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IIR Working Party
Life Cycle Climate Performance Guideline

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Proposed LCCP Guideline

Life Cycle Climate Performance Evaluation Guideline

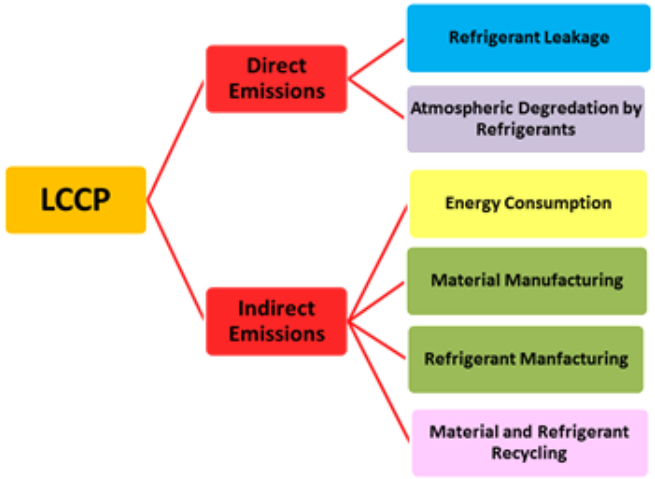
Life Cycle Climate Performance evaluation is a cradle to grave analysis of a system which includes both direct emissions and indirect emissions of a system. Direct emissions include all refrigerant leaked during the lifetime of the system. Indirect emissions include total energy consumption and emissions from manufacturing and recycling of the components. The tables and explanations in this guide provide the standard assumptions and accounting methods for the most common types of stationary cooling systems for the United States. [1-9]

A. Annual Energy Consumption

The preferred method to calculate the Annual Energy consumption of the system is to use an Annual Load Model in accordance with ASHRAE and IIR standards [10-12]. This model takes into consideration unit performance characteristics, unit load information, local weather data and regional power generation emissions rates. A modified temperature bin method should be used to analyze the weather data. Several sources for this data exist including the International Weather for Energy Calculations datasets (IWEC), 2013 and the National Renewable Energy Laboratories (NREL) – Typical Meteorological Year database (TMY3), 2011 [13-18]. Current power generation emissions rates can be found at the International Energy Agency [13] or NREL [16]. If the location is difficult to determine the national average value should be used.

B. Refrigerant Information

GWP values are taken from the IPCC's Forth Assessment: Climate Change (AR4) [22]. If the refrigerant used is not included in the report, the manufacturer's data may be used. A selection of values are listed in Table 1. These values are calculated using a 100 year integration time line for policy purposes. Known values for adaptive GWP are also included. Missing values can be extrapolated using the refrigerant mixture or from experimental data. Manufacturing emissions were gathered from various studies, and manufacturer's data [24-28]. The manufacturing emissions are for virgin refrigerant.



$$LCCP = Direct\ Emissions + Indirect\ Emissions$$

$$Direct\ Emissions = GWP * (L * ALR + EOL) + Adp.GWP\ (L * ALR + EOL)$$

$$Indirect\ Emissions = L * AEC * EM + MM * m$$

GWP = Global Warming Potential (kg CO_{2e}/kg)
Adp. GWP = GWP of Atmospheric Degradation Product of the Refrigerant (kg CO_{2e}/kg)
ALR = Annual Leakage Rate (kg)
L=Average Lifetime of Equipment (yr)
EOL = End of Life Emissions (kg)
AEC = Annual Energy Consumption (kWh)
MM = CO_2 Produced/kg of Material (kg CO_{2e}/kg)
EM = CO_2 Produced/kWh of Energy (kg CO2e/kWh)
m = Mass of Unit/Material (kg)

International Institute of Refrigeration LCCP Working Party 01/16/2015

Life Cycle Climate Performance Evaluation Guideline

Table 1: Refrigerant Information

Refrigerant	GWP[22] (kg CO2e/kg)	Adp. GWP (kg CO2e/kg)	Manufacturing Emissions (kg CO_{2e}/kg)
CO_2	1	0[22]	-
HFC-32	675	-	7.2[5]
HFC-1234yf	4	3.3[26]	13.7[26]
HFC-134a	1,430	1.6[26]	5.0[26, 28]
R-290	3	-	0.05[25]
HFC-404A	3,922	-	16.7[5]
HFC-410A	2,088	-	10.7[5]

C. System Leakage and Lifespans

Average leakage rates and lifespans for different types of systems are listed in Table 2. These values are gathered from the UNEP Technical Options Committee 2002 Report [21-23] , ICPP Fourth Assessment Report from 2007 [22] about developed countries and previous studies [1-6]. Rates have dropped considerably over the last decade and continue to drop. These values should be updated as new information becomes available.

D. Material Emissions

The emissions from the most common materials used in HVAC units are calculated by multiplying the emissions rates of the material times the mass of the material in the unit. A sample of the materials used are listed in Table 3. The rates were determined from the respective industry association [25-34]. The mixed manufacturing emission are calculated by using industry average for the mix of recycled material and virgin material in their products [25-36]. When the amount of mixed or virgin materials is known, the RM and MM terms can be replaced by those values multiplied by their respective emission rates in Table 3.

E. Material Recycling Emissions

Material disposal emissions include all emissions up to the production of recycled material. For metals and plastics this includes the shredding of the material [5, 37, 38]. For refrigerants this includes energy required to recover the refrigerant. These emissions may be included in the manufacturing emissions if the material is produced from recycled materials.

