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Life Cycle Climate Performance Model for Residential Heat Pump Systems

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ABSTRACT

A comprehensive analytical model using Excel and Visual Basic for Applications (VBA) has been developed to simulate life cycle climate performance (LCCP) for residential heat pumps. The LCCP model includes the direct impacts of refrigerant emissions, the indirect impacts of energy consumption used to operate the heat pump system, and the energy to manufacture and safely dispose the system and refrigerant. The annual energy consumption for heat pump operation, including backup heat, is calculated using input performance data at several operating points, in a number of different formats, assuming a linear relationship as defined in AHRI Standard 210/240. With appropriate input, the program can handle different heat pump systems, refrigerants, locations, and CO_2 emission profiles of power plants.

1. INTRODUCTION

Under increasing pressure to address global warming concerns, the industry is spending more effort to understand the environmental impact of air conditioning systems using different refrigerants and technologies. The environmental performance of air conditioning or heat pump systems is partially defined by life cycle impacts on climate, including the direct impacts of refrigerant emissions, the indirect impacts of energy consumption used to operate the heat pump system, and the energy to manufacture, transport, and safely dispose of the system, all expressed in terms of CO_2 equivalent emissions. Thus it is necessary to have a comprehensive method and analytical tool to count all aspects of the environmental impact by air conditioning or heat pump systems.

In the early 1990s when alternative refrigerants were implemented to replace CFC and HCFC, the US DOE and AFEAS jointly sponsored projects to examine the impacts of the refrigerants on overall emissions of greenhouse gases (Fisher et al., 1991, 1994). All conventional air conditioning and refrigeration systems can lead to the emission of two different greenhouse gases (GHGs). First, the energy consumed by the systems, in the form of electricity or the direct combustion of a fossil fuel, results in the release of carbon dioxide. Second, almost all of the refrigerants used in these applications are GHGs. If the refrigerant leaks out of the system during operation, is lost during maintenance, or is not recovered when the system is scrapped, it contributes to global warming. The two GHG contributions are expressed in Total Equivalent Warming Impact (TEWI). The TEWI methodology explicitly seeks to identify both the “direct” effect of greenhouse emissions from the product and the “indirect” effect of carbon dioxide emissions related to the energy consumption of the product. Later on, the DOE evaluated the global impacts of alternative HFCs, natural refrigerants, and new technologies that have a reasonable potential of becoming commercial products before 2015 in terms of TEWI (Sand et al., 1997). Gopalnarayanan et al. (1999) and Sand et al. (1999) reported their work at almost the same time on TEWI of R-22 alternatives (HFCs plus R-290) in air conditioning and heat pump applications. These two separate studies used similar assumptions for direct emissions (4% annual leak rate and 15 years of equipment life time), but for indirect emissions Gopalnarayanan et al. used a comprehensive computer simulation model to determine performance of the system in heating and cooling modes in detail, while Sand et al. used the SEER and HSPF data to estimate energy consumption. Both studies support the argument that the major TEWI contribution of the air conditioning system is the indirect effect. The concept of Life Cycle Climate Performance (LCCP) is more comprehensive than the TEWI, which ignores the energy embodied in product materials, the greenhouse gas emissions during chemical manufacturing, and the end-of- life loss. The LCCP concept was first proposed by the Technology and Economic Assessment Panel (TEAP) of the United Nations Environment Programme (UNEP) (1999) to calculate the “cradle-to-grave” climate impacts of the direct and indirect greenhouse gas emissions. The ADL reports (1999, 2002) used the LCCP concept to investigate overall environmental performance of specific HFCs compared to other fluids and technologies in the applications including automobile air conditioning, residential and commercial refrigeration, unitary air conditioning, HVAC chillers, foam insulation, solvent cleaning, aerosols, and fire protection. Spatz, M. W. (2003) studied performance and LCCP of thee R-22 alternatives in heat pumps including R-410A, R-407C, and R-290. A detailed system modeling for energy use was conducted using the compressor maps, tube-to-tube modeling for evaporators and condensers, and analytical models or correlations for expansion devices. Five (5) European cities with their temperature bins, the average of twenty-nine (29) American cities, and Phoenix were chosen for the analysis. A linear cooling and heating load was assumed. The evaluation showed that the indirect effect dominates the LCCP of heat pumps.

As best as we can discern, the GREEN-MAC-LCCP is the first comprehensive analytical tool that is publicly available to measure environment impact performance of mobile air conditioning (MAC) systems (Papasavva et al., 2010). It was developed by GM, but supported by a group of world experts through SAE. The first version was released for public use in 2006. The GREEN-MAC-LCCP is an Excel format based program. It is a sophisticated accounting of the expected life-cycle climate impacts of any MAC system including direct and indirect emissions. Direct emissions are an aggregate of regular emissions due to refrigerant leaks from the A/C system during operation, irregular emissions due to accidents, service emissions from professional and Do-it-Yourself (DIY) servicing operations, end-of-life (EOL) emissions considering the recovery of refrigerant at EOL of the vehicle, leakage in assembly plants, and atmospheric reaction products from the atmospheric breakdown of HFCs. Indirect emissions are an aggregate of manufacturing and EOL energy of alternative refrigerant and MAC system components, energy consumption from MAC operation during a vehicle’s lifetime, and energy from additional fuel consumption to transport the MAC mass on board the vehicle during vehicle’s lifetime. The GREEN-MAC-LCCP has become a standard tool for LCCP evaluation in automotive industry.

