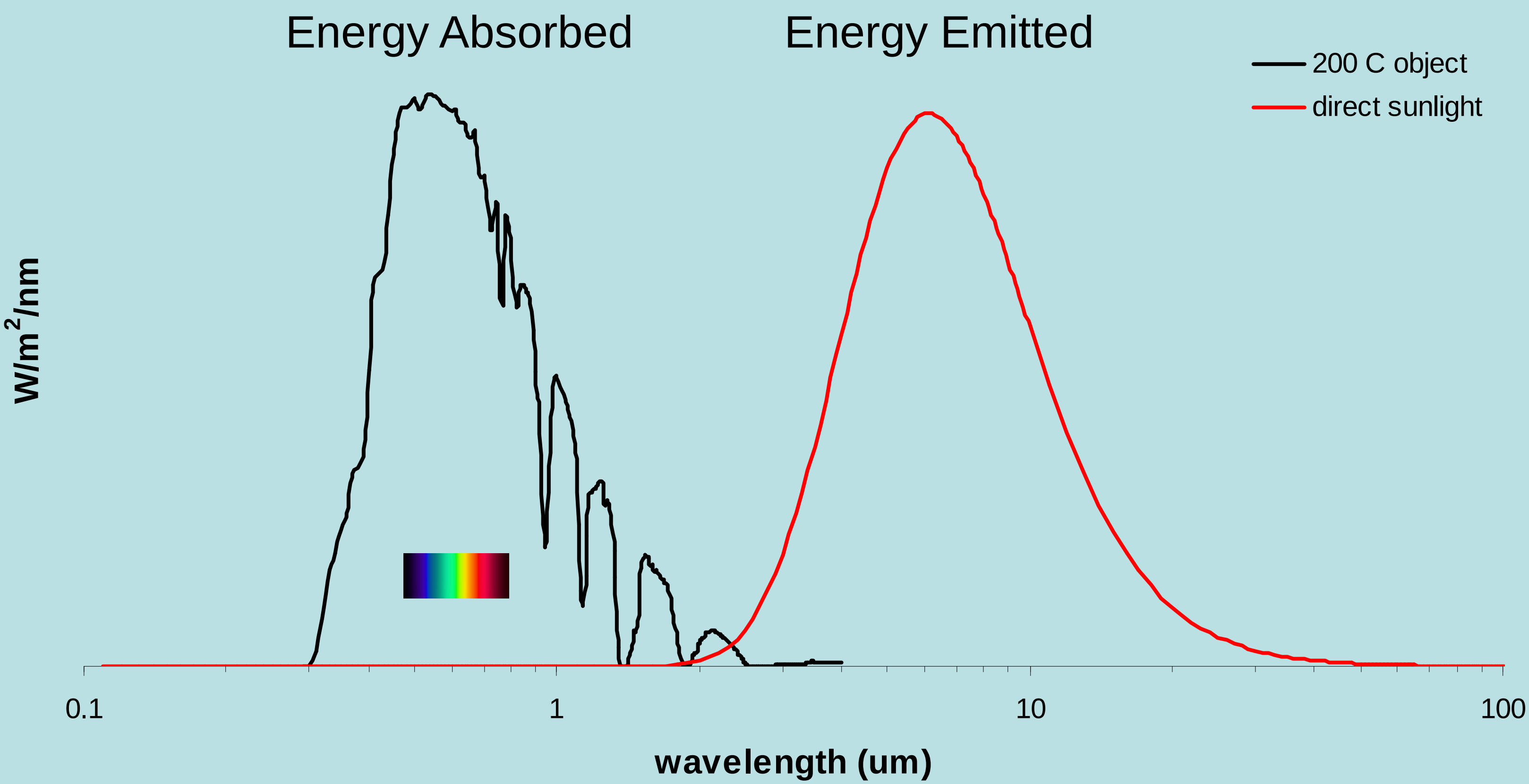
$$Q_{SF} \cdot VF \cdot \varepsilon$$

$$Q_{SF} \cdot VF \cdot \alpha$$

does $\alpha = \varepsilon$?

