

AHRI LCCP Model for Residential Heat Pump Systems

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Introduction

- ◆ Excel based program for modeling life time LCCP for residential heat pumps
- ◆ The LCCP model includes direct impact of refrigerant emissions, indirect impacts due to energy consumption to operate heat pumps, and others
- ◆ Annual energy consumption calculated for 8760 meteorological hours using performance data
- ◆ Can handle different heat pump systems (single speed, variable speed, custom unit, etc.) , refrigerants, locations, and CO₂ emission profiles of power plants
- ◆ Free download from AHRI website:
<http://www.ahrinet.org/technical+results.aspx>

Modeling Method

- ◆ Direct emission
 - Regular and irregular refrigerant leakage from heat pump equipment
 - Refrigerant loss at end-of-life (EOL)
- ◆ Indirect emission
 - System operating energy
 - Energy consumption for components manufacturing (including refrigerant manufacturing)
 - Energy consumption for components EOL (including refrigerant EOL)
- ◆ Annual energy consumption
 - Method and equations are based on AHRI standard 210/240, which uses linear relationship and heat pump performance data tested at specific operating conditions to estimate annual energy (see AHRTI reports for details)
 - 8760 meteorological hours for various locations obtained from tmy3 database

Excel Simulation Program

- ◆ A series of macros of VBA (Visual Basic for Application) were implemented for the energy calculation and all direct or indirect emission computation.

Main worksheet – to select location/refrigerant, specify data worksheet and tmy3 database path, show high level result summary, etc.

The screenshot displays an Excel spreadsheet with the following content:

Calculation Settings

TMY3 Data Folder Path: C:\AHRTI LCCP HP\tmy3data

Buttons: Quick Guide, Help, AHRT

Input Parameters

Case Number	1
Case Name	System A
Location	CHICAGO, IL
Refrigerant	R410A
HP Data Worksheet	HPData-SS-FF-EN
Results Output Sheet	Results

Run Cases

Summary Results

Status	Success
Total Lifetime Emission [kg CO2-Eq.]	168324
Total Direct Emission [kg CO2-Eq.]	8524
Emission - Ref. Leakage [kg CO2-Eq.]	7103
Emission - Ref. Loss at EOL [kg CO2-Eq.]	1421
Emission - Decomposition [kg CO2-Eq.]	0
Total Indirect Emissions [kg CO2-Eq.]	159800
Emissions - Energy Consumption [kg CO2-Eq.]	159260
Emissions - Equipment Mfg [kg CO2-Eq.]	517
Emissions - Equipment EOL [kg CO2-Eq.]	23
TMY3 Location	CHICAGO OHARE INTL AP

Print

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Excel Simulation Program (cont.)

Refrigerants worksheet – refrigerants and GWP information

Parameter / Refrigerant	R22	R134a	R152a	R32	R744	R717	R290	R1234yf	R1234ze	R407C	R410A	R404A	R407A
CO ₂ -Eq. emissions for virgin refrigerant [kg CO ₂ / kg]	0.0	10.0	2.2	7.2	1.0	2.4	1.0	8.0	8.0	10.7	11.4	16.7	11.6
Atmospheric Degradation Products [kg CO ₂ / kg]	0.0	1.6	0.0	0.0	0.0	0.0	0.0	3.3	3.3	0.0	0.0	0.0	0.0
GWP [kg CO ₂ / kg]	1810.0	1430.0	124.0	675.0	1.0	0.0	3.3	4.0	6.0	1774.0	2088.0	3922.0	2107.0

If a cell value is 0.0, then its correct value is unknown.

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User can add additional refrigerants as needed

Excel Simulation Program (cont.)

