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IIR Working Group
Life Cycle Climate Performance Guideline

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IIR Working Group: Life Cycle Climate Performance Evaluation

Latest Progress

- **Proposed 3-page Short *LCCP Guideline***
  - **On January 27, 2015, a draft version of 3-page *short LCCP guideline* was presented.**
- **Prepared and distributed a *booklet for LCCP guideline* (V.6)**
  - **On July 14, 2015, we distributed a draft *booklet for LCCP guideline* together with a *reference database* written in excel for working group member's review.**
- **Prepared an excel *LCCP Calculation Tool* (V.4)**
  - **We developed a *LCCP calculation tool for residential heat pumps* in excel.**
- **Drafting an *Informatory Note for LCCP Guideline***
  - **We drafted an *informatory note for LCCP guideline*.**

Proposed LCCP Guideline

Guideline for Life Cycle Climate Performance
August 2015

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.

2. Calculation Method

2.1 Calculation Method

The methodology for calculating **LCCP** is for stationary refrigeration and air conditioning systems that operate using the vapor compression cycle and are powered primarily by electricity from the local electricity grid. **LCCP** is calculated in kg CO_{2e}. Different systems can be directly compared when both calculations use the same assumptions and calculation method as presented. This methodology can be applied to all **HVAC&R** applications such as commercial chillers, residential heat pumps and the automotive industry. This guide uses a residential heat pump as an example.

LCCP is comprised of two general emissions categories: direct and indirect emissions. The breakdown of these factors is shown in Figure 2.1. Each factor is calculated separately. These factors are further explained in Chapters 3 and 4.

Direct emissions account for the refrigerant leaked over the course of the unit's lifetime including annual leakage, catastrophic leaks and leakage when the unit is disposed of. It also includes atmospheric degradation products created by the refrigerant when it decomposes in the atmosphere.

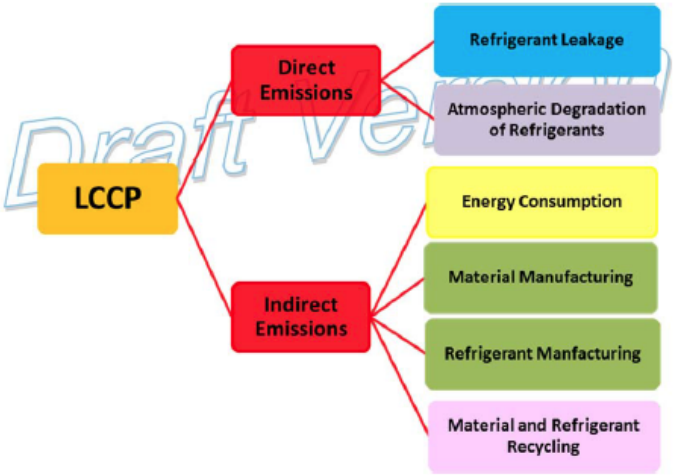


Figure 2.1: LCCP Components

LCCP Equation

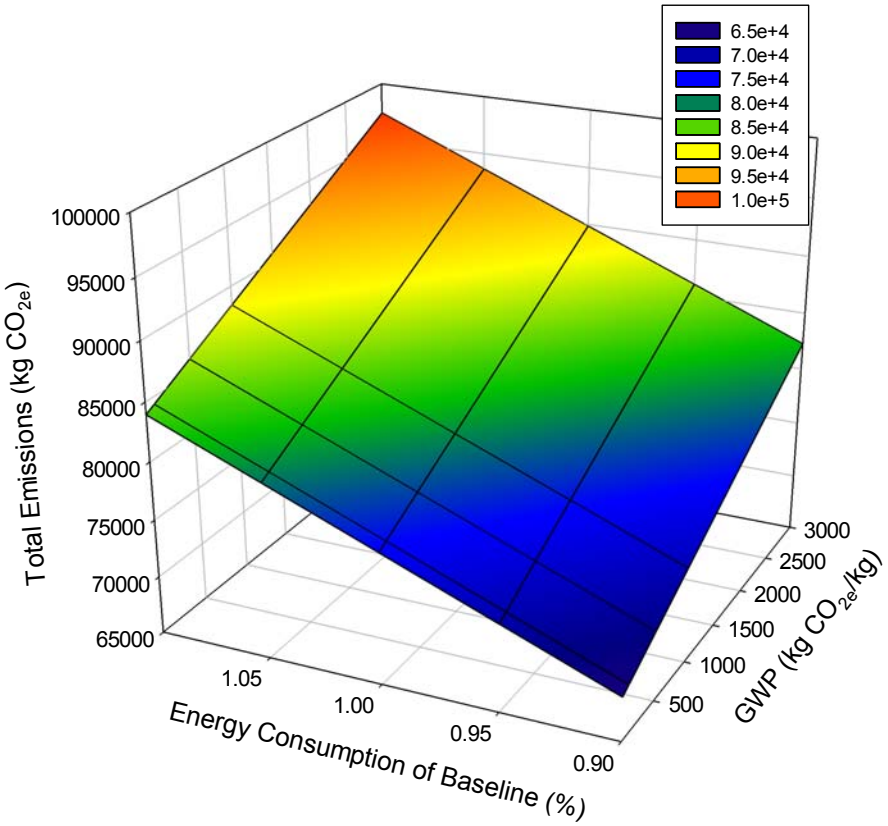
$$LCCP = \text{Direct Emissions} + \text{Indirect Emissions}$$

