IIR Working Group on *Life Cycle Climate Performance Evaluation*

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Latest Progress Summary

- ***A booklet for LCCP guideline*** **(Jan, 2016)**
  - **Submitted *a booklet for LCCP guideline* together with a *reference database* written in excel; available from IIR website:** http://www.iifiir.org/userfiles/file/about_iir/working_parties/WP_LCCP/2016-01/Booklet-LCCP-Guideline-V1.2-JAN2016.pdf

- ***An excel LCCP calculation tool*** **(Jan, 2016)**
  - **Developed *a LCCP calculation tool for residential heat pumps* in excel in SI unit; available from IIR website:** http://www.iifiir.org/userfiles/file/about_iir/working_parties/WP_LCCP/2016-01/IIR-LCCP-Calculation-Tool-V1.2-JAN2016.xlsx

- ***Addendum 1— commercial Applications*** **(May, 2016)**
  - **Submitted a final version of *an Addendum-Commercial Applications***
- ***An example problem for commercial refrigeration***
  - **We developed a *an example problem using a chiller* using the ORNL LCCP tool.**

Latest Progress Summary

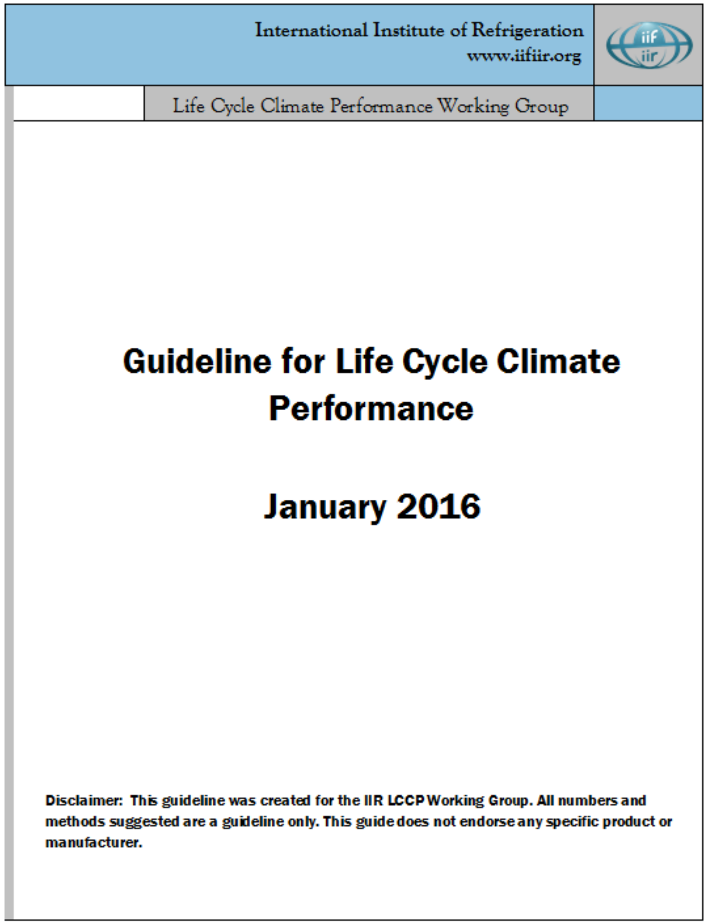
- *An Informatory Note for LCCP Guideline* (August, 2016)
  - Submitted a final version of *Informatory note for LCCP guideline*

- *Evaluation of Advanced Cycle Options using LCCP*
  - Evaluated SLHX cycle, expander cycle, ejector cycle and vapor injection cycle with various GWP values

- *Publications*
  - Published "*Harmonization of Life Cycle Climate Performance*" at 16th Int. RAC conference at Purdue, Paper No. 2382.
  - Published "*LCCP evaluation on various vapor compression cycle options and low GWP refrigerants*", Int. J. of Refrigeration, 2016, V 70, pp. 128-137.

IIR Guideline for LCCP Performance

- **Guideline for Life Cycle Climate Performance published in January 2016.**
  - Detailed explanation of calculation process
  - Recommended traceable data sources for GWP values, leakage rates, manufacturing emissions rates, recycling emissions rates
  - Recommended traceable data sources for weather data, electricity generation rates
  - Recommended standards for energy consumption calculation
  - Comparison to TEWI
  - Available LCCP calculation tools
  - Residential heat pump sample problem



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Life Cycle Climate Performance Working Group

Guideline for Life Cycle Climate Performance

January 2016

Disclaimer: This guideline was created for the IIR LCCP Working Group. All numbers and methods suggested are a guideline only. This guide does not endorse any specific product or manufacturer.

IIR LCCP Excel Tool for Residential Heat Pumps

- Residential Heat Pump
- Single Speed Compressor, Single Speed Fan
- 6 Refrigerants built in
  - HFC-32, HFC-1234yf, HFC-134a, R-290, HFC-404A, HFC-410A, L-41b, DR-5
- 5 Locations (Miami FL, Phoenix AZ, Atlanta GA, Chicago IL, Seattle WA)
  - Each location in a different climate zone
- Inputs and results in SI units

LCCP IIR Excel Tool
for Residential Heat Pumps – User Inputs

IIR LCCP Working Group Residential Heat Pump Excel Tool

System	System A
Refrigerant	HFC-410A
Charge (kg)	6
Unit Weight (kg)	115
Annual Refrigerant Leakage (% per year)	4.00%
EOL Leakage	15.00%
Lifetime (years)	15
Manufacturing Emissions Type	Virgin
Cut Off Temperature (°C)	-17.78
T_{on} (°C)	-12.22

User Input:

Energy Calculation is perform

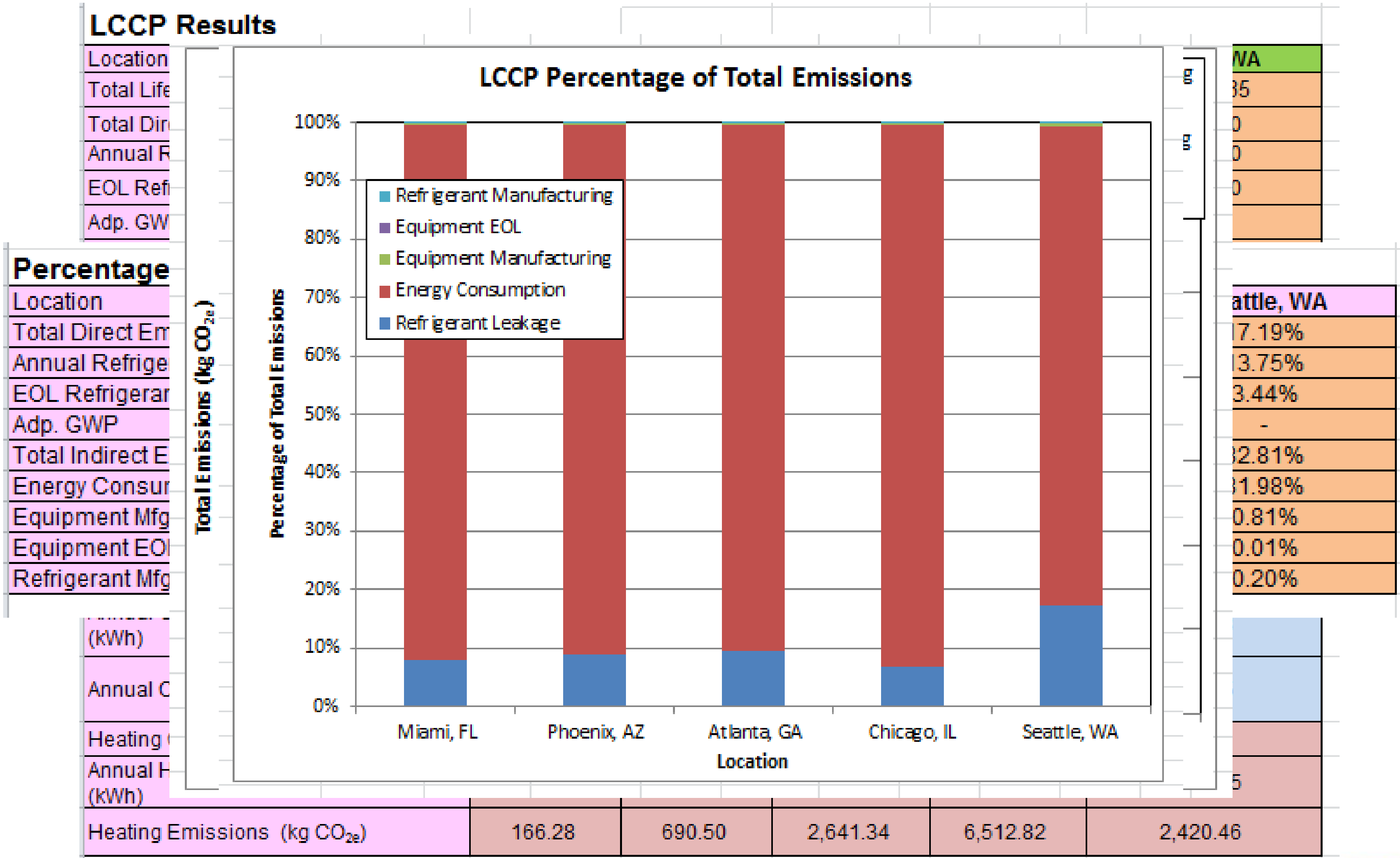
INSTRUCTIONS

1. Select the refrigerant from
2. Enter the charge, unit wei
3. Select "Virgin" or "Mixed"
4. Enter the Cut Off Temperat
5. Enter the AHRI Standard 21
6. Select the electricity gener

