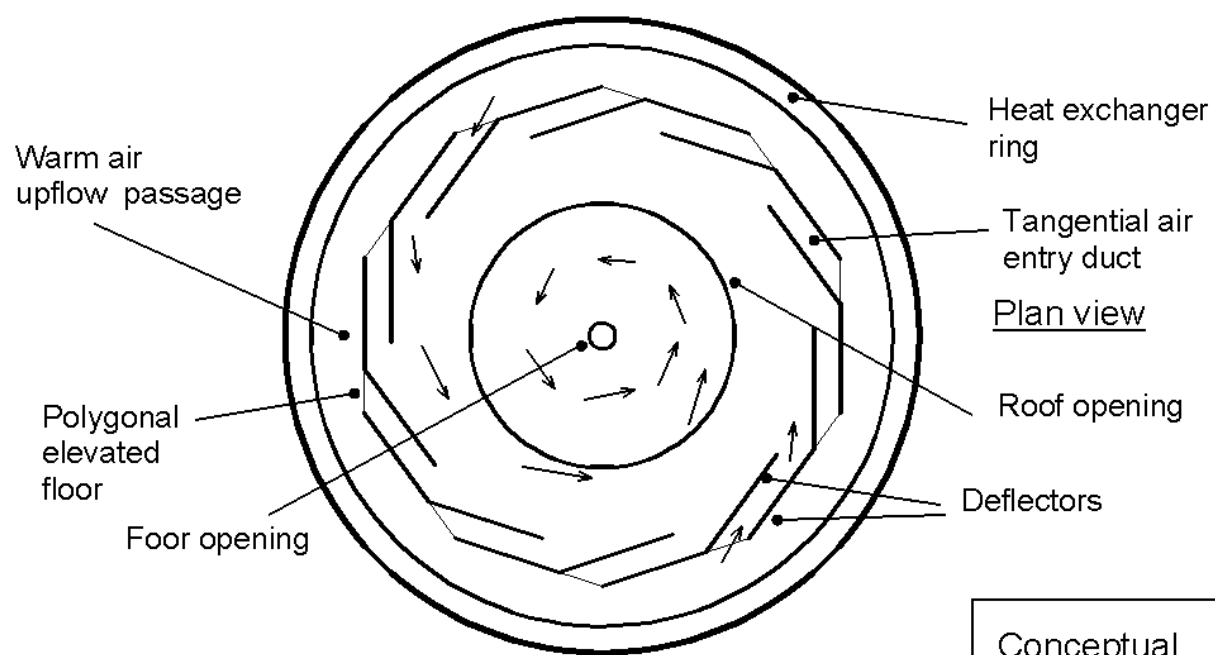


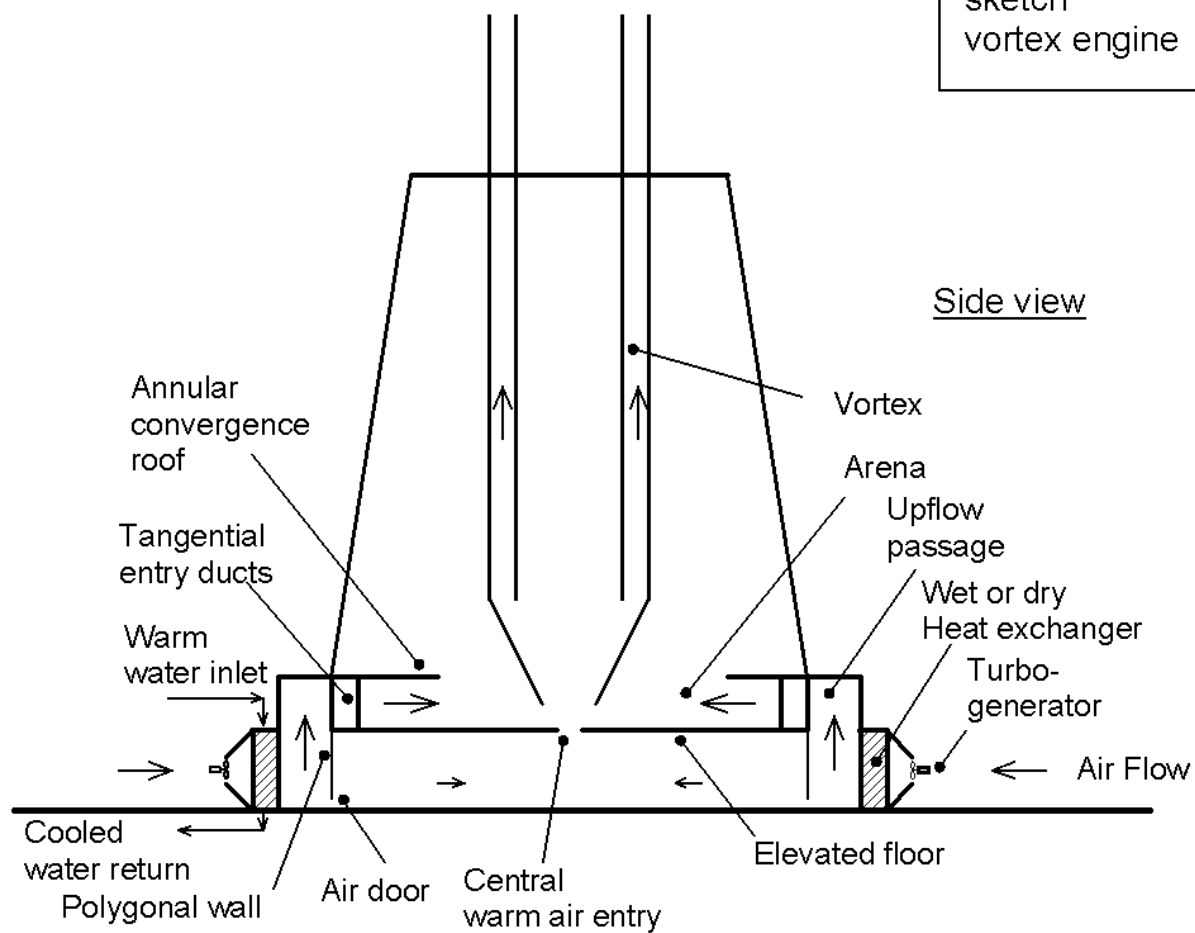


AVE THE FUTURE

[HTTP://VORTEXENGINE.CA](http://vortexengine.ca)



Conceptual
sketch
vortex engine



Prototype Vortex



HEIGHT ADVANTAGE OF A VORTEX



① MANZANARES SOLAR CHIMNEY

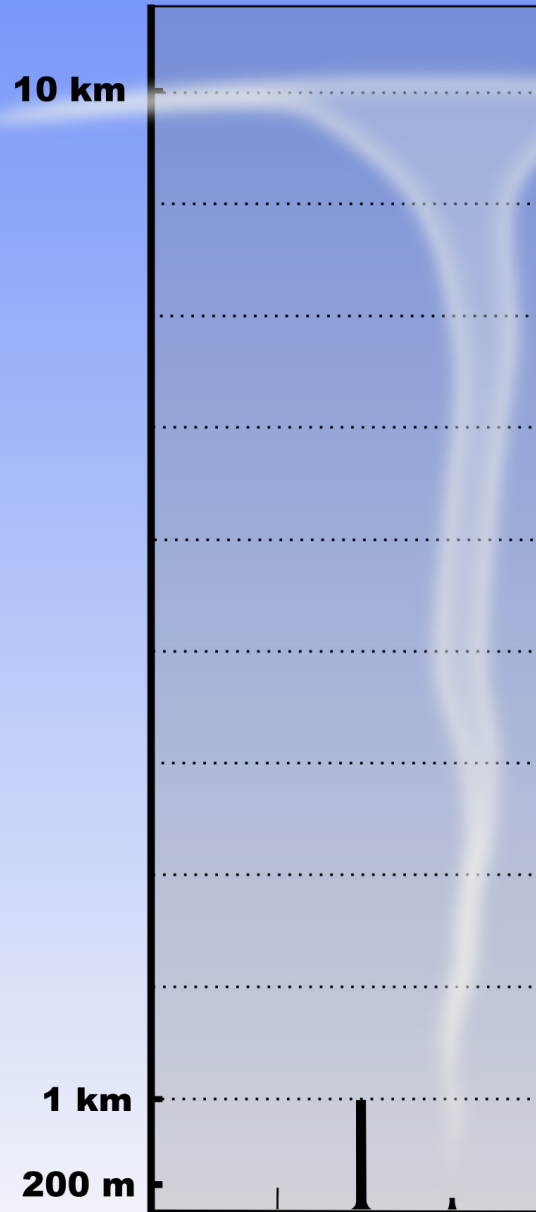
Size: 200 m high, Ø10 m
 Collector area: 0.04 km²
 Ambient air temperature: 25 °C
 Inlet air temperature: 45 °C
 Outlet air temperature: 43 °C
 Efficiency: 0.2%
 50 kW, 130 J/kg, 1 Mg/s
 Spain 1982 to 1989



TIME

② ENVIROMISSION SOLAR TOWER

Size: 1 km high, Ø130 m
 Collector area: 40 km²
 Ambient air temperature: 25 °C
 Inlet air temperature: 45 °C
 Outlet air temperature: 35 °C
 Efficiency: 1.5%
 200 MW, 800 J/kg, 300 Mg/s
 Australia, 2009+



- The AVE replaces the physical chimney with centrifugal force in a vortex
- The AVE eliminates the solar collector by using waste heat or natural low temperature heat sources



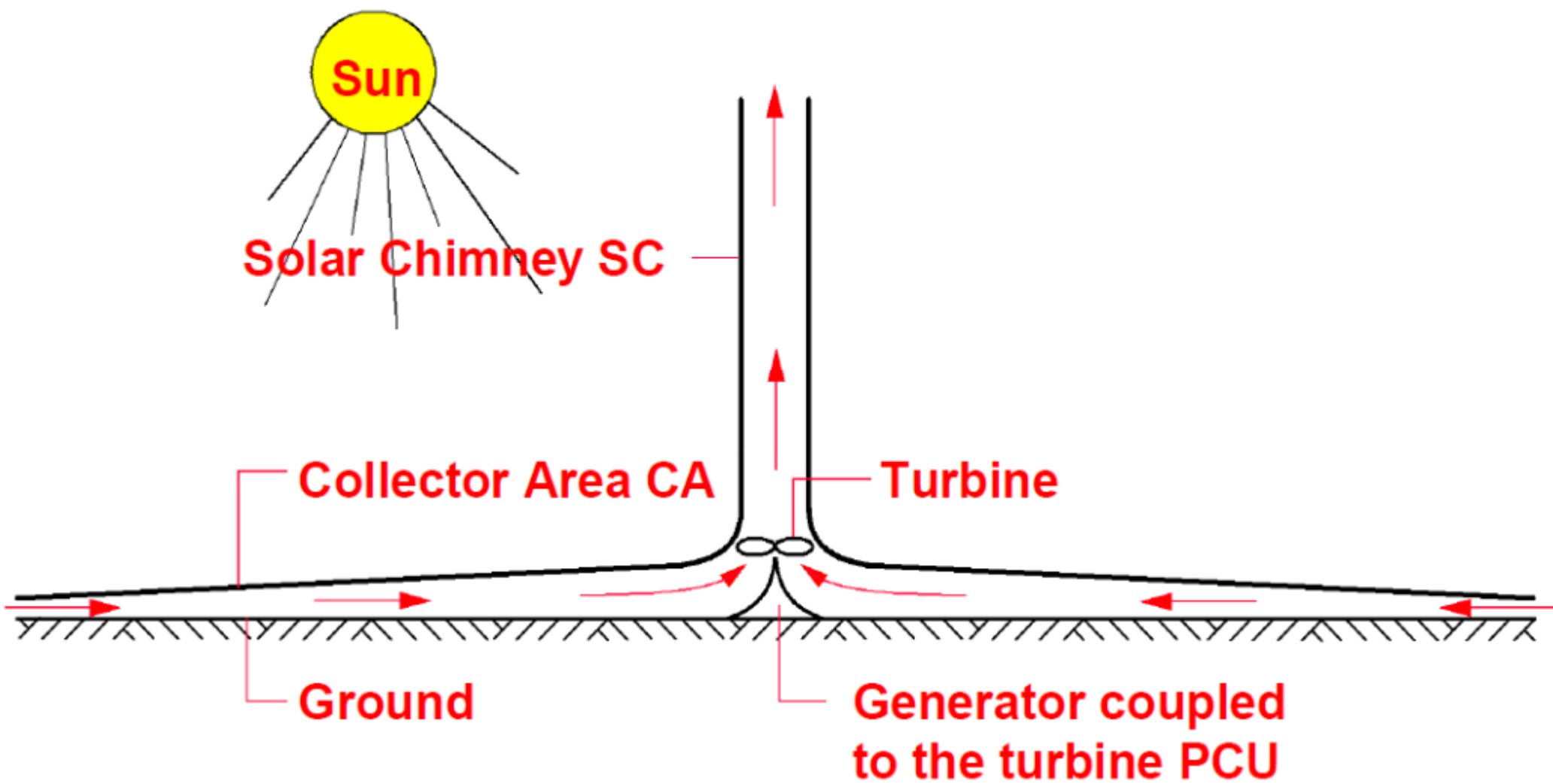
③ ATMOSPHERIC VORTEX ENGINE

Size: Structure: 50 m, Ø200 m
 Vortex: 10 km +
 Collector area: NOT REQUIRED
 Inlet air temperature: 25-50 °C
 Outlet air temperature: -60 °C
 Efficiency: 20% +
 200 MW, 10,000 J/kg, 20 Mg/s