$$\text{Direct Emissions} = C * [(GWP + \text{Adp. } GWP) * (L * ALR + EOL)]$$

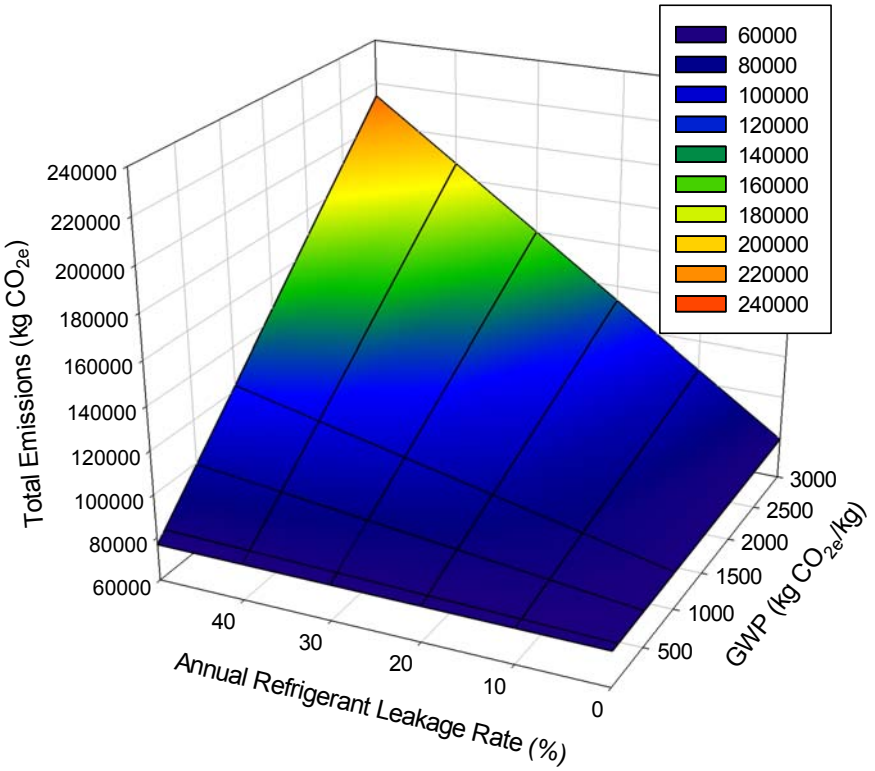
$$\text{Indirect Emissions} = L * AEC * EM + MM * m + RM * mr + RFM * C + L * ALR * RFM * C + C * (1 - EOL) * RFD$$

C = Refrigerant Charge (kg)
GWP = Global Warming Potential (kg CO_{2e}/kg)
Adp. GWP = GWP of Atmospheric Degradation Product of the Refrigerant (kg CO_{2e}/kg)
L=Average Lifetime of Equipment (yr)
ALR = Annual Leakage Rate (% of Refrigerant Charge)
EOL = End of Life Emissions (% of Refrigerant Charge)
AEC = Annual Energy Consumption (kWh)
EM = CO_2 produced/kWh (kg CO_{2e}/kWh)
MM = CO_{2e} Produced/kg of Material (kg CO_{2e}/kg)
m = Mass of Unit/Material (kg)
RM = CO_{2e} Produced/kg of Recycled Material (kg CO_{2e}/kg)
mr = Mass of Recycled Material (kg)
RFM = Refrigerant Manufacturing Emissions (kg CO_{2e}/kg)
RFD = CO_{2e} Produced/kg of Refrigerant Recycled (kg CO_{2e}/kg)

Sensitivity Study



Energy Consumption



Annual Refrigerant Leakage

- Energy Consumption has the biggest impact on total emissions
- Several terms can be neglected when GWP is small

Sensitivity Study – GWP Values

GWP Value	10	100	1,000
Total Direct Emission	0.06%	0.59%	5.57%
Annual Refrigerant Leakage	0.047%	0.47%	4.46%
EOL Refrigerant Loss	0.01%	0.12%	1.11%
Adaptive GWP	-	-	-
Total Indirect Emissions	99.94%	99.41%	94.43%
Energy Consumption	99.40%	98.87%	93.91%
Equipment Manufacturing	0.54%	0.53%	0.51%
Refrigerant Manufacturing	0.13%	0.13%	0.13%
Equipment EOL	0.01%	0.01%	0.01%

- GWP values were varied using the residential heat pump in Chapter 6 of the LCCP Guideline booklet

LCCP Equation Terms

Term	≤ GWP 10	≤ GWP 100	≤ GWP 1,000	> GWP 1,000
Annual Refrigerant Leakage	✗	✓	✓	✓
EOL Refrigerant Leakage	✗	✓	✓	✓
Adaptive GWP	✗	✗	✓	✓
Energy Consumption	✓	✓	✓	✓
Material Manufacturing	✓	✓	✓	✓
Refrigerant Manufacturing	✓	✓	✓	✓
Unit EOL	✗	✗	✗	✓
✓ - Include Term, ✗ - Neglect Term				

