High Efficiency Smart Heat Pump (novel heat pump model)

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Abstract:
Novel technology of a single stage high efficiency smart heat pump that delivers COP values significantly higher than any single stage heat pumps on the market today. Verification and validation have been completed. Some of the advantages and/or improvements over vapor compression heat pumps are: without a thermal control (isenthalpic) valve, variable temperature lift, cold side and hot side temperatures individually controlled, isothermal processes play no significant role in the efficiency, in heating -25 °F outside temperature achievable with a suitable refrigerant, integrated lubricating fluid doesn't significantly affect performance, novel thermodynamic principle exploited, and percentage of input power returned to the source of input power. Next generation design using novel thermodynamic principle presently in research and development with improvements in several areas including efficiency, complexity, HVACR applications (single and multiple stage heat pumps) and other areas or industries.

Introduction:

The novel thermodynamic principle of High Efficiency Smart Heat Pump is not new to HVACR.
Examples are:
1) ASHRAE Journal April 2023, Oklahoma State University "Improving Vapor Compression Cycle Performance"
2) US patent in 1991 by Canadian Energy of Canada patent 5,027,602.
Purpose to achieve Carnot cycle efficiency of heat pumps, etc.

Carnot cycle model has limitations which can be improved with a different model in the following presentation.

Reversible Adiabatic Expansion of a Gas

An *adiabatic* process is one in which there is no loss or gain of heat, that is, one in which the system under investigation is thermally isolated from its environment so that $q = 0$. In an adiabatic expansion work is done at

Reversible Adiabatic Expansion of a Gas 41

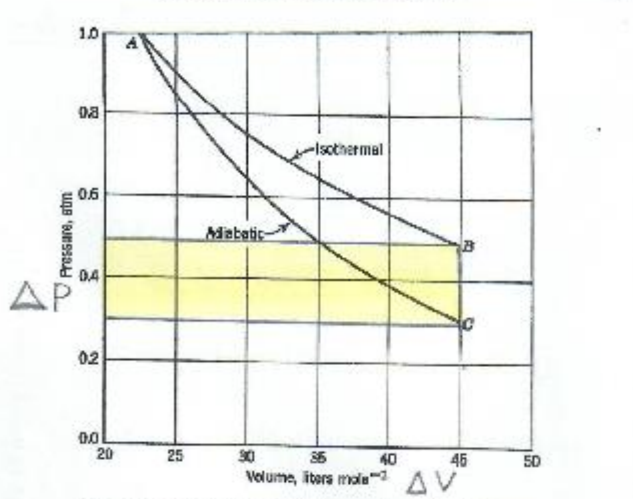

Fig. 2.1 Isothermal and adiabatic expansion of an ideal gas.

the expense of the internal energy of the gas and the temperature drops. Thus, when a gas expands adiabatically to a larger volume and a lower pressure, the volume is smaller than it would be after an isothermal expansion to the same pressure. Plots of pressure versus volume for adiabatic and isothermal expansions are shown in *Fig. 2.1*.

Isothermal & Adiabatic expansion graph of a gas:
Novel thermodynamic principle. In Physics text books.

Novel heat pump technology based on this novel thermodynamic principle.

1st Sponsored Research:
Rensselaer Polytechnic Institute: In 2018 entered into a $250.000 sponsored research agreement to design and build a 5G High Efficiency Smart Heat Pump with funding from New York State Energy Research Development Authority. Funding denied by NYSERDA.

2nd Sponsored Research:
Rensselaer Polytechnic Institute: In 2021 entered into a $50,000 sponsored research agreement for TRL4 Validation testing. Failed to reach agreement.

What if there were a machine that recycles thermal energy?

Something to think about as the presentation proceeds.

Difference between a Carnot refrigeration cycle and novel heat pump refrigeration cycle.

Carnot: Two adiabatic and two isothermal processes
A single mass flow is processed as a result of these two thermodynamic processes.
Efficiency: TL / (TH-TL)

Novel Heat Pump technology: Two adiabatic, one isobaric, and one isothermal thermodynamic process(es). Two independent mass flows created, cold liquid and hot vapor as a result of these four thermodynamic processes.
Cold Liquid – Adiabatic and Isobaric.
Hot vapor – Adiabatic and isothermal

Efficiency: It is not TL / (TH-TL). Still under research.