Refrigerant Options: HFC-32, I

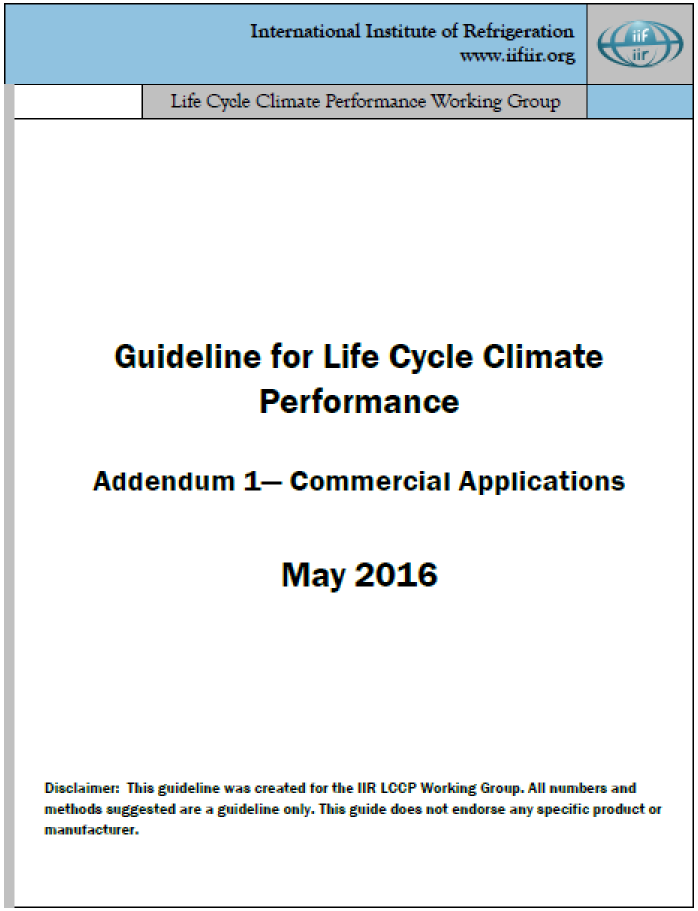
AHRI Std 210/240 Performance Data			
Cooling or Heating	Test Number	Capacity (W)	Total Power (W)
Single speed unit - Fixed Fan Speed			
Cooling	A Test	10,140	2,550
Cooling	B Test	10,474	2,378
Heating	H1 Test	10,082	2,500
Heating	H2 Test	8,382	2,370
Heating	H3 Test	6,154	2,310

LCCP IIR Excel Tool for Residential Heat Pumps – Outputs



Addendum – Commercial Application Guideline for LCCP Performance

- **Addendum-Commercial Application was submitted in May 2016**
  - Commercial applications cover supermarkets, chillers, packaged units and split units.
  - Address the differences in assumptions between commercial application and residential AC units.
  - The largest difference occurs in the calculation of the indirect emissions from the unit. Commercial sample problem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Life Cycle Climate Performance Working Group

Guideline for Life Cycle Climate Performance

Addendum 1– Commercial Applications

May 2016

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Water Chiller Description

	Value	Units
Model Number	Carrier Aqua-Snap 30RAP010	
Unit Capacity	10.5 / 36.8	Tons / kW
Total Weight	866 / 393	lbs / kg
Cooler	22.4/ 10.2	lbs / kg
Condenser	22.4 / 10.2	lbs / kg
Chassis	300 / 136.1	lbs / kg
Compressor	430 / 195	lbs / kg
Fan	50 / 22.7	lbs / kg

Input	Value	Unit
Lifetime	15	years
Annual Leakage Rate	5	% per yr
EOL Leakage Rate	15	%
Steel	407 (47%)	Lbs (% of Total)
Aluminum	150 (17%)	Lbs (% of Total)
Copper	138 (16%)	Lbs (% of Total)
Plastics	173 (20%)	Lbs (% of Total)

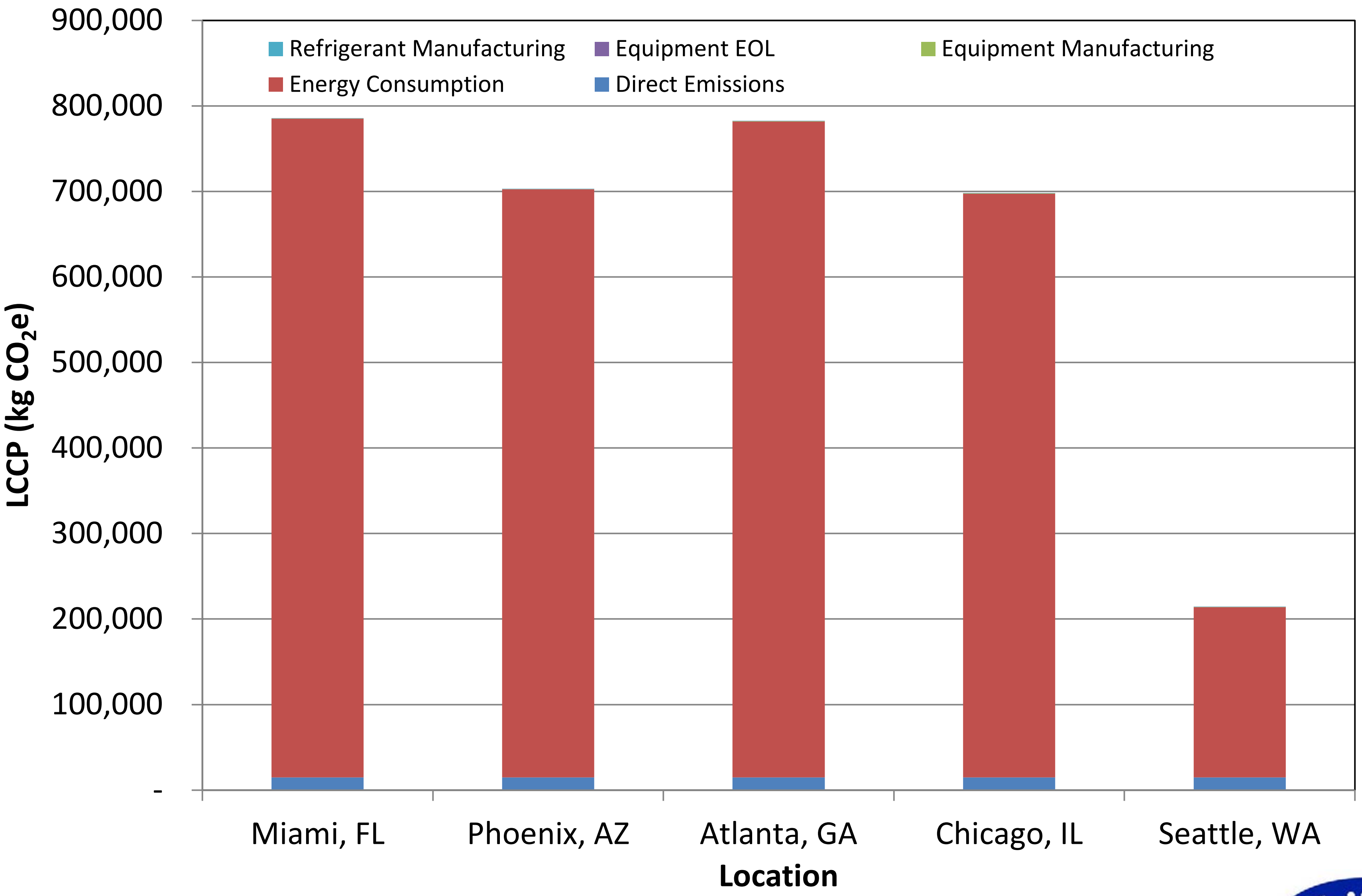
Water Chiller Sample Problem Results

Category	Phoenix, AZ	Miami, FL	Atlanta, GA	Chicago, IL	Seattle, WA
Total Direct Emissions	14,892	14,892	14,892	14,892	14,892
Annual Leakage	12,410	12,410	12,410	12,410	12,410
EOL Leakage	2,482	2,482	2,482	2,482	2,482
Adp. GWP	-	-	-	-	-
Total Indirect Emissions	771,397	688,830	768,357	683,815	200,306
Energy Consumption	769,994	687,426	766,953	682,412	198,902
Material Manufacturing	473	473	473	473	473
Refrigerant Manufacturing	161	161	161	161	161
Disposal	6	6	6	6	6
Total Emissions	785,365	702,797	782,324	697,783	214,273