Simplified LCCP Equation for 100>GWP>10

$$LCCP = \text{Direct Emissions} + \text{Indirect Emissions}$$

$$\text{Direct Emissions} = C * GWP * (L * ALR + EOL)$$

$$\text{Indirect Emissions} = L * AEC * EM + MM * m + RFM * C + L * ALR * RFM * C$$

C = Refrigerant Charge (kg)
GWP = Global Warming Potential (kg CO_{2e}/kg)
L=Average Lifetime of Equipment (yr)
ALR = Annual Leakage Rate (% of Refrigerant Charge)
EOL = End of Life Refrigerant Leakage (% of Refrigerant Charge)
AEC = Annual Energy Consumption (kWh)
EM = CO_2 Produced/kWh of Energy (kg CO_{2e}/kWh)
MM = CO_2 Produced/kg of Material (kg CO_{2e}/kg)
m = Mass of Unit/Material (kg)
RFM = Refrigerant Manufacturing Emissions (kg CO_{2e}/kg)

LCCP IIR Excel Tool for Residential Heat Pump

- 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
- Full LCCP and Simplified LCCP
- Inputs in SI units

LCCP IIR Excel Tool for Residential Heat Pump – User Inputs

IIR LCCP Working Group Residential Heat Pump Excel Tool

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

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	10,300	2,280
Cooling	B Test	11,100	2,110
Heating	H1 Test	10,300	2,500
Heating	H2 Test	8,500	2,370
Heating	H3 Test	6,200	2,310

User Input:

Energy Calculation is perform

INSTRUCTIONS

1. Select the refrigerant from
2. Enter the charge, unit weig
3. Select "Virgin" or "Mixed"
4. Enter the Cut Off Temperatu
5. Enter the AHRI Standard 21

Refrigerant Options: HFC-32, H

LCCP IIR Excel Tool for Residential Heat Pump – Outputs

LCCP Results

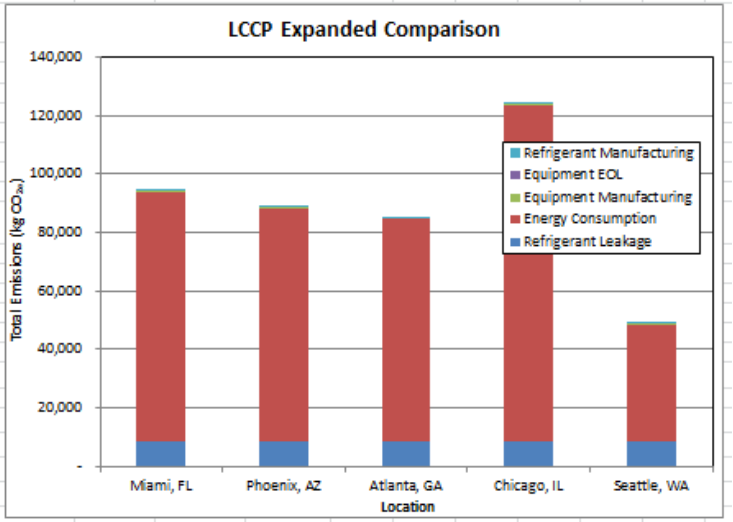
Location	Miami, FL	Phoenix, AZ	Atlanta, GA	Chicago, IL	Seattle, WA
Total Lifetime Emission (kg CO_{2e})	94,219.43	88,792.67	84,993.57	123,766.95	48,804.08
Total Direct Emission (kg CO_{2e})	8,658.00	8,658.00	8,658.00	8,658.00	8,658.00
Annual Refrigerant Leakage (kg CO_{2e})	6,926.40	6,926.40	6,926.40	6,926.40	6,926.40
EOL Refrigerant Leakage (kg CO_{2e})	1,731.60	1,731.60	1,731.60	1,731.60	1,731.60
Adp. GWP (kg CO_{2e})	-	-	-	-	-
Total Indirect Emissions (kg CO_{2e})	85,561.43	80,134.67	76,335.57	115,108.95	40,146.08
Energy Consumption (kg CO_{2e})	85,146.26	79,719.49	75,920.40	114,693.78	39,730.91
Equipment Mfg (kg CO_{2e})	408.71	408.71	408.71	408.71	408.71
Equipment EOL (kg CO_{2e})	6.46	6.46	6.46	6.46	6.46
Refrigerant Mfg (kg CO_{2e})	102.72	102.72	102.72	102.72	102.72