Energy Balance Equations.

To determine efficiencies, COP, energy balance equations are required.
ASHRAE Fundamental Handbook uses COP = Thermal cooling energy / mechanical energy (work) in. Using only the enthalpy property.

Novel heat pump in-house heat pump simulator.

The life cycle of the cold liquid and hot vapor are determined separately, start and end from a common system reservoir of the fluid,

The in-house HP simulator needs the following fluid properties for the two mass flows required for the energy balance equations.
Refrigerant, system reservoir temperature and pressure, fluid flow rate, and hot vapor condensation temperature.

The analysis for determining the COP value of this cycle follows:

1. This method uses mass flow rates. Wet mixture ratio and flow rate are required to determine the respective mass of the cold liquid and hot vapor.
2. Assuming heat exchangers are 100% efficient, determine theoretically the following using mass enthalpy, Mass Enthalpy = mass x enthalpy property of the fluid.
Start: From system reservoir the cold liquid and hot vapor mass enthalpy is determined, H_{rcl} and H_{rhv}.
End: Cold liquid at cold temperature and pressure mass enthalpy is determined, H_{cl}.
End: Hot vapor at hot vapor compressed temperature and pressure mass enthalpy is determined, H_{hv}.
Bulk Start: Cold liquid mass enthalpy + hot vapor mass enthalpy, $H_{rcl+rhv}$
Bulk End: Cold liquid mass enthalpy + hot vapor mass enthalpy, H_{cl+hv}
3. Determine the bulk change in the bulk enthalpy for both the cold liquid and hot vapor , bulk end enthalpy – bulk start enthalpy
4. Determine mass cooling enthalpy, cold liquid start mass enthalpy – cold liquid end mass enthalpy
5. COP = mass cooling enthalpy / bulk change enthalpy, item 4 / item3, $COP = (H_{rcl} - H_{cl}) / (H_{cl+hv} - H_{rcl+rhv})$

This chart from energy balance analysis is a summary of the TRL4 Validation testing on the novel heat pump with R134a. The only point to make here is how the end bulk property of Internal energy, enthalpy, and entropy compare and the effect on bulk end temperature change.

Test	Reservoir Temp. °F	Temp °F From Int. Energy Change†	Temp °F From Enthalpy Change†	Temp °F From Entropy Change†	Internal Energy Change Btu	Enthalpy Change Btu	Entropy Change Btu/R x 10^{-9}
AcqLogR134aHx (1-3) 1	73.21	72.96	73.31	73.25	-0.06609	0.02096	18
	73.00	72.43	73.28	73.00	-0.08351	0.03940	17
	73.25	72.41	73.76	73.25	-0.08518	0.05064	13
AcqLogR134aHx (1-3) 2	72.59	72.36	72.69	72.59	-0.05556	0.02234	-13
	72.99	72.49	73.30	72.99	-0.07563	0.04543	-3
	73.49	72.80	73.95	73.49	-0.08037	0.05257	-8
AcqLogR134aHx (1-3) 3	73.81	73.56	73.95	73.81	-0.05754	0.02973	-6
	74.34	73.79	74.8	74.34	-0.07136	0.05859	38
	74.44	73.88	74.84	74.44	-0.07559	0.05303	-6

Table 3.0 Energy Balance Equations

† Change in each of the thermodynamic properties; Internal Energy, Enthalpy, and Entropy is: Change = Bulk fluid energy end – bulk fluid energy begin.

