Life Cycle Climate Performance Evaluation Guideline

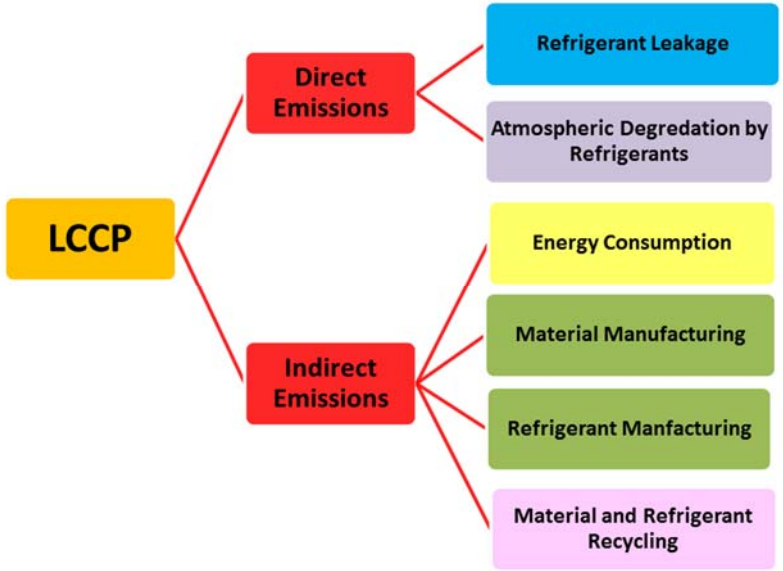
Life Cycle Climate Performance evaluation is a cradle to grave analysis of a system which includes both direct emissions and indirect emissions of a system. Direct emissions include all refrigerant leaked during the lifetime of the system. Indirect emissions include total energy consumption and emissions 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.



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

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

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

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)
MM = CO2 produced/kg of material
m = Mass of unit/material (kg)
RFM = Refrigerant Manufacturing Emissions
C = Refrigerant charge (kg)
RFD = Refrigerant disposal emissions

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

References

[1] ADL (A.D. Little, Inc), 1999: Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications. Final Report to the Alliance for Responsible Atmospheric Policy, August 23, 1999, Acorn Park, Cambridge, Massachusetts, USA.

[2] Zhang, M., Muehlbauer, J., Aute, V. and Radermacher, R., 2011, Life Cycle Climate Performance Model for Residential Heat Pump System, Air-Conditioning, Heating and Refrigeration Technology Institute, Inc. (AHRTI).

[3] Sand, J.R., S.K. Fischer and V.D. Baxter, 1997: Energy and Global Warming Impacts of HFC Refrigerants and Emerging Technologies, U.S. Department of Energy and AFEAS, Arlington, Va, USA.

[4] Papasavva, S., Hill, W. R. and Andersen, S. O., 2010. GREEN-MAC-LCCP: A Tool for Assessing the Life Cycle Climate Performance of MAC Systems. Environmental Science & Technology, 44(19), pp. 7666-7672.

[5] GREEN-MAC-LCCP program, version 3b (http://www.epa.gov/cppd/mac/compare.htm). Accessed October 2014.

[6] Abdelaziz, O., Fricke, B. and Vineyard, E., 2012, Development of Low Global Warming Potential Refrigerant Solutions for Commercial Refrigeration Systems using a Life Cycle Climate Performance Design Tool. 14th International Refrigeration and Air Conditioning Conference, Purdue University, West Lafayette, Indiana.

[7] Oak Ridge National Laboratory (ORNL), and the University of Maryland College Park (UMCP), 2013. LCCP Desktop Application v1 Engineering Reference. (http://info.ornl.gov/sites/publications/Files/Pub49128.pdf)

[8] http://lccp.umd.edu/ornllccp/ , 2014.

[9] Beshr, M., Acute, V., Fricke B., and Radermacher, R. "An Evaluation of the Environmental Impact of Commercial Refrigeration Systems Using Alternative Refrigerants." 3rd IIR International Conference on Sustainability and the Cold Chain, London, 2014.

[10] International Institute of Refrigeration Working Party on LCCP Evaluation. http://www.iifiir.org/medias/medias.aspx? INSTANCE=EXPLOITATION&PORT AL _ID = portal_model_instance__WP_LCCP_Evaluation.xml

[11] ASHRAE Handbook 2013 Fundamentals.

[12] ASHRAE Standard 169 (2013) Climatic Data for Building Design Standards

[13] International Energy Agency, http://data.iea.org/ieastore/product.asp?dept_id=101&pf_id=305

[14] International Weather for Energy Calculations Version 2.0, 2012 ASHRAE, Atlanta GA.