To systematically evaluate the environmental impact of residential heat pump systems, Air-conditioning, Heating and Refrigeration Technology Institute (AHRTI) completed its research project (AHRTI 09003) for which a comprehensive analytical program has been developed to simulate LCCP performance of this type equipment (Zhang et al., 2011). With appropriate input for leakage estimate and performance data, the program can predict LCCP for various heat pumps (single speed, two capacity, and variable speed) at different locations. The following sections introduce the methodology, the Excel program and its validation, and case studies using the tool.

2. AHRTI LCCP CALCULATION METHODOLOGY

For residential heat pumps, the direct emission due to refrigerant leakage includes the following:

- Regular and irregular refrigerant leakage from heat pump equipment
- Refrigerant loss at end-of-life (EOL)

Other minor direct emissions such as leakage during the manufacturing process are not listed here but they can be taken into account by adjusting the input to the above major refrigerant loss.

The indirect emission due to energy consumption is an aggregate of:

- System operating energy
- Energy consumption for components manufacturing (including refrigerant manufacturing)
- Energy consumption for components EOL (including refrigerant EOL)

Thus the lifetime LCCP is calculated as follows:

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

$$= (Ref.\ GWP + Adp.GWP) \times (\text{annual leakage} \times \text{years of lifetime} + \text{refrigerant loss at EOL}) + \text{years of lifetime} \times \Sigma\,(\text{equivalent } CO_2\ kg/kWh \times \text{operating energy } kWh)_{annual} + \Sigma\,(\text{equivalent } CO_2\ kg/kg\ \text{material} \times \text{mass of materials } kg) + \Sigma\,(\text{equivalent } CO_2\ kg/kg\ \text{material} \times \text{mass of recycled materials } kg) \qquad (2)$$

where *Ref.GWP* is the refrigerant GWP value and *Adp.GWP* is the GWP of atmospheric degradation product of the refrigerant. *Annual leakage* includes both regular leakage and irregular leakage (such as leakage due to service) and represents the average over the years of lifetime being evaluated. Note that the indirect emission due to transport of refrigerant, components, and systems is not addressed here because it is relatively small.

The details regarding the calculation of heat pump operating energy are described in the AHRTI report (Zhang et al., 2011). The method adopted is based on the AHRI 210/240 standard (2008). It essentially uses test data obtained at specific conditions (35°C and 27.8°C for cooling, and 8.3°C, 1.7°C, and -8.3°C for heating) and a linear relationship to derive energy for each temperature bin to obtain annual energy consumption. Different algorithms (equations) are used for different types of units (single speed, two capacity, and variable speed). The ambient temperature data is obtained from the TMY3 database (Wilcox et al., 2008). The annual energy plus the information describing equivalent CO_2 emission per kWh by the utility can give indirect emission due to heat pump operation. All other direct and indirect emissions are calculated with appropriate inputs or assumptions such as leakage rate.

3. EXCEL SIMULATION TOOL AND ITS VALIDATION

3.1 Development of the Excel LCCP Simulation Tool

Using the methodology described in the previous section, a Microsoft Excel-based simulation has been developed. A series of macros of Visual Basic for Application (VBA) are implemented for the energy calculation described in the AHRTI report (Zhang et al., 2011) and other direct or indirect emission computation. The Excel simulation program has the following spreadsheets:

3.1.1 “Main” worksheet: This spreadsheet provides high level input data like refrigerant, location, name of the heat pump data sheet, and path for TMY3 weather database. It also gives high level calculation results.

3.1.2 “Refrigerants” worksheet: This sheet lists a majority of refrigerants that are of interest to the industry with the refrigerant GWP value, CO_2-equivalent emission for virgin refrigerant manufacturing, and the GWP for atmospheric reaction byproducts. The refrigerant GWP is from AR4 reports (IPCC, 2007). The GWP values of other refrigerants, currently not listed in AR4, were provided by manufacturers or compiled from publicly available information. The user can add more refrigerants to this spreadsheet.

3.1.3: “CityUtilityInfo” worksheet: The sheet provides the list of the cities and their heating region and utility region that is needed to obtain the CO_2 emission for each kWh of electricity by the power plant. The user can define the CO_2 emission rate as a function of hour in a day and month in a year. The existing number of the average CO_2 rate for each region is obtained from the NREL technical report NREL/TP-550-38617 (Deru et al., 2007). The NREL report divides North America into five (5) interconnected utility regions – Eastern Interconnection, Western Interconnection, Ercot Interconnection, Alaska, and Hawaii, which have the average CO_2 rates of 0.788, 0.594, 0.834, 0.774, and 0.865 kg CO_2/kWh, respectively. Within each of the five utility regions, the power network is interconnected and one cannot tell which specific location or power plant electricity comes from, and so the CO_2 emission rate for power generation within each utility region is considered to be the same. This method is utilized in the current program. The user can expand the city list by including more cities following the user guide.

3.1.4: Heat pump data sheet: This sheet provides heat pump performance data at operating conditions required by the AHRI 210/240 standard (e.g., 35°C and 27.8°C for cooling, and 8.3°C, 1.7°C, and -8.3°C for heating), leakage information, and CO_2 emission for components manufacturing and EOL. It also provides input for backup heat, setting for heat pump shutdown when ambient temperature is too low, etc. The user can choose to do energy calculation for both heating and cooling, or cooling only; detailed energy calculation using performance data, or simple energy estimate based on SEER and HSPF; backup heat using electric heating, or gas/oil heating, or without backup heat; calculation of CO_2 emission for components manufacturing and EOL based on detailed material mass of each individual component, or lump sum mass of the unit. Different types of equipment (single speed, two capacity, variable speed, and custom unit) use different spreadsheets for data input.

