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Harmonization of the Life Cycle Climate Performance Methodology

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ABSTRACT

Life Cycle Climate Performance (LCCP) is an evaluation method by which heating, ventilation, air conditioning and refrigeration systems can be evaluated for the global warming impact over the course of their complete life cycle. LCCP is more inclusive than previous metrics such as Total Equivalent Warming Impact. It is calculated as the sum of direct and indirect emissions generated over the lifetime of the system “from cradle to grave”. Direct emissions include all effects from the release of refrigerants into the atmosphere during the lifetime of the system. This includes annual leakage and losses during the disposal of the unit. The indirect emissions include emissions from the manufacturing process, energy consumption, and disposal of the system. This paper proposes a standardized approach to the use of LCCP and traceable data sources for all aspects of the calculation. An equation was proposed that unifies the efforts of previous researchers. Data sources were recommended for average values for all LCCP inputs. An excel tool was developed for residential heat pumps using the proposed method. A residential heat pump sample problem is presented illustrating the methodology and the developed excel tool. The residential heat pump is evaluated at five U.S. locations in different climate zones. The primary factor in the LCCP calculation is the energy consumption of the system.

1. INTRODUCTION

Climate change is an increasing important global concern with far reaching effects. The HVAC&R industry is spending a large amount of effort in studying the environmental impacts of heating and air conditioning systems. Several tools have been developed to measure this impact including Total Equivalent Warming Impact (TEWI), Life Cycle Analysis (LCA) and Life Cycle Climate Performance (LCCP). In an effort to better understand the environmental impacts that HVAC units have, LCCP was developed (UNEP, 1999). LCCP is an evaluation method by which HVAC&R systems can be evaluated for the global warming impact over the course of their complete life cycle. It is calculated as the sum of direct and indirect emissions generated over the lifetime of the system “from cradle to grave”. Direct emissions include all effects from the release of refrigerants into the atmosphere during the lifetime of the system. This includes annual leakage and losses during the disposal of the unit. The indirect emissions include emissions from the manufacturing process, energy consumption, and disposal of the system warming impact of a HVAC&R system by quantifying the amount of greenhouses gases it emits during its usage phase, from commissioning to end of life. It takes into account the direct and indirect emissions over this period. The direct emissions result from the leakages, and the fluid that is not recovered at the end of life (“EOL”). The indirect emissions result from the energy use over the same period. LCCP is a more comprehensive evaluation than TEWI. It includes all the direct and indirect emissions generated by the system during its complete lifetime from “cradle to grave.” To do this, in addition to TEWI, LCCP accounts for energy embodied in the product materials, greenhouse gas emissions from chemical manufacturing and end-of-life disposal of the unit. LCCP can also account for minor emission sources that are not accounted for in TEWI such as transportation leakage, manufacturing leakage, and refrigerant manufacturing emissions. The International Institute of Refrigeration (IIR) established a working group in January 2012 to assess the merits of the LCCP methodology. This project developed a guideline for performing LCCP calculations for air conditioning and refrigeration systems with standard assumptions and data sources for different types of units. The guideline was released by IIR in January 2016 (IIR, 2016). The developed guideline provides a harmonized method to calculate the LCCP for all types of stationary air conditioning and heat pump systems. The process and assumptions by which LCCP should be approached were discussed. This guideline aims to provide designers, facility operators and manufacturers a way to effectively evaluate and compare the environmental impact of different systems over the course of their lifetimes.