$$\alpha\left(\lambda\right) = \varepsilon\left(\lambda\right)$$

Spectra of sun and feather heated to 200 C

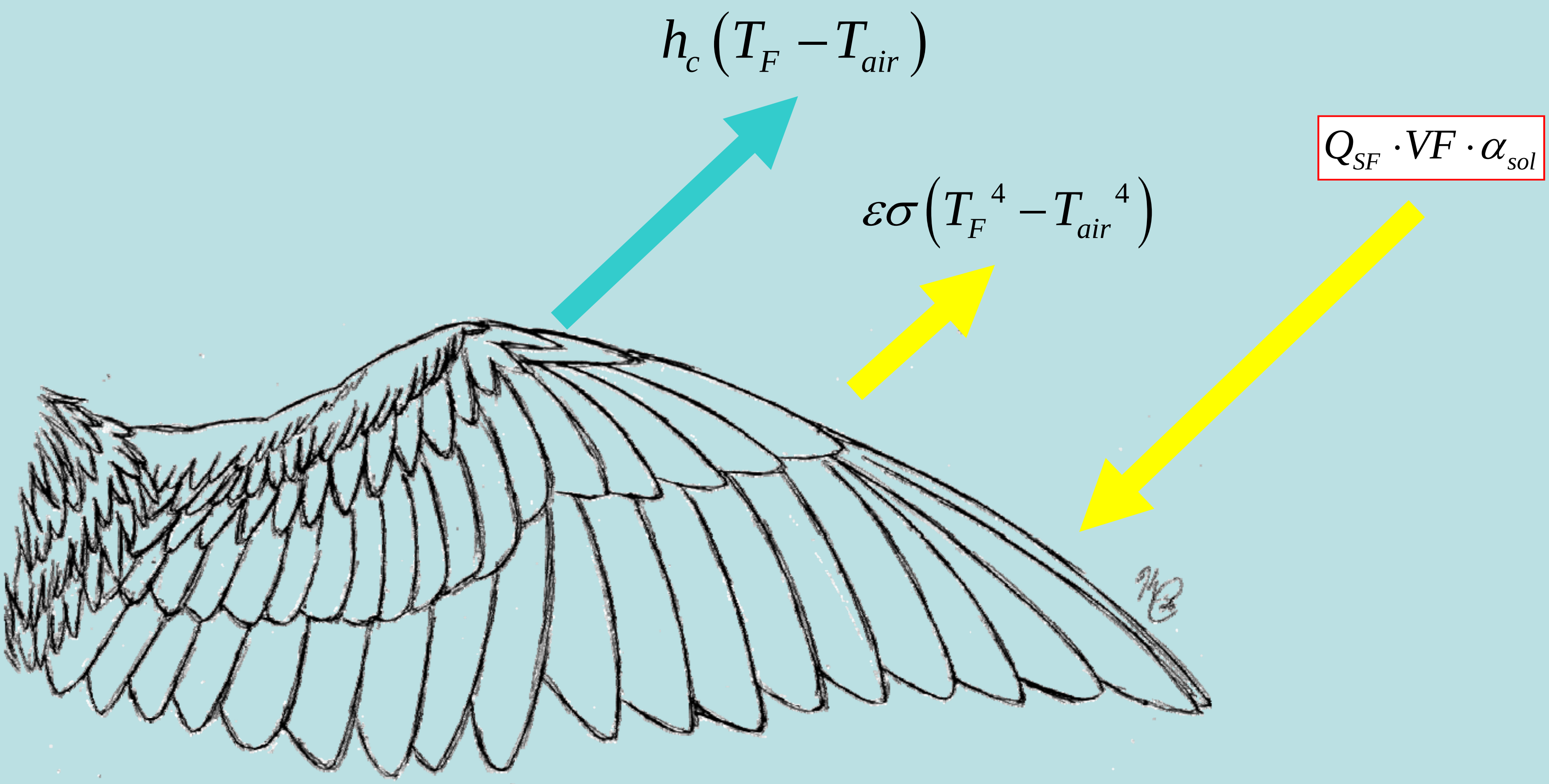


nearly all < 2um

nearly all > 2um

$$\alpha \neq \varepsilon$$

First correction of equations



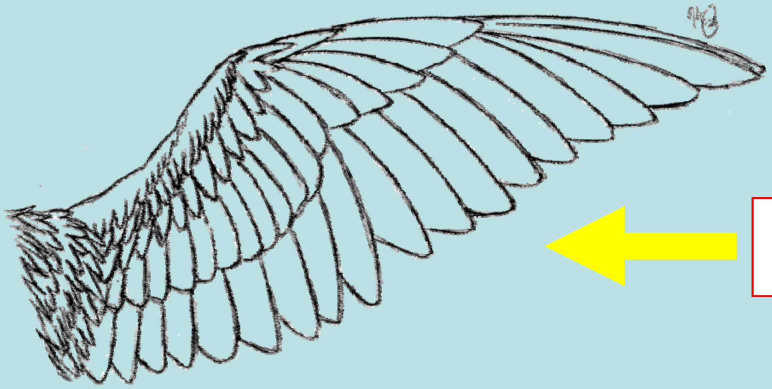
Results after first correction kW/m^2

α_{sol}	Absorptivity correction				
0.95	4.7 From PSA				
0.65	6.9				
0.75	6.0				
0.85	5.3				

View Factor

(VF = 1)