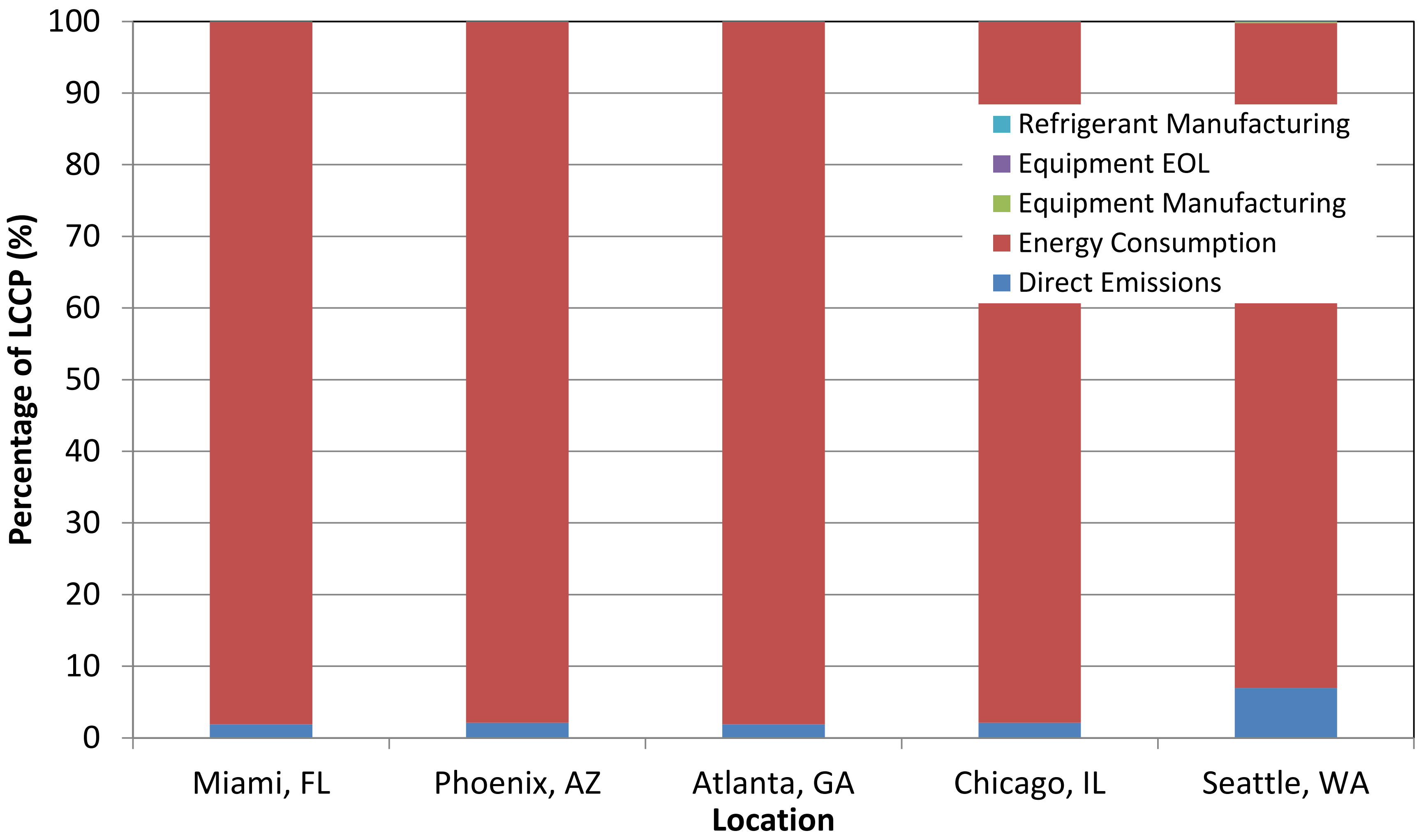
Water Chiller Sample Problem

	Percentage of Composition				
Location	Miami, FL	Phoenix, AZ	Atlanta, GA	Chicago, IL	Seattle, WA
Total Direct Emission	1.90%	2.12%	1.90%	2.13%	6.95%
Annual Refrigerant Leakage	1.58%	1.77%	1.59%	1.78%	5.79%
EOL Refrigerant Leakage	0.32%	0.35%	0.32%	0.36%	1.16%
Adp. GWP	-	-	-	-	-
Total Indirect Emission	98.10%	97.88%	98.10%	97.87%	93.05%
Energy Consumption	98.04%	97.81%	98.04%	97.80%	92.83%
Equipment Mfg	0.06%	0.07%	0.06%	0.07%	0.22%
Equipment EOL	0.00%	0.00%	0.00%	0.00%	0.00%
Refrigerant Mfg	0.02%	0.02%	0.02%	0.02%	0.08%