Test	Carnot Cycle $T_L / (T_H - T_L)$		DC Motor Power		HP Simulator		Energy Balance Eq. of test files	
	COPr	COPh	COPr	COPh	COPr	COPh	COPr	COPh
AcqLogR134a Hx (1-3) 1	32.6	33.6	54.2	---	37.68	38.68	37.71	38.71
	22.6	23.6	50.4	---	28.24	29.24	28.26	29.26
	19.1	20.1	49.8	---	24.15	25.15	24.18	25.18
AcqLogR134a Hx (1-3) 2	28.2	29.2	30.97	---	31.75	32.75	31.79	32.79
	19.9	20.9	38.3	---	24.20	25.20	24.23	25.23
	17.8	18.9	43.8	---	22.86	23.86	22.88	23.88
AcqLogR134a Hx (1-3) 3	23.6	24.6	28.2	---	26.74	27.74	26.77	27.77
	16.3	17.3	27.8	---	20.15	21.14	20.16	21.16
	17.8	18.8	32.1	---	21.99	22.99	22.01	23.01

Table 3.1 Comparison of Four Different Means of Determining COP Values

For a better understanding of **Table 10.2**, **Figure 10.2** illustrates the COP data below, excluding the HP Simulator COP data.

Comparison of COP Values Using Four Methods

The chart will not be discussed but the visual graph deserves comment. The DC Motor Power is clear evidence that mechanical energy is leaving the system, i.e. Result of novel thermodynamic principle. More evidence in slide 5.

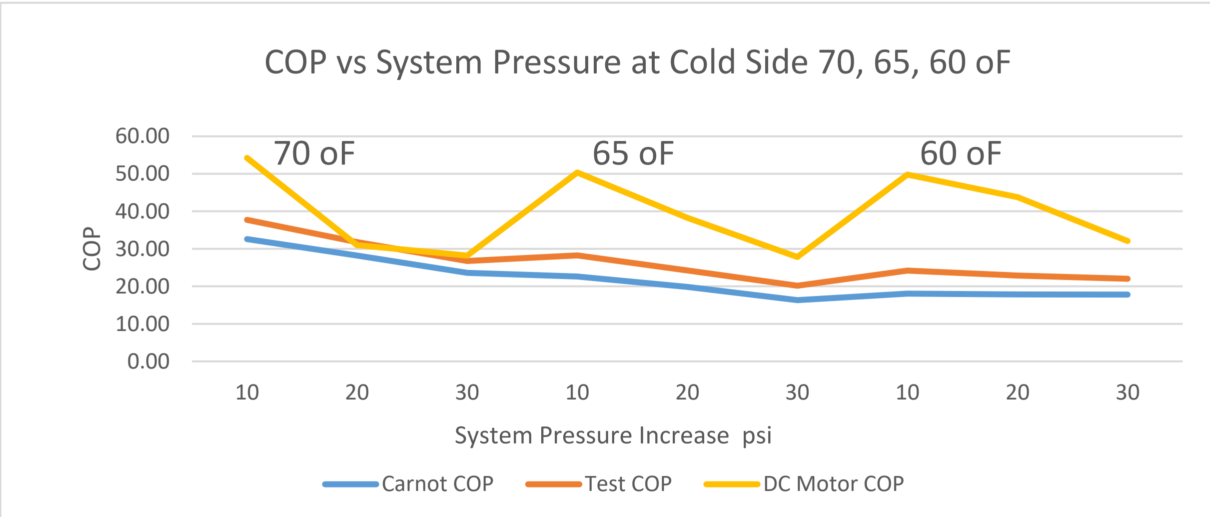

Figure 4.0 Graph of Three Different COP Values in **Table 10.1**.

Repeated from slide 3 item 5 for the next discussion. COP = $(H_{rcl} - H_{cl}) / (H_{c+hv} - H_{rcl+rhv})$
DC Motor Power is a method that needs clarification. Simply put, the same calculation as slide 3 item 5 above for COPr except $(H_{c+hv} - H_{rcl+rhv})$ is replaced with the actual DC Motor Power required. The data for this calculation is from the data measured with the ValDaq power measurement system.

Point to make is enthalpy is misleading as to its relationship to motor power. Therefore, looked at two other methods of calculating COPr and COPh.

COPr = $\Delta U_{cl} / \Delta H_{bulk}$ Cooling energy based on internal energy ΔU_{cl} with ΔH_{bulk} , the traditional bulk change enthalpy.
COPh = $\Delta U_{hv} / \Delta H_{bulk}$ Heating energy based on internal energy ΔU_{hv} with ΔH_{bulk}, the traditional bulk change enthalpy.