versus

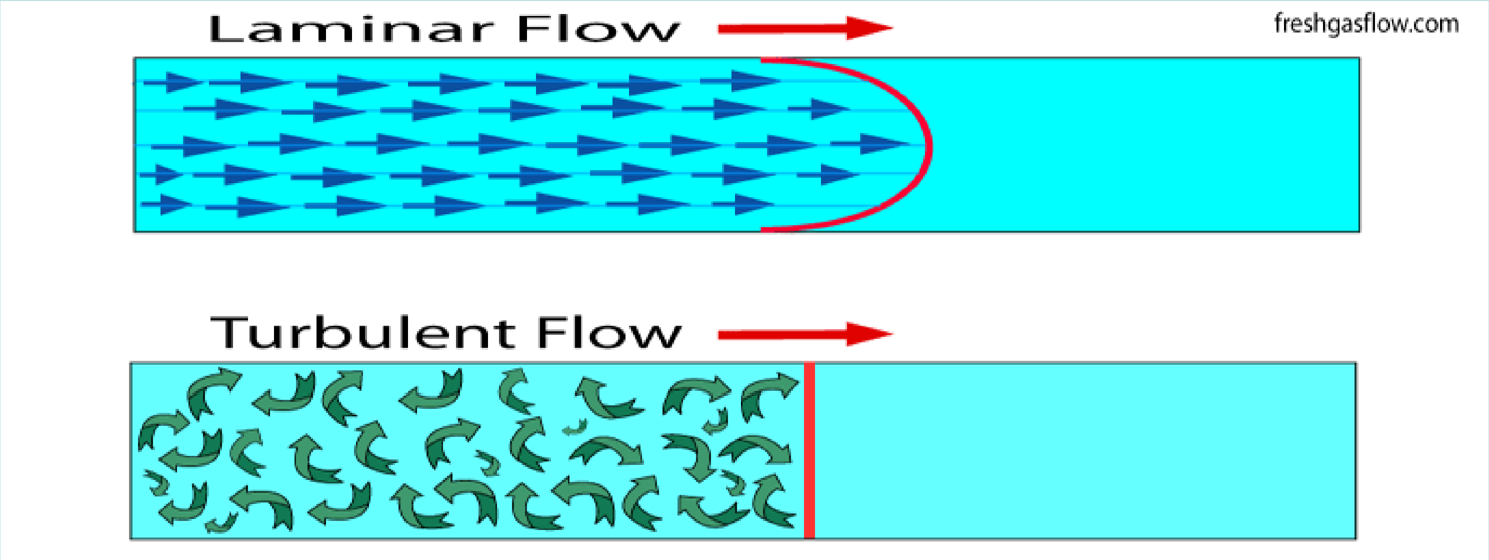


(VF = 0.342)

Results after second correction kW/m^2

α_{sol}	Absorptivity correction	View Factor VF = 0.342			
0.95	4.7 From PSA	14			
0.65	6.9	20			
0.75	6.0	17			
0.85	5.3	15			

Heat Transfer Coefficient h_c



$$h_c = \frac{k_{air}}{L} Nu = 0.664 \frac{k_{air}}{L} \sqrt{\mathrm{Re}} \sqrt[3]{\mathrm{Pr}} \cong 28.5$$

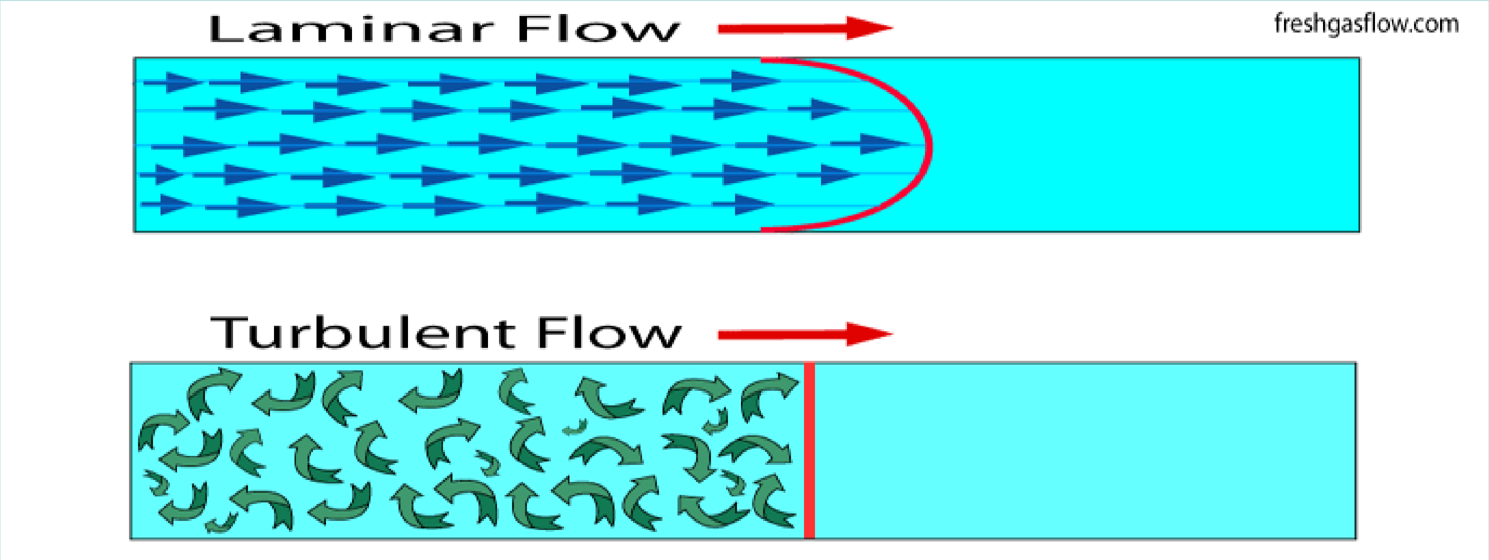
versus

$$h_c = \frac{k_{air}}{L} Nu = 0.0592 \frac{k_{air}}{L} (\mathrm{Re})^{4/5} \sqrt[3]{\mathrm{Pr}} \cong 71.8$$