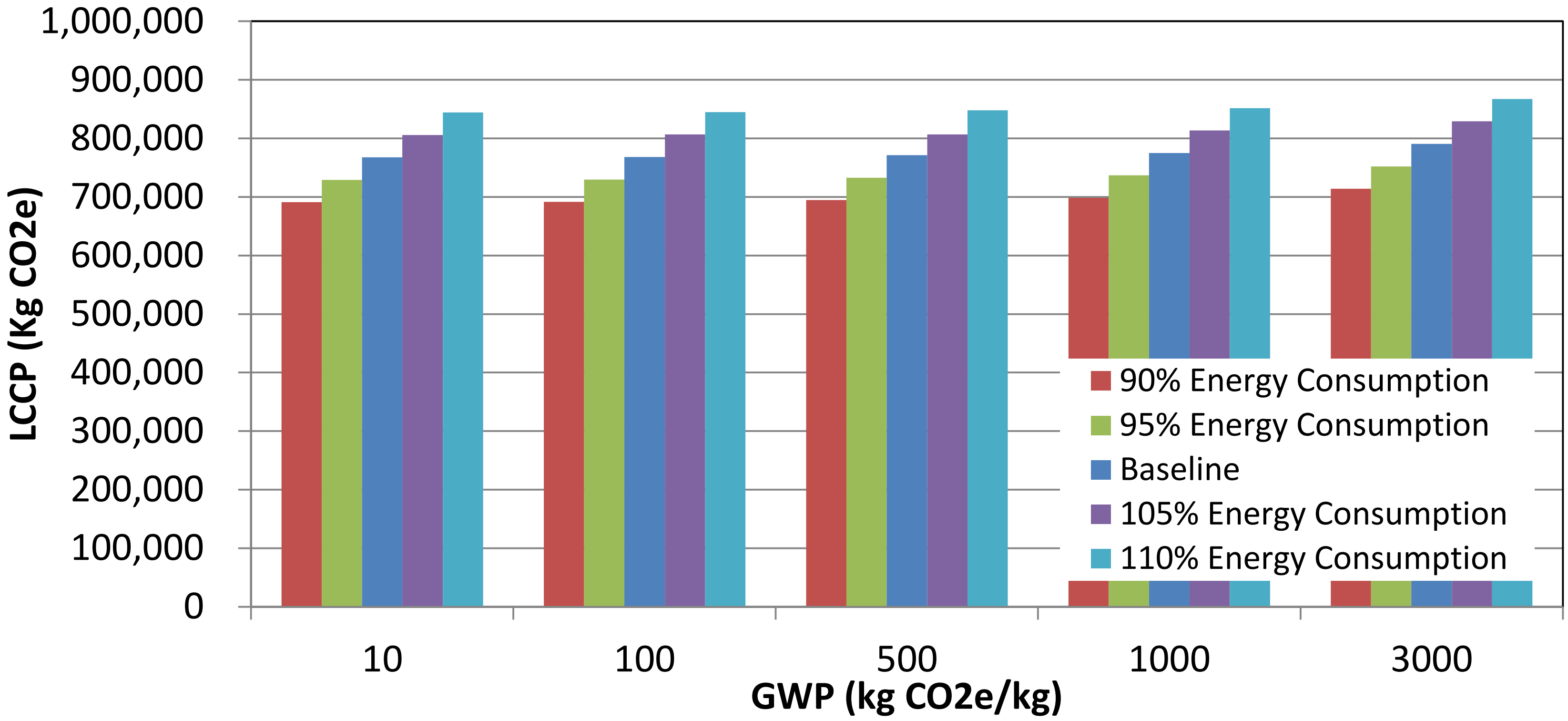
Water Chiller Sample Problem



Water Chiller Sample Problem



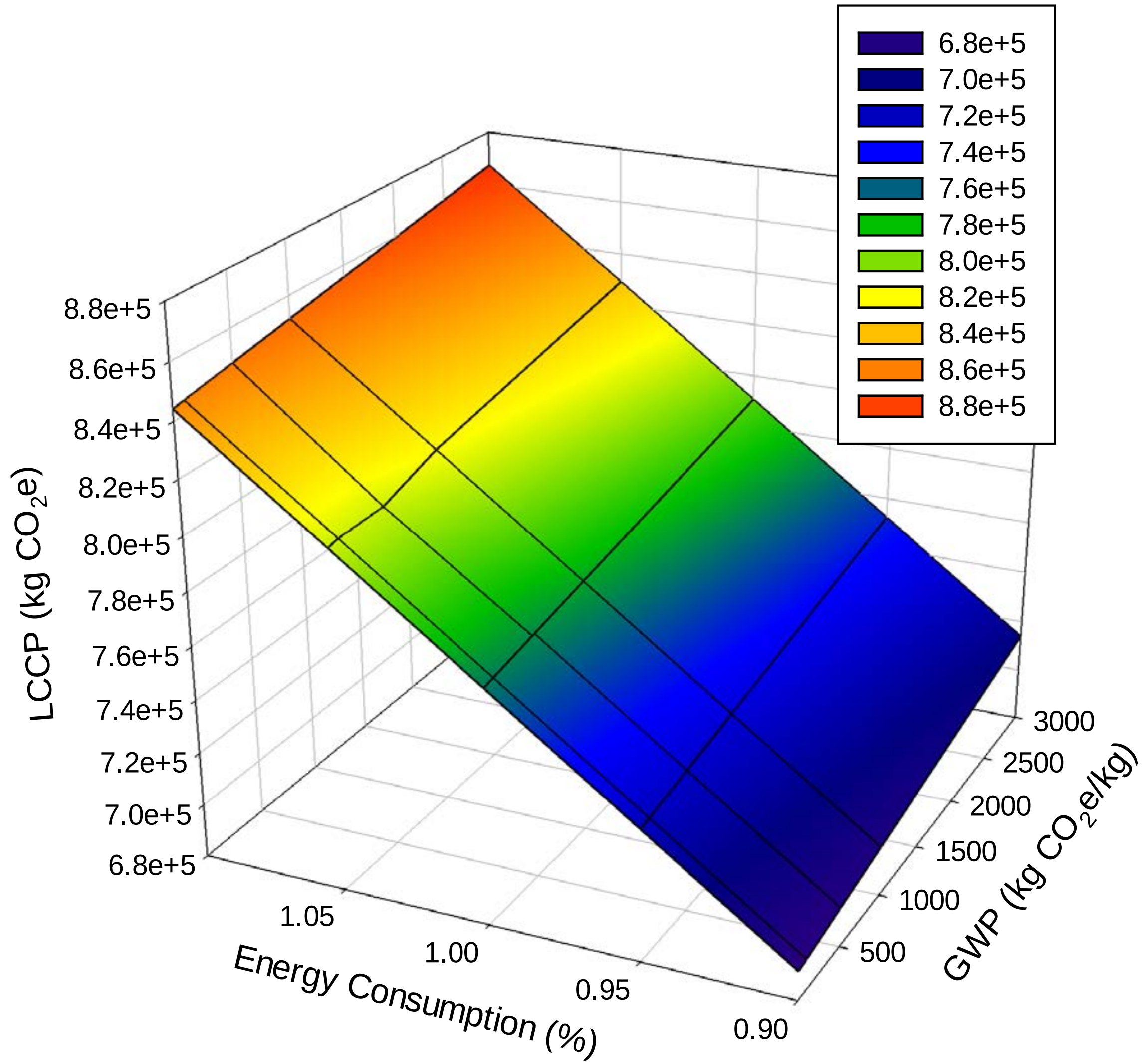
Energy Efficiency Sensitivity Study



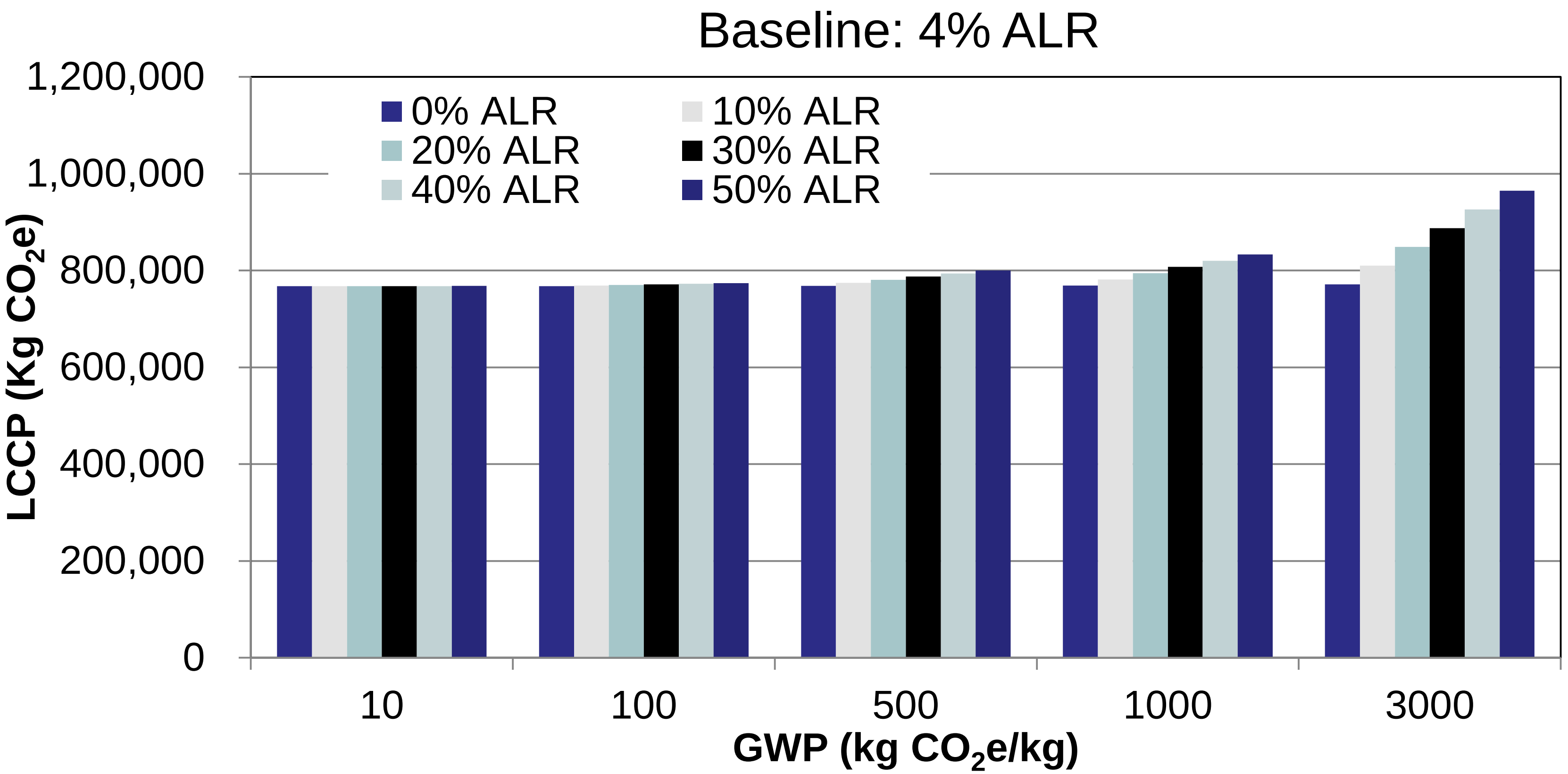
% Change in LCCP from Baseline Model

GWP	10	100	500	1000	3000
90% Energy Consumption	-10.0	-10.0	-9.9	-9.9	-9.7
110% Energy Consumption	10.0	10.0	9.9	9.9	9.7