Table 2: System Information

System Type	ALR (%)	EOL (%)	L (years)
Residential Packaged Units [1, 21]	2.5	15	15
Residential Split Units[3, 21]	4	15	15
Packaged Refrigeration[3, 21]	2	15	15
Supermarket - Direct System[1, 9, 21]	18	10	7-10
Supermarket - Indirect System[1, 9, 21]	12	10	7-10
Commercial Refrigeration - Stand alone[21]	5	15	15
Commercial - Packaged Units [21]	5	15	10
Commercial - Split Units [21]	5	15	10
Chillers[1, 21]	5	15	15
Marine [21]	20	15	15

Table 3: Material Information

Material	Virgin Manufacturing Emissions (kg CO_{2e}/kg)	Mixed Manufacturing Emissions (kg CO_{2e}/kg)
Steel	1.8[29]	1.43[37]
Aluminum	12.6[30-32]	4.5[31]
Copper	3.0[33]	1.64[33]
Plastics	2.8[34]	2.61[35],[36]

Table 4: Recycling Information

Material	Recycling Emissions (kg CO_{2e}/kg)
Metal[5, 37, 38]	0.07
Plastics[5, 35, 36]	0.01
Refrigerant	—

Life Cycle Climate Performance Evaluation Guideline

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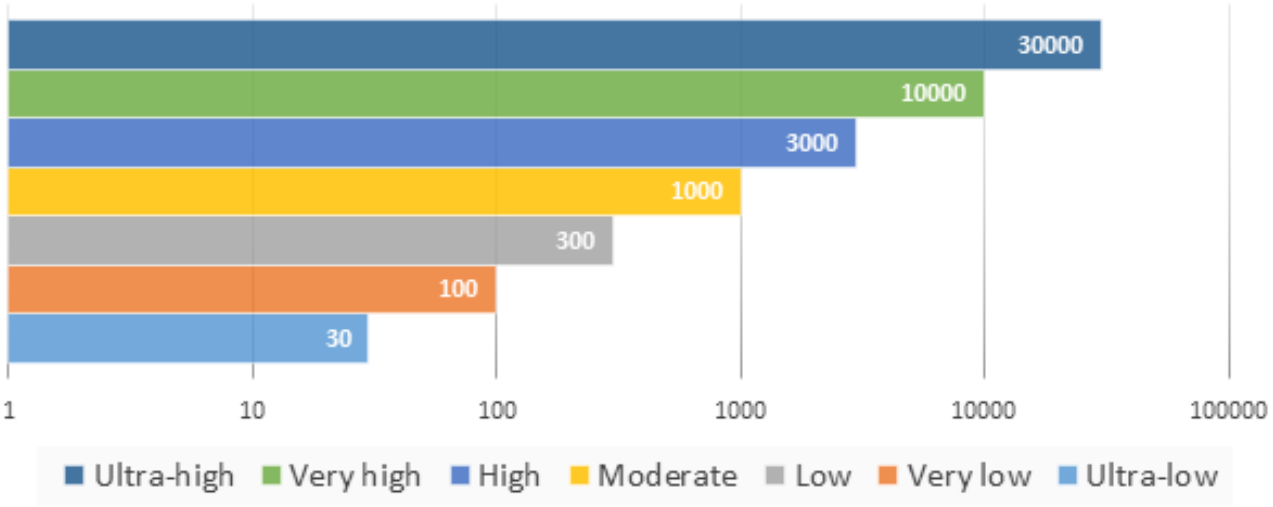
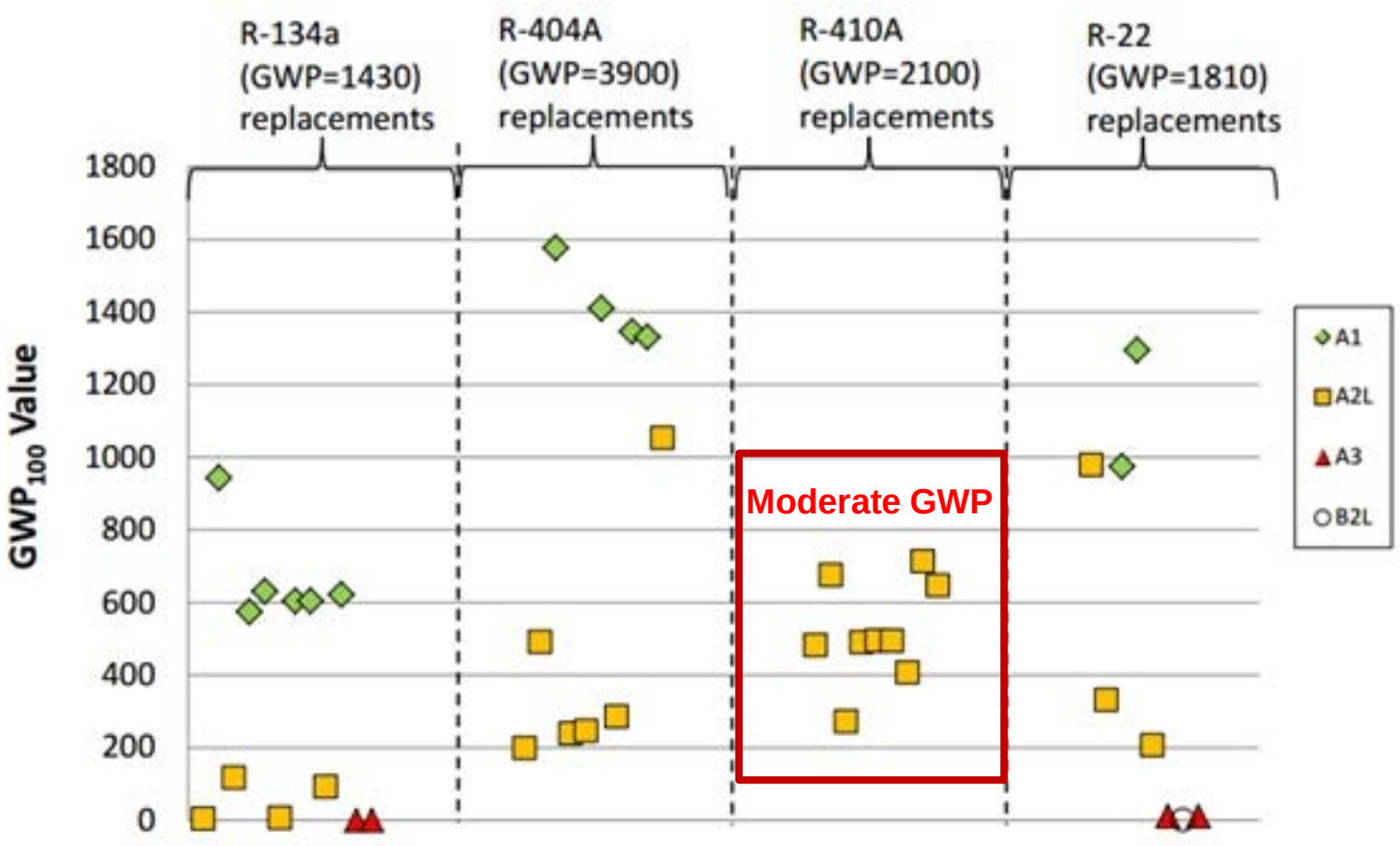
Refrigerant GWP Classifications