Laminar

Turbulent

Heat Transfer Coefficient h_c



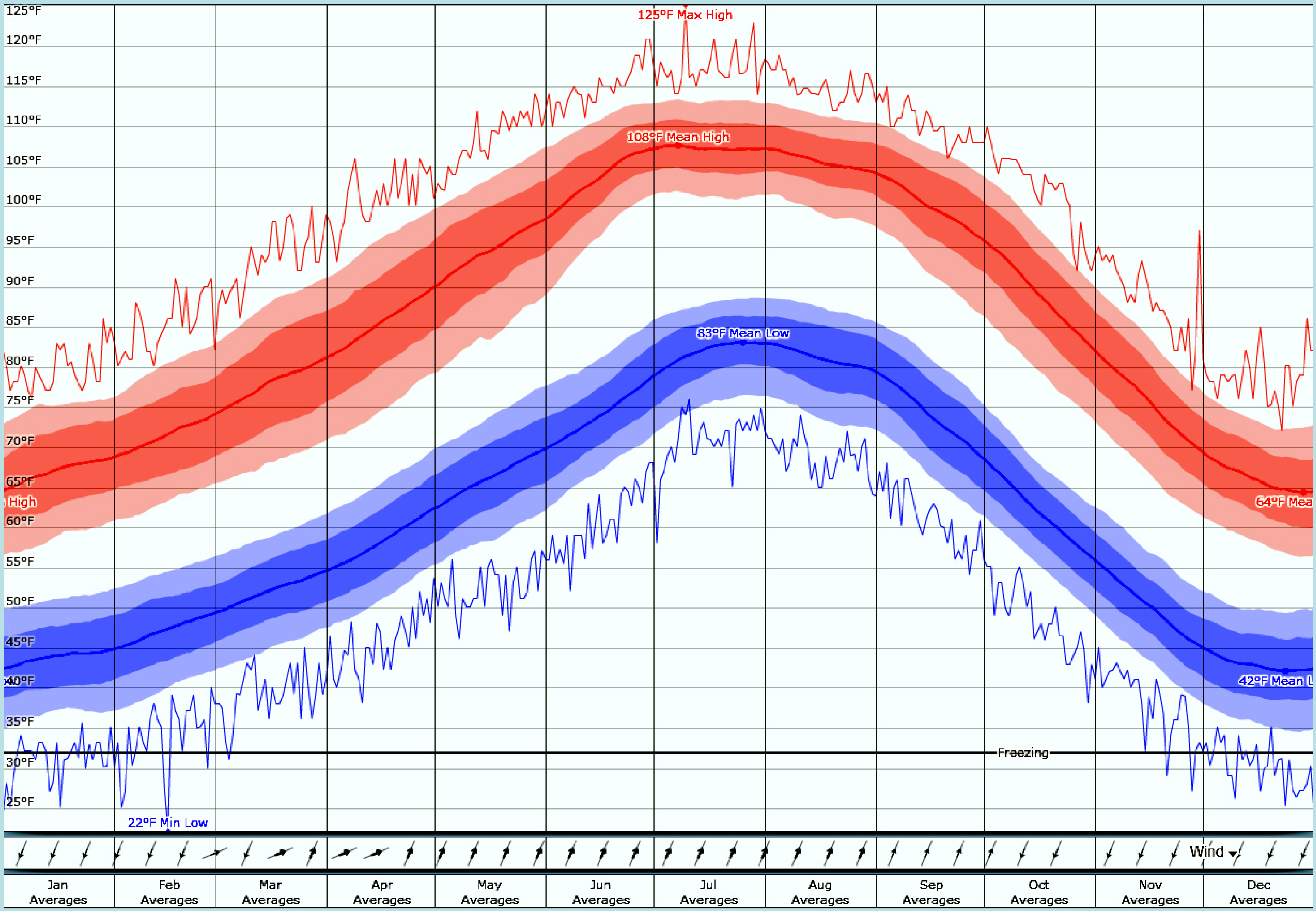
$h_c = \frac{k_{air}}{L} Nu = 0.664 \frac{k_{air}}{L} \sqrt{\text{Re}} \sqrt[3]{\text{Pr}} \cong 28.5$ versus $h_c = \frac{k_{air}}{L} Nu = 0.0592 \frac{k_{air}}{L} (\text{Re})^{4/5} \sqrt[3]{\text{Pr}} \cong 71.8$

Re = ~68,000 --- Turbulent flow

Results after third correction
kW/m^2

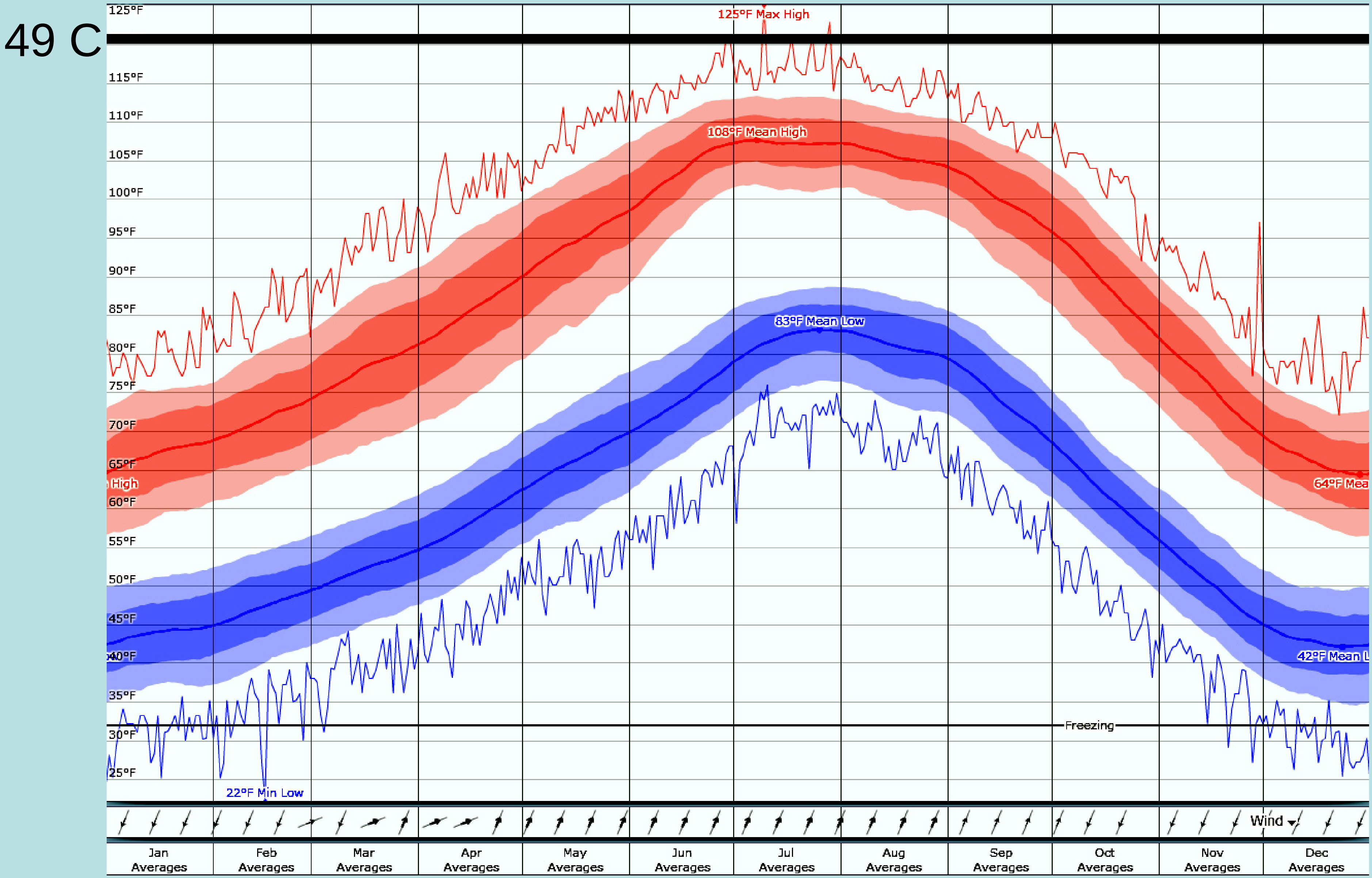
α_{sol}	Absorptivity correction	View Factor VF = 0.342	Heat Xfer Coef. H_c = 71.8		
0.95	4.7 From PSA	14	29		
0.65	6.9	20	42		
0.75	6.0	17	36		
0.85	5.3	15	32		