Energy Efficiency Sensitivity Study



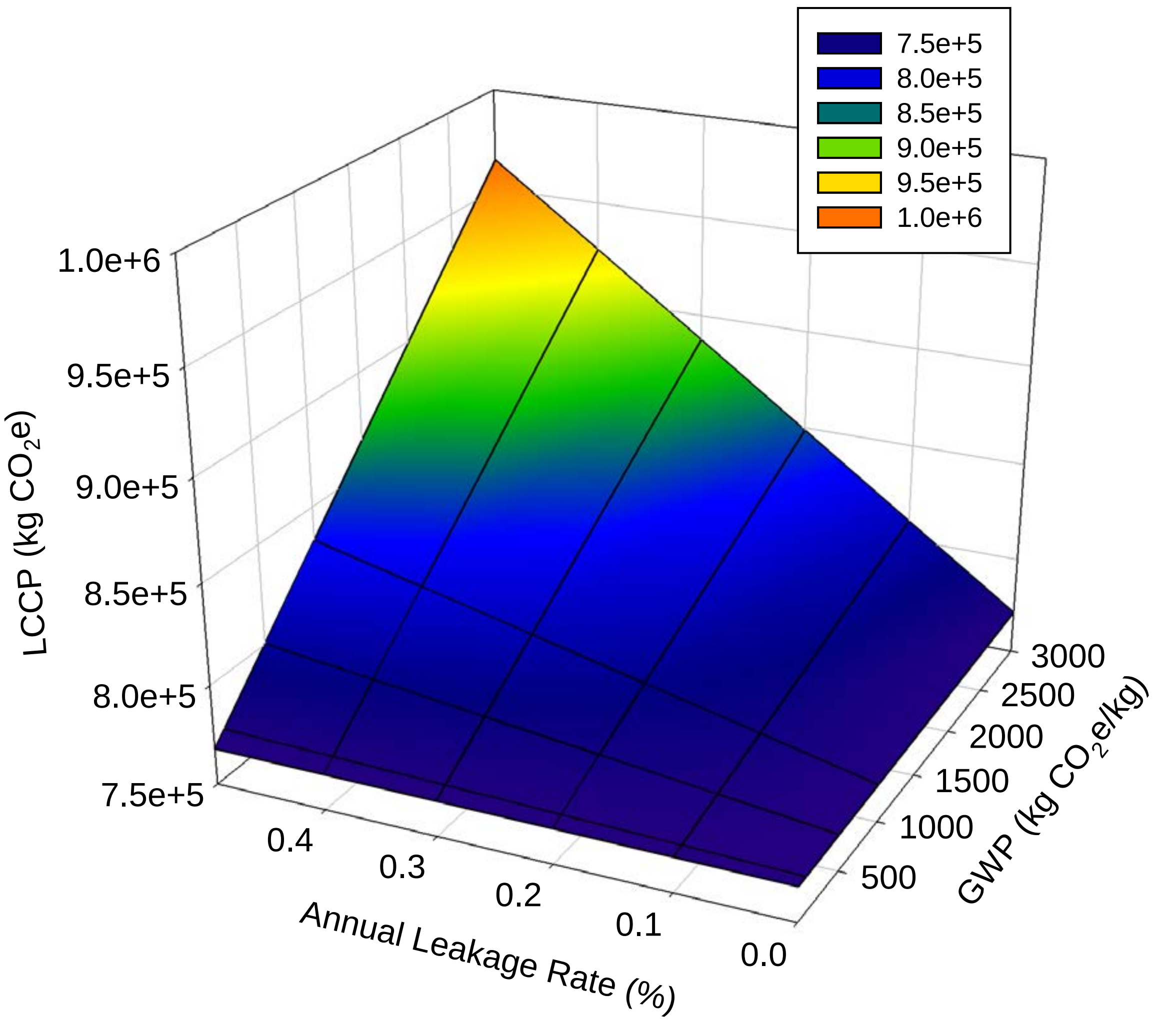
Annual Leakage Rate Sensitivity Study



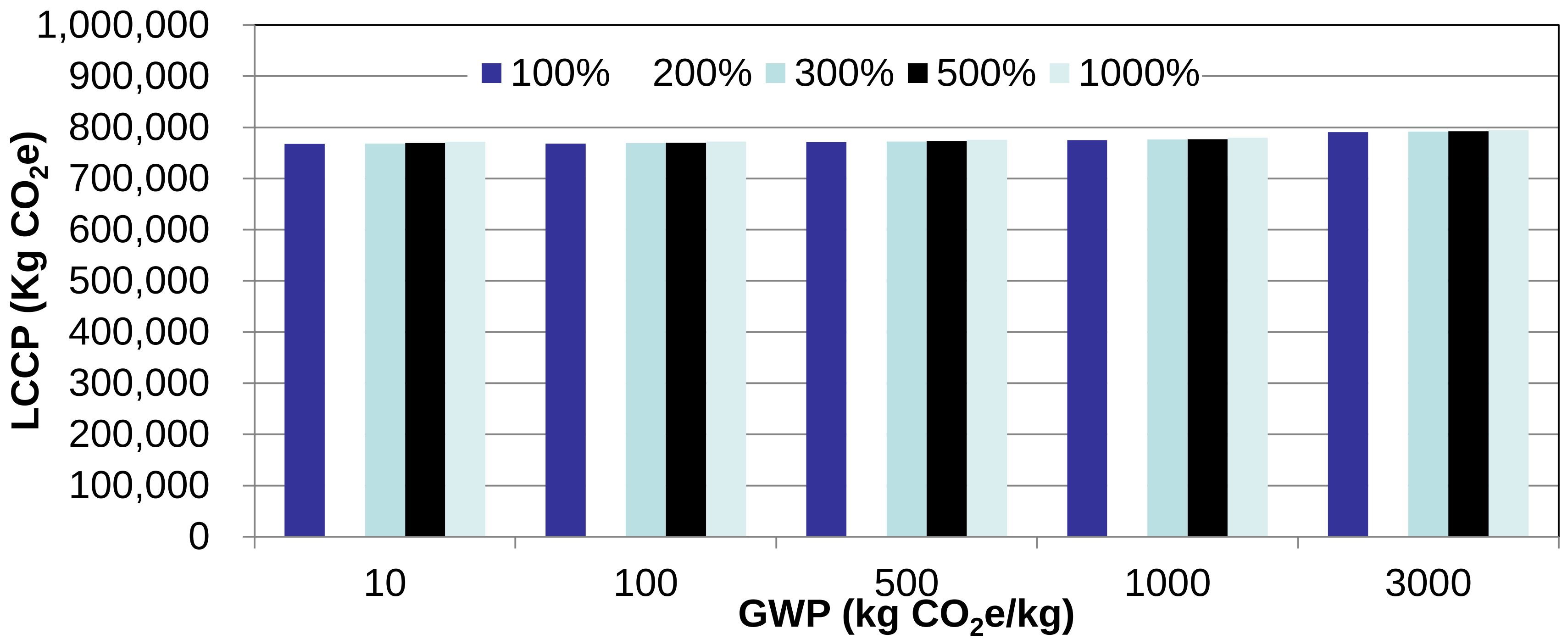
% Change in LCCP from Baseline Model

GWP	10	100	500	1000	3000
0% ALR	-0.01	-0.08	-0.42	-0.83	-2.45
30% ALR	0.04	0.42	2.1	4.2	12.2
50% ALR	0.1	0.8	3.8	7.5	22

Annual Leakage Rate Sensitivity Study



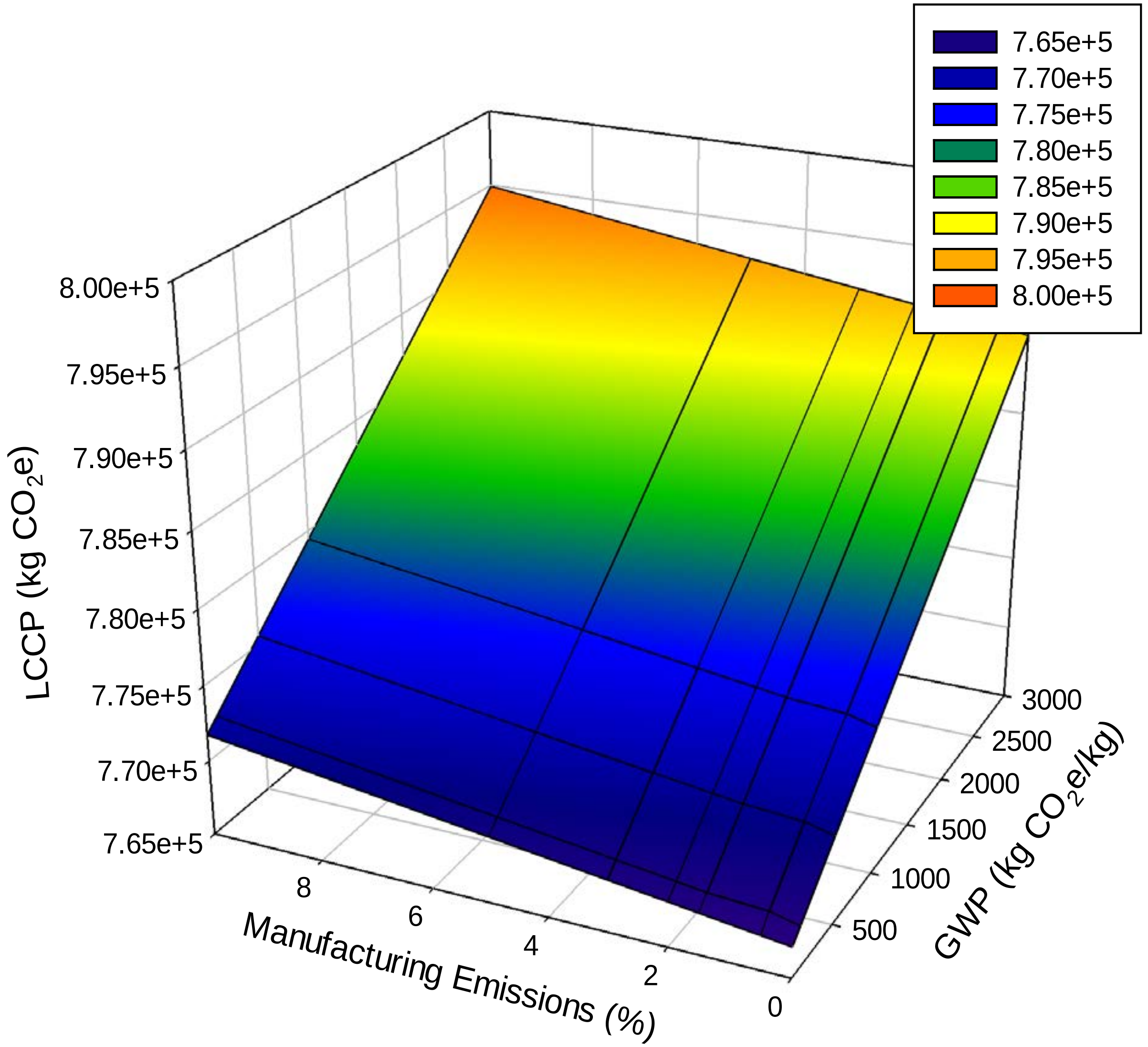
Manufacturing Emissions Sensitivity Study