CityUtilityInfo worksheet – to define city utility region/heating region, and CO₂ emission profiles (as function of hours and months) of power plants for 5 interconnected utility

Utility Region	Average Emission Rate(kg CO2 Eq./kW-h)
Western Interconnection	0.5940
Eastern Interconnection	0.7880
ERCOT Interconnection	0.8340
Alaska	0.7740
Hawaii	0.8650

Detailed Utility Region for Calculation

View/ Edit Hourly Utility Region Emission Rates

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City	Heating Region	Utility Region	HLH _a	CLH _a
ALBANY, NY	5	Eastern Interconnection	2550	580
ATLANTA, GA	3	Eastern Interconnection	1800	1300
BALTIMORE, MD	4	Eastern Interconnection	2220	830
BIRMINGHAM, AL	3	Eastern Interconnection	1550	1500
BOSTON, MA	4	Eastern Interconnection	2450	530
CHARLOTTE, NC	3	Eastern Interconnection	1730	1160
CHICAGO, IL	4	Eastern Interconnection	2470	700
CINCINNATI MUNICIPAL AP LUNKI, OH	4	Eastern Interconnection	2200	930
CLEVELAND HOPKINS INTL AP, OH	4	Eastern Interconnection	2500	700
COLUMBUS PORT COLUMBUS INTL A,	4	Eastern Interconnection	2250	850
DALLAS-FORT WORTH INTL AP, TX	2	ERCOT Interconnection	1400	1640
DENVER INTL AP, CO	5	Western Interconnection	2580	630
DETROIT METROPOLITAN ARPT, MI	5	Eastern Interconnection	2650	600
GREENSBORO, NC	3	Eastern Interconnection	1800	1100
HOUSTON BUSH INTERCONTINENTAL	4	ERCOT Interconnection	1000	2100

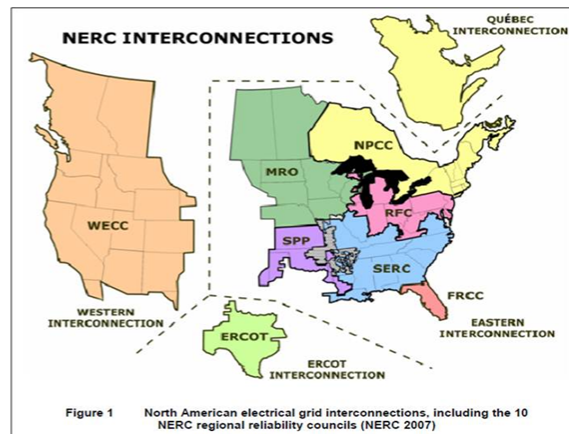


Figure 1 North American electrical grid interconnections, including the 10 NERC regional reliability councils (NERC 2007)

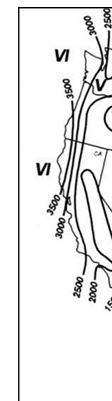


Figure 2 Heating region map

(41 North American cities are included at present. User can add more cities per user instruction.)

Time	Western Interconnection											
	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
0:00-1:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
1:00-2:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
2:00-3:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
3:00-4:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
4:00-5:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
5:00-6:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
6:00-7:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
7:00-8:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
8:00-9:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
9:00-10:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
10:00-11:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
11:00-12:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
12:00-13:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
13:00-14:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
14:00-15:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
15:00-16:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
16:00-17:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
17:00-18:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
18:00-19:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
19:00-20:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
20:00-21:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
21:00-22:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
22:00-23:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940
23:00-24:00	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940	0.5940

Done

Time	Eastern Interconnection											
	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
0:00-1:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
1:00-2:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
2:00-3:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
3:00-4:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
4:00-5:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
5:00-6:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
6:00-7:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
7:00-8:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
8:00-9:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
9:00-10:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
10:00-11:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
11:00-12:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
12:00-13:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
13:00-14:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
14:00-15:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
15:00-16:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
16:00-17:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
17:00-18:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
18:00-19:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
19:00-20:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
20:00-21:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
21:00-22:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
22:00-23:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880
23:00-24:00	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880	0.7880

Done

Excel Simulation Program (cont.)

Heat pump data sheet – to select system type, backup heat, etc., and input performance data, component mass and equivalent emission information, etc.