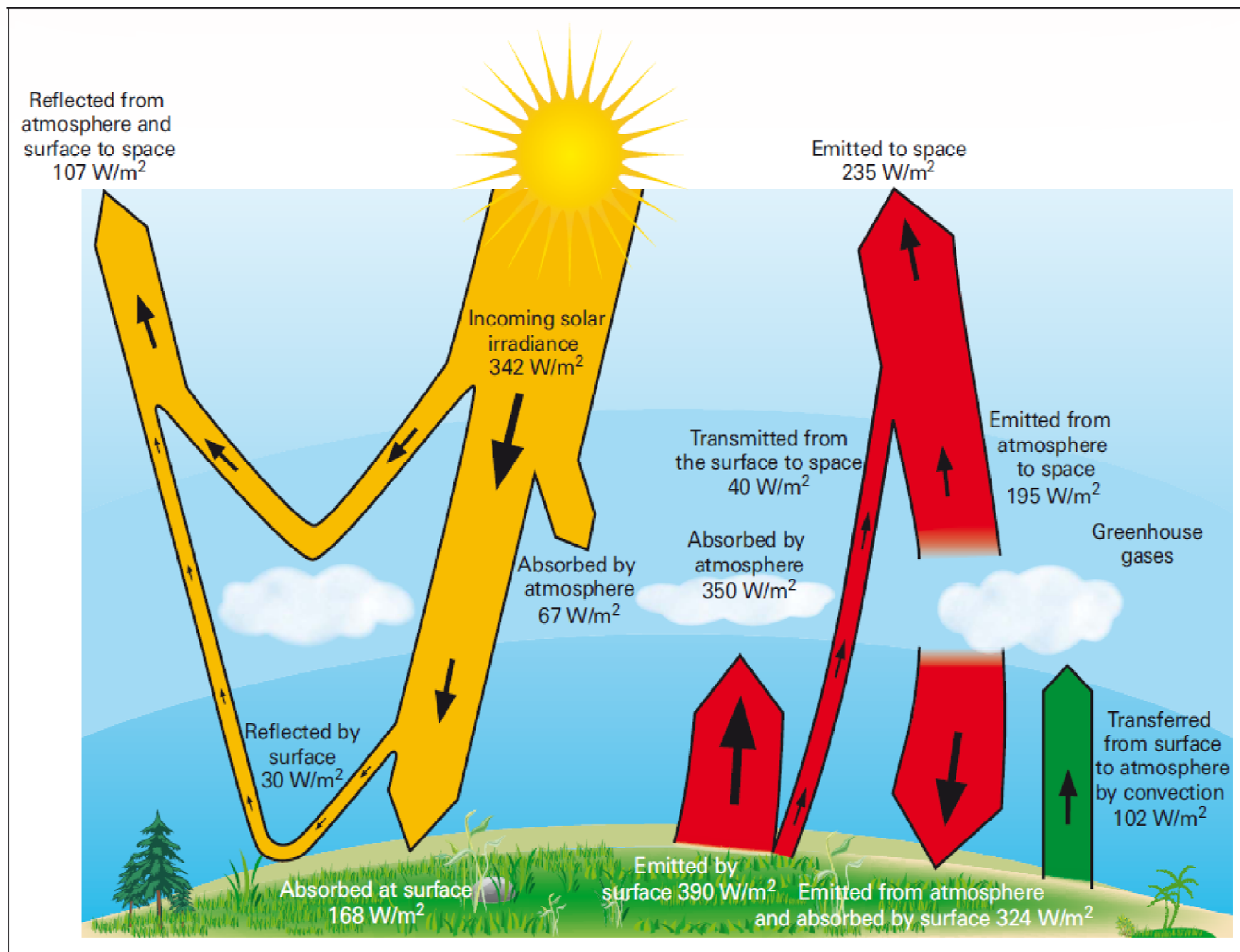
①

②

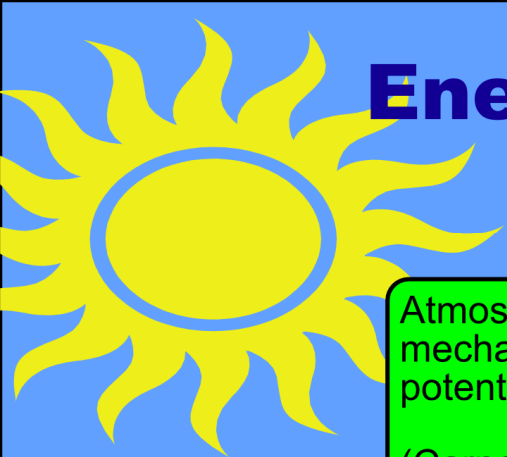
③



Earth's Energy Budget

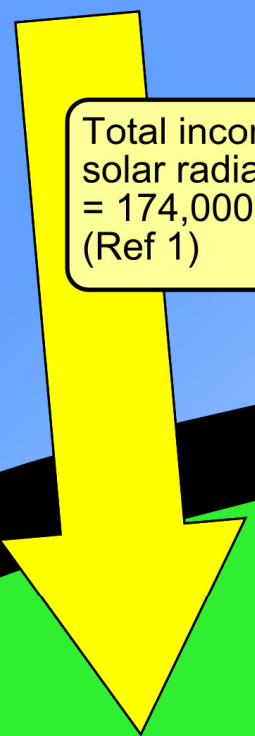


Energy Production Potential of the Atmospheric Vortex Engine



Atmospheric Vortex Engine
mechanical energy production
potential = 6,000 TW (Ref 3)

(Carnot Efficiency 12%
X 52,000 TW = 6,000 TW)



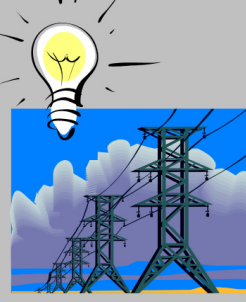
Total incoming
solar radiation
= 174,000 TW
(Ref 1)



Atmospheric
upward heat
convection
= 52,000 TW
(Ref 1)

Total global energy production rate = 15 TW (Ref 2)

Total global electrical energy
production rate = 2 TW (Ref 2)



References

- 1) Tremberth and NASA
- 2) US Department of Energy
- 3) L.M. Michaud

AVE Combined Cycle Power Plant

Cold Source – upper troposphere

$T_L = -60^\circ\text{C}$
(213 K)

Stage 2: Atmospheric Vortex Engine

Carnot Efficiency

$$n_c = 1 - T_L / T_H = 1 - 213/303 = 29.7\%$$

Typical Efficiency (Estimated)
 $n = 20\%$

Qout

780 MW

Heat Engine

Wout

195 MW

Qin

975 MW

$T = 30^\circ\text{C}$
(303 K)

Overall Efficiency
(Thermal Power Plant +
Atmospheric Vortex Engine
combined)

$$n = (525 + 195) / 1500 = 48\%$$

$$W_{\text{total}} = 525 + 195 = 720 \text{ MW}$$

Incremental Efficiency Increase
 $= (525 + 195) / 525 = 37.1\%$

Qout

975 MW

Heat Engine

Wout

525 MW

Qin

1500 MW

$T_H = 540^\circ\text{C}$
(813 K)

Stage 1: Thermal Power Plant (Coal)

Carnot Efficiency

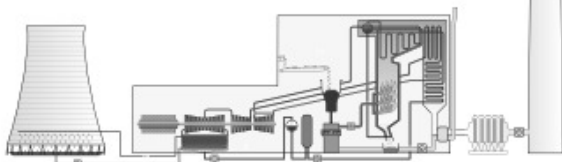
$$n_c = 1 - T_L / T_H = 1 - 303/813 = 62.7\%$$

Typical Efficiency
 $n = 35\%$



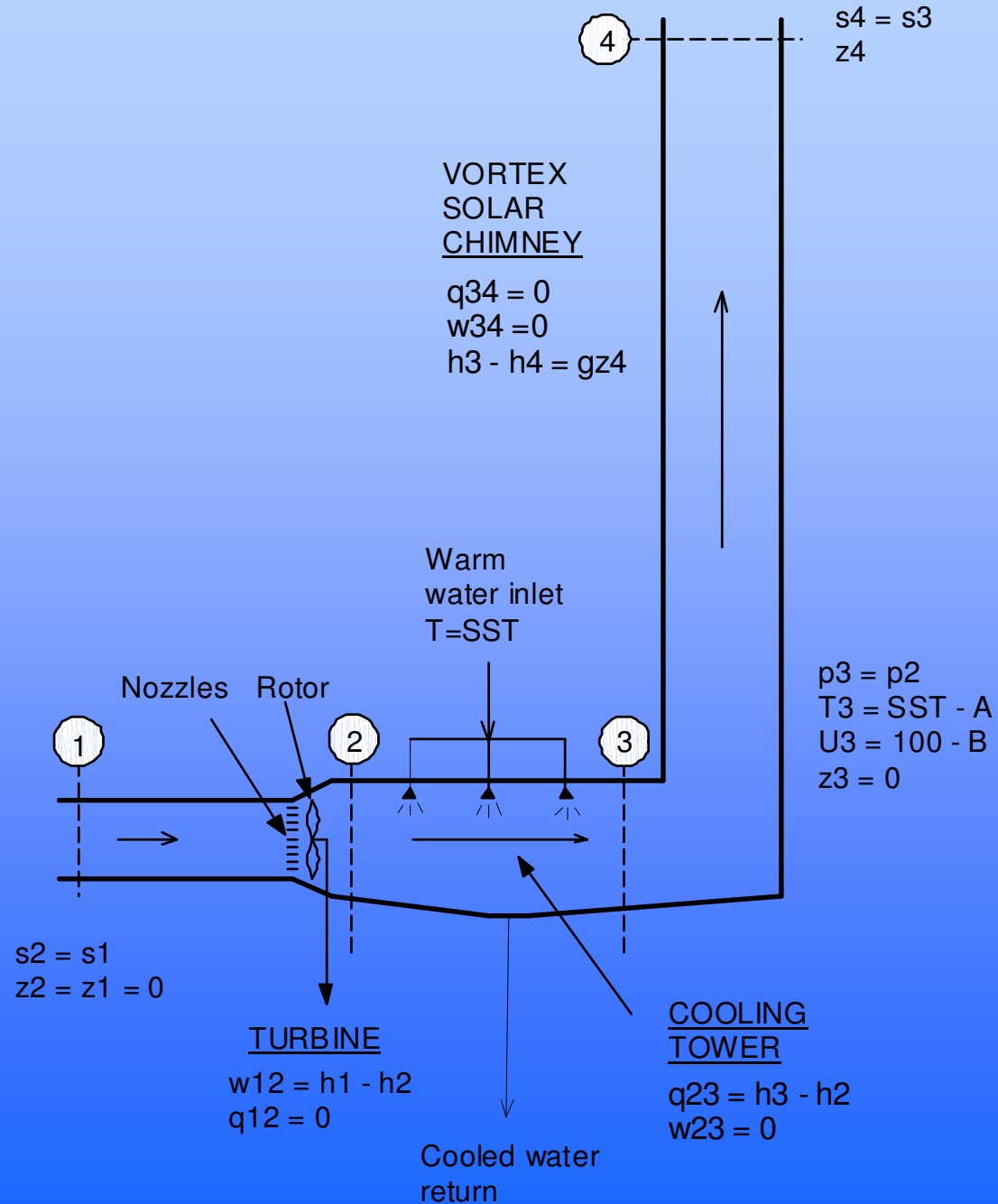
AVE heat source
EQUALS
waste heat rejected
from thermal power
plant at condenser
temperature

Thermal
Power Plant
(Coal)