% Change in LCCP from Baseline Model

GWP	10	100	500	1000	3000
300% Manufacturing Emissions	0.12	0.12	0.12	0.12	0.12
500% Manufacturing Emissions	0.25	0.25	0.25	0.25	0.24
1000% Manufacturing Emissions	0.55	0.55	0.55	0.55	0.54

Manufacturing Emissions Sensitivity Study



Commercial Applications Summary

- Energy efficiency is the most influential fact in LCCP for chillers.
- The climate of the location has a large impact on the energy consumption of the unit. The more temperate the location the less emissions the unit generates.
- Annual leakage rate does not have an appreciable impact on the results for GWPs of less than 100.
- Manufacturing emissions do not have an appreciable impact on the results unless they are magnified by at least a factor of 5.
- The sensitivity studies show similar trend to the residential heat pump sensitivity studies.

Advanced VCC Options

Subcooling Cycles

- Increases the amount of subcooling the refrigerant is subjected to prior to entering the expansion valve
- Increases efficiency of cycle by enhancing the refrigeration effect

Modeled: Suction Line Heat Exchanger

Expansion Loss Recovery Cycles

- Uses various devices to recover work performed by the expansion device
- Increases the cooling capacity through an isentropic process
- Recovered work can be used to power the compressor

Modeled: Expander Cycle, Ejector Cycle

Multi-stage Cycles

- Decreases the performance degradation that occurs when the temperature difference between the condenser and evaporator is high
- Reduces the irreversibility in compression that occurs at extreme temperatures

Modeled: Vapor Injection Flash Tank Cycle

Baseline VCC Modeling Assumptions

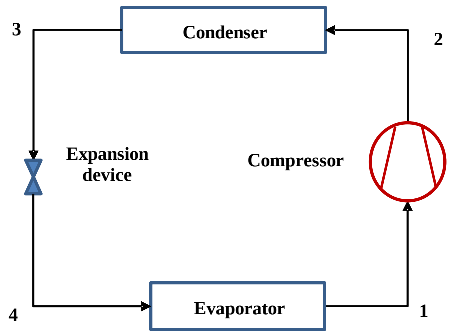
Unit: Goodman SSZ140361B
Experimental Work: AREP #20
Refrigerant: R-410A

Compressor Efficiency	(0.9-0.0467*PR)*.95
Isentropic Efficiency	0.9-0.0467*PR
Volumetric Efficiency	1-0.04*PR
Motor Efficiency	0.90
Condenser Air Flow Rate	0.59 m^3/s
Evaporator Air Flow Rate	0.63 m^3/s
Compressor RPM	3,500
Compressor Displacement	27.4 cc/rev

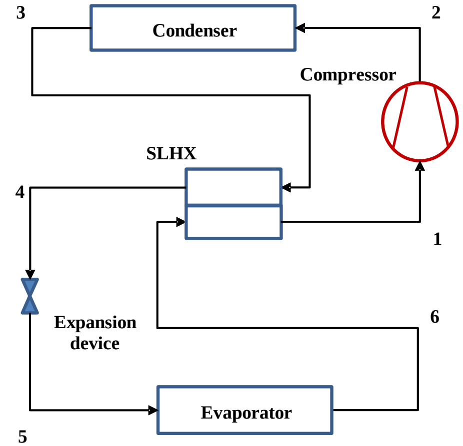
AHRI 210/240 Test	A	B	H1	H2	H3
Low Pressure (kPa)	1099	1082.7	835.8	710.2	521.7
High Pressure (kPa)	2608.8	2201.1	2304.5	2160.1	1943.3
Subcooling (K)	3	3	9	10	10
Superheating (K)	2	2	5	5	5