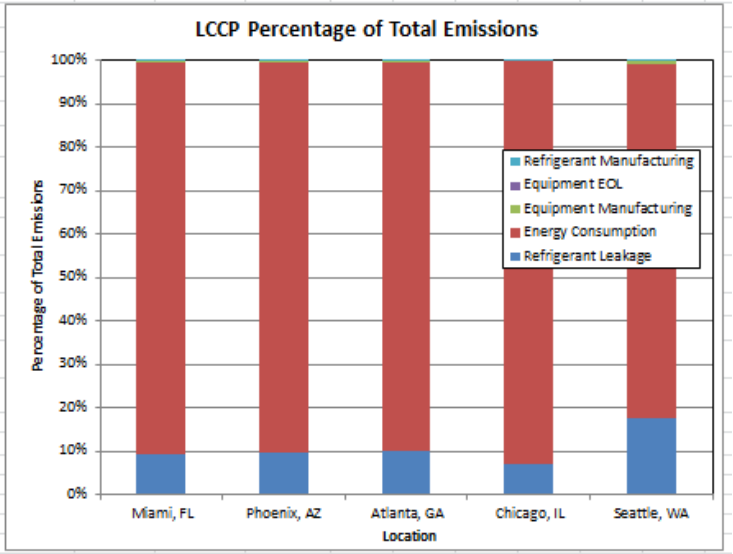
Expanded Energy Consumption Results

Location	Miami, FL	Phoenix, AZ	Atlanta, GA	Chicago, IL	Seattle, WA
Electricity Generation Region	Eastern Interconnection	Western Interconnection	Eastern Interconnection	Eastern Interconnection	Western Interconnection
Annual Cooling Energy Consumption (kWh)	6,995.97	7,830.47	3,146.52	1,644.95	465.66
Annual Cooling Emissions (kg CO_{2e})	5,512.83	4,651.30	2,479.45	1,296.22	276.60
Heating Climate Region	I	II	III	IV	V
Annual Heating Energy Consumption (kWh)	207.60	1,116.73	3,276.53	8,058.41	3,993.47
Heating Emissions (kg CO_{2e})	163.59	663.34	2,581.91	6,350.03	2,372.12

Percentage of Composition

Location	Miami, FL	Phoenix, AZ	Atlanta, GA	Chicago, IL	Seattle, WA
Total Direct Emission	9.19%	9.75%	10.19%	7.00%	17.74%
Annual Refrigerant Leakage	7.35%	7.80%	8.15%	5.60%	14.19%
EOL Refrigerant Leakage	1.84%	1.95%	2.04%	1.40%	3.55%
Adp. GWP	-	-	-	-	-
Total Indirect Emissions	90.81%	90.25%	89.81%	93.00%	82.26%
Energy Consumption	90.37%	89.78%	89.32%	92.67%	81.41%
Equipment Mfg	0.43%	0.46%	0.48%	0.33%	0.84%
Equipment EOL	0.01%	0.01%	0.01%	0.01%	0.01%
Refrigerant Mfg	0.11%	0.12%	0.12%	0.08%	0.21%





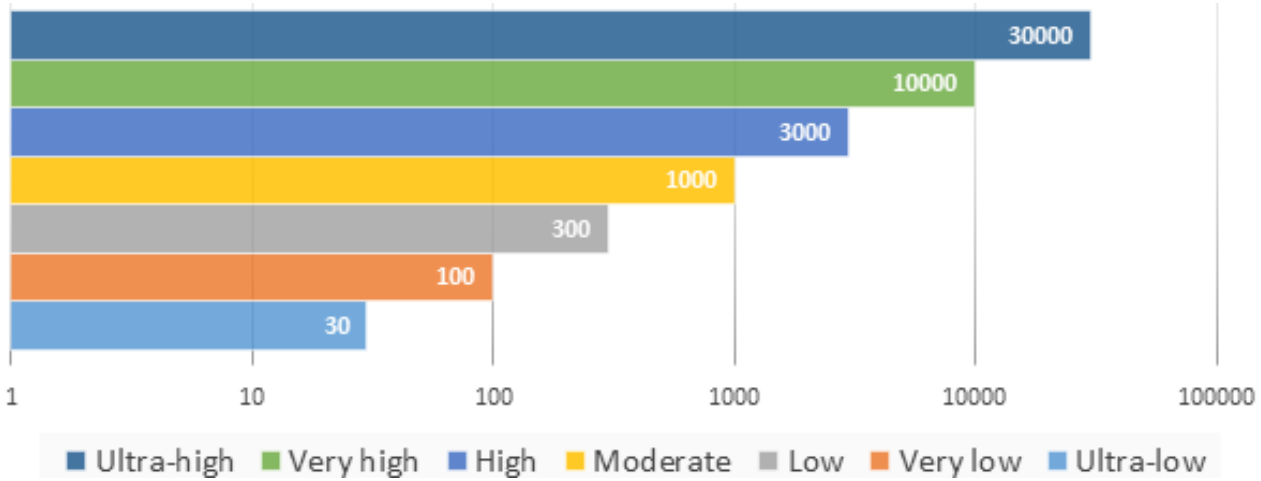
LCCP Tool Recommendations

Application	GWP <10	GWP <100	GWP <1000	GWP >1000
Mobile Air Conditioning	GREEN-MAC-LCCP	GREEN-MAC-LCCP	GREEN-MAC-LCCP	GREEN-MAC-LCCP
Residential Heat Pumps	TEWI	IIR LCCP Simplified	IIR LCCP	AHRI LCCP
Commercial Applications	TEWI	ORNL LCCP	ORNL LCCP	ORNL LCCP

Available Tools:

- GREEN-MAC-LCCP
- AHRI LCCP Excel Tool
- ORNL LCCP Excel Tool
- IIR LCCP Excel Tool