T_{air}= 49 C?

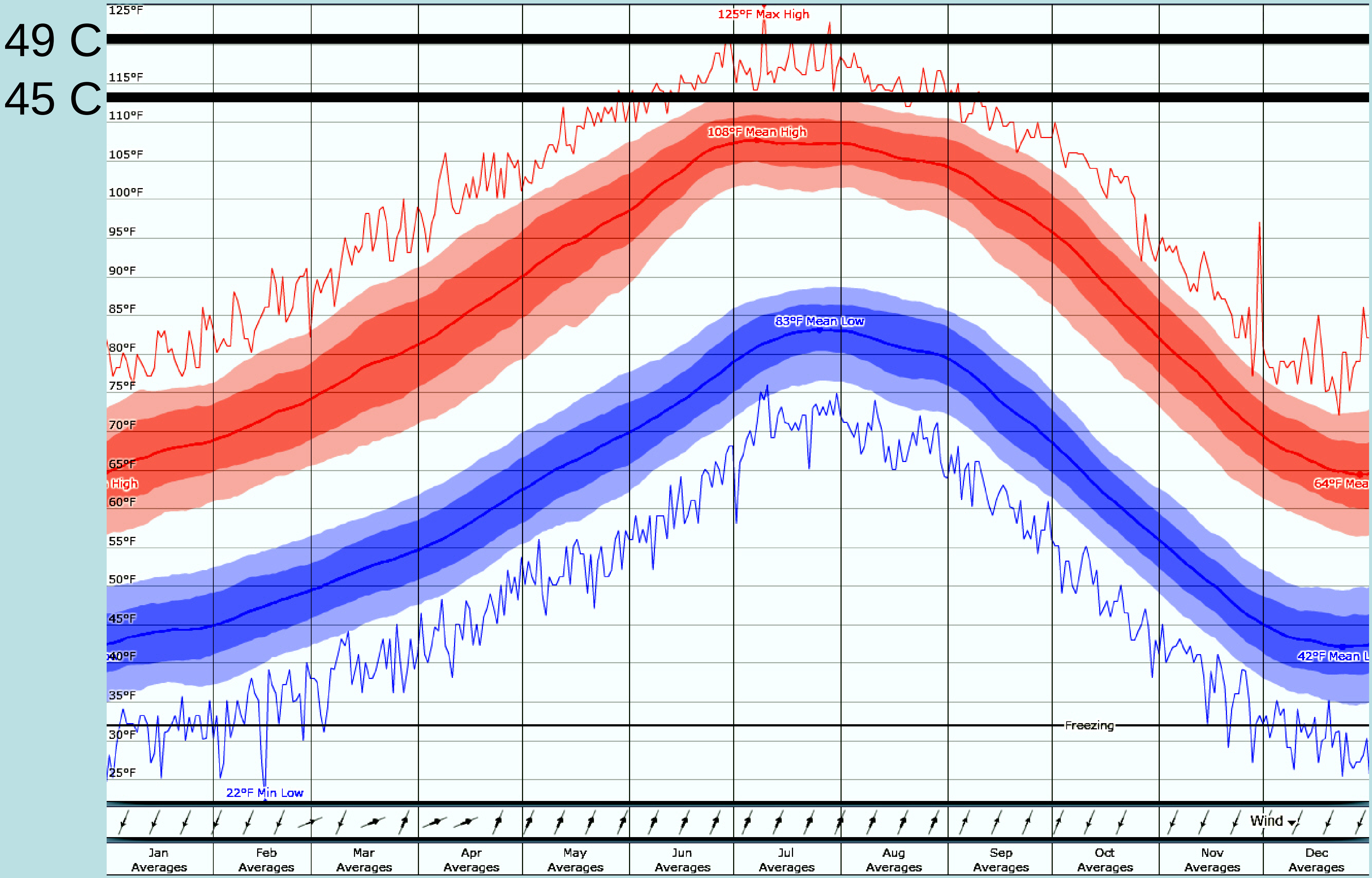


http://weatherspark.com/#!dashboard;ws=29776;t0=1/1;t1=12/31;graphs=temperature:1