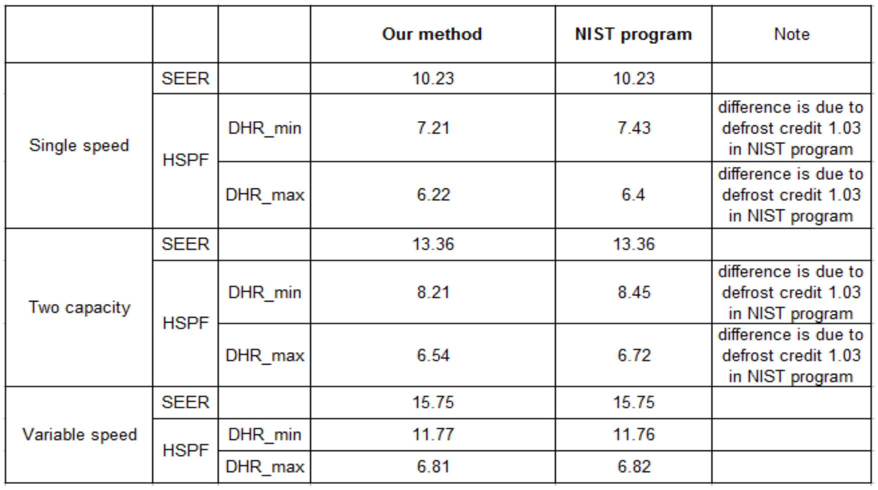
3.1.5: “Results” worksheet: Once input data are provided and computation starts, the program reads in climate data from the TMY3 database, conducts hourly energy calculation for all 8760 hours of a meteorological year, and computes all indirect and direct emission. The “Results” sheet gives detailed calculation results which include: emission charts; numerical data – direct and indirect emission, as well as the breakdown of numbers; temperature bins and energy bins for heat pump operation. Two useful numbers – SEER and HSPF are also given on the results sheet. SEER and HSPF are calculated using the unit performance data and standard temperature bins defined in AHRI 210/240.

3.2 Validation of the Program

It is necessary to validate the LCCP program. Since indirect emission due to energy consumption accounts for a majority of the total LCCP, it is critical to validate the energy calculation. Two steps were taken to validate the program: (1) Implement the equations using Excel cells, and compare to the program from the National Institute of Standards and Technology (NIST) (“NIST -SEER-HSPF-MacroV4.xls”); (2). Implement the equations of annual energy and total emission to Excel files step-by-step and compare the results with output of our LCCP program. The validation covers single speed, two capacity, and variable speed.

3.2.1 Comparison to the NIST program: All the equations for energy calculation used in our program were implemented in the Excel cells step by step. Unit performance data were kept the same as the default numbers in the NIST program (“NIST -SEER-HSPF-MacroV4.xls”), and the calculated SEER and HSPF based on standard bins were compared to that from the NIST program. The comparison is given in Table 1.

Table 1: Comparison of SEER and HSPF values calculated using the NIST program and the equations within the LCCP program



			Our method	NIST program	Note
Single speed	SEER		10.23	10.23	
	HSPF	DHR_min	7.21	7.43	difference is due to defrost credit 1.03 in NIST program
		DHR_max	6.22	6.4	difference is due to defrost credit 1.03 in NIST program
Two capacity	SEER		13.36	13.36	
	HSPF	DHR_min	8.21	8.45	difference is due to defrost credit 1.03 in NIST program
		DHR_max	6.54	6.72	difference is due to defrost credit 1.03 in NIST program
Variable speed	SEER		15.75	15.75	
	HSPF	DHR_min	11.77	11.76	
		DHR_max	6.81	6.82	

One can see from the table that our calculation results match the NIST program except for single speed and two capacity heating HSPF data, for which the difference is caused by the fact that the NIST program uses “demand defrost credit” of 1.03. The defrost heat is not included in the LCCP program at present because it would involve extensive information to define details of the defrost cycle.

3.2.2: Implementation of energy and total emission equations in Excel cells and Comparison to the LCCP program: This was implemented for several cities including Chicago, Miami, and LA. The hand calculation completely matches the output from the LCCP program.

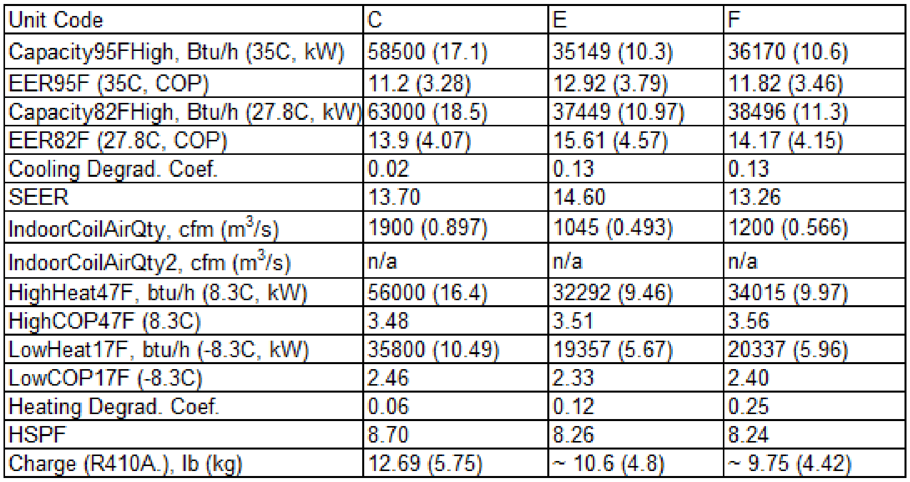
4. CASE STUDIES

Case studies were conducted using the program to show the consistency of the prediction results.