Modeled in Engineering Equation Solver

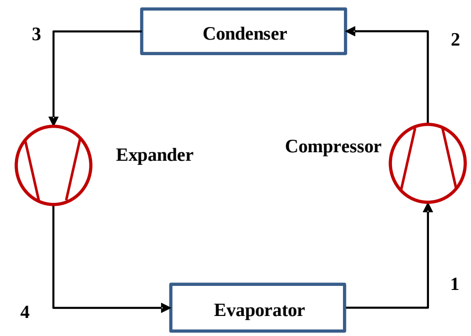
Cycle Options



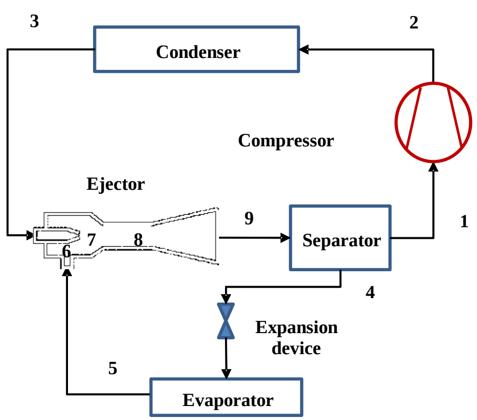
(a) Baseline VCC



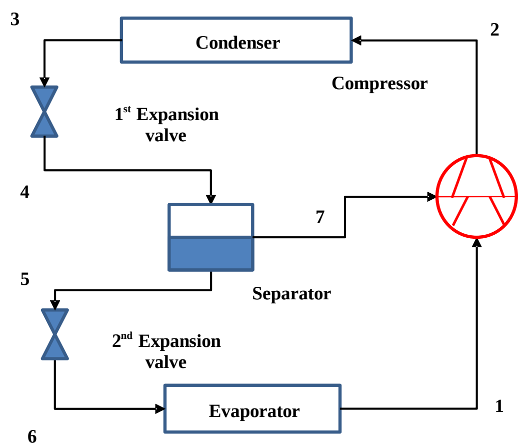
(b) SLHX cycle



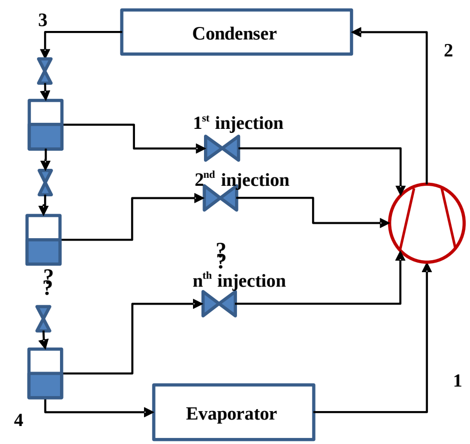
(c) Expander cycle



(d) Ejector VCC

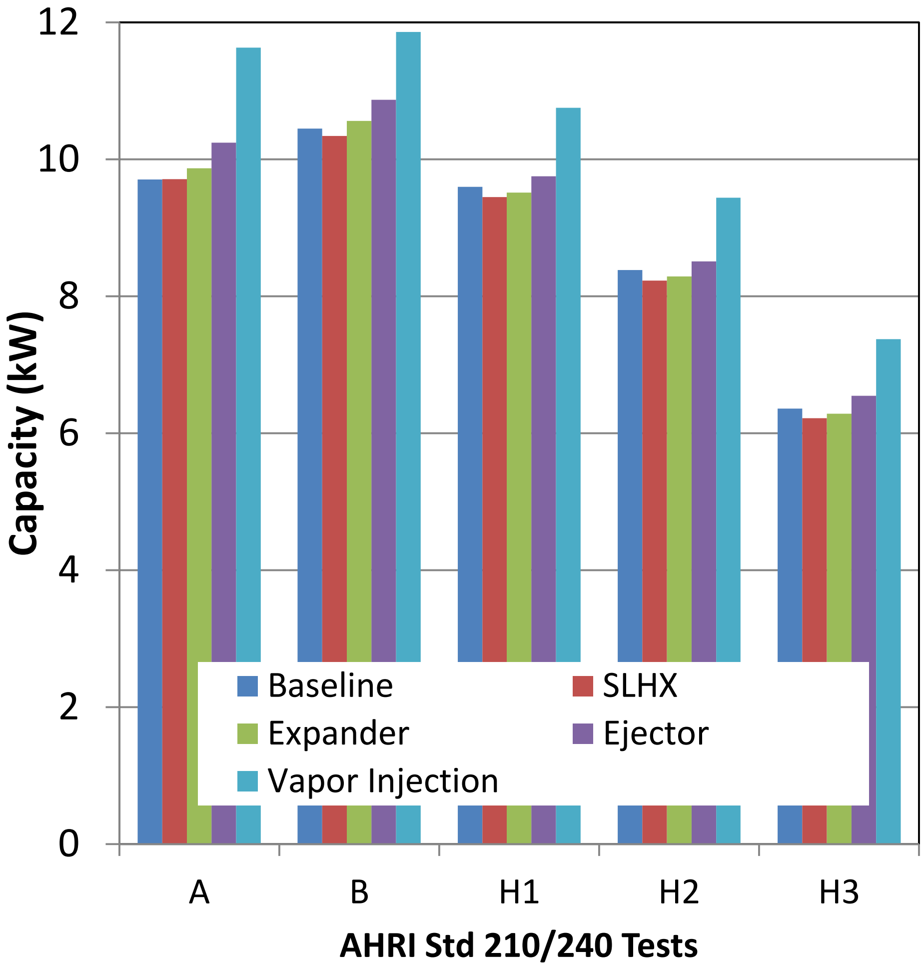


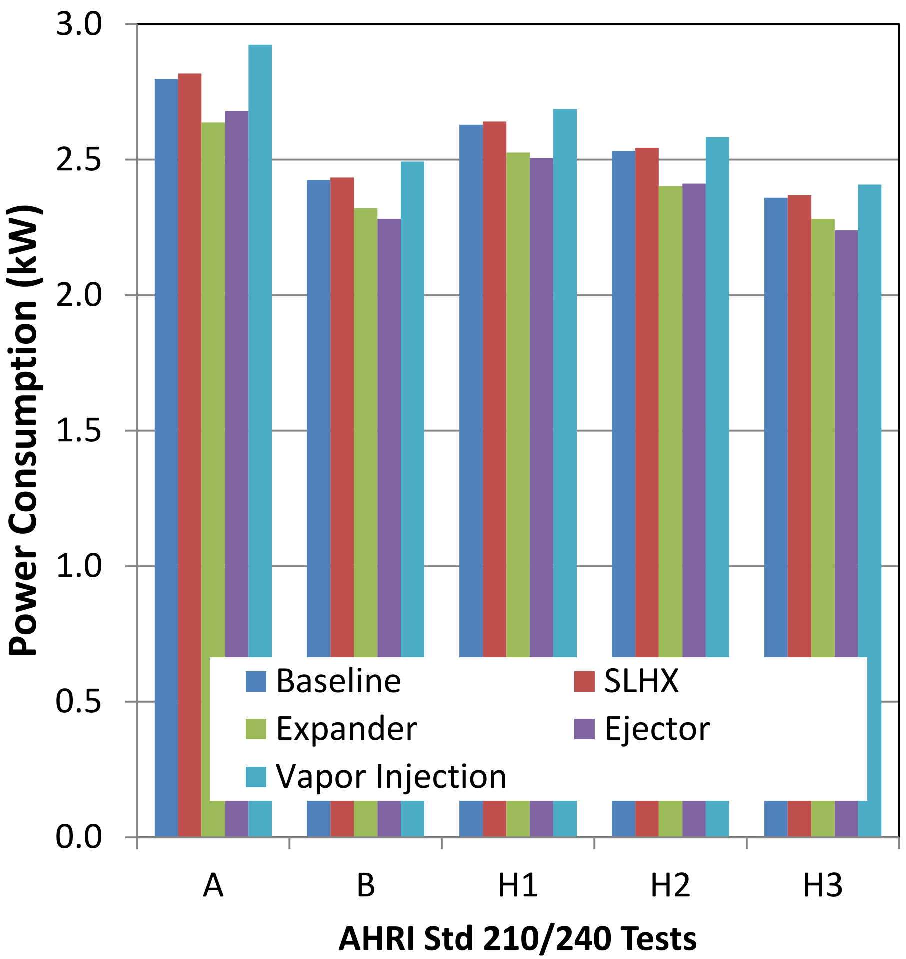
(e) VI cycle



(f) Saturation VCC

Advanced Cycles: Modeling Results





Advanced Cycles: LCCP Comparison

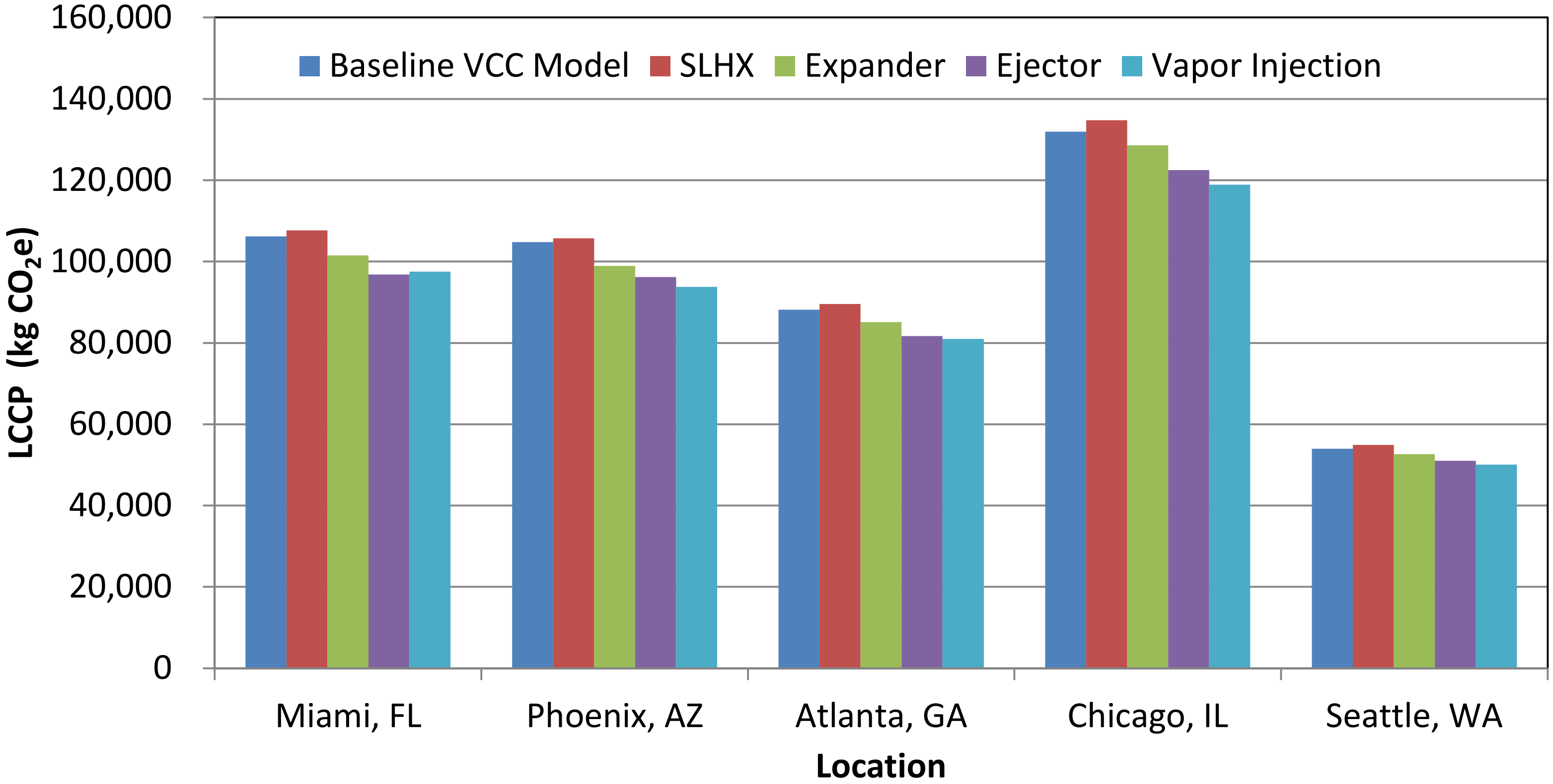
Parametric study was conducted for each temperature bin

Power consumption was prorated for each bin for the same capacity as the baseline cycle