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

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

Refrigerant Types



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

LCCP Equation

$$LCCP = Direct\ Emissions + Indirect\ Emissions$$

$$Direct\ Emissions = GWP * (L * ALR + EOL) + Adp.GWP\ (L * ALR + EOL)$$

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

GWP = Global Warming potential
Adp. GWP = GWP of atmospheric degradation product of the refrigerant
ALR = Annual Leakage Rate (kg)
L=Average lifetime of Equipment (yr)
EOL = End of Life Emissions (kg)
AEC = Annual Energy Consumption (kWh)
EM = CO2 produced/kWh (CO2e/kWH)
MM = CO2 produced/kg of material
m = Mass of unit/material (kg)
RM = CO2 produced/kg of recycled material
mr = mass of recycled material (kg)
RFM = Refrigerant Manufacturing Emissions
C = Refrigerant charge (kg)
RFD = Refrigerant disposal emissions

Reduced LCCP Equation

$$LCCP = Direct\ Emissions + Indirect\ Emissions$$

$$Direct\ Emissions = GWP * (L * ALR + EOL) + Adp.GWP\ (L * ALR + EOL)$$

$$Indirect\ Emissions = L * AEC * EM + MM * m$$

GWP = Global Warming Potential (kg CO_{2e}/kg)
Adp. GWP = GWP of Atmospheric Degradation Product of the Refrigerant (kg CO_{2e}/kg)
ALR = Annual Leakage Rate (kg)
L=Average Lifetime of Equipment (yr)
EOL = End of Life Emissions (kg)
AEC = Annual Energy Consumption (kWh)
MM = CO_2 Produced/kg of Material (kg CO_{2e}/kg)
EM = CO_2 Produced/kWh of Energy (kg CO2e/kWh)
m = Mass of Unit/Material (kg)

Reference Heat Pump: Carrier 25HBB336 Heat Pump

Inputs	Value	Units
Capacity	3.0	tons
Refrigerant	R410A	
System Lifetime	15	yr
System Charge	3.06	kg
Annual Leakage Rate	5	%
Refrigerant loss at EOL	15	%
Unit Weight	233	lbs
Aluminum	*11.93 (12%)*	kg
Copper	*19.87 (19%)*	kg
Plastics	*24.10 (23%)*	kg
Steel	*49.56 (47%)*	kg
Location	*Atlanta, GA*	

- Unit used for testing in AREP Test Report #22
- Composition percentages were taken from the AHRTI LCCP tool

Heat Pump Sample Problem

Refrigerant	GWP	Emissions Category
HFC-410A	2,088	High
HFC-32	675	Moderate
L-41b	494	Moderate
DR-5	490	Moderate
R-290	3	Ultra Low

- **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	103%	89%	103%
L-41b	92%	89%	95%
DR-5	95%	89%	97%
R-290	100%	49%	97%

- **Information gathered from AHRI Low GWP AREP Reports 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”**

Heat Pump Sample Problem - Atlanta GA High GWP: HFC-410A (2,088 kg CO_{2e}/kg)