4.1 Comparison of Different Units with Same Refrigerants and Location

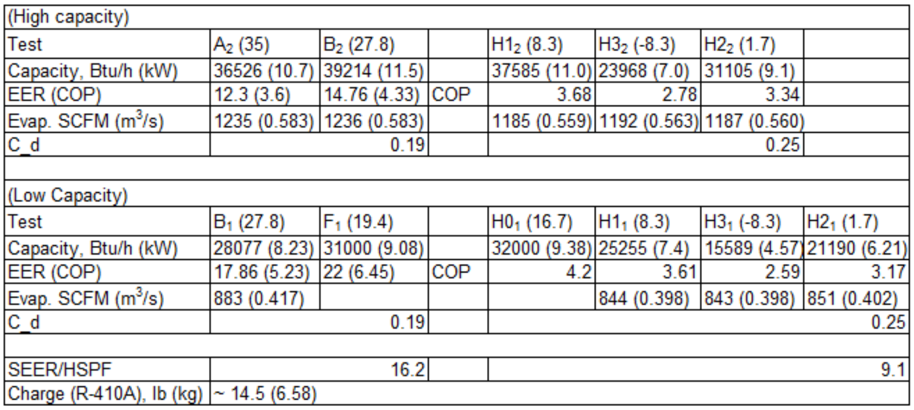
Table 2 gives performance data of three single speed units provided by AHRI. Unit “F” is a 3 ton unit with a SEER of 13, unit “E” is a 3 ton with a SEER of 14.5, and unit “C” is a 5 ton with a SEER of 13.5. Table 3 shows data of a 3 ton two capacity unit with a SEER of 16 (data provided by an OEM). It is assumed that the location is Washington DC, and the refrigerant is R-410A. The mass of component materials needs to be scaled up for the 5 ton unit (unit “C”) from the default 3 ton numbers. With all data input the program can complete the calculations quickly (1 ~ 2 minutes). Figure 1 shows detailed results and a comparison of the units.

Table 2: Representative data provided by AHRI for single speed units



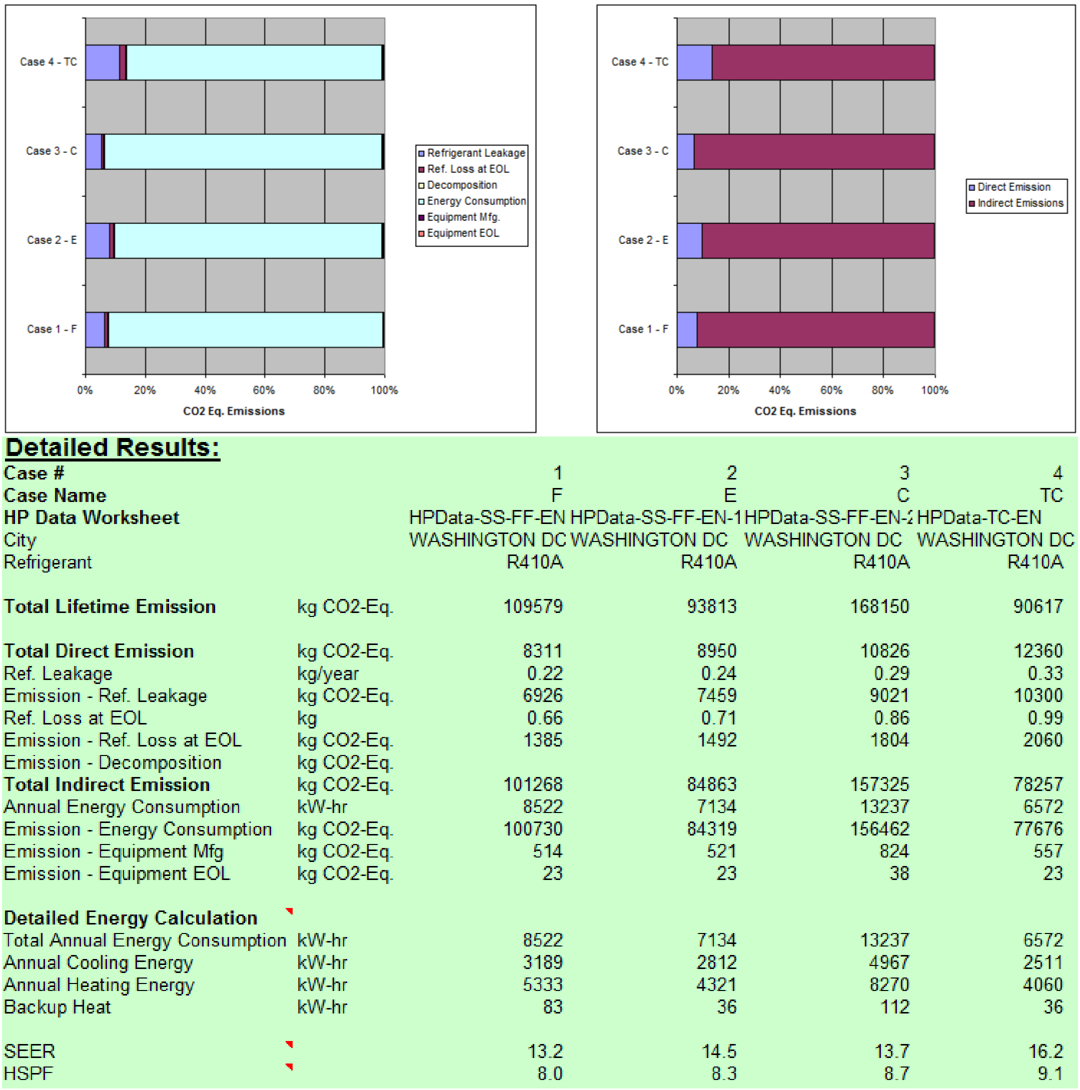
Unit Code	C	E	F
Capacity95FHigh, Btu/h (35C, kW)	58500 (17.1)	35149 (10.3)	36170 (10.6)
EER95F (35C, COP)	11.2 (3.28)	12.92 (3.79)	11.82 (3.46)
Capacity82FHigh, Btu/h (27.8C, kW)	63000 (18.5)	37449 (10.97)	38496 (11.3)
EER82F (27.8C, COP)	13.9 (4.07)	15.61 (4.57)	14.17 (4.15)
Cooling Degrad. Coef.	0.02	0.13	0.13
SEER	13.70	14.60	13.26
IndoorCoilAirQty, cfm (m^3/s)	1900 (0.897)	1045 (0.493)	1200 (0.566)
IndoorCoilAirQty2, cfm (m^3/s)	n/a	n/a	n/a
HighHeat47F, btu/h (8.3C, kW)	56000 (16.4)	32292 (9.46)	34015 (9.97)
HighCOP47F (8.3C)	3.48	3.51	3.56
LowHeat17F, btu/h (-8.3C, kW)	35800 (10.49)	19357 (5.67)	20337 (5.96)
LowCOP17F (-8.3C)	2.46	2.33	2.40
Heating Degrad. Coef.	0.06	0.12	0.25
HSPF	8.70	8.26	8.24
Charge (R410A.), lb (kg)	12.69 (5.75)	~ 10.6 (4.8)	~ 9.75 (4.42)