2. LCCP EQUATION DEVELOPMENT

Previous work on the LCCP methodology was surveyed including the work done by Technology and Economic Assessment Panel of the United Nations Environmental Program (UNEP) (1999), ADL (1999), Zhang *et al.* (2011), Beshr *et al.* (2014) and Papasavva *et al.* (2012). The common elements from the previous works were clarified and combined to form Eqs. 1-3. The LCCP equation is split into two main parts, direct and indirect emissions. Each component accounts for a different type of emissions released over the lifetime of the unit. The emission terms are in the units of kg CO_2e/kg. Direct emissions account for the refrigerant leaked over the course of the unit's lifetime including annual leakage, catastrophic leaks, and losses when the unit is disposed of. It also includes atmospheric degradation products created by the refrigerant when it decomposes in the atmosphere during its usage time and afterwards. Indirect emissions account for all other sources of emissions generated by the manufacture use and disposal of the unit. This includes the emissions from the generation of electricity, manufacturing of materials to build the unit, manufacturing of the refrigerant, and the end of life emissions when the unit is disposed of.

$$LCCP = Direct\ Emissions + Indirect\ Emissions \tag{1}$$

$$Direct\ Emissions = C*(L*ALR + EOL)*(GWP + Adp.\ GWP) \tag{2}$$

$$Indirect\ Emissions = L*AEC*EM + \Sigma(m*MM) + \Sigma(mr*RM) + C*(1+ L*ALR)*RFM + C*(1-EOL)*RFD \tag{3}$$

where: C = Refrigerant Charge (kg), L=Average Lifetime of Equipment (yr), ALR = Annual Leakage Rate (% of Refrigerant Charge), EOL = End of Life Refrigerant Leakage (% of Refrigerant Charge), GWP = Global Warming Potential (kg CO_2e/kg), Adp. GWP = GWP of Atmospheric Degradation Product of the Refrigerant (kg CO_2e/kg), AEC = Annual Energy Consumption (kWh), EM = CO_2 Produced/kWh (kg CO_2e/kWh), m = Mass of Unit (kg), MM = CO_{2e} Produced/Material (kg CO_2e/kg), mr = Mass of Recycled Material (kg), RM = CO_2e Produced/Recycled Material (kg CO_2e/kg), RFM = Refrigerant Manufacturing Emissions (kg CO_2e/kg), RFD = Refrigerant Disposal Emissions (kg CO_2e/kg).

3. LCCP GUIDELINE DATA SOURCES

One of the contributions of the LCCP Guideline was to establish traceable and verified sources for all components of the equation. A literature review was conducted of publically available information for each of the emissions categories. Average values for developed countries were selected for the guideline.

3.1 Direct Emissions

Refrigerant GWP values were taken from the United Nations Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment: Climate Change (AR5) (2011). These values were calculated using a 100 year integration time line for policy and consistency purposed. If the refrigerant was not included AR5, AR4, or manufacturers' GWP values may be used. To calculate refrigerant mixtures a weighted average of the component refrigerants could be used. The unit's charge of refrigerant should be obtained from the manufacturer of the units being compared. If a split system is used, the refrigerant charge calculation should include the average piping length between indoor and outdoor units. The baseline equation as written in the guideline assumes that the system is recharged to its optimal refrigerant charge annually, and the effects of the energy consumption on the system are minimal. However, the equations could be modified to account for a longer period between recharging of the unit and its effects. Average unit usage lifetimes (L) are taken from AR4, AR5 reports, and the United Nation Environmental Program (UNEP) Technical Options Committee 2002 report. Units have become more reliable over the past decades and continue to improve. Annual leakage rates (ALR) are the sum of the gradual leakage of a system over the course of a year. These averages also include catastrophic leaks spread out over the lifetime of the unit. This term does not include refrigerant lost when the unit is disposed of. These rates vary widely for different types of systems, equipment design, workmanship when the unit was installed, quality of maintenance, and various other factors. The end of life leakage (EOL) rates include the amount of refrigerant that is lost when the unit is disposed of. The annual leakage rates and end of life leakage rates shown in Table 1 are taken from AR4 (2007), AR5 (2013), UNEP Technical Options Committee's 2002 report, and previous researches. Like for the losses at the end of life, efforts are constantly being made to reduce leakages, due to the growing awareness of the importance of good practices for management of refrigerants. Work is ongoing from various sources to determine more accurate leakage rates.