Refrigerant Classifications



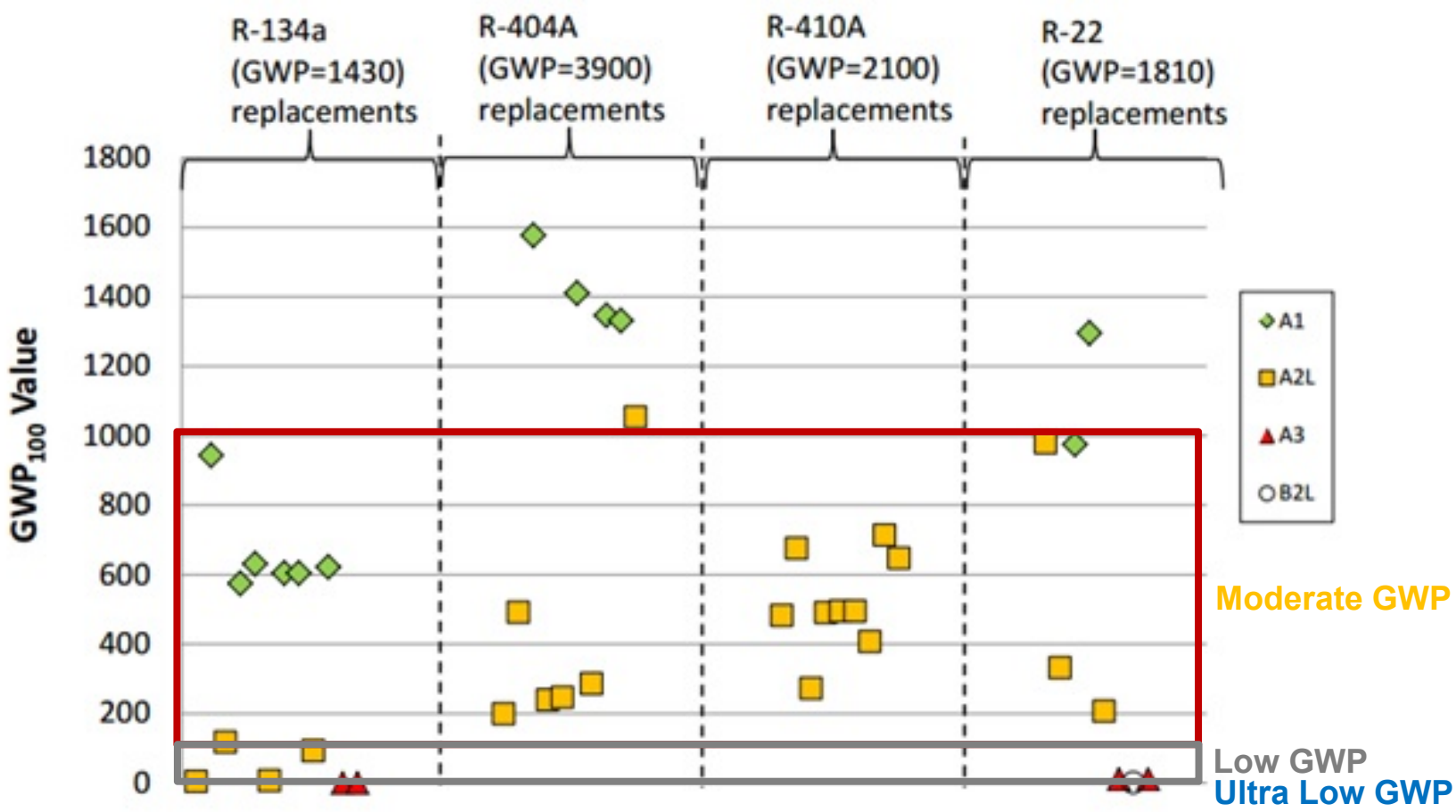
UNEP, TEAP 2010 progress report. Volume 1., 2010.

Classification	GWP Range
Ultra High	> 10,000
Very High	3,000 - 10,000
High	1,000 - 3,000
Moderate	300 - 1,000
Low	100 – 300
Very Low	30 – 100
Ultra Low	0 - 30

IIR LCCP WG, 2015

Classification	GWP Range
Ultra High	> 10,000
High	1,000 - 10,000
Moderate	100 - 1,000
Low	10 - 100
Ultra Low	0 - 10

Refrigerant Types



K. Amrane, Overview of AHRI Research on Low-GWP Refrigerants, 2013.

Reference Heat Pump

Inputs	Value	Units
Capacity	3.0	tons
Refrigerant	R-410A	
System Lifetime	15	yr
System Charge	6	kg
Annual Leakage Rate	4	%
Refrigerant loss at EOL	15	%
Unit Weight	115	kg
Aluminum	*11.93 (12%)*	kg
Copper	*19.87 (19%)*	kg
Plastics	*24.10 (23%)*	kg
Steel	*49.56 (47%)*	kg
Location	*Atlanta, GA*	

Performance Characteristics from the IIR LCCP Guideline booklet Chapter 6: Residential Heat Pump sample problem

Residential Heat Pump Sample Problem

Refrigerant	GWP	GWP Category
HFC-410A	1,924	High
HFC-32	677	Moderate
L-41b	494	Moderate
DR-5	490	Moderate

- All refrigerants are treated as near drop in replacements for R-410A for evaluation purposes
- The A/C unit mass and composition percentages are consistent for all refrigerants