COPr = $\Delta U_{cl} / \Delta U_{bulk}$ the same as above except the work in is now liquid bulk change internal energy.
COPh = $\Delta U_{hv} / \Delta U_{bulk}$ Heating energy based on internal energy ΔU_{hv}, the work in is liquid bulk change internal energy.

Only the second chart will be discussed.

Test	DC Motor Power		Energy Balance Eq. of test files		Energy Balance COPr = $\Delta U_{cl} / \Delta H_{bulk}$ COP$_h$ = $\Delta U_{hv} / \Delta H_{bulk}$		Energy Balance COPr = $\Delta U_{cl} / \Delta U_{bulk}$ COP$_h$ = $\Delta U_{hv} / \Delta U_{bulk}$	
	COPr	COPh	COPr	COPh	COPr	COPh	COPr	COPh
AcqLogR134a Hx (1-3) 1	54.2	---	37.71	38.71	37.66	34.51	-11.94	-10.94
	50.4	---	28.26	29.26	28.22	26.10	-13.31	-12.31
	49.8	---	24.18	25.18	24.14	22.46	-14.35	-13.35
AcqLogR134a Hx (1-3) 2	30.97	---	31.79	32.79	31.74	29.26	-12.76	-11.76
	38.3	---	24.23	25.23	24.19	22.52	-14.53	-13.53
	43.8	---	22.88	23.88	22.85	21.32	-13.81	-12.81
AcqLogR134a Hx (1-3) 3	28.2	---	26.77	27.77	26.73	24.79	-13.81	-12.81
	27.8	---	20.16	21.16	20.13	18.91	-16.53	-15.53
	32.1	---	22.01	23.01	21.97	20.55	-15.42	-14.42

Table 4.0 Comparison of Three Energy Balance Methods

Observations:

New Method	COPr	COPh
$COPr = \Delta U_{cl} / \Delta H_{bulk}$ $COPh = \Delta U_{hv} / \Delta H_{bulk}$	Closely matches "test files" values in all 9 validation tests.	In all 9 validation tests. New method is not COPh = COPr +1. Always lower than COPr. Seems like COPh = COPr -2.
$COPr = \Delta U_{cl} / \Delta U_{bulk}$ $COPh = \Delta U_{hv} / \Delta U_{bulk}$	Always negative while "test files" always positive in all 9 validation tests.	In all 9 validation tests. Always negative, not positive as COPh in "test files".

Table 5.0 Comments of Comparison of Three Energy Balance Methods

Conclusion:

1. Traditional Energy Balance Equations are only valid for a system with two isothermal and two adiabatic processes like the Carnot cycle.
2. The DC Motor Power method COPr = ΔU / ΔH is appropriate but fails for COPh since mechanical energy leaving the system is not accounted for.
3. New Energy Balance Equations required for a system that does not rely on two isothermal and two adiabatic processes.

Input Power Returned To Input Power Source Discussion:

This property is not achievable with Carnot cycle and, therefore, new to HVACR.

Test	ValDAQ % DC Motor Power Returned	HP Simulator % DC Motor Power Returned
AcqLogR134aHx (1-3) 1	12.2	14.7
	13.4	21.6
	13.3	27.6
AcqLogR134aHx (1-3) 2	16.4	16.2
	14.1	23.6
	13.9	26.9
AcqLogR134aHx (1-3) 3	11.6	19.1
	5.9	28.0
	3.3	26.1