T_{air}= 49 C?



http://weatherspark.com/#!dashboard;ws=29776;t0=1/1;t1=12/31;graphs=temperature:1

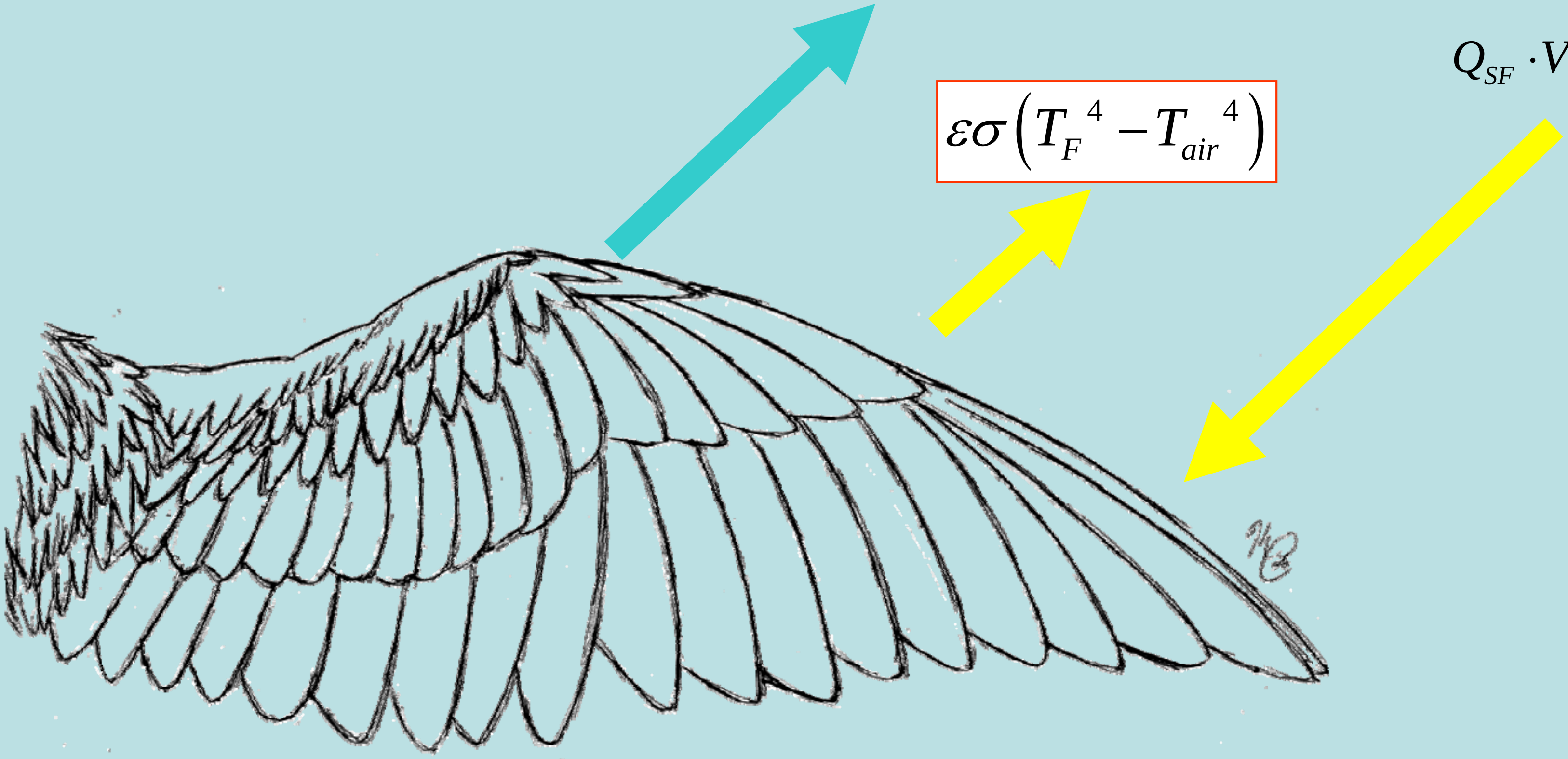


http://weatherspark.com/#!dashboard;ws=29776;t0=1/1;t1=12/31;graphs=temperature:1