Table 3: Performance data of two capacity unit



(High capacity)							
Test	A_2 (35)	B_2 (27.8)		$H1_2$ (8.3)	$H3_2$ (-8.3)	$H2_2$ (1.7)	
Capacity, Btu/h (kW)	36526 (10.7)	39214 (11.5)		37585 (11.0)	23968 (7.0)	31105 (9.1)	
EER (COP)	12.3 (3.6)	14.76 (4.33)	COP	3.68	2.78	3.34	
Evap. SCFM (m^3/s)	1235 (0.583)	1236 (0.583)		1185 (0.559)	1192 (0.563)	1187 (0.560)	
C_d		0.19				0.25	
(Low Capacity)							
Test	B_1 (27.8)	F_1 (19.4)		$H0_1$ (16.7)	$H1_1$ (8.3)	$H3_1$ (-8.3)	$H2_1$ (1.7)
Capacity, Btu/h (kW)	28077 (8.23)	31000 (9.08)		32000 (9.38)	25255 (7.4)	15589 (4.57	21190 (6.21)
EER (COP)	17.86 (5.23)	22 (6.45)	COP	4.2	3.61	2.59	3.17
Evap. SCFM (m^3/s)	883 (0.417)				844 (0.398)	843 (0.398)	851 (0.402)
C_d		0.19					0.25
SEER/HSPF		16.2					9.1
Charge (R-410A), lb (kg)	~ 14.5 (6.58)						

For this specific case the direct emission is only 8 ~ 13% of the total emission. Unit “E” has lower lifetime CO_2 emission than unit “F” because it is more energy efficient with a SEER of 14.5 compared to a SEER of 13 for unit “F”. Unit “C” has much higher emission because it is a 5 ton unit compared to 3 ton of others. The two capacity unit has the lowest lifetime emissions. It appears that all other elements (equipment manufacturing, etc.) in the LCCP are negligible except for direct effect of refrigerant leakage and EOL, and indirect effect of energy consumption.



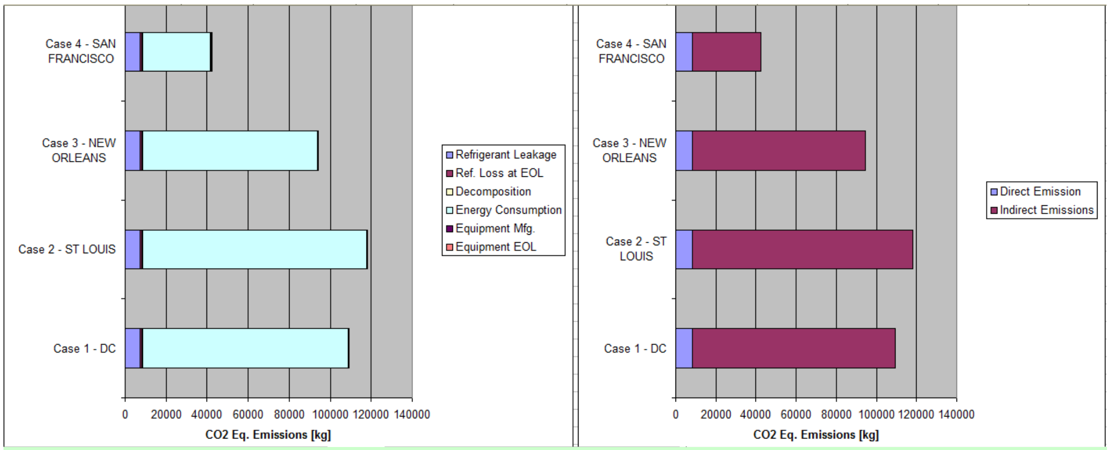
Detailed Results:

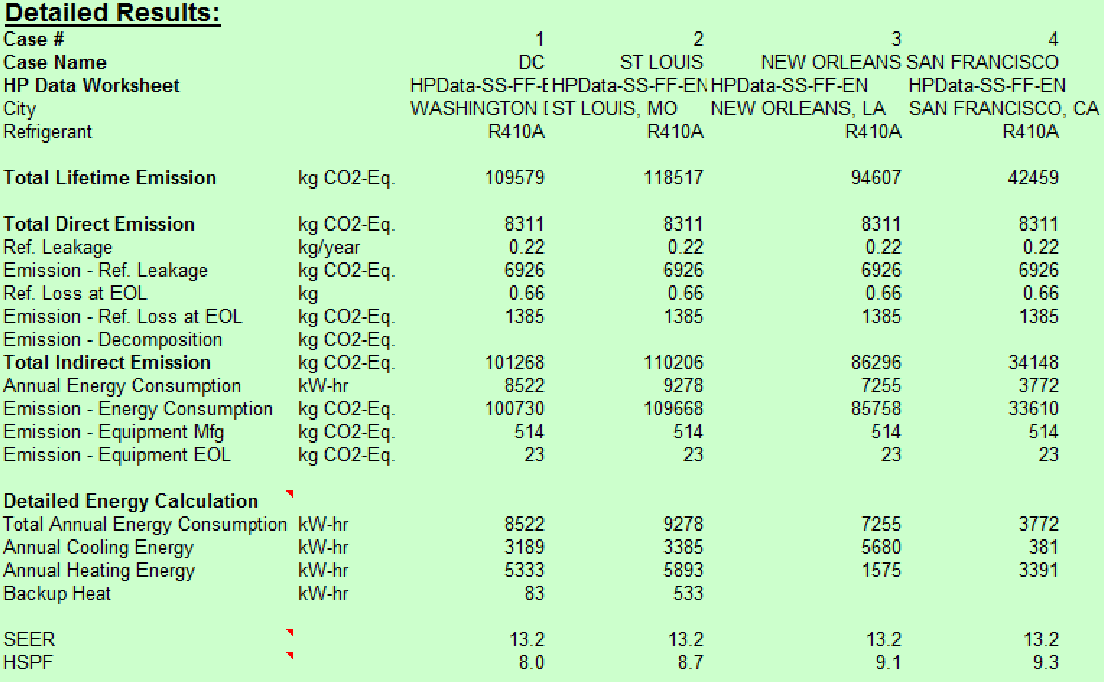
Case #		1	2	3	4
Case Name		F	E	C	TC
HP Data Worksheet		HPData-SS-FF-EN	HPData-SS-FF-EN-1	HPData-SS-FF-EN-	HPData-TC-EN
City		WASHINGTON DC	WASHINGTON DC	WASHINGTON DC	WASHINGTON DC
Refrigerant		R410A	R410A	R410A	R410A
Total Lifetime Emission	kg CO2-Eq.	109579	93813	168150	90617
Total Direct Emission	kg CO2-Eq.	8311	8950	10826	12360
Ref. Leakage	kg/year	0.22	0.24	0.29	0.33
Emission - Ref. Leakage	kg CO2-Eq.	6926	7459	9021	10300
Ref. Loss at EOL	kg	0.66	0.71	0.86	0.99
Emission - Ref. Loss at EOL	kg CO2-Eq.	1385	1492	1804	2060
Emission - Decomposition	kg CO2-Eq.				
Total Indirect Emission	kg CO2-Eq.	101268	84863	157325	78257
Annual Energy Consumption	kW-hr	8522	7134	13237	6572
Emission - Energy Consumption	kg CO2-Eq.	100730	84319	156462	77676
Emission - Equipment Mfg	kg CO2-Eq.	514	521	824	557
Emission - Equipment EOL	kg CO2-Eq.	23	23	38	23
Detailed Energy Calculation					
Total Annual Energy Consumption	kW-hr	8522	7134	13237	6572
Annual Cooling Energy	kW-hr	3189	2812	4967	2511
Annual Heating Energy	kW-hr	5333	4321	8270	4060
Backup Heat	kW-hr	83	36	112	36
SEER		13.2	14.5	13.7	16.2
HSPF		8.0	8.3	8.7	9.1

Figure 1: Comparison of different units with the same refrigeration and location

4.2 Comparison of Different Locations

Unit “F” in Table 2 is modeled for different locations – Washington DC, St. Louis, New Orleans, and San Francisco, and results are shown in Figure 2. St. Louis has both higher cooling energy and higher heating energy than the DC area although their latitudes are almost the same. This may be because of the more extreme weather in the Midwest. New Orleans has much higher cooling energy, but also much lower heating energy, and the total energy and lifetime emissions are lower than DC and St. Louis. San Francisco has the lowest CO_2 emission.