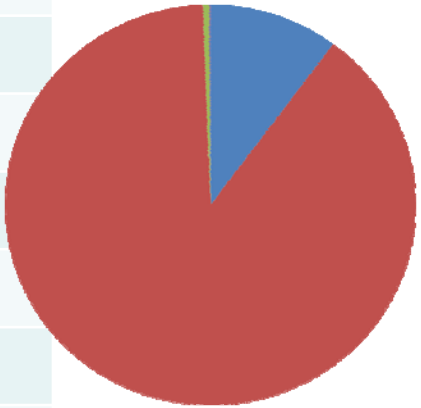
Refrigerant Characteristic Comparison with R-410A for Cooling

Refrigerant	Energy Usage	Charge	Total Capacity
HFC-32	93%	77%	102%
L-41b	92%	89%	95%
DR-5	95%	89%	97%
R-290	100%	49%	97%

- Information gathered from AHRI Low GWP AREP Reports 20, 22 and 31 and other research performed by CEEE at the University of Maryland
- Capacities vary for each refrigerant in comparison to HFC-410A and each other
- Most of replacement refrigerants are near to “drop-in” replacements for R-410A but can be improved by “soft optimization”

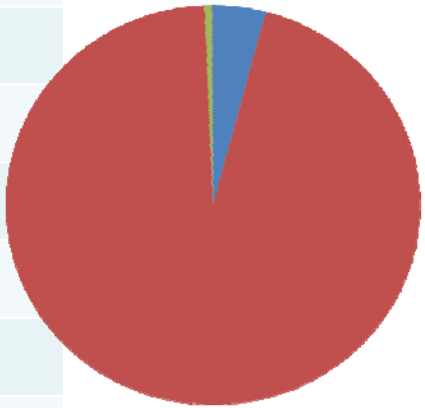
Residential Heat Pump Sample Problem
R-410A Emissions

Emission Category	Total Emissions (kg CO_{2e})	Percentage of Total Emissions
Total Direct Emissions	**8,658.00**	**10.17%**
Annual Refrigerant Leakage	6,926.40	8.14%
EOL Refrigerant Leakage	1,731.60	2.03%
Adp. GWP	-	0.00%
Total Indirect Emissions	**76,438.29**	**89.83%**
Energy Consumption	75,920.40	89.22%
Equipment Manufacturing	408.71	0.48%
Equipment EOL	6.46	0.01%
Refrigerant Manufacturing	102.72	0.12%
Total Emissions	**85,096.29**	-



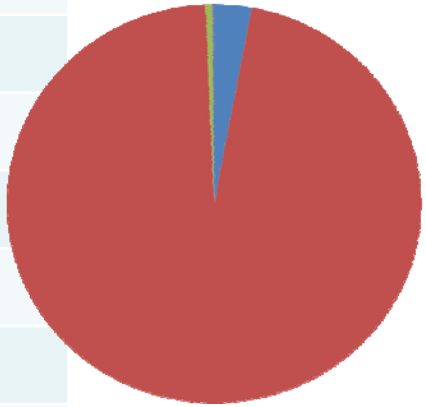
Residential Heat Pump Sample Problem
R-32 Emissions

Emission Category	Total Emissions (kg CO_{2e})	Percentage of Total Emissions
Total Direct Emissions	**3,046.50**	**4.11%**
Annual Refrigerant Leakage	2,437.20	3.28%
EOL Refrigerant Leakage	609.30	0.82%
Adp. GWP	-	0.00%
Total Indirect Emissions	**71,150.29**	**95.89%**
Energy Consumption	70,681.89	95.26%
Equipment Manufacturing	408.71	0.55%
Equipment EOL	6.46	0.01%
Refrigerant Manufacturing	53.22	0.07%
Total Emissions	**74,196.79**	-



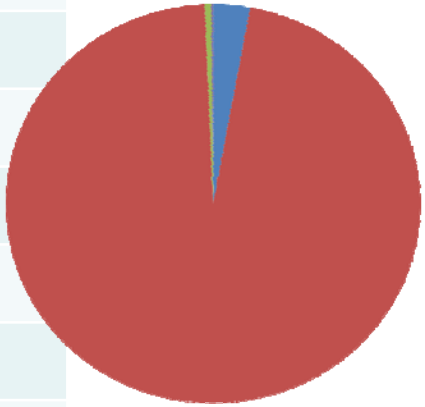
Residential Heat Pump Sample Problem
L-41b Emissions

Emission Category	Total Emissions (kg CO_{2e})	Percentage of Total Emissions
Total Direct Emissions	**2,223.00**	**2.91%**
Annual Refrigerant Leakage	1,778.40	2.33%
EOL Refrigerant Leakage	444.60	0.58%
Adp. GWP	-	0.00%
Total Indirect Emissions	**74,134.52**	**97.09%**
Energy Consumption	73,642.79	96.44%
Equipment Manufacturing	408.71	0.54%
Equipment EOL	6.46	0.01%
Refrigerant Manufacturing	76.55	0.10%
Total Emissions	**76,357.52**	-



Residential Heat Pump Sample Problem
DR-5 Emissions

Emission Category	Total Emissions (kg CO_{2e})	Percentage of Total Emissions
Total Direct Emissions	2,205.00	2.86%
Annual Refrigerant Leakage	1,764.00	2.29%
EOL Refrigerant Leakage	441.00	0.57%
Adp. GWP	-	0.00%
Total Indirect Emissions	74,893.98	97.14%
Energy Consumption	74,401.99	96.50%
Equipment Manufacturing	408.71	0.53%
Equipment EOL	6.46	0.01%
Refrigerant Manufacturing	76.81	0.10%
Total Emissions	77,098.98	-