Table 5.1 Comparison of % Power Returned ValDAQ vs. HP Simulator

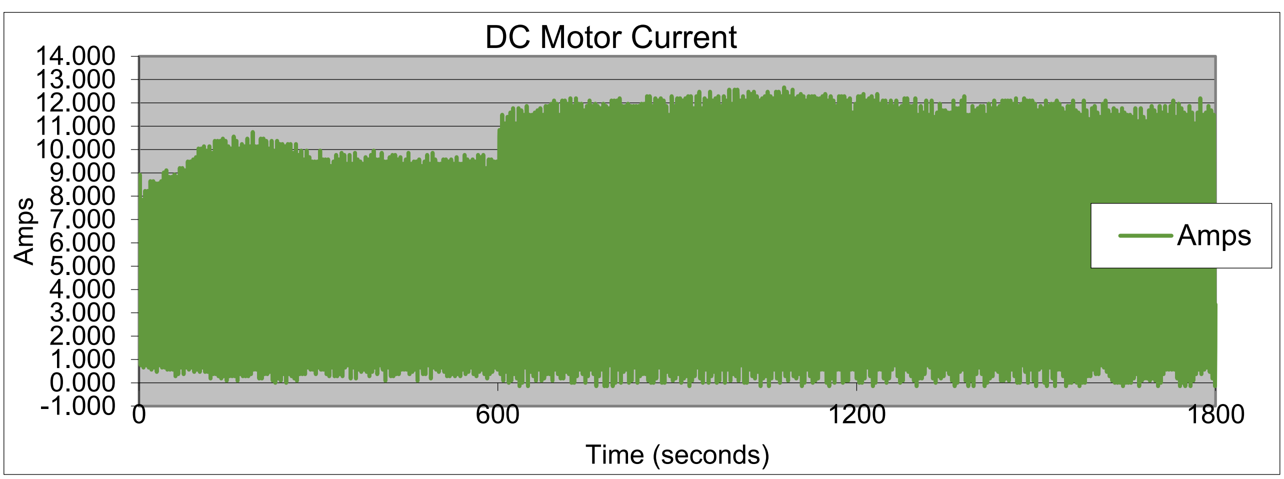

Figure 5.0 DC Motor current during a 30 minute test

This graph illustrates the current of the DC motor during the last validation test. Note that the range of the current is from about 12 amps to 0 and also to about -0.015 amps. The -0.015 amps indicates that the novel heat pump is driving the DC motor instead of the DC motor driving the novel heat pump. During this time the DC motor is now a DC generator. The modest -0.015 amps is the reverse current of the protective diode of the forward current from the DC power supply. A simple set of two steering diodes or a simple op-amp circuit could deliver the DC generator current to an external device.