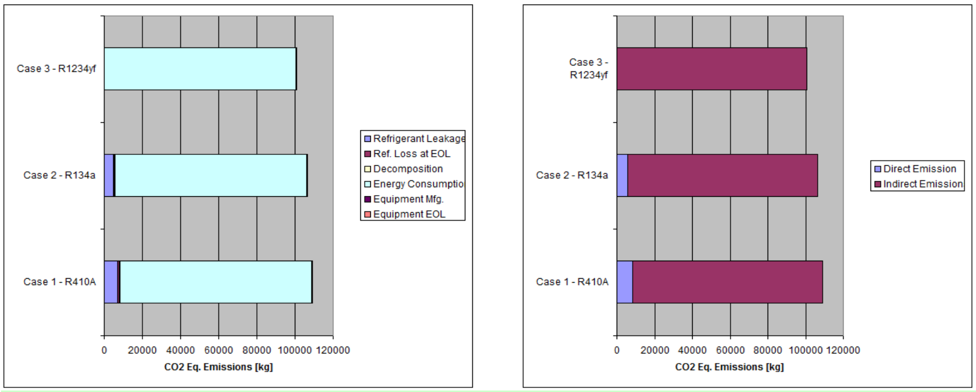
Detailed Results:

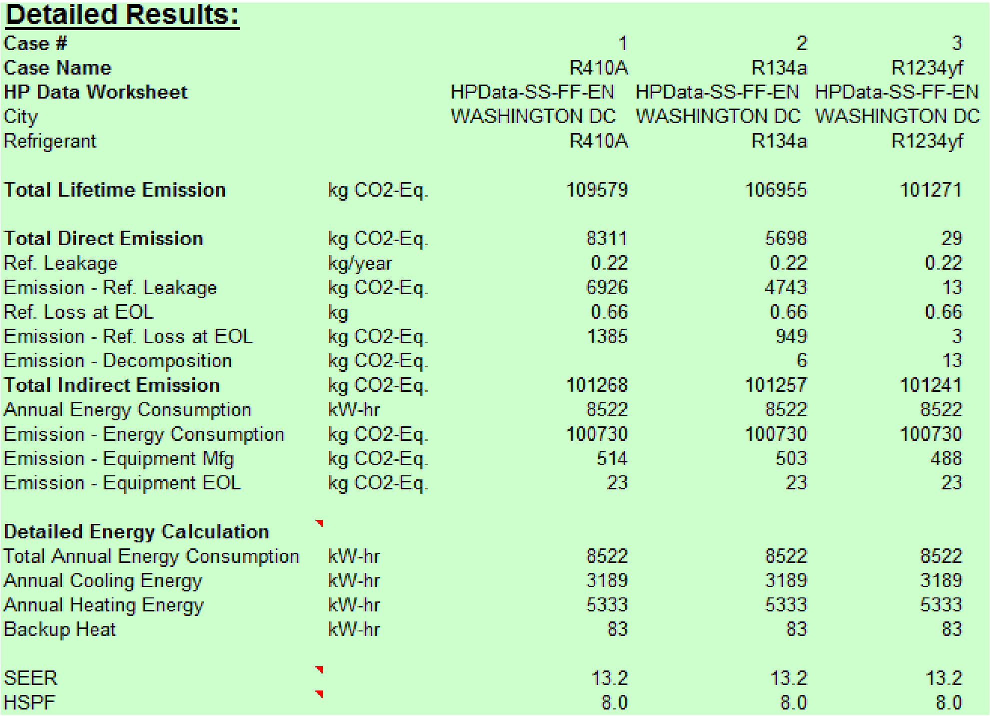
Case #		1	2	3	4
Case Name		DC	ST LOUIS	NEW ORLEANS	SAN FRANCISCO
HP Data Worksheet		HPData-SS-FF-E	HPData-SS-FF-EN	HPData-SS-FF-EN	HPData-SS-FF-EN
City		WASHINGTON [	ST LOUIS, MO	NEW ORLEANS, LA	SAN FRANCISCO, CA
Refrigerant		R410A	R410A	R410A	R410A
Total Lifetime Emission	kg CO2-Eq.	109579	118517	94607	42459
Total Direct Emission	kg CO2-Eq.	8311	8311	8311	8311
Ref. Leakage	kg/year	0.22	0.22	0.22	0.22
Emission - Ref. Leakage	kg CO2-Eq.	6926	6926	6926	6926
Ref. Loss at EOL	kg	0.66	0.66	0.66	0.66
Emission - Ref. Loss at EOL	kg CO2-Eq.	1385	1385	1385	1385
Emission - Decomposition	kg CO2-Eq.				
Total Indirect Emission	kg CO2-Eq.	101268	110206	86296	34148
Annual Energy Consumption	kW-hr	8522	9278	7255	3772
Emission - Energy Consumption	kg CO2-Eq.	100730	109668	85758	33610
Emission - Equipment Mfg	kg CO2-Eq.	514	514	514	514
Emission - Equipment EOL	kg CO2-Eq.	23	23	23	23
Detailed Energy Calculation					
Total Annual Energy Consumption	kW-hr	8522	9278	7255	3772
Annual Cooling Energy	kW-hr	3189	3385	5680	381
Annual Heating Energy	kW-hr	5333	5893	1575	3391
Backup Heat	kW-hr	83	533		
SEER		13.2	13.2	13.2	13.2
HSPF		8.0	8.7	9.1	9.3

Figure 2: Results for different locations

4.3 **Modeling for Different Refrigerants**

To understand the LCCP for different refrigerants, unit "F" in Table 2 is modeled with R-134a, R-410A, and R-1234yf. This is not a perfect way to compare refrigerants because a unit with a different refrigerant should have different performance, or, in order for a system to have the same performance, the system should have different components or system design. In this work we simply assume unit "F" maintains the same performance for each refrigerant. This actually only allows one to see the effect of refrigerants on direct emissions at the same charge level. Figure 3 gives the calculation results. As expected, R-1234yf has the lowest lifetime emission because its GWP is only 4 compared to a GWP of 1430 for R-134a and 2088 for R-410A.