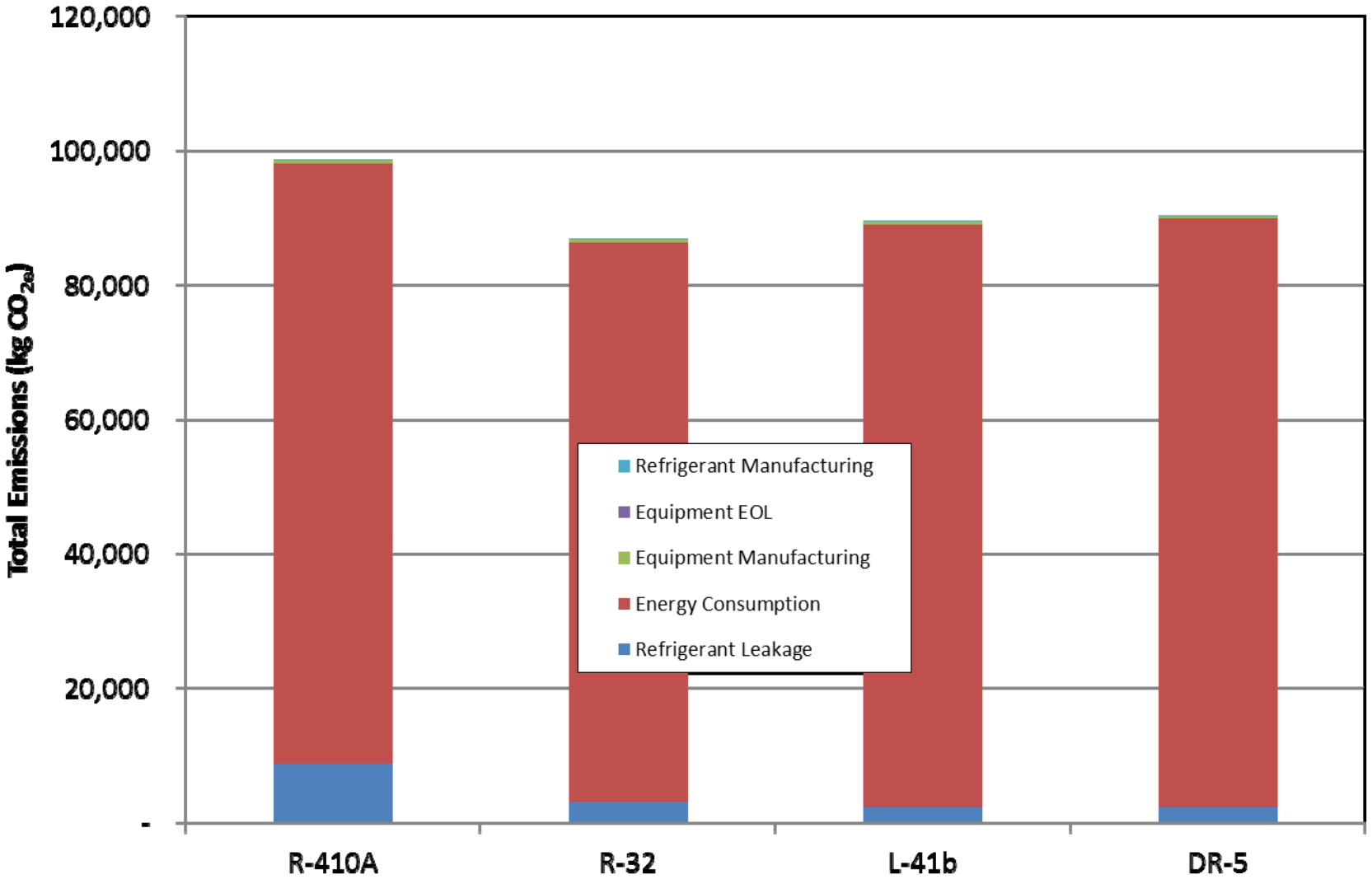


LCCP Comparison

Unit: kg CO_{2e}

Emission Category	HFC-410A	HFC-32	L-41b	DR-5
Total Direct Emissions	**8,658.00**	**3,046.50**	**2,223.00**	**2,205.00**
Annual Refrigerant Leakage	6,926.40	2,437.20	1,778.40	1,764.00
EOL Refrigerant Leakage	1,731.60	609.30	444.60	441.00
Adp. GWP	-	-	-	-
Total Indirect Emissions	**76,438.29**	**71,150.29**	**74,134.52**	**74,893.98**
Energy Consumption	75,920.40	70,681.89	73,642.79	74,401.99
Equipment Manufacturing	408.71	408.71	408.71	408.71
Equipment EOL	6.46	6.46	6.46	6.46
Refrigerant Manufacturing	102.72	53.22	76.55	76.81
Total Emissions	**85,096.29**	**74,196.79**	**76,357.52**	**77,098.98**