Table 1: System Information

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

3.2 Indirect Emissions

Indirect emissions consist of emissions from electricity production, emissions from the manufacture of materials and refrigerants, the disposal of the unit and refrigerant. The data sources for each emissions type were identified from an extensive literature review of publically available sources. Material manufacturing emissions were gathered from various industry sources in the United States and the European Union. These sources included trade associations, governmental departments, and previous research efforts. The four most common materials in the manufacture of HVAC&R units are included in LCCP. As a demonstration of the method, the average percentage of the mass composition of a residential heat pump was obtained from the work done by Zhang *et al.* (2011) and Beshr *et al.* (2014). Other unit types will have different breakdown of percentages. These percentages should be used to calculate the manufacturing emissions for the unit.

Table 2: Manufacturing Emissions

Material	Percentage of Unit Mass Composition	Virgin Manufacturing Emissions (kg CO_{2e}/kg)	Mixed Manufacturing Emissions (kg CO_{2e}/kg)
Steel	46%	1.8	1.43
Aluminum	12%	12.6	4.5
Copper	19%	3.0	2.78
Plastics	23%	2.8	2.61

The preferred method to calculate the annual energy consumption of the system is to use an annual load model in accordance with ISO and ASHRAE standards. This model takes into consideration unit performance characteristics, unit load information, and local weather. A temperature bin method should be used to analyze the weather data. For air conditioning, heating, refrigeration units, and chillers whose performance is dependent on the ambient weather conditions, a minimum of four temperature bins for cooling and four bins for heating should be used. The load should be calculated for each bin, and then added to determine the total energy consumption per year. For units whose energy consumption is not dependent on ambient weather conditions, the calculation procedure in the respective standard should be used and summed for the unit's lifetime. Once the total energy consumption is calculated, this should be multiplied by the electricity generation emissions rate for the area to obtain the indirect CO_{2e} emissions from power consumption. Standby power or compressor crankcase heaters may also consume a significant amount of energy. These devices should be considered in climates where the compressor is off or in standby for a significant amount of time such as Canada or Scandinavia. The baseline equation as written in the guideline assumes that the system is recharged to its optimal refrigerant charge annually so that the effects on the energy consumption on the system are minimal. However, refrigerant leakage will have a negative impact on the performance of HVAC&R units over their lifetime. This performance degradation may be considered when calculating the energy consumption of the unit. The performance degradation can be determined using unit test data or data from previous research. Multiple sources for accurate weather data exist. The International Weather for Energy Calculations datasets (IWEC, 2013) and the National Renewable Energy Laboratories – Typical Meteorological Year database (TMY3, 2015) should be used whenever possible. The International Energy Agency and the U.S. Department of Energy provide lists of alternative sources if the location being modeled is not included in the IWEC datasets or TMY3. The LCCP methodology assumes that the unit being evaluated uses the electric grid for 100% of the required power. Electricity generation emissions rates vary dramatically across the world and within countries. The rates depend on the type of generation that is used in the region. Where hydro power is prevalent, the emissions rates are much lower than where coal power plants are the primary source of generation. The emission rate chosen should be the most localized rate for the location in question. If the local or regional rate is not available the country average should be used. The North American Electricity Reliability Corporation (NERC) (Deru *et al.*, 2007) and the International Energy Association (IEA) provide current electrical power generation emissions. NERC measures the emissions for North America in five zones or interconnections. Within each interconnection it is extremely difficult to determine from which power plant the energy consumed was generated; therefore, the interconnection average should be used. The emission rate to be chosen depends on the purpose of the calculation. For a specific user, who wants to minimize a specific application's emissions, the local rates can be used. In general, it is relevant to use a common rate over an area where the electrical networks are interconnected. Refrigerant manufacturing emission rates were gathered from various studies and manufacturers' information. The values presented were averages of the available sources. They need to be updated as more efficient methods of manufacturing are developed. Material disposal emissions include all emissions up to the production of recycled material. For metals and plastics, this includes the shredding of the material. These emissions may be included in the manufacturing emissions if the material is produced from recycled materials. For recycled refrigerants, this includes energy required to recover the refrigerant.