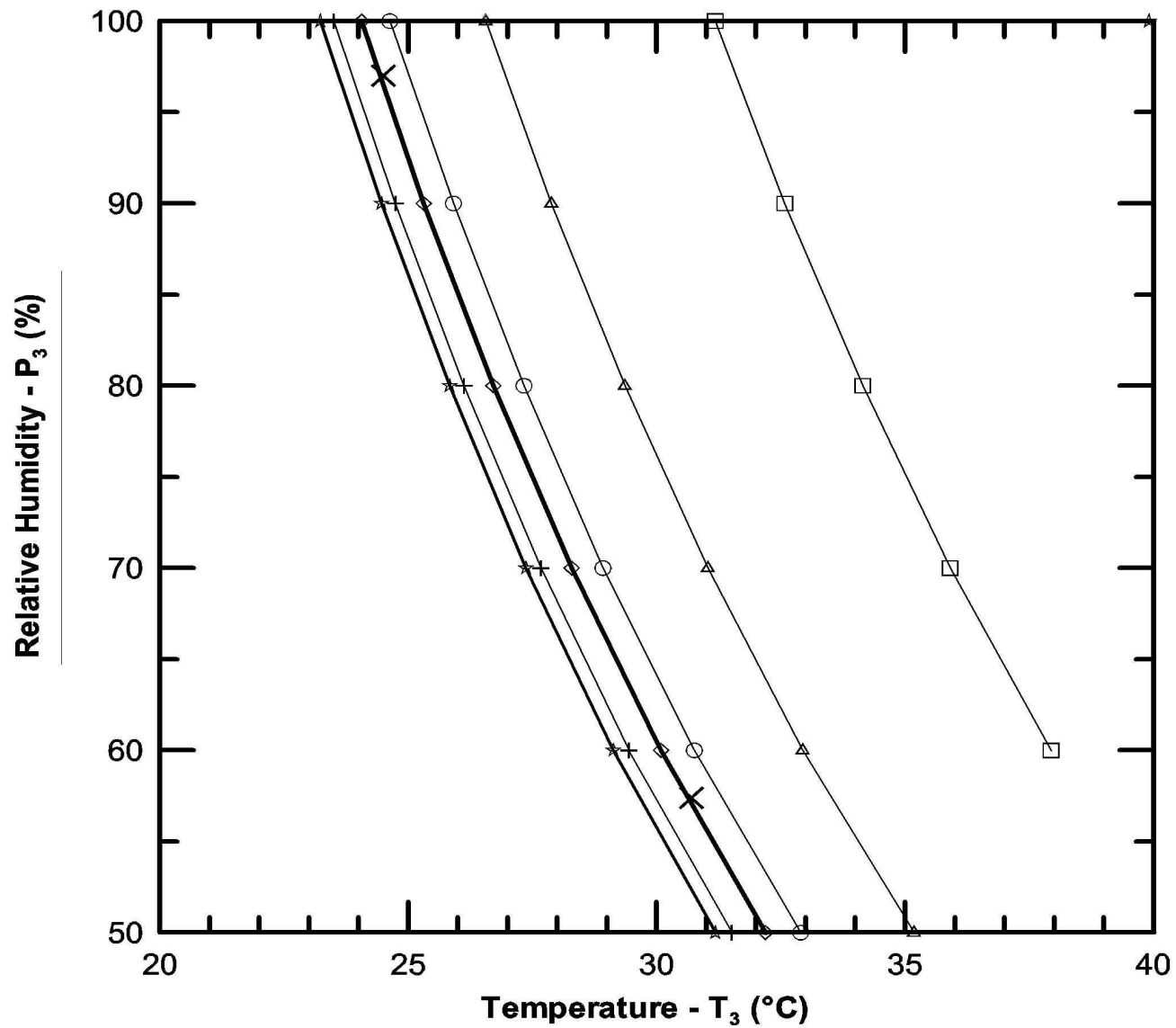
Hot Source - superheated steam

Thermodynamic Calculation Method



Vortex Engine Ideal Process Calculations.

<u>Heat source</u>	None	26 °C water at P_2	36 °C dry heat at P_2	40 °C dry heat at P_1
<u>Air properties:</u>				
P_1 (kPa)	101.1	101.1	101.1	101.1
T_1 (°C)	25.8	25.8	25.8	33.6
$r_1 = r_2$ (g kg ⁻¹)	16.87	16.87	16.87	16.87
U_1 (%)	80.0	80.0	80.0	50.1
$s_1 = s_2$ (J K ⁻¹ kg ⁻¹)	241.0	241.0	241.0	267.7
h_1 (J kg ⁻¹)	68913	68913	68913	76992
$P_2 = P_3$ (kPa)	101.1	97.72	97.70	97.73
ΔP_{12}	0	3.38	3.40	3.37
T_2 (°C)	25.8	22.92	22.91	30.6
U_2 (%)	80.0	92.3	92.3	57.6
h_2 (J kg ⁻¹)	68913	65943	65916	73941
T_3 (°C)	25.8	24.5	30.7	30.6
U_3 (%)	80	97	57.4	57.6
$r_3 = r_4$ (g kg ⁻¹)	16.87	19.57	16.87	16.87
$h_3 = \mu_3 = \mu_4$ (J kg ⁻¹)	68913	74433	74003	73941
$s_3 = s_4$ (J K ⁻¹ kg ⁻¹)	241.0	269.7	268.0	267.7
P_4 (kPa)	10.0	10.0	10.0	10.0
T_4 (°C)	-87.1	-80.92	-82.2	-82.3
z_4 (m)	16570	16570	16570	16570
h_4 (J kg ⁻¹)	-96209	-91130	-91150	-91180
<u>Heat Input (J kg⁻¹)</u>				
$Q = h_3 - h_2$	0	8504	8072	8079
<u>Work (J kg⁻¹)</u>				
$W = h_1 - h_2$	0	2984	2996	3048
<u>Velocity (m s⁻¹)</u>				
$v = (2 W)^{0.5}$	0	77.2	77.4	78.1
<u>Efficiency (%)</u>				
$\eta = W_{12}/Q_{23}$	n/a	35.1	37.1	37.7
$\eta = 1 - T_4/T_3$	n/a	35.4	37.2	37.8



Minimum eyewall pressure lines. Based on $P_4 = 10$ kPa, $z_4 = 16570$ m.

For $P_1 = 101$ kPa corresponding convective energy (CE) and velocity (v) are:

Symbol	P_3 (kPa)	CE (J/kg)	Velocity (m/s)
☆	101	0	0
+	100	890	42
◇	98	2660	72
×	97.7	3000	77 (Table cases 2&3)
○	96	4430	94
▲	90	10100	142
□	80	20240	201