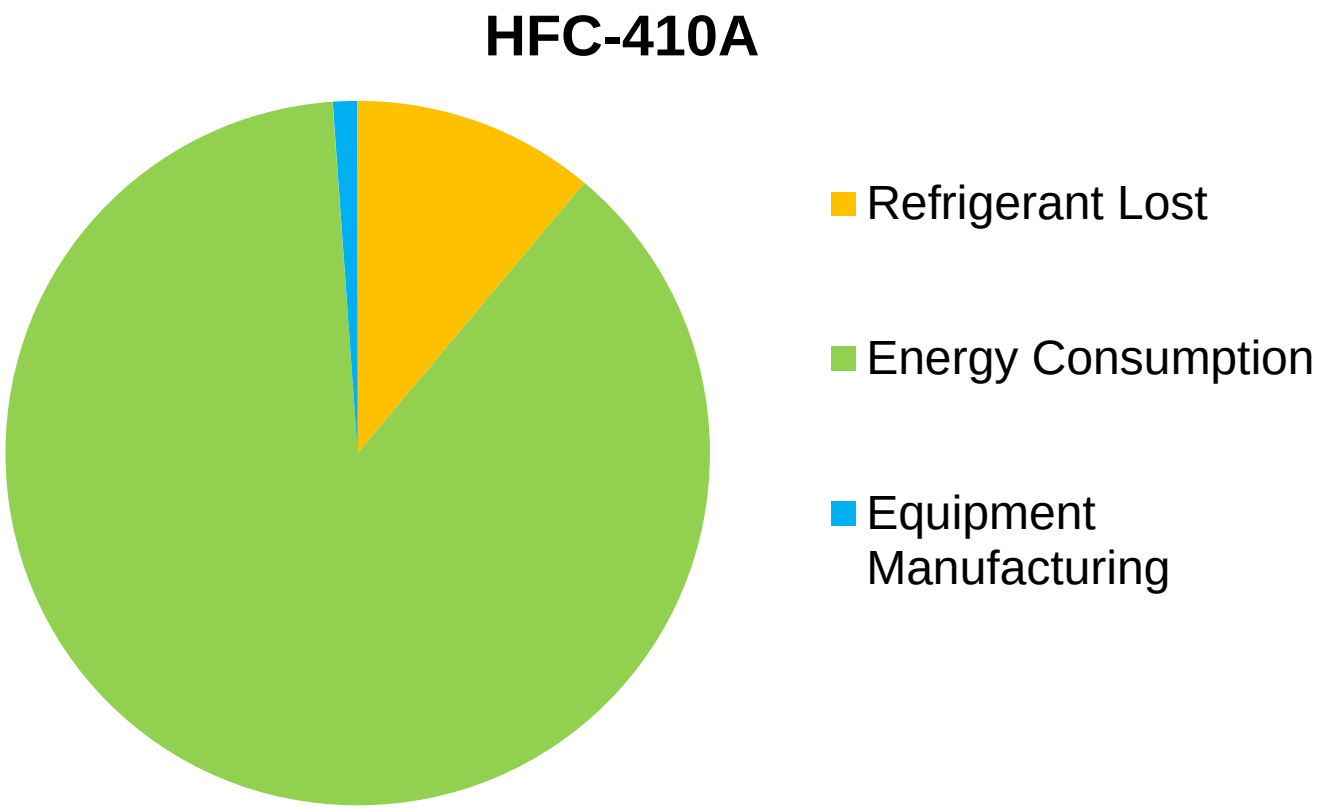
Emission Category	Results (kg CO_{2e})	% of Total
Total Direct Emissions	**5,679.4**	**11.1%**
Refrigerant Lost	5,679.4	11.1%
Adp. GWP	0	0
Total Indirect Emissions	**45,500**	**88.9%**
Energy Consumption	44,855	87.6%
Equipment Manufacturing	579.3	1.1%
~~Equipment EOL~~	~~9.34~~	~~0.01%~~
~~Refrigerant Manufacturing~~	~~57.3~~	~~0.11%~~

Terms can be ignored because of their insignificant contributions

Total Lifetime Emissions: 51,180.3 kg CO_{2e}

- Energy consumption was calculated using the AHRTI LCCP tool with the performance information from AREP Report #22

Heat Pump Sample Problem - Atlanta GA High GWP: HFC-410A (2,088 kg CO_{2e}/kg)



Total Lifetime Emissions: 51,180.3 kg CO_{2e}

Heat Pump Sample Problem - Atlanta GA Moderate GWP: HFC-32 (675 kg CO_{2e}/kg)

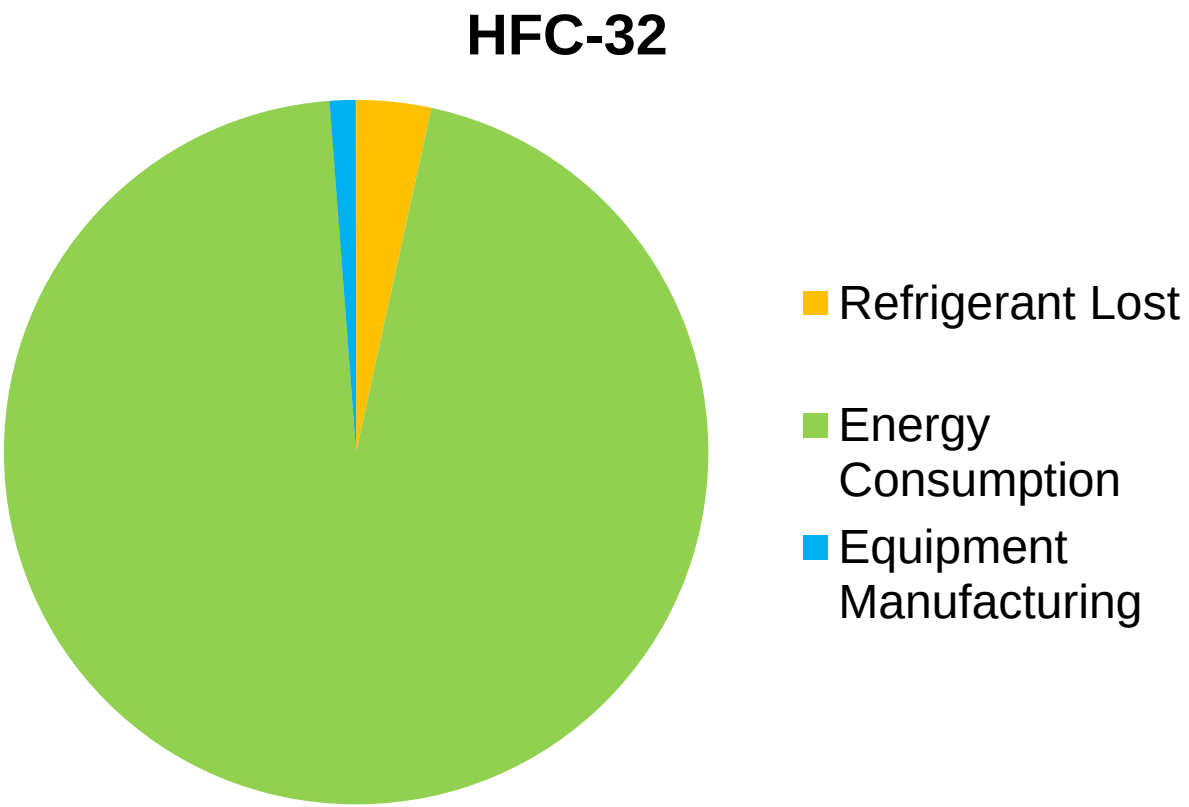
Emission Category	Results (kg CO_{2e})	% of Total
Total Direct Emissions	**1,625.4**	**3.4%**
Refrigerant Lost	1,652.4	3.4%
Adp. GWP	0	0
Total Indirect Emissions	**46,417.9**	**96.6%**
Energy Consumption	45,795	95.3%
Equipment Manufacturing	579.3	1.2%
~~Equipment EOL~~	~~9.34~~	~~0.02%~~
~~Refrigerant Manufacturing~~	~~34.3~~	~~0.07%~~