4. RESIDENTIAL HEAT PUMP EXCEL TOOL

An excel tool was built for a single speed compressor, single speed fan residential heat pump system. The inputs and outputs are in SI units. The tool includes six refrigerants: HFC-32, HFC-1234yf, HFC-134a, R-290, HFC-404A, HFC-410A, L-41b, and DR-5. The calculation is performed at five locations in five different climate zones including: Miami, FL, Phoenix, AZ, Atlanta, GA, Chicago, IL and Seattle, WA. The material manufacturing can be set to either virgin material or a mix of recycled and virgin materials. The tool uses AHRI 210/240 standard for energy consumption calculation. The tool shows the breakdown of the different LCCP components in table and graph forms. The results are also shown as a percentage of the total. Specific LCCP is calculated for each city in terms of cooling and heating delivered by the unit divided by the total emissions. The weather data can be easily changed for a different city in the same climate zone. The tool was used for the sample problem in section 6.

5. LIMITATIONS OF LCCP

Like for TEWI, LCCP calculations are dependent on a number of assumptions about the system performance, manufacturing emissions, typical system characteristics, and energy generation emissions. These values are all subject to a certain amount of uncertainty. LCCP should be used as a comparison tool for systems with similar performance and function. It is not intended to be used as a definitive estimate of lifetime emissions. Small variations between different units may not have significance because of the inherent uncertainty in the assumed emission values. When comparing solutions using different refrigerants, care must be taken to make "apple-to-apple" comparisons. For instance, inter-comparisons are only meaningful between systems having similar capacities. It is often difficult to have precisely the same capacity at the same conditions with different technologies. In that case, the use of "specific LCCP" provides a more relevant comparison.

6. RESIDENTIAL HEAT PUMP SAMPLE PROBLEM

A representative residential heat pump was evaluated in five locations in the continental U.S., representing different climatic conditions. The cities evaluated are: Miami, FL, Phoenix, AZ, Atlanta, GA, Seattle, WA and Chicago, IL. The heat pump has the characteristics shown in Table 3. The heat pump's characteristics are typical values of an 11 kW unit available in the USA. The heat pump modeled is Goodman SSZ16-0361A. The unit is a single speed compressor unit with a fixed fan speed and a resistance heater for backup heat. The heat pump performance characteristics were evaluated according to AHRI Standard 210/240 (2008). The refrigerant used was R-410A with a charge of 6 kg. The lifetime was assumed to be 15 years. The unit has a weight of 115 kg. The annual leakage rate was assumed to be 4% and the end of life leakage rate was assumed to be 15%.

Table 3: AHRI Std. 210/240 Test Data for Residential Heat Pump Sample Problem

Cooling or Heating	Test Number	Capacity (W)	Total Power (W)
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

The values were input into the IIR Residential Heat Pump Excel tool detailed in section 4. The virgin manufacturing emissions option was chosen. The results from the tool are shown below in Tables 4 and 5. Table 4 shows the energy calculation performed using the temperature bin method and the AHRI Stdard 210/240. Table 5 includes the LCCP results for each of the components of the equation.

Table 4: Residential Heat Pump Annual Energy Consumption Calculation

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)	8,227.67	8,923.68	3,700.31	1,946.45	559.18
Annual Cooling Emissions (kg CO_{2e})	6,483.41	5,300.66	2,915.84	1,533.80	332.15
Heating Climate Region	I	II	III	IV	V
Annual Heating Energy Consumption (kWh)	211.02	1,162.46	3,351.95	8,265.00	4,074.85
Heating Emissions (kg CO_{2e})	166.28	690.50	2,641.34	6,512.82	2,420.46