A Comparison of the Earth's Stored Energy Resources

Crude Oil Reserves

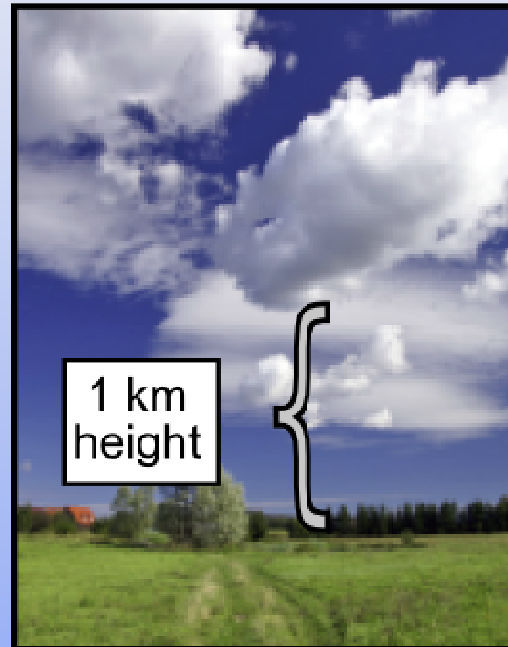


$7.3 \times 10^{21} \text{ J}$



Latent heat of water vapor

in the bottom kilometer of the atmosphere



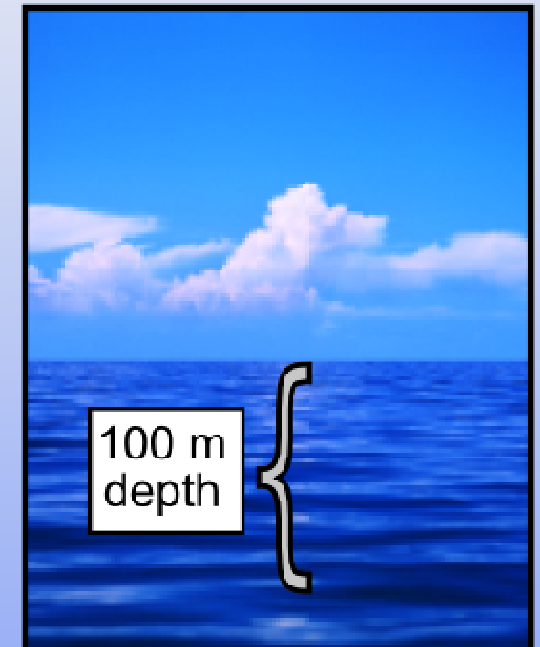
1 km
height

$13 \times 10^{21} \text{ J}$



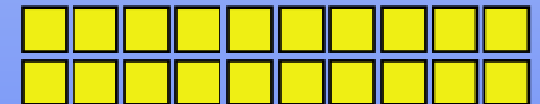
Heat content of tropical ocean water

100 m layer, 3°C



100 m
depth

$130 \times 10^{21} \text{ J}$



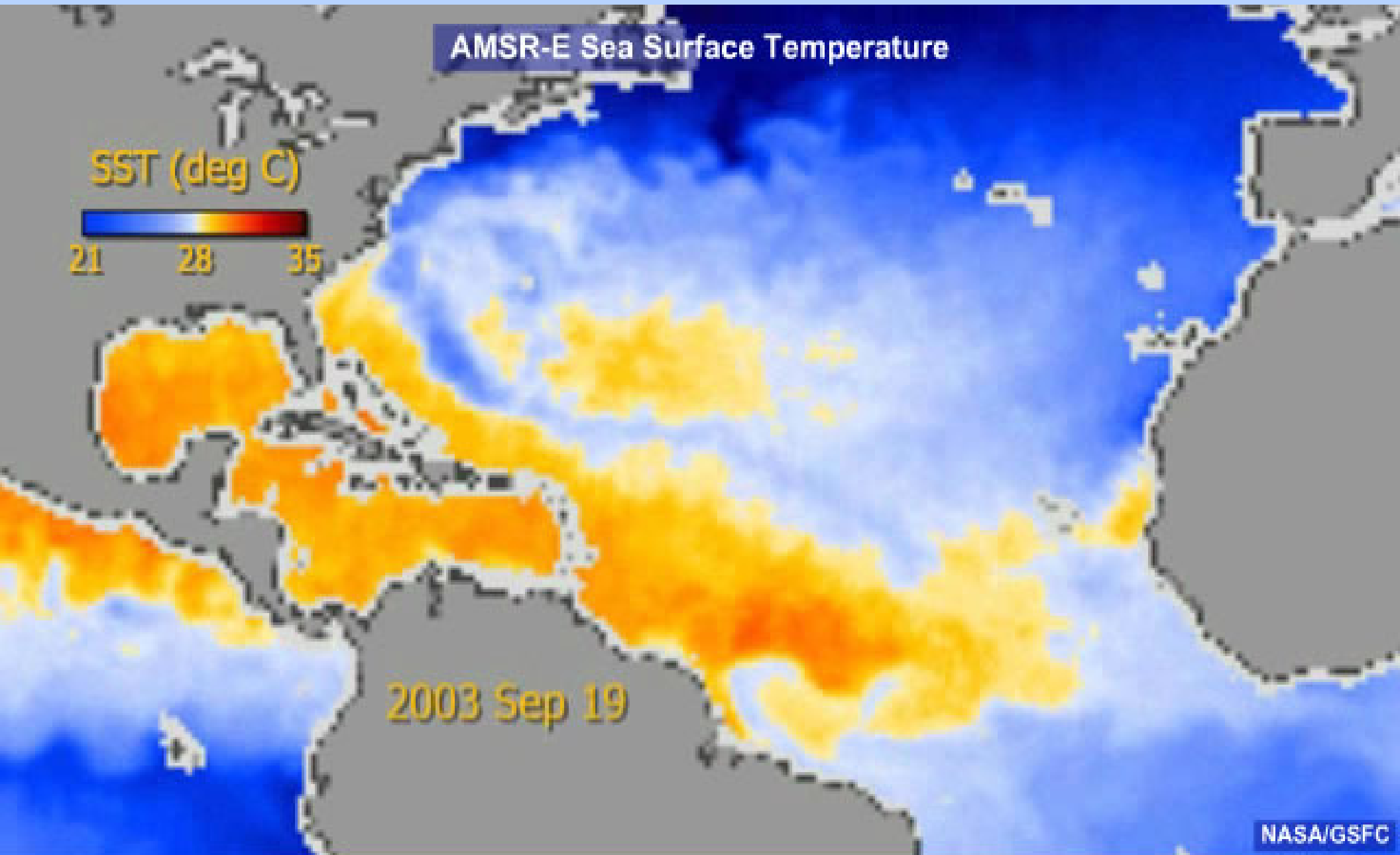
Replenishment times

10^8 years

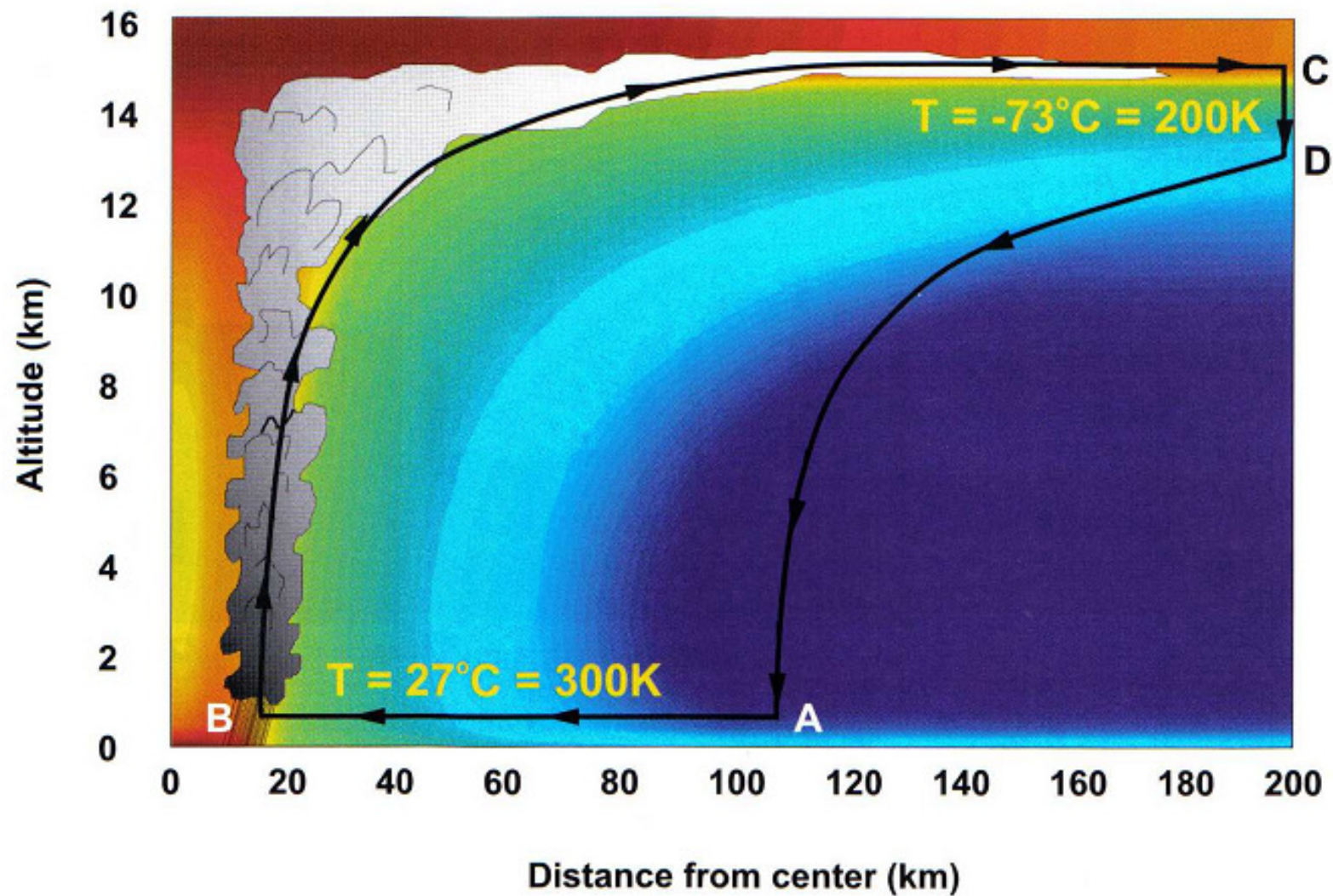
10 days

100 days

Hurricane Isabel effect on sea surface temperature as observed from satellite



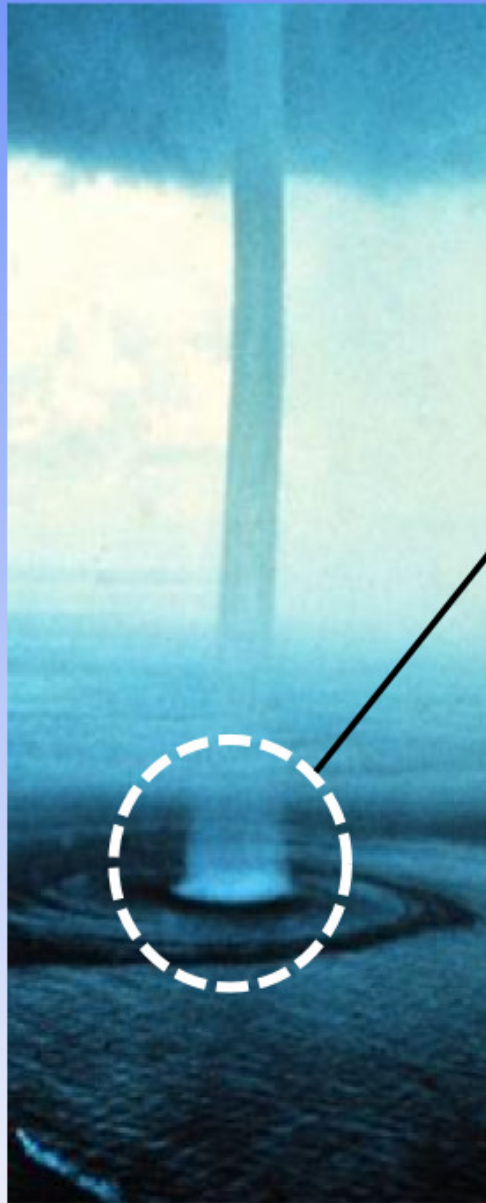
A hurricane viewed as a Carnot cycle



Efficiency $n = 1 - T_c / T_h = 1 - 200/300 = 33\%$

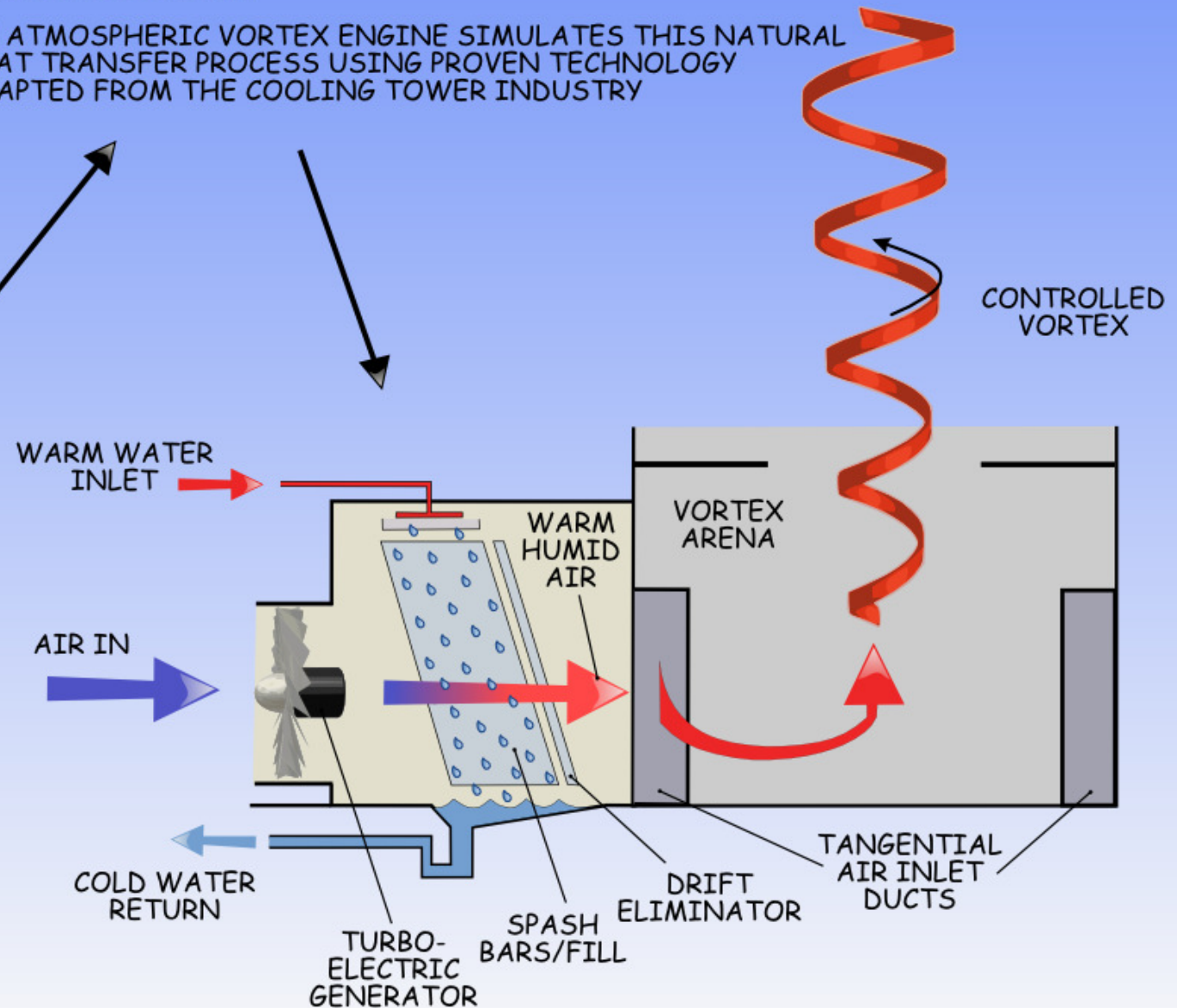
SIMULATION OF HEAT TRANSFER IN A WATERSPOUT USING COOLING TOWER TECHNOLOGY

<http://vortexengine.ca>



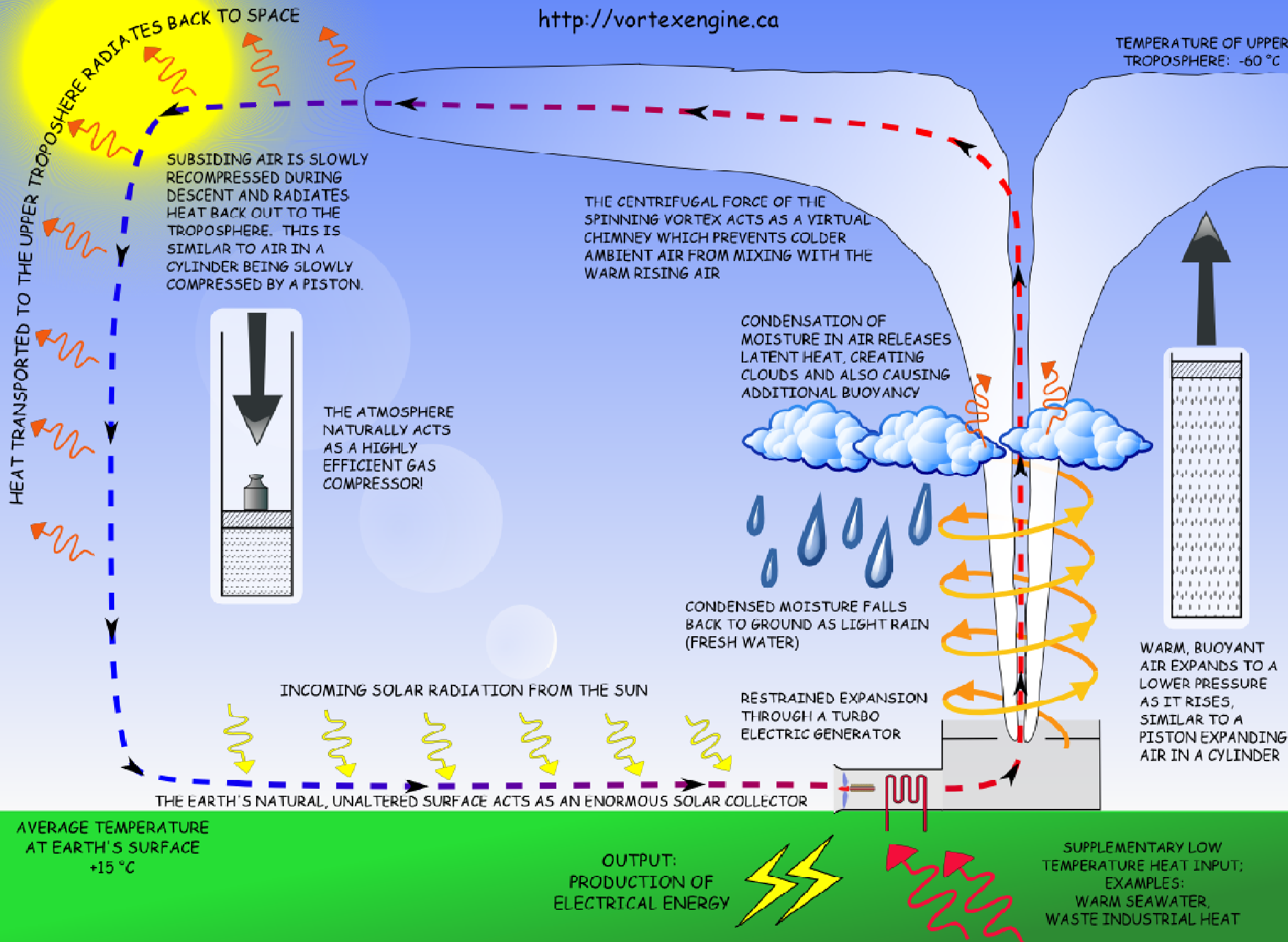
AT THE BASE OF A NATURAL WATERSPOUT, SPRAY FROM WARM SEA WATER TRANSFERS SENSIBLE AND LATENT HEAT TO THE RISING AIR COLUMN.