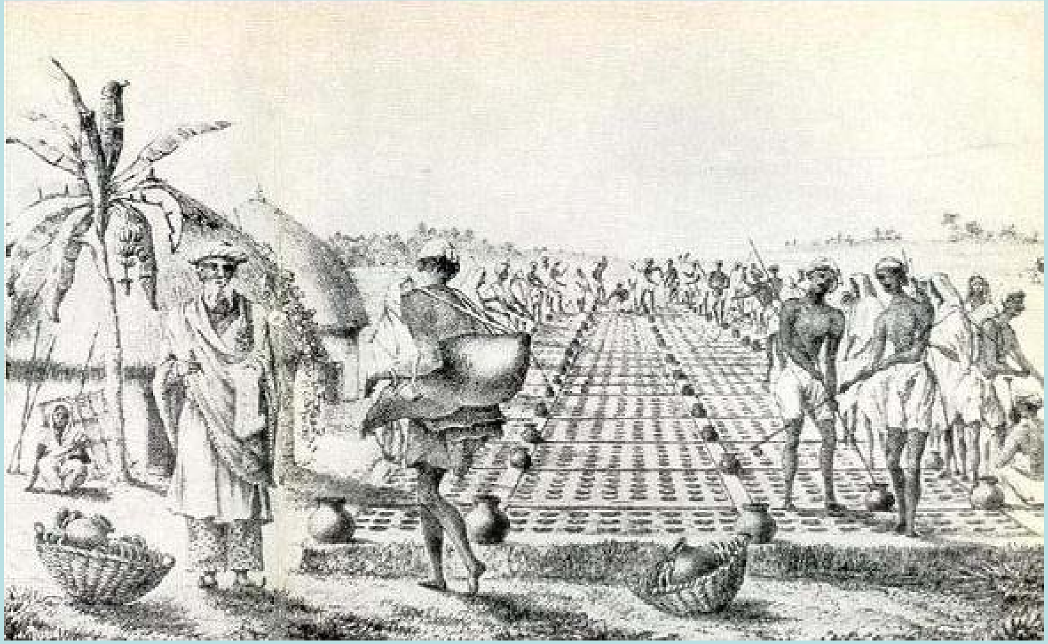
Results after fourth correction
kW/m^2

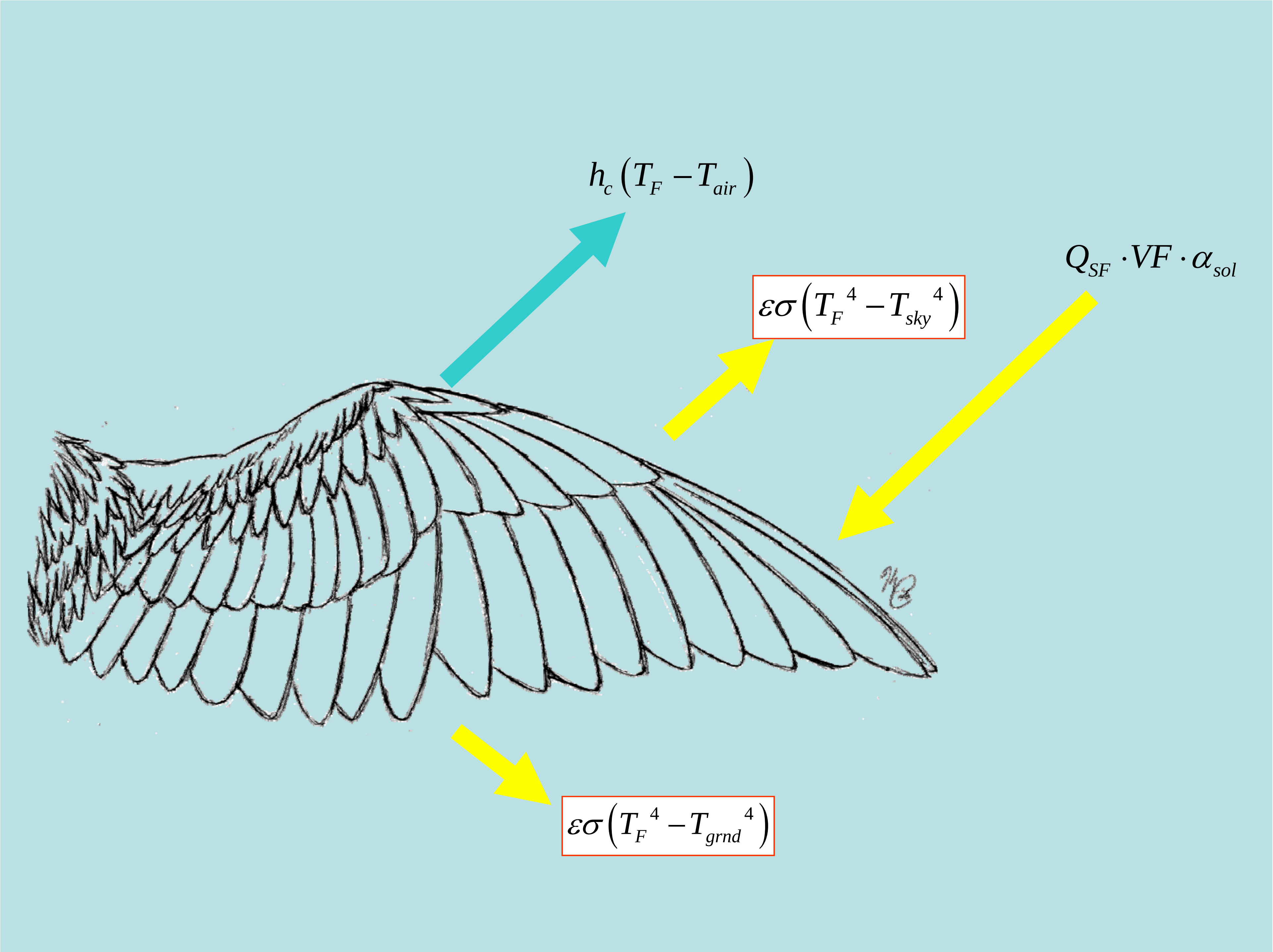
α_{sol}	Absorptivity correction	View Factor VF = 0.342	Heat Xfer Coef. H_c = 71.8	Ambient Air T_{air} = 45 C	
0.95	4.7 From PSA	14	29	29	
0.65	6.9	20	42	43	
0.75	6.0	17	36	37	
0.85	5.3	15	32	33	