Table 5: Residential Heat Pump Sample Problem's LCCP Results

Results (kg CO_2e)	Miami, FL	Phoenix, AZ	Atlanta, GA	Chicago, IL	Seattle WA
Annual Refrigerant Leakage	6,926	6,926	6,926	6,926	6,926
EOL Refrigerant Loss	1,732	1,7312	1,7312	1,732	1,732
Adaptive GWP	-	-	-	-	-
Energy Consumption	99,745	89,868	83,358	120,700	41,289
Equipment Manufacturing	409	409	409	409	409
Equipment EOL	6.6	6.6	6.6	6.6	6.6
Refrigerant Manufacturing	103	103	103	103	103
Total Direct Emission	8,658	8,658	8,658	8,658	8,658
Total Indirect Emissions	100,161	90,283	83,773	121,114	41,704
LCCP	108,819	98,941	92,431	129,772	50,362

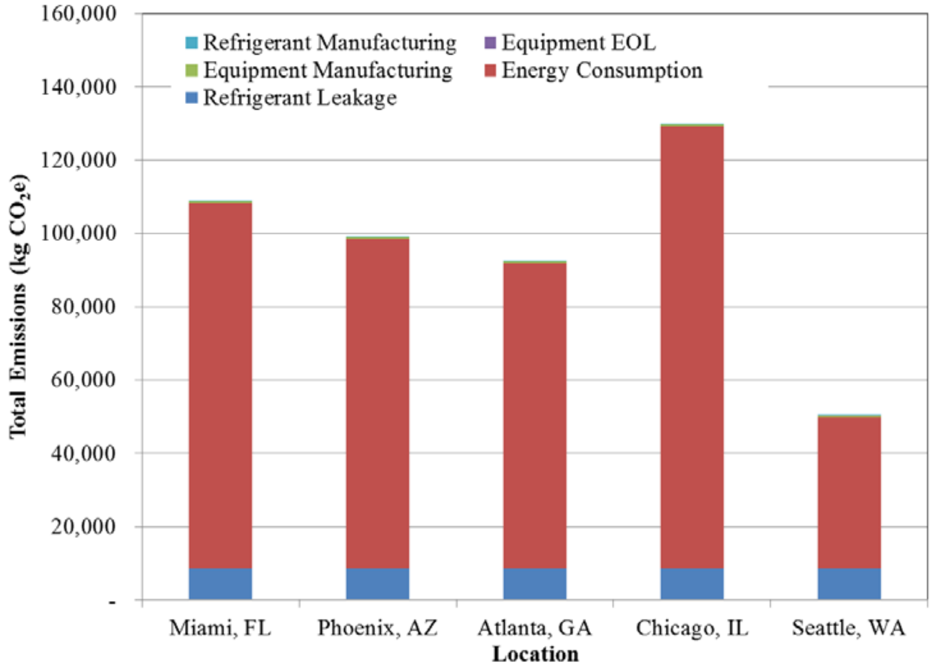

Fig. 1: LCCP Comparison for Residential Heat Pump Sample

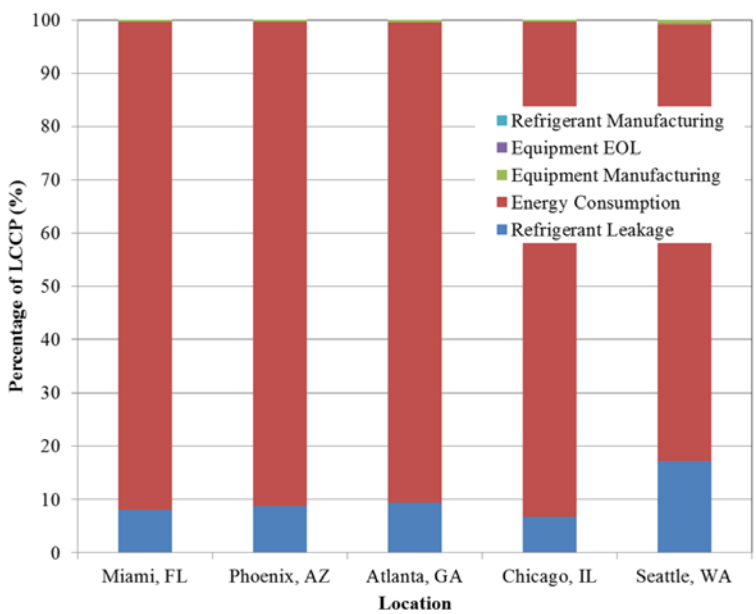

Fig 2: Composition of LCCP Percentage of Total Emissions for Residential Heat Pump Sample Problem