AN ATMOSPHERIC VORTEX ENGINE SIMULATES THIS NATURAL HEAT TRANSFER PROCESS USING PROVEN TECHNOLOGY ADAPTED FROM THE COOLING TOWER INDUSTRY

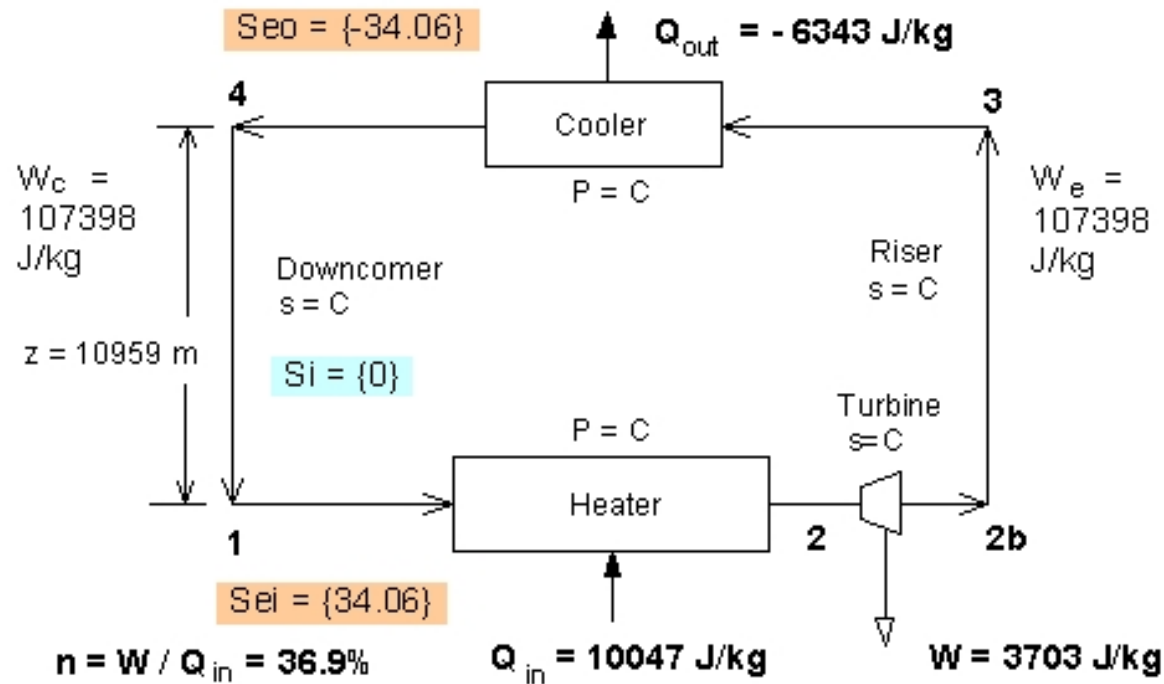


THE AVE POWER CYCLE

<http://vortexengine.ca>



Gravity Power Cycle

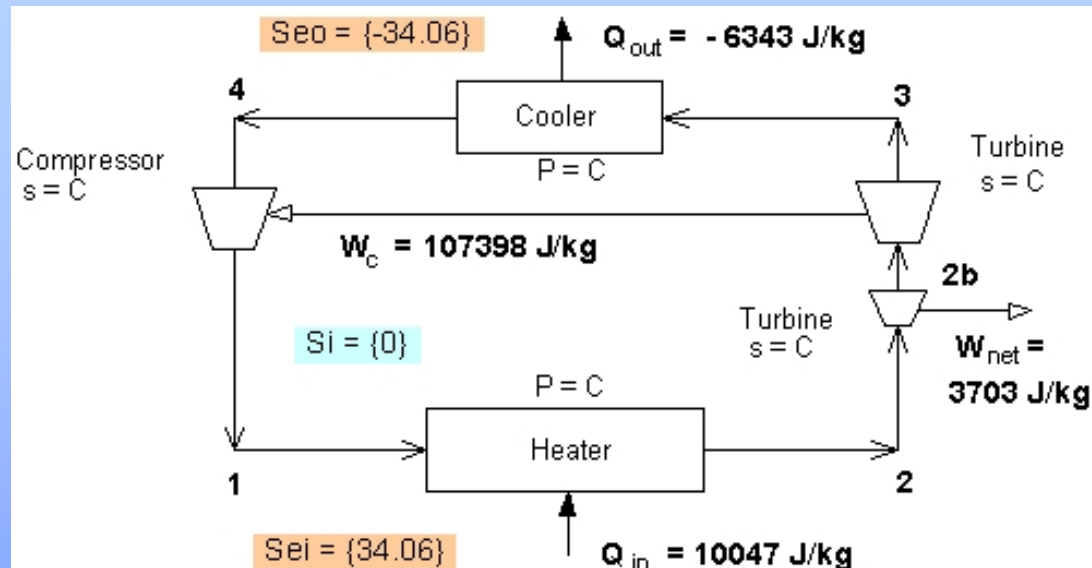


State	P (kPa)	T (K)	s (J/ K kg)	h (J/kg)	gz (J/kg)	h+gz (J/kg)
1	100	290	60.14	16929	0	16929
2	100	300	94.20	26975	0	26975
2b	95.77	296.31	94.20	23272	0	23372
3	20	189.42	94.20	-84126	107398	23372
4	20	183.10	60.14	-90467	107398	16929

Gravity cycle - Case 1

Cooling at constant pressure, dry air, reversible.
Height based on lapse rate of 9.75 K/km

Brayton gas-turbine power cycle



$$W_{net} = Q_{in} - Q_{out} = 10047 - 6343 = 3703 \text{ J/kg}$$

$$n = 1 - T_3 / T_2 = 1 - T_4 / T_1 = 1 - (P_3 / P_2)^{R/C_p}$$

$$n = 1 - T_4 / T_1 = 1 - 183.1 / 290.0 = 36.9 \%$$

$$W_{net} = n Q_{in} = 0.369 * 10047 = 3703 \text{ J/kg}$$

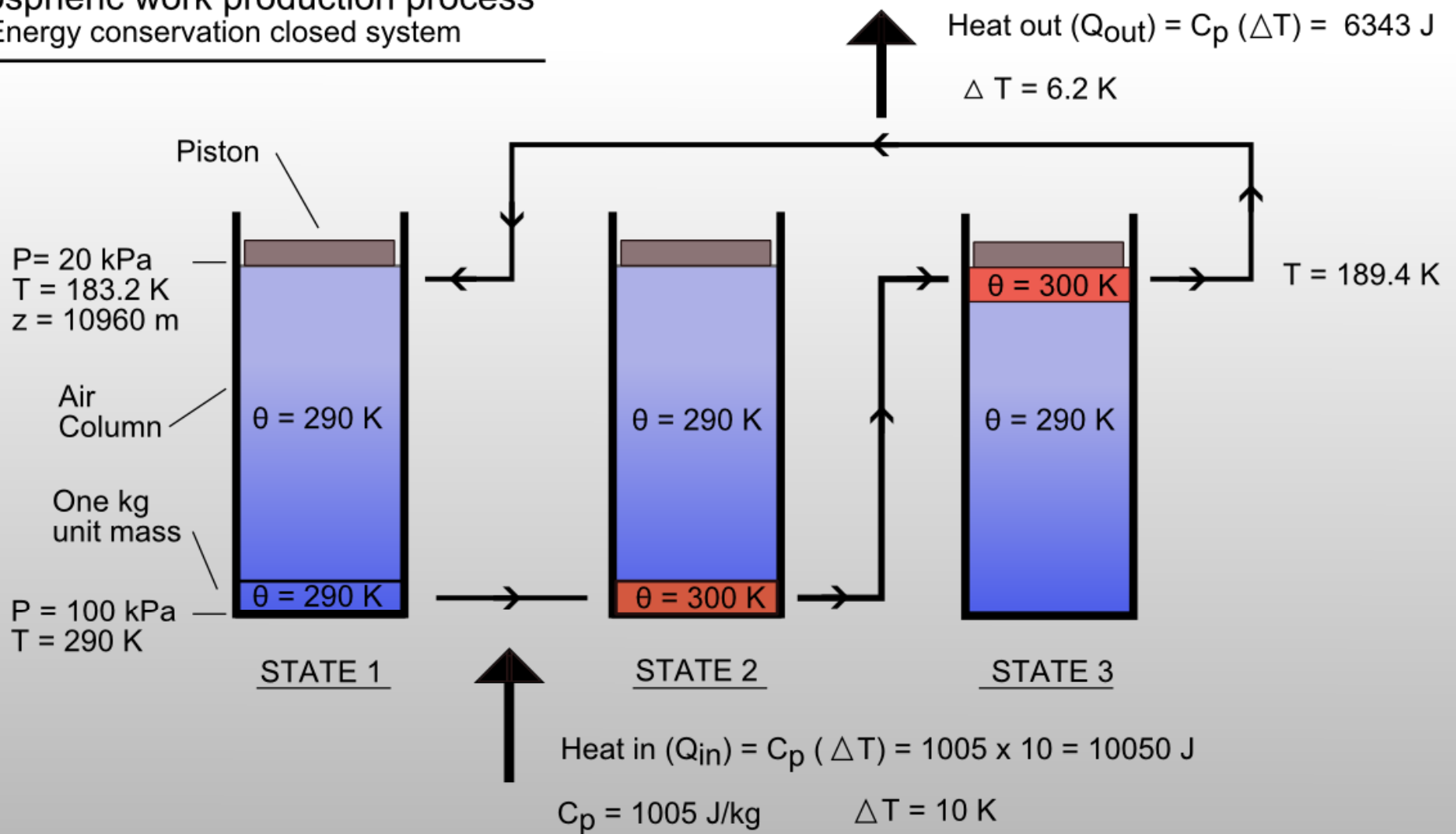
State	P (kPa)	T (K)	s (J/ K kg)	h (J/kg)
1	100	290	60.14	16929
2	100	300	94.20	26975
2b	95.77	296.31	94.20	23272
3	20	189.42	94.20	-84126
4	20	183.10	60.14	-90467

Brayton gas-turbine power cycle

Case 1 process conditions

Atmospheric work production process

Energy conservation closed system



1. Heat received minus heat given up

$$W = Q_{\text{in}} - Q_{\text{out}} = 10050 - 6343 = 3703 \text{ J}$$

2. Heat in multiplied by the Carnot efficiency

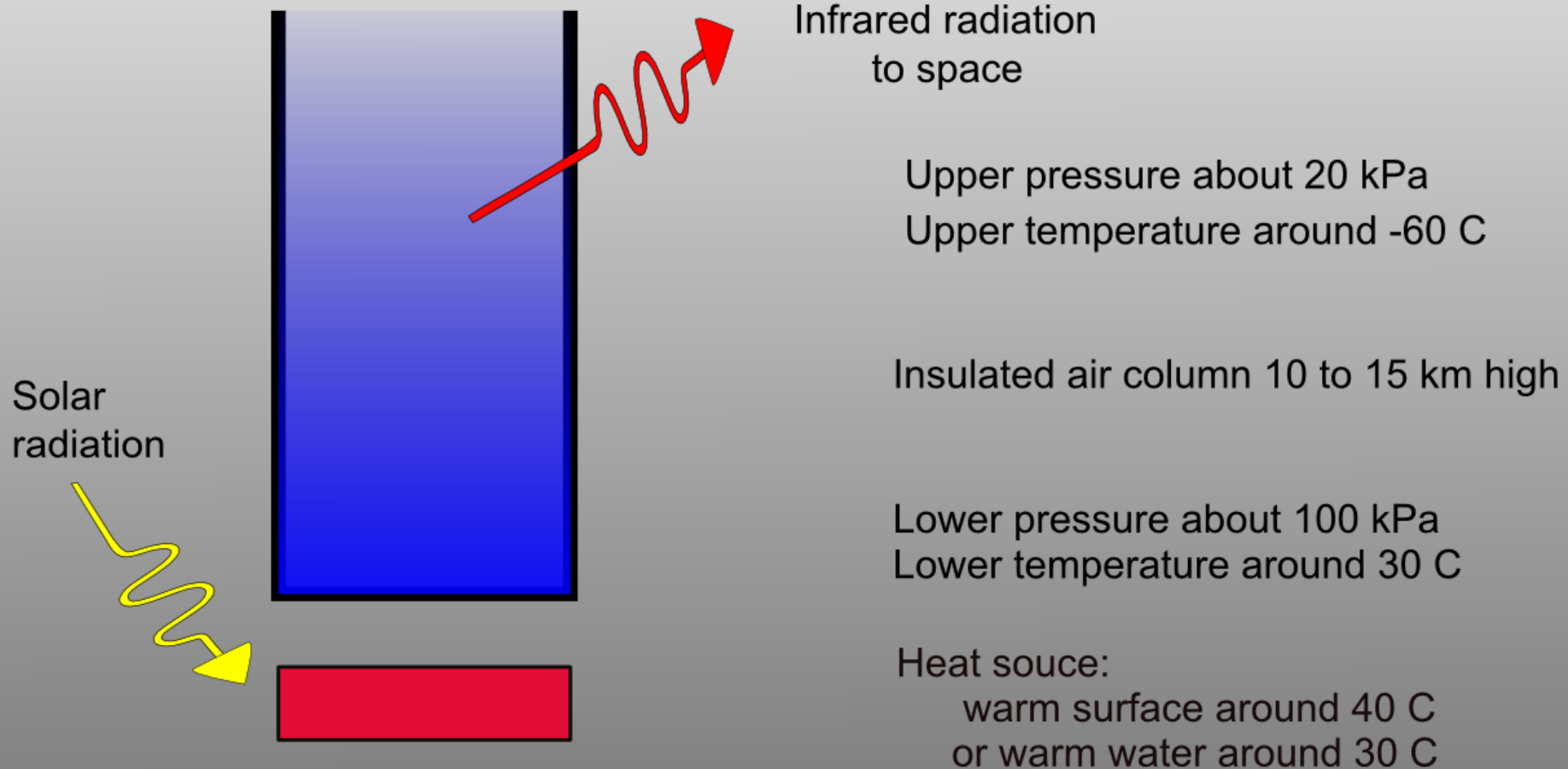
$$W = Q_{\text{in}} (1 - T_{\text{out}} / T_{\text{in}}) = 10050 (1 - 183.2 / 290) = 3703 \text{ J}$$