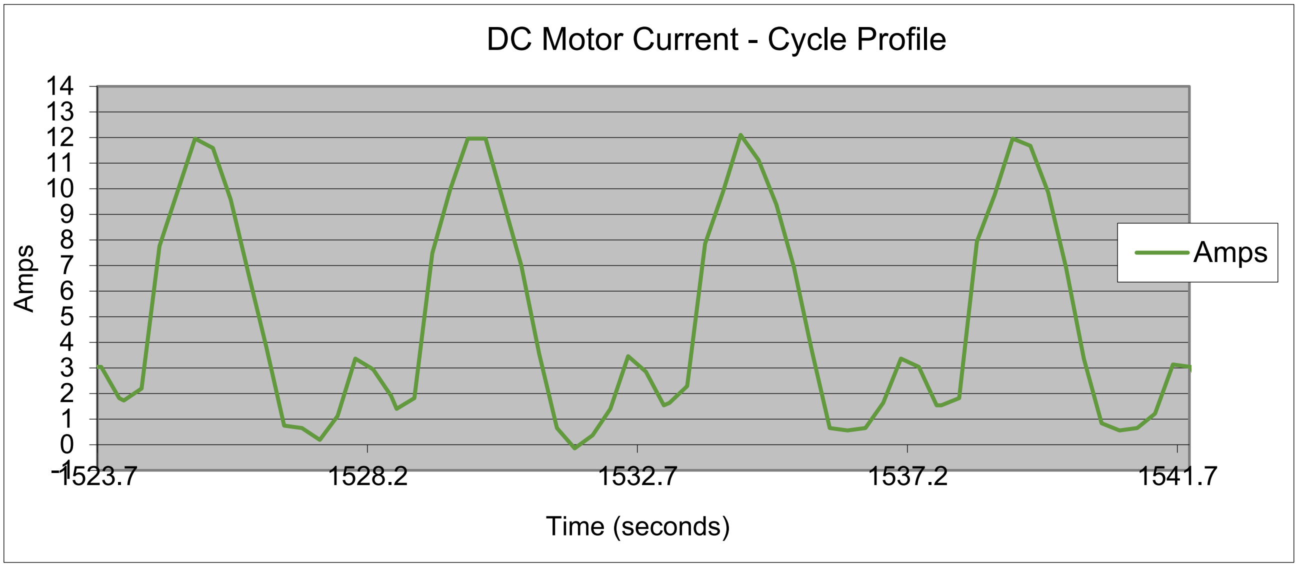

Figure 6.0 DC Motor current of four cycles during 30 minute test

The previous 30 minute graph of DC motor current is too detailed to observe the DC motor current during one cycle of operation. The following graph is one cycle of DC motor current which is sampled 16 times per cycle.

Note the first eight samples are during the expansion phase and the last eight samples during the compression phase. It is obvious when the DC motor becomes a DC generator.

Testing Novel Heat Pump Without Heat Exchangers:

Testing of the novel heat pump without heat exchangers reveals an interesting phenomena that supports the claim I would like to make at this point. “This novel thermodynamic principle and novel heat pump technology recycles thermal energy”. These graphs illustrate that mechanical energy is leaving the system, supporting the claim of “recycling thermal energy”. The graphs are measured temperature data except the blue line. The HP simulator was modified to simulate the heat pump after operating conditions were met to the end of the test by using the internal energy at the end of a current cycle to recalculate the reservoir temperature and use it as the reservoir temperature of the next cycle. In all four temperature tests the blue line closely matches the measured temperature of the reservoir. The system was 20 psi above system pressure for these tests.