Radiative heat loss



Radiative temperature
versus
Air temperature

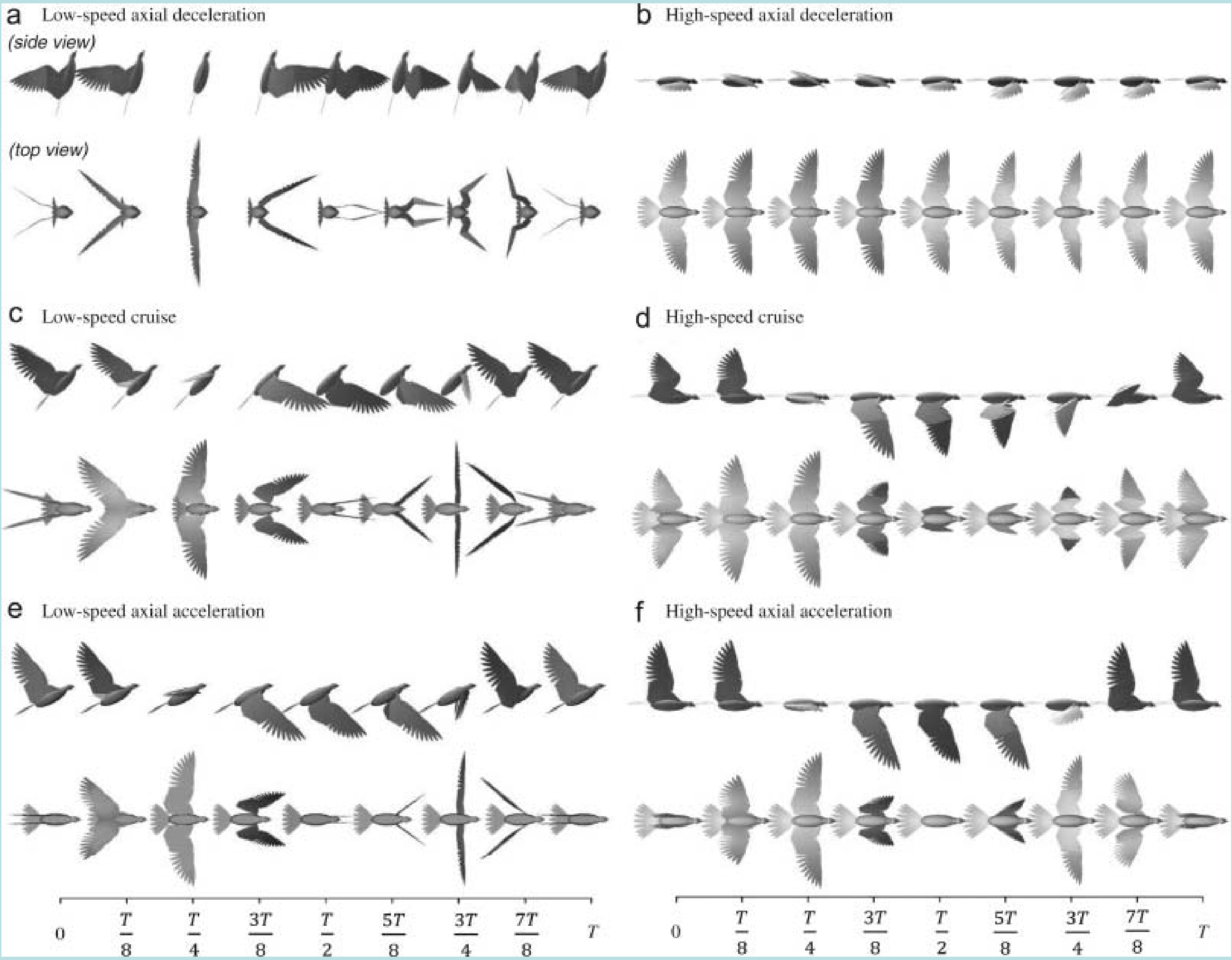



$h_c(T_F - T_{air})$
$Q_{SF} \cdot VF \cdot \alpha_{sol}$
$\varepsilon\sigma(T_F{}^4 - T_{sky}{}^4)$
$\varepsilon\sigma(T_F{}^4 - T_{grnd}{}^4)$

Results after fourth correction kW/m^2

α_{sol}	Absorptivity correction	View Factor VF = 0.342	Heat Xfer Coef. H_c = 71.8	Ambient Air T_{air} = 45 C	T_{sky} = 0 C T_{grnd} = 45
0.95	4.7 From PSA	14	29	29	34
0.65	6.9	20	42	43	**50**
0.75	6.0	17	36	37	**44**
0.85	5.3	15	32	33	**39**

Wings Flap!



a Low-speed axial deceleration
(side view)
(top view)
b High-speed axial deceleration
c Low-speed cruise
d High-speed cruise
e Low-speed axial acceleration
f High-speed axial acceleration
0 T/8 T/4 3T/8 T/2 5T/8 3T/4 7T/8 T
0 T/8 T/4 3T/8 T/2 5T/8 3T/4 7T/8 T

Conclusions

- Equations presented in the PSA are incorrect.
- Revised analysis presented here represents a reasonable, yet very conservative lower bound for flux effects.
- Wing flapping may significantly effect the heat transfer coefficient further reducing potential for flux effects.

STATE OF CALIFORNIA

Energy Resources Conservation
and Development Commission

APPLICATION FOR CERTIFICATION for the RIO MESA SOLAR ELECTRIC GENERATING FACILITY	))))	Docket No. 11-AFC-04

PROOF OF SERVICE

I, Karen A. Mitchell, declare that on December 5, 2012, I served the attached *December 5 2012 CEC Workshop Presentation by Dr. Sonke Johnsen* via electronic and U.S. mail to all parties on the attached service list.

I declare under the penalty of perjury that the foregoing is true and correct.

Karen A. Mitchell

Karen A. Mitchell

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