[15] Energy Data Sources, U. S. Department of Energy, Feb. 2014 http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_sources.cfm.

[16] Deru, M. and Torcellini, P., 2007, Source Energy and Emission Factors for Energy Use in Buildings, Technical Report NREL/TP-550-38617.

[17] NREL - National Solar Radiation Data Base - TMY3 Data, January 2011 (http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/)

[18] Wilcox, S. and W. Marion. 2008. User's Manual for TMY3 Data Sets, NREL/TP-581-43156. April 2008. Golden, Colorado: National Renewable Energy Laboratory.

[19] US DOE. "EnergyPlus Energy Simulation Software". Available at: http://apps1.eere.energy.gov/buildings/energyplus/, Accessed 10Oct2014.

[20] European Environment Agency, http://eea.europa.eu/, 2014.

[21] UNEP, 2003c: 2002 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee – 2002 Assessment. [L. Kuijpers (ed.)]. UNEP Ozone Secretariat, Nairobi, Kenya.

[22] Intergovernmental Panel on Climate Change (IPCC), 2007, Fourth Assessment Report: Climate Change, Geneva, Switzerland.

[23] UNEP/TEAP report, 1999. "The Implications to the Montreal Protocol of the Inclusion of HFCs and PFCs in the Kyoto Protocol".

[24] Spatz, M.W., Motta, S.F.Y., 2004. "An evaluation of options for replacing HCFC-22 in medium temperature refrigeration systems". International Journal of Refrigeration, Volume 27, Issue 5, pp. 475-483.

[25] Hill, W., Papasavva, S., 2005. "Life Cycle Analysis Framework; a Comparison of HFC-134a, HFC-134a Enhanced, HFC-152a, R744, R744 Enhanced, and R290 Automotive Refrigerant Systems". SAE Technical Series Paper, 2005-01-1511, Society of Automotive Engineers, Warrendale, PA.

[26] Baral, A, Minjares, R., and Urban, R., Upstream Climate Impacts from Production of R-134a and R-1234yf refrigerants used in Mobile Air Conditioning Systems. International Council on Clean Transportation, Aug. 2013.

[27] Johnson, E., "Air-Source Heat Pump Carbon Footprints: HFC Impacts and Comparison to Other Heat Sources." Energy Policy 39 (2011) 1369-1381.

[28] Banks, R. and Sharratt, P., "Environmental Impacts of the Manufacture of HFC-134a." 07 Nov. 1996.

[29] Steel's Contribution to a Low Carbon Future: WorldSteel Position Paper. 2014 World Steel Association.

[30] U.S. Energy Requirements for Aluminum Production BCS Report prepared for DOE, Feb 2007.

[31] International Aluminum Institute, "Global Life Cycle Inventory Data for the Primary Aluminum Industry: 2010 Data. World Aluminum, August 2013.

[32] "Aluminum the Element of Sustainability: A North American Aluminum Industry Sustainability Report.." The Aluminum Association, September 2011.

[33] "The Environmental Profile of Copper Products: A Cradle to Gate Life-Cycle Assessment for Copper Tube, Sheet and Wire Produced in Europe.", European Copper Institute Copper Alliance, 2012.

[34] Franklin Associates report prepared for the American Chemistry Council , July 2014, "Cradle-To-Gate Life Cycle Inventory of Nine Plastic Resins and Four Polyurethane Precursors".

[35] EPA "Plastics" U. S. Environmental Protection Agency, Waste Reduction Model Version 13. June 2014.

[36] PlasticsEurope. Eco-profiles of the European Plastics Industry: HDPE bottles. March 2005 http://lca.plasticseurope.org/main2.htm.

[37] EPA, "Metals." U. S. Environmental Protection Agency, Waste Reduction Model Version 13. June 2014.

[38] EPA, "Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2012." U. S. Environmental Proection Agency. 2012.

[39] "IIR-LCCP-EmissionsDatabase_Version1.exp" University of Maryland Department of Mechanical Engineering ACTA Consortium. 2014.

International Institute of Refrigeration
LCCP Working Party

Chair: Dr. Yunho Hwang, yhhwang@umd.edu
Vice Chair: Dr. Carlos Infante Ferreira
Vice Chair: Dr. Chu-Cheng Piao
Secretary: Dr. Vikrant
Researcher: Sarah Troch, stroch@umd.edu
Website: http://www.iifiir.org/medias/medias.aspx ?INSTANCE=EXPLOITATION &PORTAL _ID= portal_model_instance__WP_LCCP_ Evaluation.xml