Terms can be ignored because of their insignificant contributions

Total Lifetime Emissions: 48,043.3 kg CO_{2e}

- Energy consumption was calculated using the AHRTI LCCP tool with the performance information from AREP Report #22

Heat Pump Sample Problem - Atlanta GA Moderate GWP: HFC-32 (675 kg CO_{2e}/kg)



Total Lifetime Emissions: 48,043.3 kg CO_{2e}

Heat Pump Sample Problem - Atlanta GA Moderate GWP: L-41b (494 kg CO_{2e}/kg)

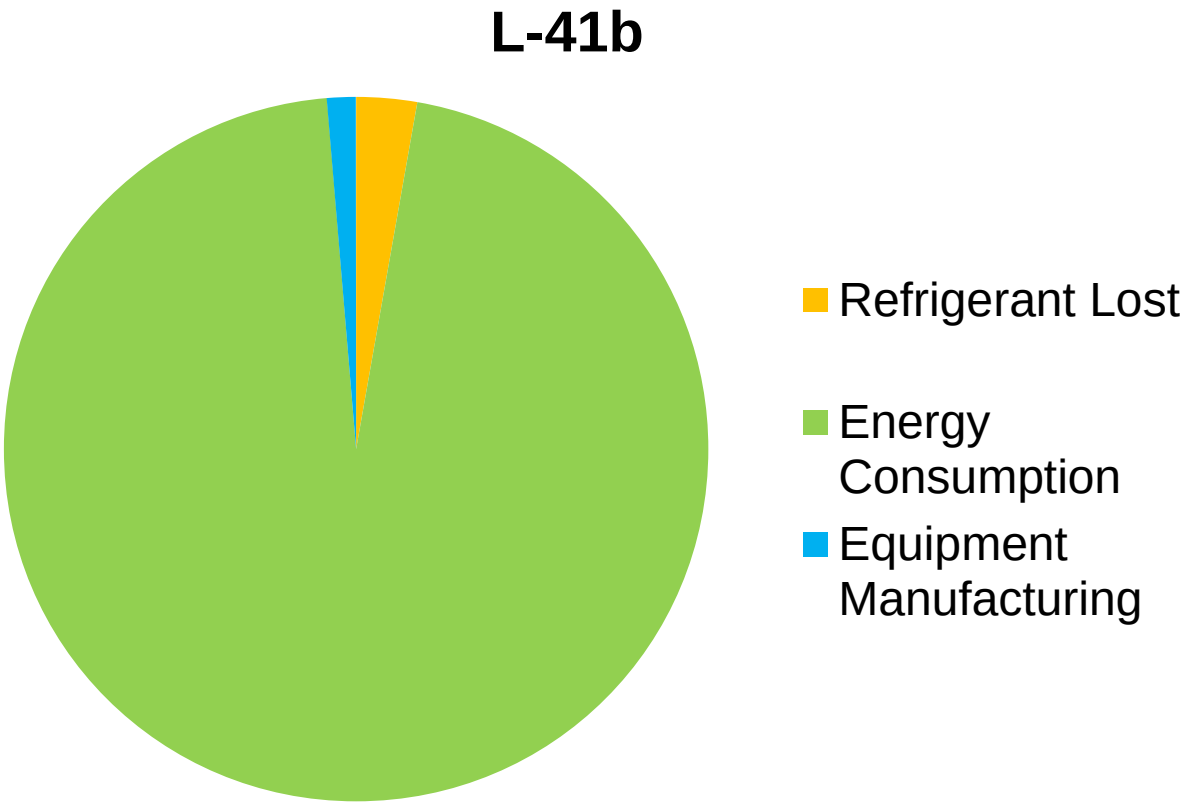
Emission Category	Results (kg CO_{2e})	% of Total
Total Direct Emissions	**1,209.3**	**2.8%**
Refrigerant Lost	1,209.3	2.8%
Adp. GWP	0	0
Total Indirect Emissions	**42,453.2**	**97.2%**
Energy Consumption	41,822	95.8%
Equipment Manufacturing	579.3	1.3%
~~Equipment EOL~~	~~9.34~~	~~0.02%~~
~~Refrigerant Manufacturing~~	~~42.6~~	~~0.10%~~

Terms can be ignored because of their insignificant contributions

Total Lifetime Emissions: 43,662.5 kg CO_{2e}

- Energy consumption was calculated using the AHRTI LCCP tool with the performance information from AREP Report #22
- Used a weighted average of the mixed refrigerants to calculate the manufacturing emissions (8.96 kg CO2e/kg)

Heat Pump Sample Problem - Atlanta GA Moderate GWP: L-41b (494 kg CO_{2e}/kg)



Total Lifetime Emissions: 43,662.5 kg CO_{2e}

Heat Pump Sample Problem - Atlanta GA Moderate GWP: DR-5 (490 kg CO_{2e}/kg)