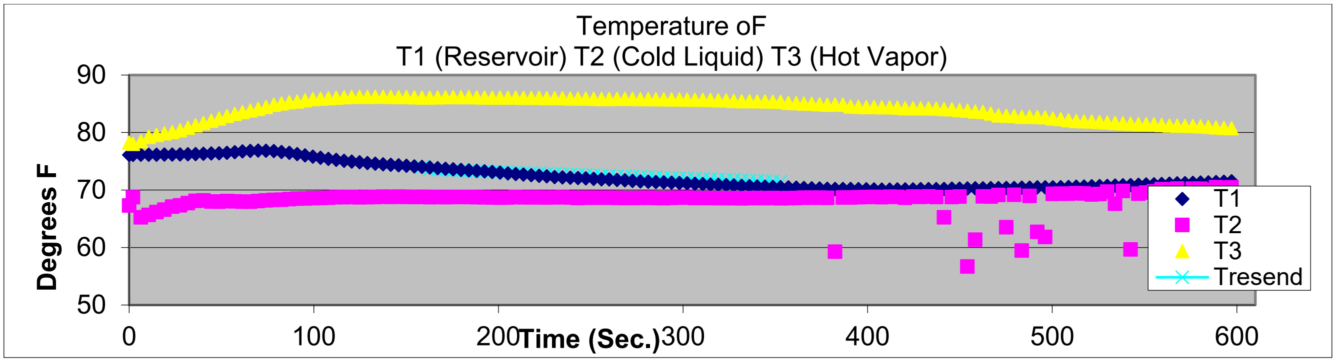

Figure 7.0 Temperature graph of cold side 8 °F below reservoir temperature

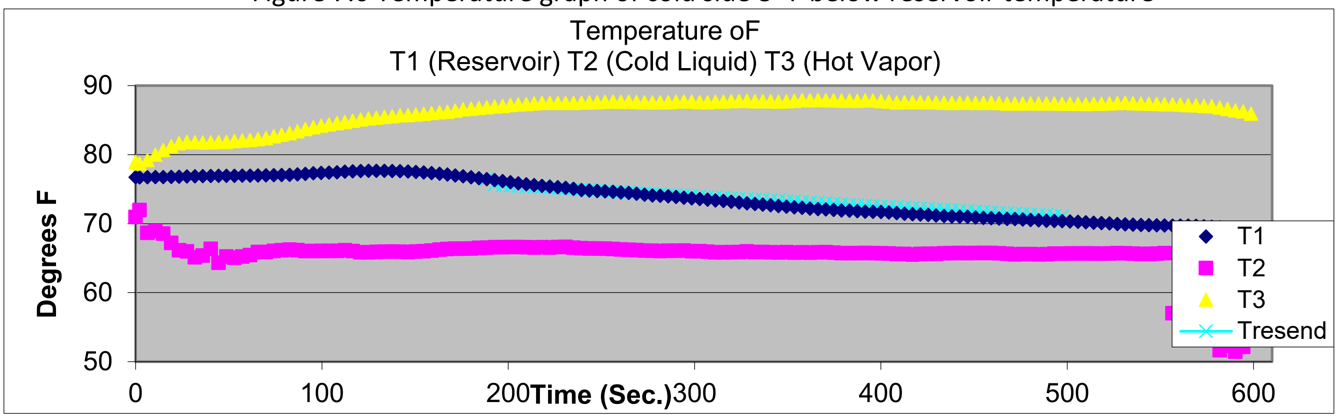

Figure 7.1 Temperature graph of cold side 11 °F below reservoir temperature

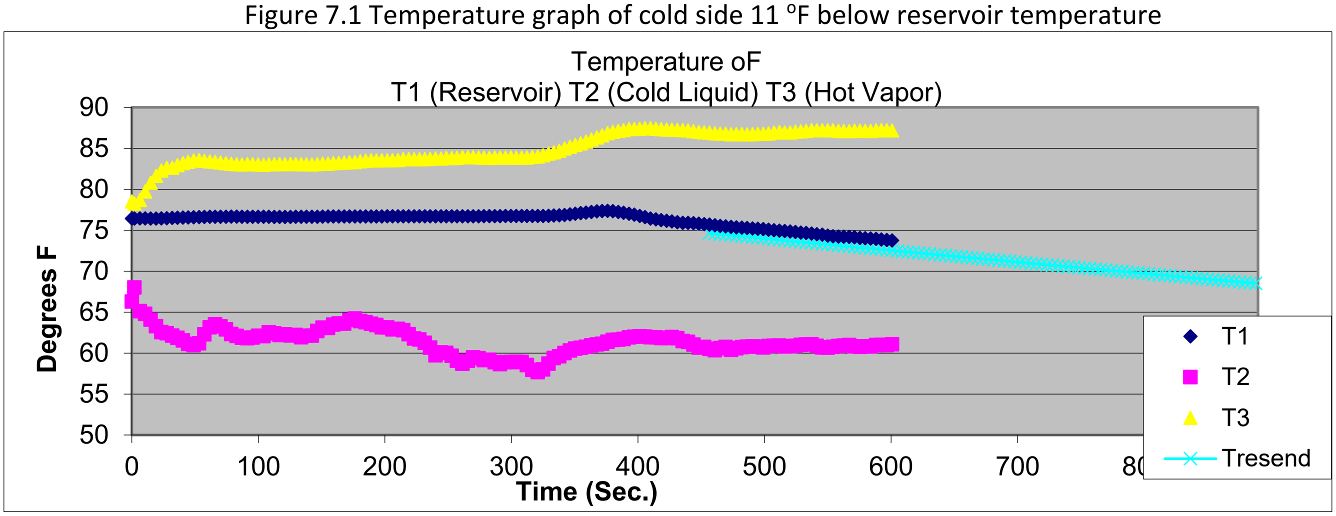

Figure 7.2 Temperature graph of cold side 16 °F below reservoir temperature

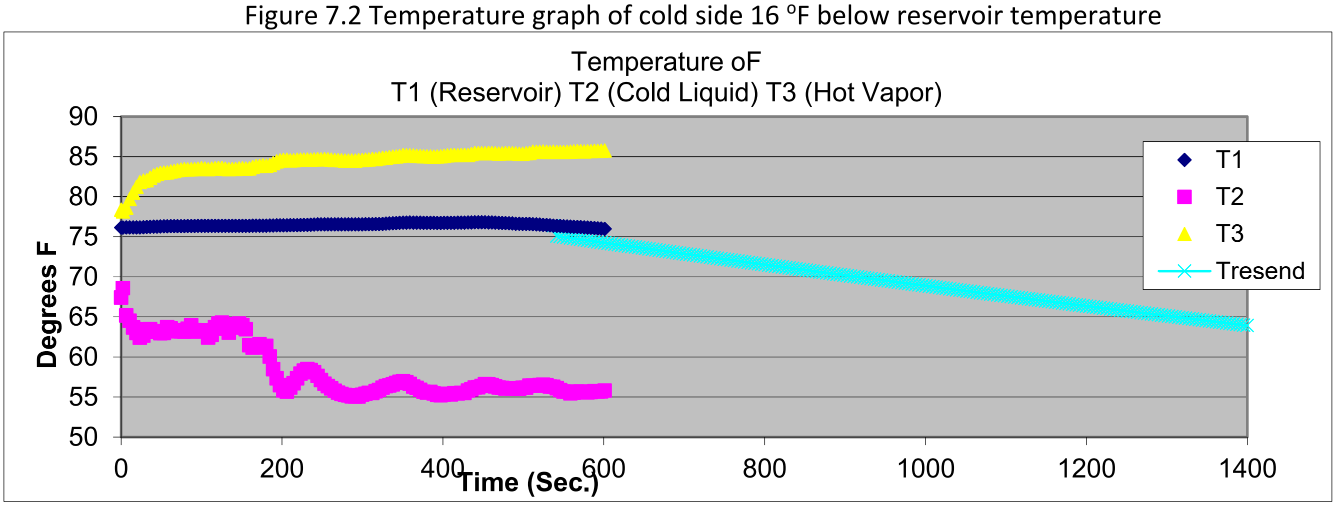

Figure 7.3 Temperature graph of cold side 20 °F below reservoir temperature

Comprehensive Study of Refrigerants.

A comprehensive study of the refrigerants from NIST in the RefProp program was done Sept. 18 2018 before the 4G heat pump design was started. 136 Refrigerants were analyzed. Less than 40 were suitable. Less than 10 showed another interesting phenomena. First, if hot vapor condensation is near the critical temperature the efficiency approaches three times more than a Carnot refrigerant cycle. Second, and this pertains to all candidate refrigerants, the greater the temperature lift the more input power is returned. In some cases about 80%.

Claims made about the novel Thermodynamic principle and novel heat pump technology (5G).

1. Recycles thermal energy.
2. Variable temperature lift.
3. Cold side and hot side temperatures nearly independently controlled,
4. Isothermal processes play no role in the efficiency.
5. No thermal control valve
6. In heating mode operation down to -25 ^{o}F achievable and hot side nearly unaffected.
7. Resistive heating supplied from power company eliminated.
8. Resistive heating available from novel heat pump.
9. Integrated lubricating fluid doesn't significantly affect performance