% change in power consumption between the baseline and the advanced cycle was applied to the LCCP calculation

$$\frac{Modeled\ Capacity}{Modeled\ Power\ Consumption} = \frac{Baseline\ Capacity}{Prorated\ Power\ Consumption}$$

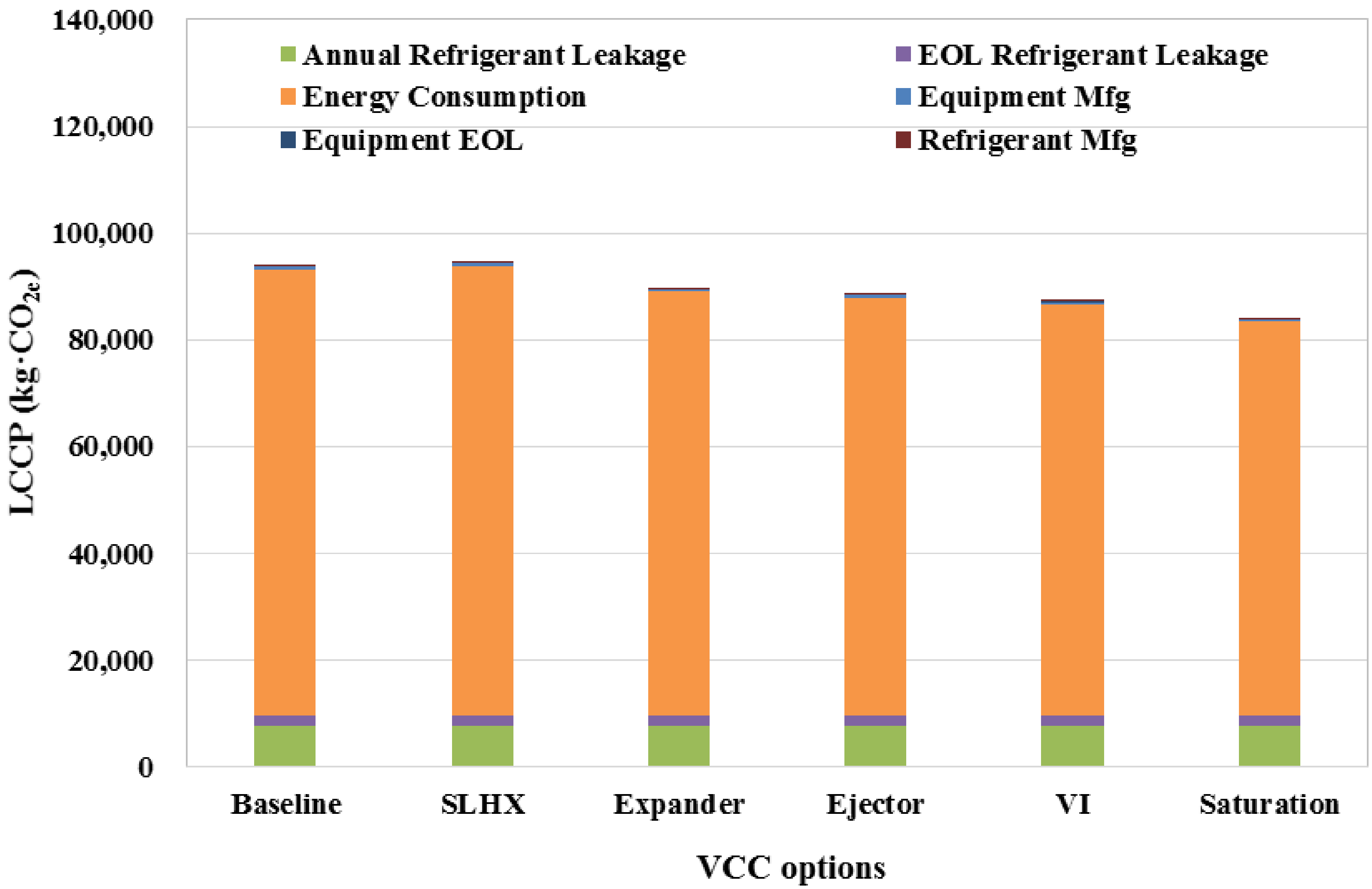
Advanced Cycles with R410A



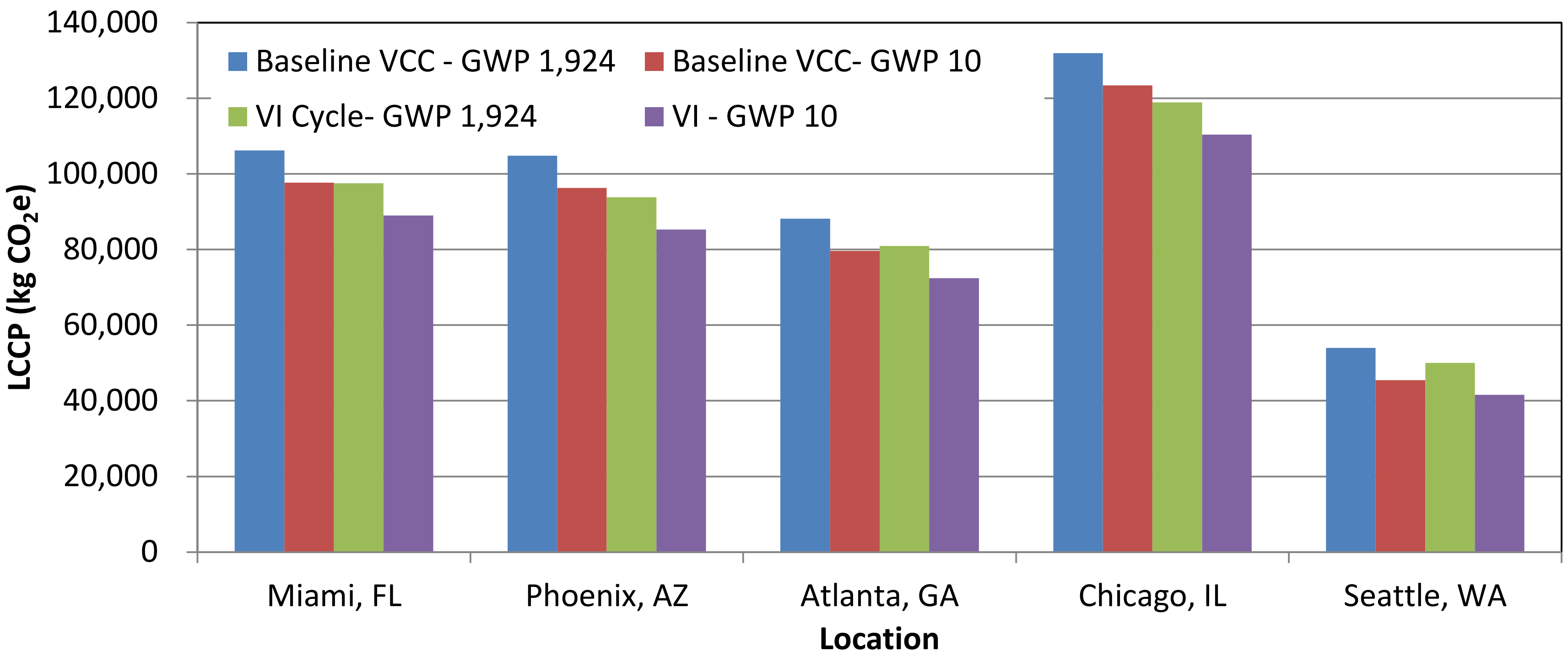
% Change in LCCP versus Baseline Model

Location	Miami, FL	Phoenix, AZ	Atlanta, GA	Chicago, IL	Seattle, WA
SLHX	1.4%	0.8%	1.6%	2.1%	1.7%
Expander	-4.4%	-5.6%	-3.5%	-2.6%	-2.4%
Ejector	-8.8%	-8.2%	-7.3%	-7.2%	-5.4%
VI-FT	-8.2%	-10.5%	-8.2%	-9.9%	-7.3%

Advanced Cycles with R410A



Advanced Cycles with Low GWP Refrigerants



% Change in LCCP versus Baseline Model

Location	Miami, FL	Phoenix, AZ	Atlanta, GA	Chicago, IL	Seattle, WA
Baseline – GWP 10	-8.0	-8.1	-9.7	-6.5	-15.8
Vapor Injection – GWP 1,924	-8.2	-10.5	-8.2	-9.9	-7.3
Vapor Injection – GWP 10	-16.2	-18.6	-17.8	-16.3	-23.0

Conclusions

- IIR LCCP Guideline recommends how to perform the LCCP calculation and data sources for the individual components.
- The more temperate the climate, such as Seattle, WA, the more of an impact direct emissions will have.
- Energy consumption is the main contributor to the LCCP followed by annual refrigerant leakage.
- Using low GWP refrigerant (GWP=10) is equivalent to improving energy efficiency by 8% in Miami, US.
- Reducing the LCCP more than 20% requires innovative energy efficient technologies and ultra low GWP refrigerants.