Detailed Results:

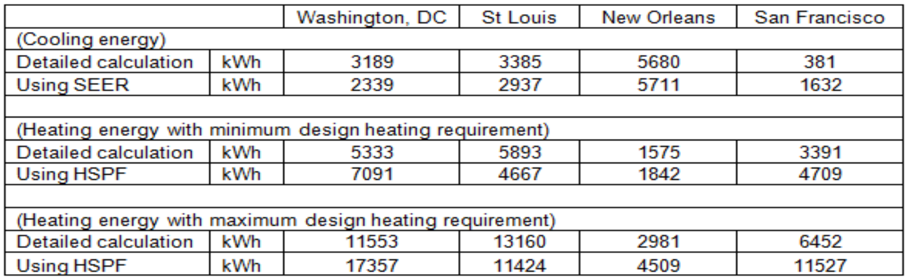
Case #		1	2	3
Case Name		R410A	R134a	R1234yf
HP Data Worksheet		HPData-SS-FF-EN	HPData-SS-FF-EN	HPData-SS-FF-EN
City		WASHINGTON DC	WASHINGTON DC	WASHINGTON DC
Refrigerant		R410A	R134a	R1234yf
Total Lifetime Emission	kg CO2-Eq.	109579	106955	101271
Total Direct Emission	kg CO2-Eq.	8311	5698	29
Ref. Leakage	kg/year	0.22	0.22	0.22
Emission - Ref. Leakage	kg CO2-Eq.	6926	4743	13
Ref. Loss at EOL	kg	0.66	0.66	0.66
Emission - Ref. Loss at EOL	kg CO2-Eq.	1385	949	3
Emission - Decomposition	kg CO2-Eq.		6	13
Total Indirect Emission	kg CO2-Eq.	101268	101257	101241
Annual Energy Consumption	kW-hr	8522	8522	8522
Emission - Energy Consumption	kg CO2-Eq.	100730	100730	100730
Emission - Equipment Mfg	kg CO2-Eq.	514	503	488
Emission - Equipment EOL	kg CO2-Eq.	23	23	23
Detailed Energy Calculation				
Total Annual Energy Consumption	kW-hr	8522	8522	8522
Annual Cooling Energy	kW-hr	3189	3189	3189
Annual Heating Energy	kW-hr	5333	5333	5333
Backup Heat	kW-hr	83	83	83
SEER		13.2	13.2	13.2
HSPF		8.0	8.0	8.0

Figure 3: Comparison of different refrigerants

4.4 Simple Calculation Using SEER and HSPF

The user can also choose to perform a simple energy calculation using SEER and HSPF data. The details of this method are introduced in the AHRTI report (Zhang et al., 2011). Unit "F" in Table 2 is modeled using SEER and HSPF data for four cities – Washington, St. Louis, New Orleans, and San Francisco. The comparison of energy consumption based on detailed calculation and SEER/HSPF is given in Table 4.

Table 4: Comparison of energy consumption based on detailed calculation and SEER/HSPF



		Washington, DC	St Louis	New Orleans	San Francisco
(Cooling energy)					
Detailed calculation	kWh	3189	3385	5680	381
Using SEER	kWh	2339	2937	5711	1632
(Heating energy with minimum design heating requirement)					
Detailed calculation	kWh	5333	5893	1575	3391
Using HSPF	kWh	7091	4667	1842	4709
(Heating energy with maximum design heating requirement)					
Detailed calculation	kWh	11553	13160	2981	6452
Using HSPF	kWh	17357	11424	4509	11527

Compared to the detailed calculation, the SEER/HSPF method works well for New Orleans, but underpredicts cooling energy for Washington DC, overpredicts cooling energy for San Francisco, underpredicts heating energy for St. Louis, and overpredicts heating energy for Washington DC and San Francisco. The under or overprediction by the SEER/HSPF method could be caused by the following factors:

- The actual local heating or cooling hours are different from those suggested by AHRI 210/240 standard ;
- The actual local outdoor design temperature is different from the standard outdoor design temperature;
- The HSPF value is normally published for Region IV. Although a correction factor is introduced to correct for other heating regions, this could still be a factor affecting results.

The user should take the results from the simple SEER/HSPF method as reference only.

Since the value of HSPF for unit "F" (in Table 2) is based on minimum design heating requirement, the HSPF method using maximum design heating requirement tends to overpredict the heating energy significantly for most cities, as shown by the data of the last two rows of Table 4.

5. CONCLUSIONS

- An Excel program with VBA subroutines has been developed for predicting the LCCP of residential heat pumps. The program uses heat pump performance data and a linear relationship to derive annual energy consumption, as well as inputs for refrigerant charge and loss, mass of component materials, and others to calculate all direct or indirect emission.
- The program has been validated by implementing the equations and computing process used in the program to cells of an Excel file step by step (hand calculation), and comparing the (hand calculation) results to the NIST program and output of the LCCP program.
- The program has been utilized to analyze the LCCP of different units with different refrigerants and locations. The program gives consistent results for different scenarios. It appears that all other elements (equipment manufacturing, etc.) in the LCCP composition are negligible except for the indirect effect of energy consumption and the direct effect of refrigerant leakage and EOL.
- A simplified energy calculation method utilizing nominal SEER and HSPF data is provided, but caution is warranted as the results using this method do not appear to correlate with the results from the detailed calculation.
- Significant effort has been made to investigate default parameter inputs such as annual leak rate, recycling loss, equivalent CO_2 emission for component manufacturing, etc. Further study may be needed.

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