3. Total energy equation

$$W = \Delta h - \Delta gz = 1005 (300 - 189.4) - 9.8 (10960) = 3703 \text{ J}$$

Atmospheric work production process

Basic requirements

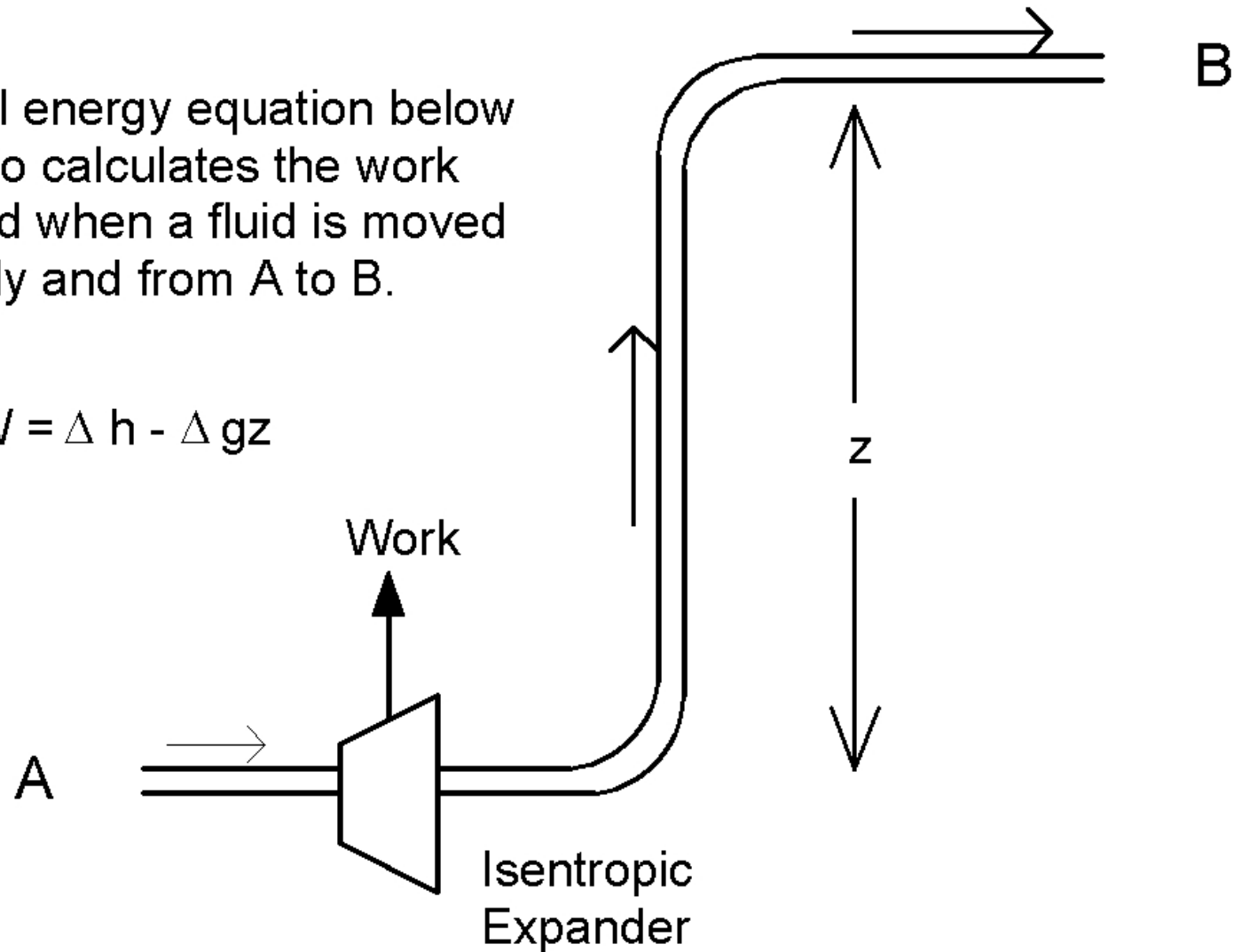


Heat to work conversion efficiency equals
Carnot efficiency based on average temperatures
at which heat is received and given up.

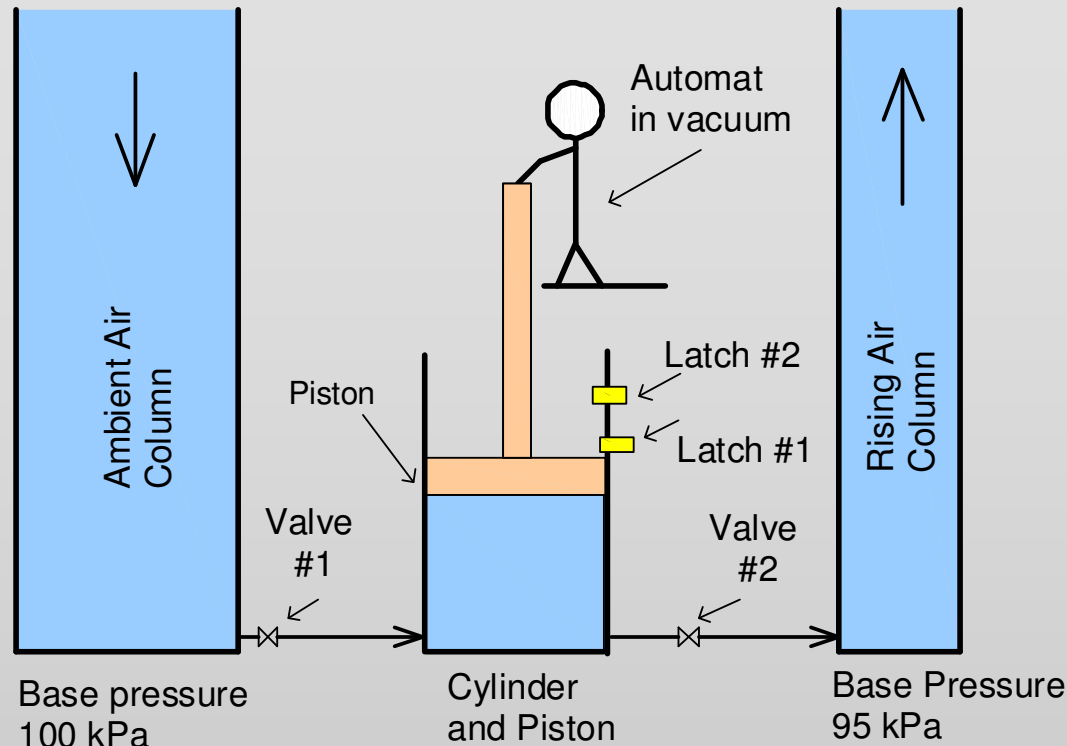
Atmospheric work production process
Energy conservation in an open system

The total energy equation below is used to calculate the work produced when a fluid is moved reversibly and from A to B.

$$W = \Delta h - \Delta gz$$



Reversible and Irreversible Expansion



Constrained reversible expansion - Work is produced - No Latch

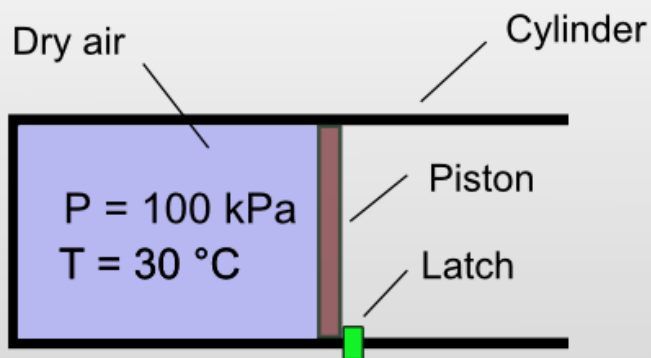
1. Start with piston at bottom of the cylinder, open valve #1,
2. Automat raises piston and let 1 kg of air at 100 kPa in cylinder,
3. Close valve #1,
4. Automat raises piston until cylinder pressure decreases to 95 kPa,
5. Open valve #2,
6. Automat pushes piston to the bottom of the cylinder.

The air temperature decreases.

Unconstrained irreversible expansion - No work is produced - Two Latches

- 1-3. As above except after step 3. set latch #1 and #2, set latch #2 so that the final pressure is 95 kPa,
4. Automat lets go of the piston,
5. Let go latch #1, piston snaps against latch #2 without doing any work,
6. Automat pushes piston to the bottom of the cylinder.

The air temperature does not decrease.

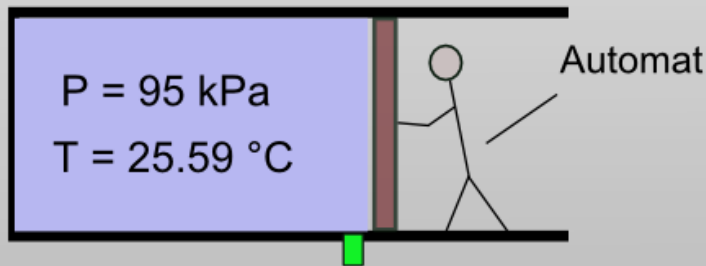


INITIAL CONDITION

Work production requires that expansion be restrained

Ambient pressure: $P = 95 \text{ kPa}$

Initial pressure difference: 5 kPa

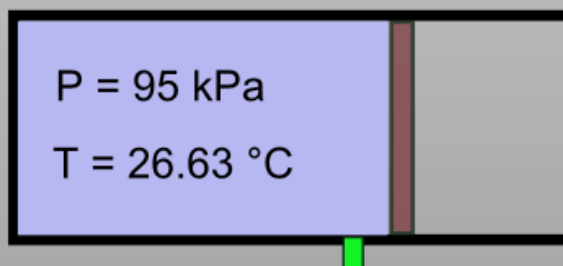


AFTER RESTRAINED
ISENTROPIC EXPANSION

Work against environment 3085 J

Work against automat 1346 J

Total work 4431 J



AFTER UNRESTRAINED
EXPANSION

Work against environment 3384 J

Total work 3384 J

Loss work 1047 J

Additional enthalpy of the air 1047 J

Capturing work of expansion produced when the latch lets go requires that the expansion be restrained, otherwise the energy remains in the cylinder.

Approximately 22% of the work of expansion is lost no matter how small the initial pressure difference.

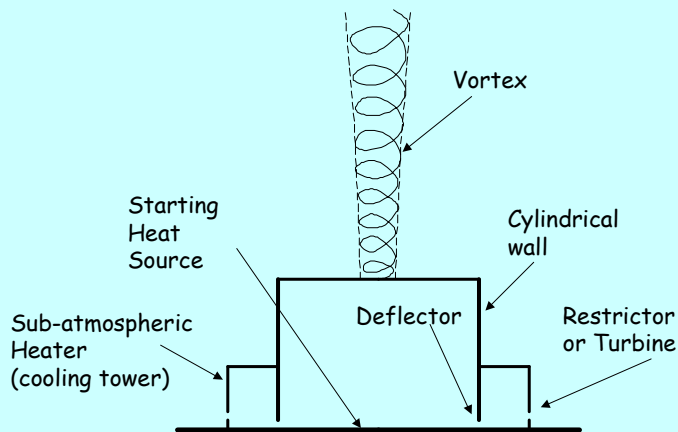
Cooling Towers



Mechanical Draft: \$15 million 40 m tall mechanical draft tower uses 1% to 4% of power output to drive fans. (uses energy)



Natural Draft: doesn't need fans but is 150 m tall and costs \$60 million. (saves energy)



Vortex Engine

Vortex Cooling Tower: \$15 million 40 m tall to function like a natural draft tower. (produces energy!)