Settings

Unit System	English
System type	Single Speed Unit Heat Pump
Performance	Calculation based on Capacity/Power Data
Backup Heat	Backup Heat with Electric Heater
CO ₂ from Manufacturing / End Of Life	Detailed

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AHRI Std 210/240 Performance Data

Item	Cooling or Heating	Test Number	Air Ent. Indoor DBT	Air Ent. Indoor WBT	Air Ent. Outdoor DBT	Air Ent. Outdoor WBT	Capacity	Total Power	SEER/HSPF
Units			°F	°F	°F	°F	Btu/hr	W	[-]
Single speed unit - Fixed Fan Speed									
Cooling	A Test	80	67	95	75	40704	3444		
Cooling	B Test	80	67	82	65	45100	2931		
Heating	H1 Test	70	47	43	38600	3353			
Heating	H2 Test	70	60	35	30912	3233			
Heating	H3 Test	70	60	17	22199	3064			

Next Input

System Properties

Input	Units	Value
System Lifetime	years	15
System Charge	lb	10
Annual Leak Rate / Annual Loss	%	5
Refrigerant Loss at EOL	%	15
Component Manufacturing	TOTAL CO ₂ -Eq (lb)	939
Component EOL	TOTAL CO ₂ -Eq (lb)	49.2
Unit Temperature Switch		
T _{off}	°F	0
T _{on}	°F	10
Backup Heat - Fuel Combustion Data		
Heat Value	MBtu/lb fuel	
CO ₂ Emission	lb CO ₂ /lb fuel	

HP Component Manufacturing - Mass & CO₂-Equivalent Emissions (Detailed)

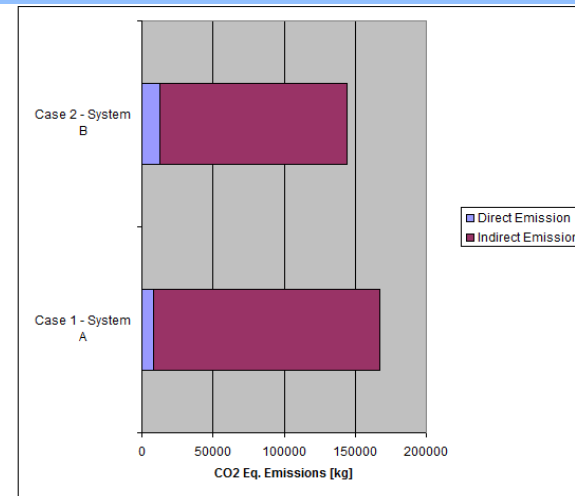
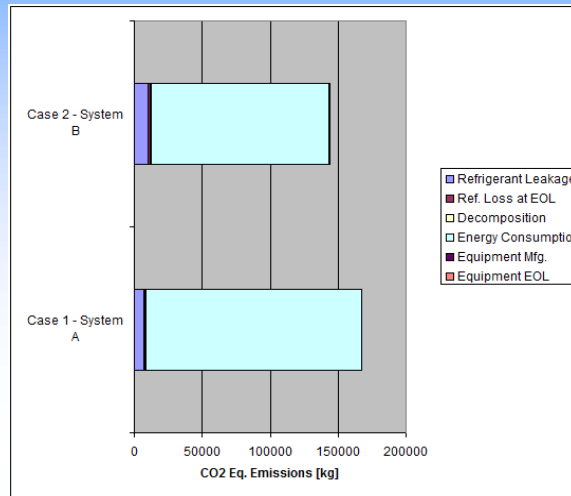
HP Components	CO ₂ -Eq (lb/lb)	% of each component	(lb)	Total CO ₂ -Eq (lb)
Indoor Chassis & Heat Exch.		100%	72.00	
Aluminum	1.6	14%	10.08	16.13
Copper	3.3	20%	14.40	47.52
Plastics	3	0%	0.00	0.00
Steel	2.3	66%	47.52	109.30
Brass	2.5	0%	0.00	0.00
Outdoor Chassis & Heat Exch.		100%	115.00	
Aluminum	1.6	20%	23.00	36.80
Copper	3.3	20%	23.00	75.90
Plastics	3	0%	0.00	0.00
Steel	2.3	60%	69.00	158.70
Brass	2.5	0%	0.00	0.00
Compressor		100%	50.00	
Aluminum	1.6	10%	5.00	8.00
Copper	3.3	20%	10.00	33.00
Plastics	3	2%	1.00	3.00
Steel	2.3	68%	34.00	78.20
Brass	2.5	0%	0.00	0.00