The extremes of the climate zones in the United States are demonstrated by the results. The unit generates 2.6 times more emissions in Chicago, IL than it would in Seattle, WA. Chicago, IL has the highest LCCP and the highest energy consumption. Its climate is heating dominated resulting in a much heavier use of the resistance heating which is much less efficient than the use of the vapor compression cycle. Seattle, WA demonstrates the mildest climate. The bin hours that require heating and cooling are much smaller. The resistance heater is not used. This results in drastically reduced energy consumption. Miami, FL encompasses a hot and humid climate and Phoenix, AZ encompasses a hot and arid climate. The energy consumption of the unit is the most influential component of LCCP. It is 82% of total emissions for Seattle, WA and 93% of total emissions for Chicago. The direct emission is the second most influential component of the calculation which varies from 5.3% to 13% of the total emissions.

These emissions become more influential when the unit is located in a milder climate. The manufacturing emissions vary from 0.3% to 0.8% of the total emissions. The refrigerant manufacturing emissions are 0.08% to 0.2% of the total emissions for all locations and the EOL emissions are approximately 0.01% for all locations.

Specific LCCP was calculated by summing the cooling and heating provided for each location and then divided by the total emissions. Chicago, IL has the highest specific LCCP at 0.3 while Phoenix, AZ has the lowest at 0.17. Chicago, IL requires the most use of the unit in comparison to the other locations because of its harsh winters. Phoenix required more cooling energy but benefits from the higher efficiency of the cooling cycle than the resistance heater.

Table 7: Residential Heat Pump Specific LCCP

Location	Miami, FL	Phoenix, AZ	Atlanta, GA	Chicago, IL	Seattle, WA
Cooling Provided (kWh)	474,900	512,972	213,578	112,211	32,143
Heating Provided (kWh)	10,261	54,532	154,841	317,509	187,573
Specific LCCP (kg CO_{2e}/kWh)	0.22	0.17	0.25	0.30	0.23

7. CONCLUSIONS

A guideline for the use of LCCP and an Excel based tool for residential heat pumps were developed by the IIR LCCP working group. An overview of the guideline was presented in this paper. The equation was developed combining and clarifying the common elements of previous researches. Traceable data sources were established for all components of LCCP. Average values for developed countries were included in the LCCP Guideline from governmental agencies, trade associations and other researches. A sample problem demonstrating the methodology using residential heat pump was presented. Of the five locations analyzed the location with the highest heating load resulted in the highest LCCP value. The milder climates results in a lower LCCP. The indirect emissions dominate the calculation for all locations specifically energy consumption. With a more temperate climate, the direct emissions have more of an influence on the results.

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NOMENCLATURE

LCCP	Life Cycle Climate Performance	(kg CO_2e)
C	Charge	(kg)
L	Lifetime	(years)
ALR	Annual Leakage Rate	(% of Refrigerant Charge)
EOL	End of Life Refrigerant Leakage	(% of Refrigerant Charge)
GWP	Global Warming Potential	(kg CO_2e/kg)
Adp. GWP	Adaptive Global Warming Potential	(kg CO_2e/kg)
AEC	Annual Energy Consumption	(kWh)
EM	CO_2e Produced/kWh	(kg CO_2e/kWh)
m	Mass of Unit	(kg)
MM	CO_2e Produced/Material	(kg CO_2e/kg)
mr	Mass of Recycled Material	(kg)
RM	CO_2e Produced/Material Recycled	(kg CO_2e/kg)
RFM	Refrigerant Manufacturing Emission	(kg CO_2e/kg)
RFD	Refrigerant Disposal Emissions	(kg CO_2e/kg)

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