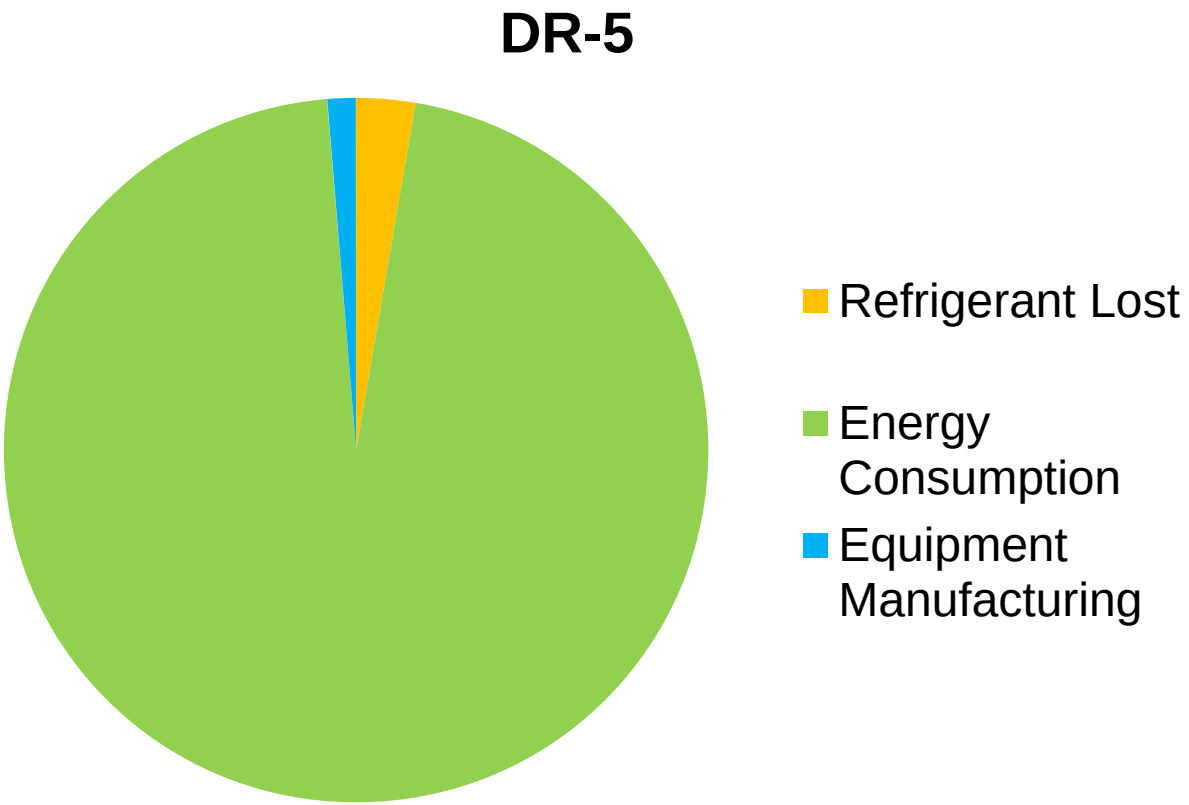
Emission Category	Results (kg CO_{2e})	% of Total
Total Direct Emissions	**1,199.5**	**2.7%**
Refrigerant Lost	1,199.5	2.7%
Adp. GWP	0	0
Total Indirect Emissions	**42,974.3**	**97.3%**
Energy Consumption	42,343	95.9%
Equipment Manufacturing	579.3	1.3%
~~Equipment EOL~~	~~9.34~~	~~0.02%~~
~~Refrigerant Manufacturing~~	~~42.7~~	~~0.1%~~

Terms can be ignored because of their insignificant contributions

Total Lifetime Emissions: 44,173.8 kg CO_{2e}

- Energy consumption was calculated using the AHRTI LCCP tool with the performance information from AREP Report #22
- Used a weighted average of the mixed refrigerants to calculate the manufacturing emissions (8.987 kg CO2e/kg)

Heat Pump Sample Problem - Atlanta GA Moderate GWP: DR-5 (490 kg CO_{2e}/kg)



Total Lifetime Emissions: 44,173.8 kg CO_{2e}

Heat Pump Sample Problem - Atlanta GA Ultra Low GWP: R-290 (3 kg CO_{2e}/kg)

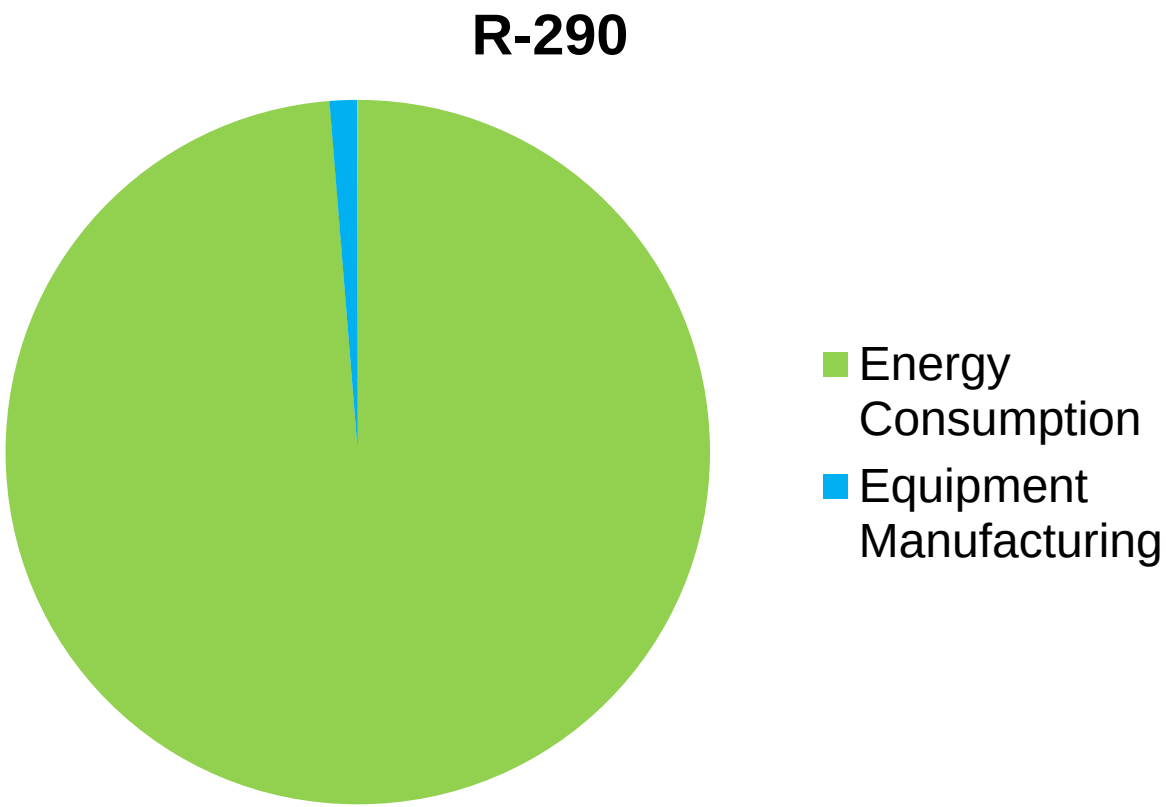
Emission Category	Results (kg CO_{2e})	% of Total
~~**Total Direct Emissions**~~	~~**4.15**~~	~~**0.01%**~~
~~Refrigerant Lost~~	~~4.15~~	~~0.01%~~
Adp. GWP	0	0
Total Indirect Emissions	**45,443.8**	**99.99%**
Energy Consumption	44,855	98.7%
Equipment Manufacturing	579.3	1.3%
~~Equipment EOL~~	~~9.34~~	~~0.02%~~
~~Refrigerant Manufacturing~~	~~0.13~~	~~0.0003%~~