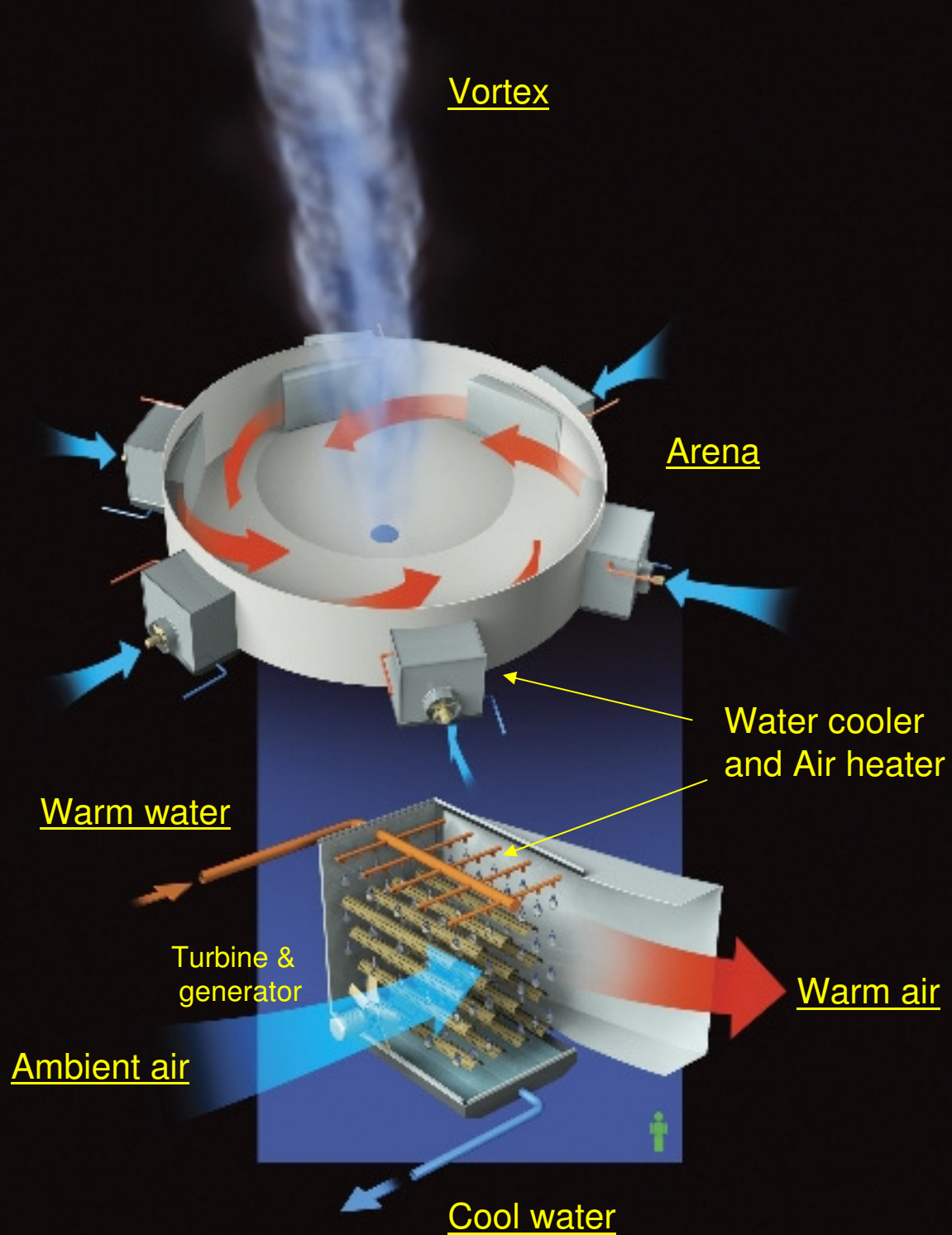
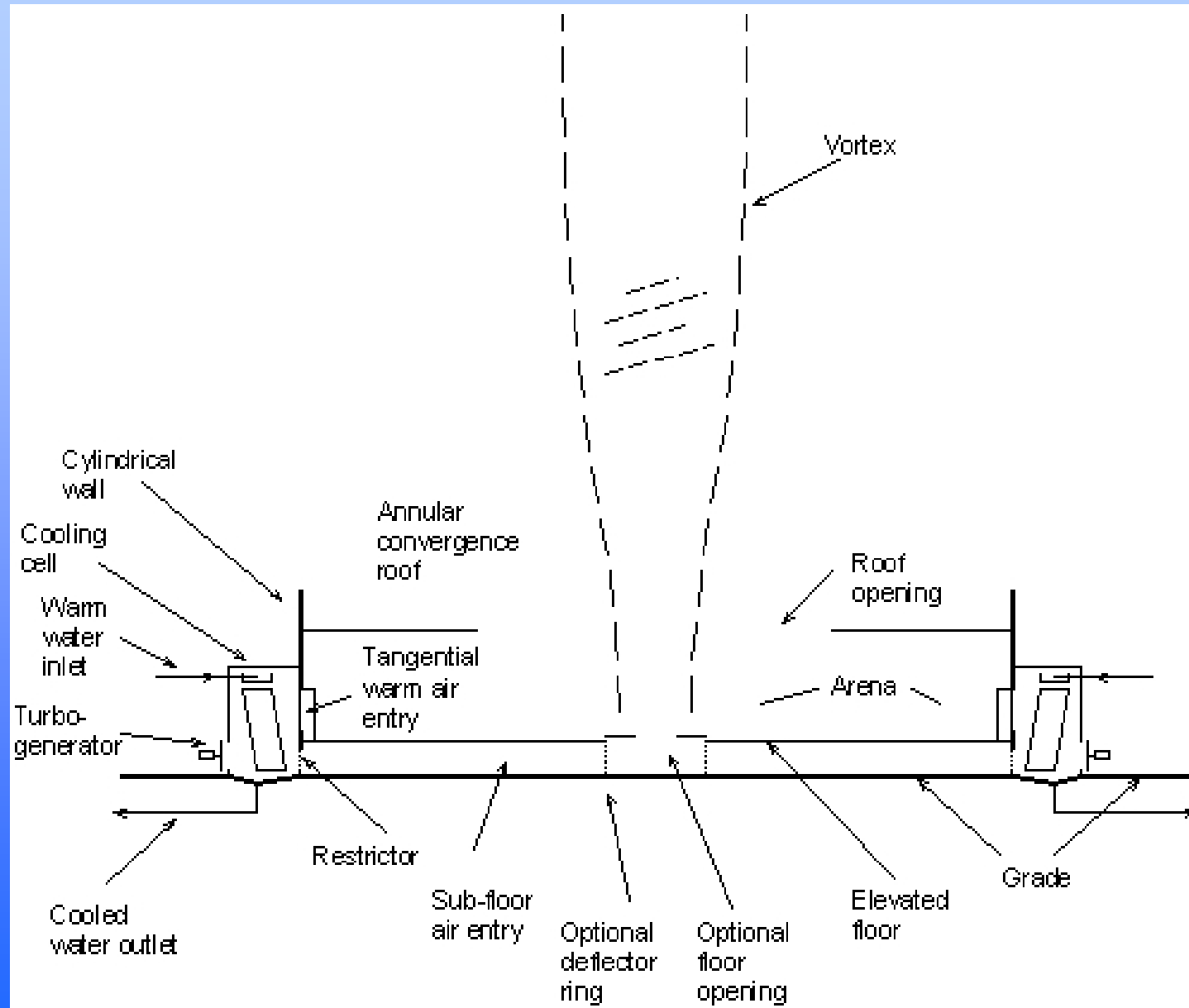