Total Emissions Comparison

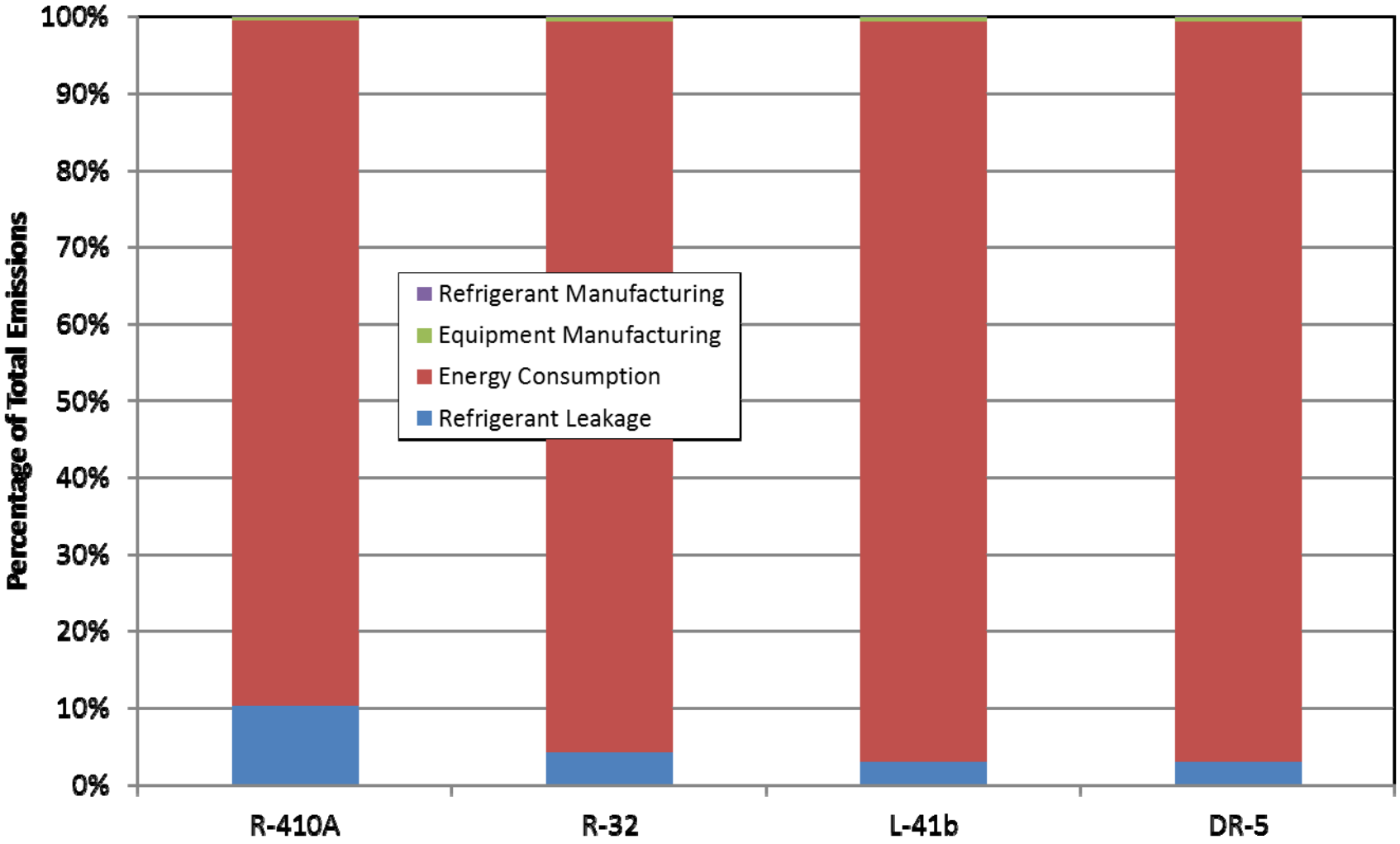


Comparison – Percentage of Total Emissions

Emission Category	HFC-410A	HFC-32	L-41b	DR-5
Total Direct Emissions	10.17%	4.11%	2.91%	2.86%
Annual Refrigerant Leakage	8.14%	3.28%	2.33%	2.29%
EOL Refrigerant Leakage	2.03%	0.82%	0.58%	0.57%
Adp. GWP	0.00%	0.00%	0.00%	0.00%
Total Indirect Emissions	89.83%	95.89%	97.09%	97.14%
Energy Consumption	89.22%	95.26%	96.44%	96.50%
Equipment Manufacturing	0.48%	0.55%	0.54%	0.53%
Equipment EOL	0.01%	0.01%	0.01%	0.01%
Refrigerant Manufacturing	0.12%	0.07%	0.10%	0.10%

- Categories can be ignored because of their insignificant contribution to the overall lifetime emissions.
  - Equipment EOL (includes disposal of unit and refrigerant)
  - Refrigerant Manufacturing

Emissions Categories as Percentages



Conclusions

- Energy Consumption is the main contributor to total lifetime emissions (from 87.6% to 98.7% of total emissions in this example).
- The more temperate the climate, such as Seattle, WA, the more of an impact direct emissions will have.
- The most effective way to reduce emissions is to increase the energy efficiency of the unit.
- LCCP equation can be much simplified when negligible emission parameters are disregarded for lower GWP refrigerants.

Future Work

- Collect public comments
- Perform LCCP analysis for various locations
- Finalize and publish a booklet for LCCP guideline and informatory note
- Expand LCCP analysis to commercial applications
- Create excel tools and sample problems for commercial applications
  - Water chillers
  - Supermarkets

References

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