10. Flywheel employed would improve efficiency substantially.
11. Push –Pull arrangement where two independent novel heat pumps are driven by one DC motor where they are 180 degrees out of phase from each other.
12. Without a flywheel, returned energy could be used for external application purposes.
13. Zeotrope refrigerants with different vapor pressures would allow achieving greater temperature lifts.
14. Suspect scalability similar to heat pumps of today.
15. Air conditioner would be possible with only a heat addition heat exchanger.

Advanced research of novel thermodynamic principle and related new 6G (previous 3G) design.

1. Most claims as 5G design
2. Significantly less complicated mechanically, also applies to computer requirements.
3. Broader range of applications beyond HVACR.

Why was this a 3G version? This 2016 design was somewhat successful but stalled on moving forward with the necessary research. A medical issue in 2017 forced me to this simpler novel heat pump technology due to ease of understanding and explaining. During the development of 5G design I had to solve three important design issues. These three design issues, I believe, were preventing the 3G design from working as envisioned.

Thermodynamic History:

Publication: "The Historical and Theoretical Foundations of Thermodynamics." Page 251.
James Prescott Joule and Julius Robert von Mayer pursued a "Perpetual Motion Concept" and failed.

Thermodynamic History: Critical years were from 1830 to 1850. Before that was the 1798 caloric theory that stood the test of time until 1830.