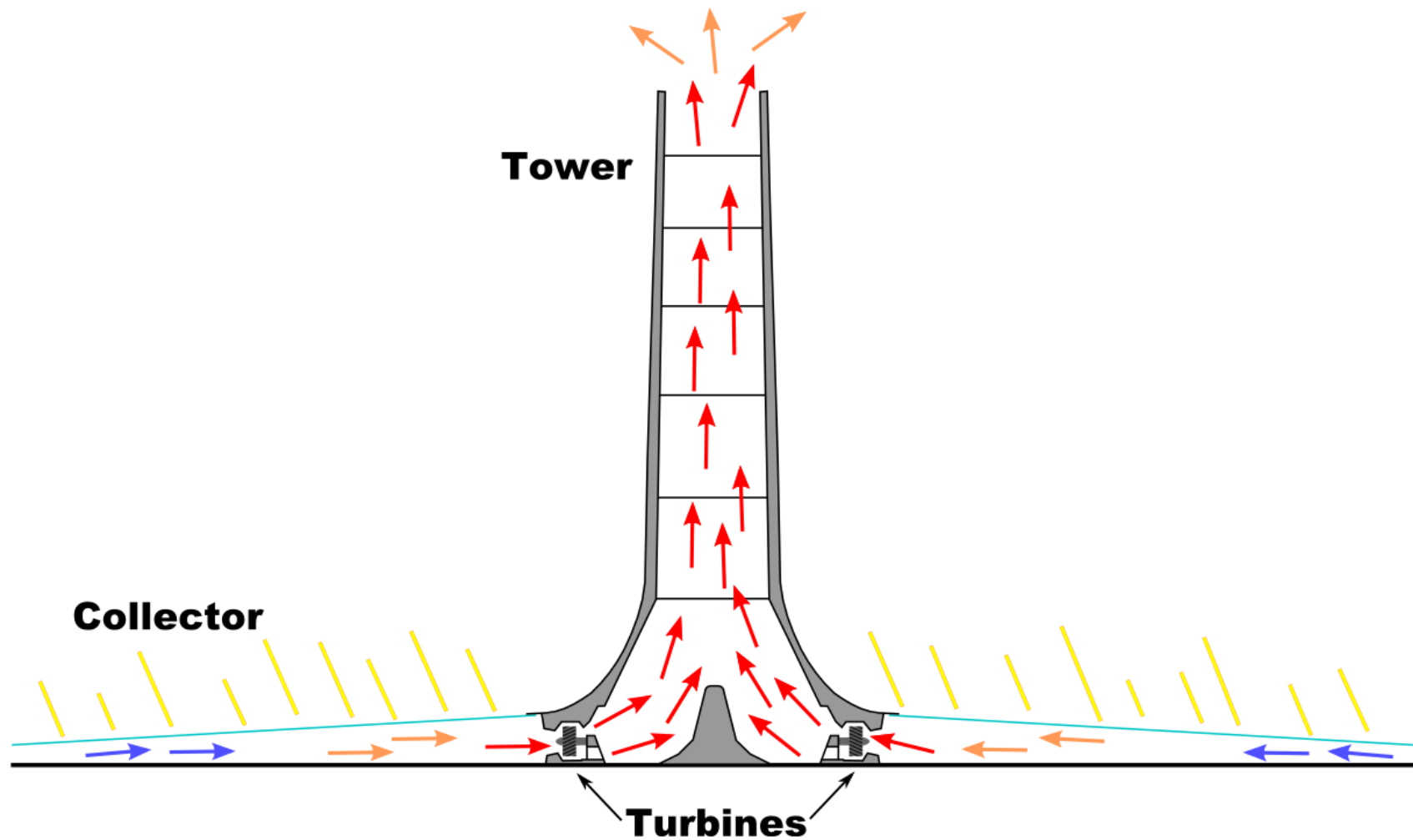
Illustration by:
Charles Floyd

Wet cooling tower AVE – Side view

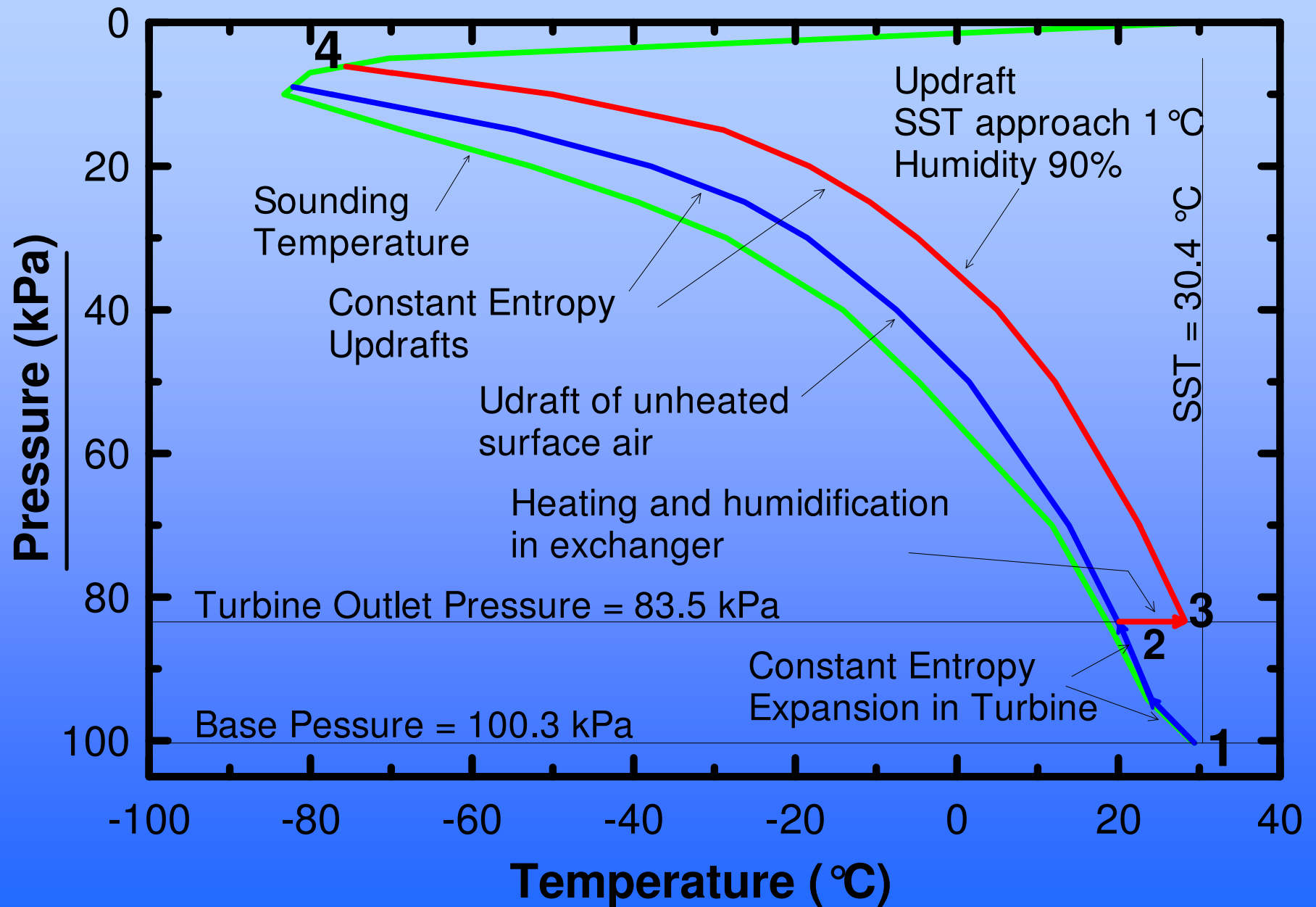
Capacity approximately 200 MW



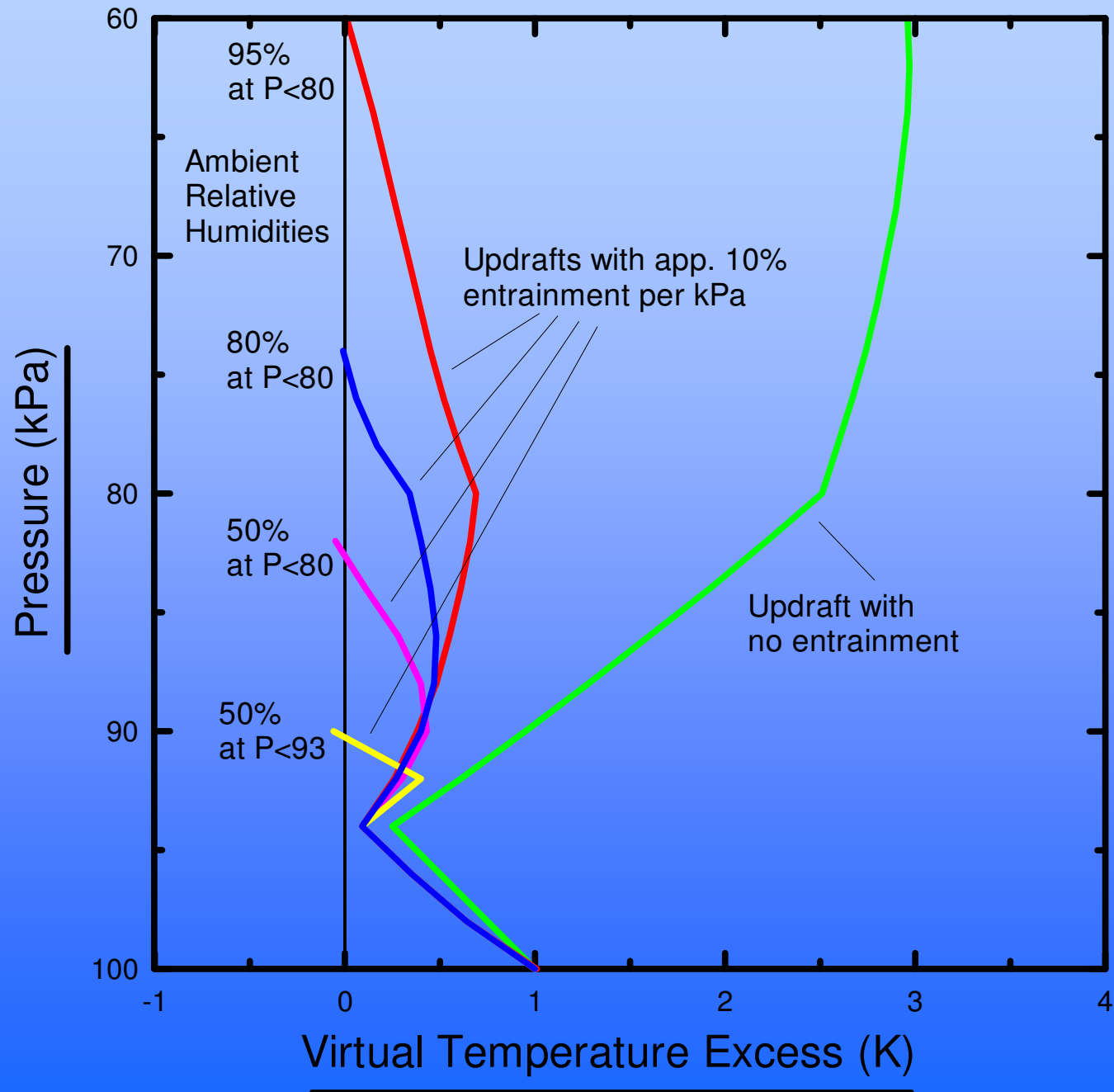
Solar Updraft Tower



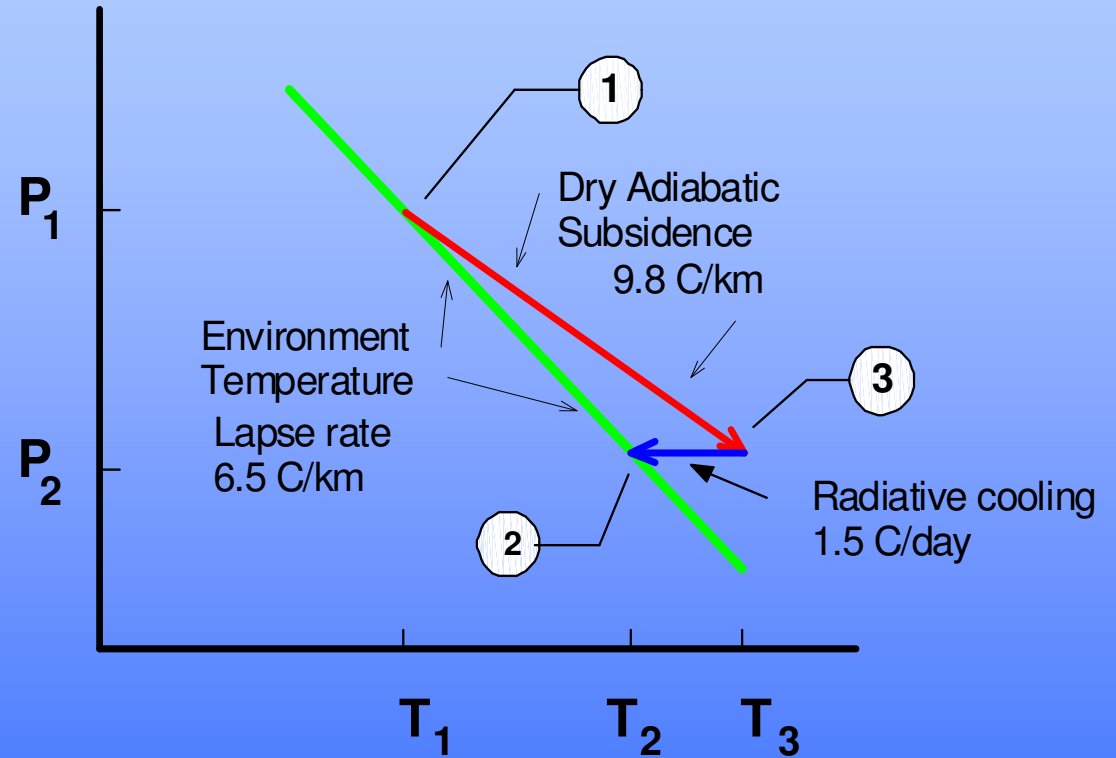
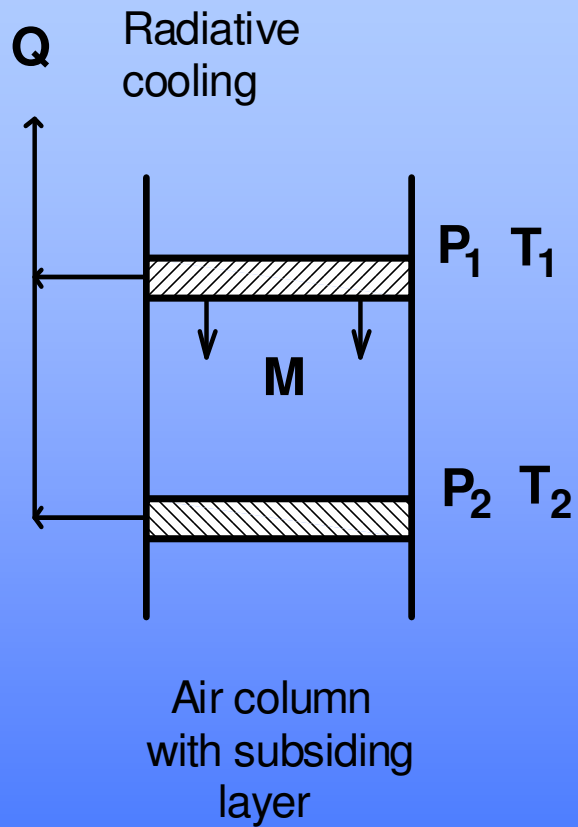
Willis Island sounding and updraft temperatures



Effect of entrainment and ambient relative humidity on updraft buoyancy



Subsidence warming and radiative cooling



Hurricane Isabel Intensity SST 25 to 26.5 C

Temperature approach 1 C - Relative humidity 97%

Surface air properties: $P_1 = 101.1$ kPa, $T_1 = 27.8$ °C, $U_1 = 80$, $r_1 = r_2 = 19.06$ g kg⁻¹, $h_1 = 76572$ J kg⁻¹, $s_1 = s_2 = 266.8$ J K⁻¹kg⁻¹.

Eyewall SST (°C)	25.0	25.5	26.0	26.5
$P_2 = P_3$ (kPa)	99.14	97.72	96.01	94.36
T_2 (°C)	26.12	24.90	23.41	22.72
U_2 (%)	86.8	92.2	99.3	101.75
h_2 (J kg ⁻¹)	74830	73557	72005	70490
T_3 (°C)	24	24.5	25.0	25.5
U_3 (%)	97	97	97	97
$r_3 = r_4$ (g kg ⁻¹)	18.69	19.57	20.55	21.57
$h_3 = h_4 + (1+r_4)$ gz	71686	74434	77459	80590
$s_3 = s_4$ (J K ⁻¹ kg ⁻¹)	256.2	269.7	285.2	300.8
P_4 (kPa)	15.0	10.0	10.0	10.0
T_4 (°C)	-61.45	-80.92	-77.72	-74.42
T_{4V} (°C)	-65.32	-84.69	-81.65	-78.61
T_{4A} (°C)	-62.9	-80.1	-80.1	-80.1
z_4 (m)	14220	16570	16570	16570
h_4 (J kg ⁻¹)	-70275	-91130	-88264	-85299
ΔP_{12}	1.96	3.38	5.09	6.74
$W = h_1 - h_2$	1742	3015	4567	6081
$v = (m/s)$	59.0	77.6	95.6	110.3
n (%) = $\Delta W_{12}/\Delta Q_{23r}$	n/a	base	33.9	33.2
n (%) = $1 - T_4/T_3$	28.8	35.4	33.5	33.5

Typical Energy Calculations - SST 30.4 C

Vortex solar chimney energy calculations for a range of temperature and humidity approach to sea surface temperature (SST). Ambient surface air conditions: $P_1 = 100.3$ kPa, $T_1 = 29.4$ °C, $U_1 = 77.5\%$, $r_1 = r_2 = 20.50$ g kg⁻¹, $s_1 = s_2 = 287.0$ J kg⁻¹ K⁻¹, $h_1 = 81920$ J kg⁻¹. Heights based on 17 January 1999, 0000Z Willis Island sounding. Approach based on SST = 30.4 °C.

<u>Properties</u>	<u>Case 0</u> <u>$q_{23} = 0$</u>	<u>Case 1</u> <u>$A=3, B=10$</u>	<u>Case 2</u> <u>$A=1, B=10$</u>	<u>Case 3</u> <u>$A=1, B=5$</u>	<u>Case 4</u> <u>$A=0, B=0$</u>
$P_2 = P_3$ (kPa)	95.80	91.38	83.42	81.02	74.62
$P_1 - P_2$ (kPa)	4.50	8.92	16.88	19.28	25.68
T_2 (°C)	25.47	23.10	19.99	18.99	16.14
U_2 (%)	94	103	115	119	131
h_2 (J kg ⁻¹)	77820	73670	65720	63200	56150
$T_3 = \text{SST} - A$ (°C)	25.47	27.4	29.4	29.4	30.4
$U_3 = 100 - B$ (%)	94	90	90	95	100
$r_3 = r_4$ (g kg ⁻¹)	20.50	23.25	28.87	31.43	38.35
h_3 (J kg ⁻¹)	77820	86840	103320	109840	128590
$s_3 = s_4$ (J K ⁻¹ kg ⁻¹)	287.0	331.3	413.5	444.1	531.1
P_4 (kPa)	10	10.0	7.0	7.0	5.0
T_4 (°C)	-77.39	-68.01	-69.91	-63.21	-62.77
z_4 (m)	16570	16570	18580	18580	20560
h_4 (J kg ⁻¹)	-87890	-79330	-84020	-77970	-80630
$h_4 + gz_4(1+r_4)$	77820	86840	103320	109840	128590
$q_{23} = h_3 - h_2$ (J kg ⁻¹)	0	13170	37590	46650	72440
$w_{12} = h_1 - h_2$ (J kg ⁻¹)	4090	8250	16190	18720	25770
v_x (m s ⁻¹)	90	128	180	193	227
$\Delta w_{12}/\Delta T_3$	n/a	4050	base	n/a	n/a
$\Delta w_{12}/\Delta U_3$	n/a	n/a	base	512	n/a
$\Delta w_{12}/\Delta r_3$	n/a	n/a	base	1000	n/a
$\Delta w_{12}/\Delta q_{23}$	n/a	32.8%	base	28.1%	28.2%