HP Component End-of-Life (EOL) - Mass & CO₂-Equivalent Emissions (Detailed)

	CO ₂ -Eq (lb/lb)	Total Mass (lb)	TOTAL CO ₂ -Eq (lb)
Indoor Chassis & Heat Exch.			
Metals	0.170	72.00	12.2
Plastics	0.015	0.00	0.0
Outdoor Chassis & Heat Exch.			
Metals	0.170	115.00	19.6
Plastics	0.015	0.00	0.0
Compressor			
Metals	0.170	49.00	8.3
Plastics	0.015	1.00	0.0
Piping			
Metals	0.170	20.00	3.4
Plastics	0.015	5.00	0.1
Fan & Blower Wheel			
Metals	0.170	15.00	2.6
Plastics	0.015	0.00	0.0
Motors (fan/blower)			
Metals	0.170	6.29	1.1
Plastics	0.015	0.33	0.0
Expansion Device			

Excel Simulation Program (cont.)

Results



Detailed Results:

Case #		1	2
Case Name		System A	System B
HP Data Worksheet		HPData-SS-FF-E	HPData-TC-EN
City		CHICAGO, IL	CHICAGO, IL
Refrigerant		R410A	R410A
Total Lifetime Emission	kg CO2-Eq.	168324	144716
Total Direct Emission	kg CO2-Eq.	8524	12360
Ref. Leakage	kg/year	0.23	0.33
Emission - Ref. Leakage	kg CO2-Eq.	7103	10300
Ref. Loss at EOL	kg	0.68	0.99
Emission - Ref. Loss at EOL	kg CO2-Eq.	1421	2060
Emission - Decomposition	kg CO2-Eq.		
Total Indirect Emission	kg CO2-Eq.	159800	132356
Annual Energy Consumption	kW-hr	13474	11149
Emission - Energy Consumption	kg CO2-Eq.	159260	131776
Emission - Equipment Mfg	kg CO2-Eq.	517	557
Emission - Equipment EOL	kg CO2-Eq.	23	23
Detailed Energy Calculation			
Total Annual Energy Consumption	kW-hr	13474	11149
Annual Cooling Energy	kW-hr	2172	1639
Annual Heating Energy	kW-hr	11302	9509
Backup Heat	kW-hr	2521	2222
SEER		13.3	15.8
HSPF		7.5	9.0

Cooling Season Temp./Energy Bins

Temp Bin	Unit	Case 1	Case 2
65 ~ 69F	hrs	767	767
	(building load) MBtu	2936	2634
	MJ	3097	2779
	(cooling delivered) MBtu	2936	2634
	MJ	3097	2779
	(power consumed) kW-hr	184	156
70 ~ 74F	hrs	538	538
	(building load) MBtu	4926	4420
	MJ	5197	4663
	(cooling delivered) MBtu	4926	4420
	MJ	5197	4663
	(power consumed) kW-hr	327	264
75 ~ 79F	hrs	531	531
	(building load) MBtu	7706	6915
	MJ	8130	7296
	(cooling delivered) MBtu	7706	6915
	MJ	8130	7296
	(power consumed) kW-hr	543	417
80 ~ 84F	hrs	428	428
	(building load) MBtu	9101	8166
	MJ	9601	8616
	(cooling delivered) MBtu	9101	8166
	MJ	9601	8616
	(power consumed) kW-hr	686	499
85 ~ 89F	hrs	160	160
	(building load) MBtu	4452	3995
	MJ	4697	4215
	(cooling delivered) MBtu	4452	3995
	MJ	4697	4215