Terms can be ignored because of their insignificant contributions

Total Lifetime Emissions: 45,447.9 kg CO_{2e}

- Energy consumption was calculated using the AHRTI LCCP tool with the performance information from AREP Report #22

Heat Pump Sample Problem - Atlanta GA Ultra Low GWP: R-290 (3 kg CO_{2e}/kg)



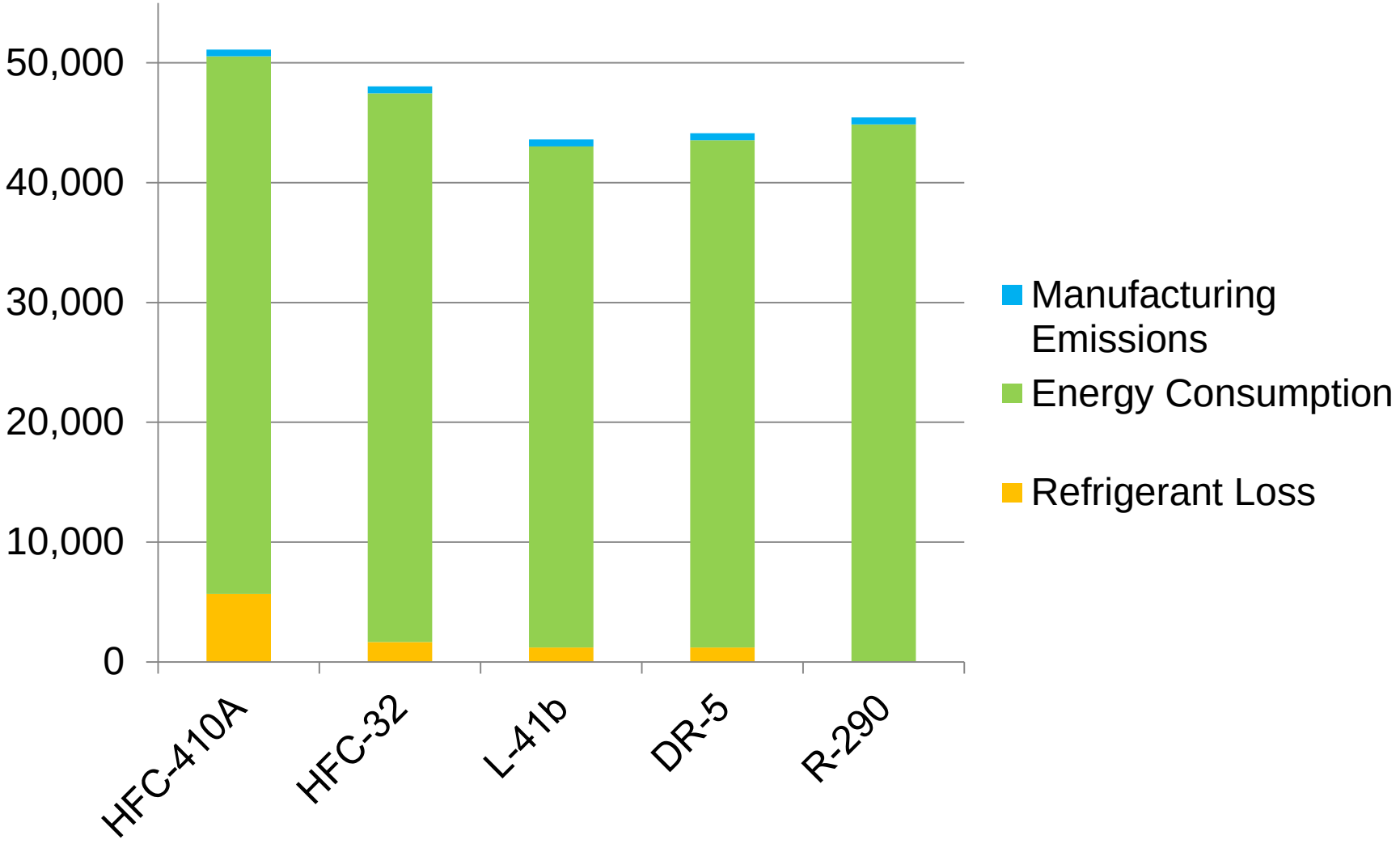
Total Lifetime Emissions: 45,447.9 kg CO_{2e}

LCCP Comparison

Unit: kg CO_{2e}

Emission Category	HFC-410A	HFC-32	L-41b	DR-5	R-290
Total Direct Emissions	**5,679.4**	**1,625.4**	**1,209.3**	**1,199.5**	**~~4.15~~**
Refrigerant Lost	5,679.4	1,652.4	1,209.3	1,199.5	~~4.15~~
Adp. GWP	0	0	0	0	0
Total Indirect Emissions	**45,500**	**46,417.9**	**42,453.2**	**42,974.3**	**45,443.8**
Energy Consumption	44,855	45,795	41,822	42,343	44,855
Equipment Manufacturing	579.3	579.3	579.3	579.3	579.3
Equipment EOL	~~9.34~~	~~9.34~~	~~9.34~~	~~9.34~~	~~9.34~~
Refrigerant Manufacturing	~~57.3~~	~~34.3~~	~~42.6~~	~~42.7~~	~~0.13~~
Total Emissions	**51,180.3**	**48,043.3**	**43,662.5**	**44,173.8**	**45,447.9**

Total Emissions Comparison

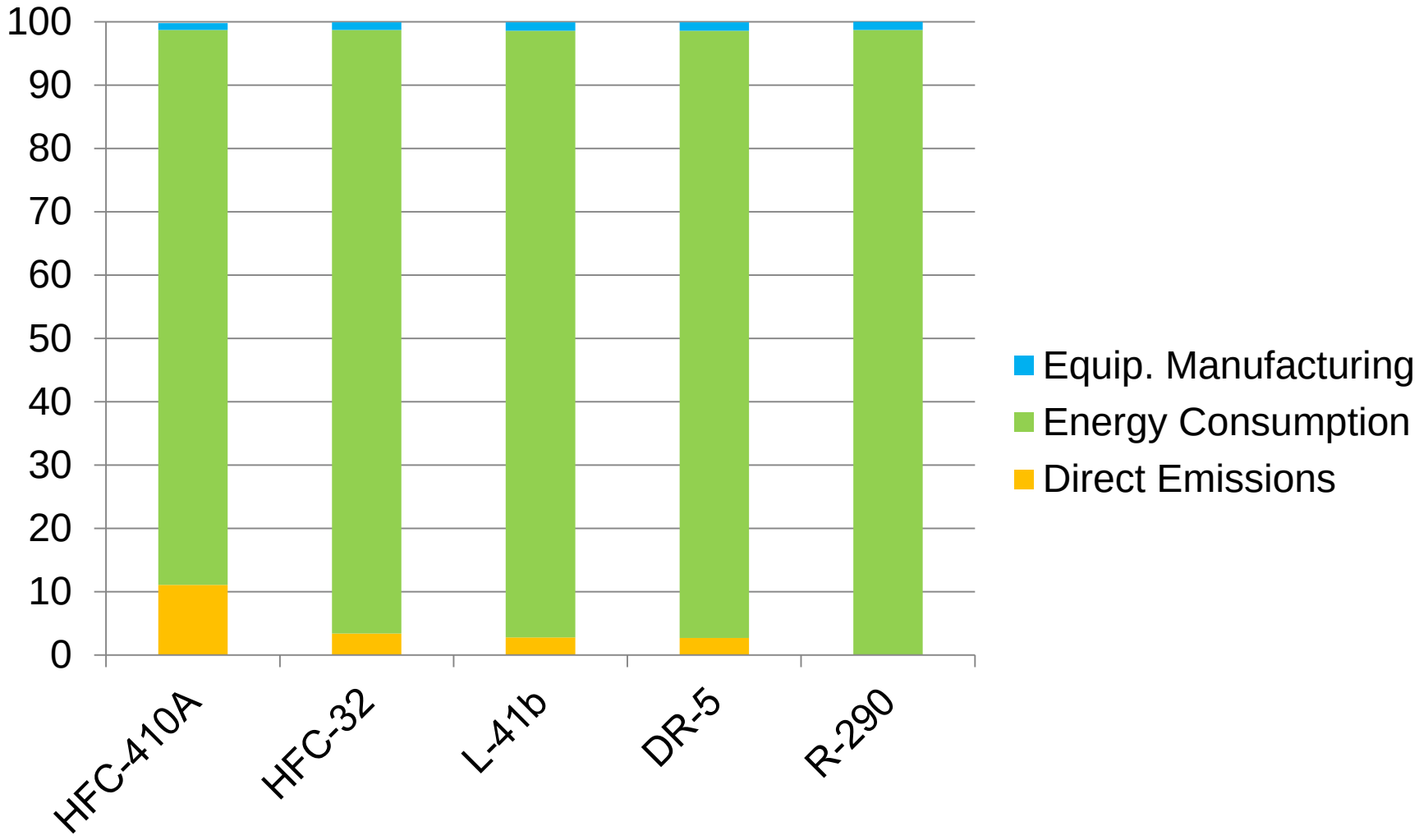


Comparison – Percentage of Total Emissions

Emission Category	HFC-410A	HFC-32	L-41b	DR-5	R-290
Total Direct Emissions	**11.1%**	**3.4%**	**2.8%**	**2.7%**	**~~0.01%~~**
Refrigerant Lost	11.1%	3.4%	2.8%	2.7%	~~0.01%~~
Adp. GWP*	0	0	0	0	0
Total Indirect Emissions	**88.9%**	**96.6%**	**97.2%**	**97.3%**	**99.99%**
Energy Consumption	87.6%	95.3%	95.8%	95.9%	98.7%
Equipment Manufacturing	1.1%	1.2%	1.3%	1.3%	1.3%
Equipment EOL	~~0.01%~~	~~0.02%~~	~~0.02%~~	~~0.02%~~	~~0.02%~~
Refrigerant Manufacturing	~~0.11%~~	~~0.07%~~	~~0.10%~~	~~0.1%~~	~~0.0003%~~

- **Several 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 most effective way to reduce emissions is to increase the energy efficiency of the unit.**
- **Not enough information is available for adjusted GWP values.**
- **LCCP equation can be much simplified when disregards negligible emission parameters.**

Future Work

- LCCP reevaluation at same system capacity.
- Sensitivity studies will be conducted aimed at reducing the complexity of the equations for different GWP refrigerants.
- Expand sample calculations to other applications and regions.
- Collect public comments
- Finalize and publish LCCP guidelines

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