ORNL – LCCP: An extensible Framework for Life Cycle Climate Performance based Design of Energy Systems

Vikrant Aute (vikrant@umd.edu)

Oak Ridge National Laboratory
Managed by UT-Battelle for the Department of Energy

University of Maryland 1856

ETSD Energy & Transportation Science Division

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- Background
- Project Objectives
- ORNL LCCP Framework
- Demo

Emissions Due to HVAC&R

- Emissions occur throughout lifetime
  - Leakages, service & disposal
  - Operation
  - Manufacturing & transport
- Mitigation
  - Low/No GWP alternatives
  - Efficient recovery/reuse
  - Efficient systems
  - **Systems approach towards design**

Life Cycle Climate Performance

- Total CO_2 equivalent global warming impact over total lifetime of the system
- Comprised of
  - Direct emissions: refrigerant released
  - Indirect emissions
    - Energy consumption over lifetime and recycling
    - Power input during operation, transport, processing
    - Manufacturing of systems/components, recycling
- Units: kg CO_2 /kg OR CO_2 e

LCCP History

- ORNL
  - Life cycle analysis for alternative refrigerants
  - Total Equivalent Warming Impact (TEWI)
- Papasavva (1997)
  - Expanded TEWI to Life Cycle Warming Impact (LCWI)
- Andersen (1999)
  - Montreal Protocol, Technology & Economic Assessment Panel
  - Coined: Life Cycle Climate Performance (LCCP)

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LCCP Software Efforts

- GREEN-MAC LCCP (2004)
  - Automotive
  - Peer reviewed, contribution from 50 experts,
  - http://www.epa.gov/cppd/mac/
- AHRTI (2011)
  - October 2011, AHRTI Report No. 09003-01
  - Residential heat pumps
- ORNL – LCCP (2012)
  - Project at CEEE/UMD funded by DOE/ORNL

AHRI LCCP

- ***Life Cycle Climate Performance Model for Residential Heat Pump Systems***
- Excel-based simulation tool for calculating the direct and indirect emissions for residential heat pump systems
- http://www.ahrinet.org/technical+results.aspx

Future Energy Systems

- Engineered for performance, cost,…, **LCCP**,…
- LCCP needs to be one of the design metric
- Should be one of the objectives or constraints during design optimization

Challenges

- Standardized LCCP calculation
- Bring diverse set of analysis tools onto a single platform – without exposing any IP
  - Can serve as a platform or component of a bigger platform
- System (refrigeration vs. A/C) independent
- Transparent calculations, peer-reviewed
- Input uncertainty
- Standardized outputs

ORNL LCCP Objectives

- **<u>Design Tool</u>**
- Build on existing methodologies
- Extensible framework for LCCP design
  - Can be coupled with existing system/load calculations tools
- Wide range of applications
  - Supermarket refrigeration, heat pumps,…
- Desktop and Web/Cloud based interfaces
- Open Source

LCCP

Direct Emissions

- Regular emissions
- Irregular emissions
- Service emissions
- End-of-life emission
- Leakage during production & transport

Indirect Emissions

- Energy consumption of the system
- Energy to make system/components
- Energy to produce refrigerant
- Energy to transport
- Energy for end-of-life, recycling/recovery of system and refrigerant

* Also included are place-holders for user-defined emissions

Direct Emissions

$$Em_{direct} = Em_{ref,leak} + Em_{acc} + Em_{serv} + Em_{ref,EOL} + Em_{ref,prod} + Em_{reaction}$$

$Em_{ref,leak}$ = Charge * System lifetime * Annual leak rate * GWP

Em_{acc} = Charge * System lifetime * Annual accident leak rate * GWP

Em_{serv} = Total number of services * Charge * Servicing leak rate * GWP

$Em_{ref,EOL}$ = Percent of refrigerant lost at end of life * Charge * GWP

$Em_{ref,prod}$ = Ref production & transportation leak rate * Charge * GWP

Indirect Emissions

$$Em_{indirect} = Em_{sys,man} + Em_{ref,man} + Em_{sys,EOL} + Em_{ref,disp} + Em_{elec} + Em_{sys,trans}$$

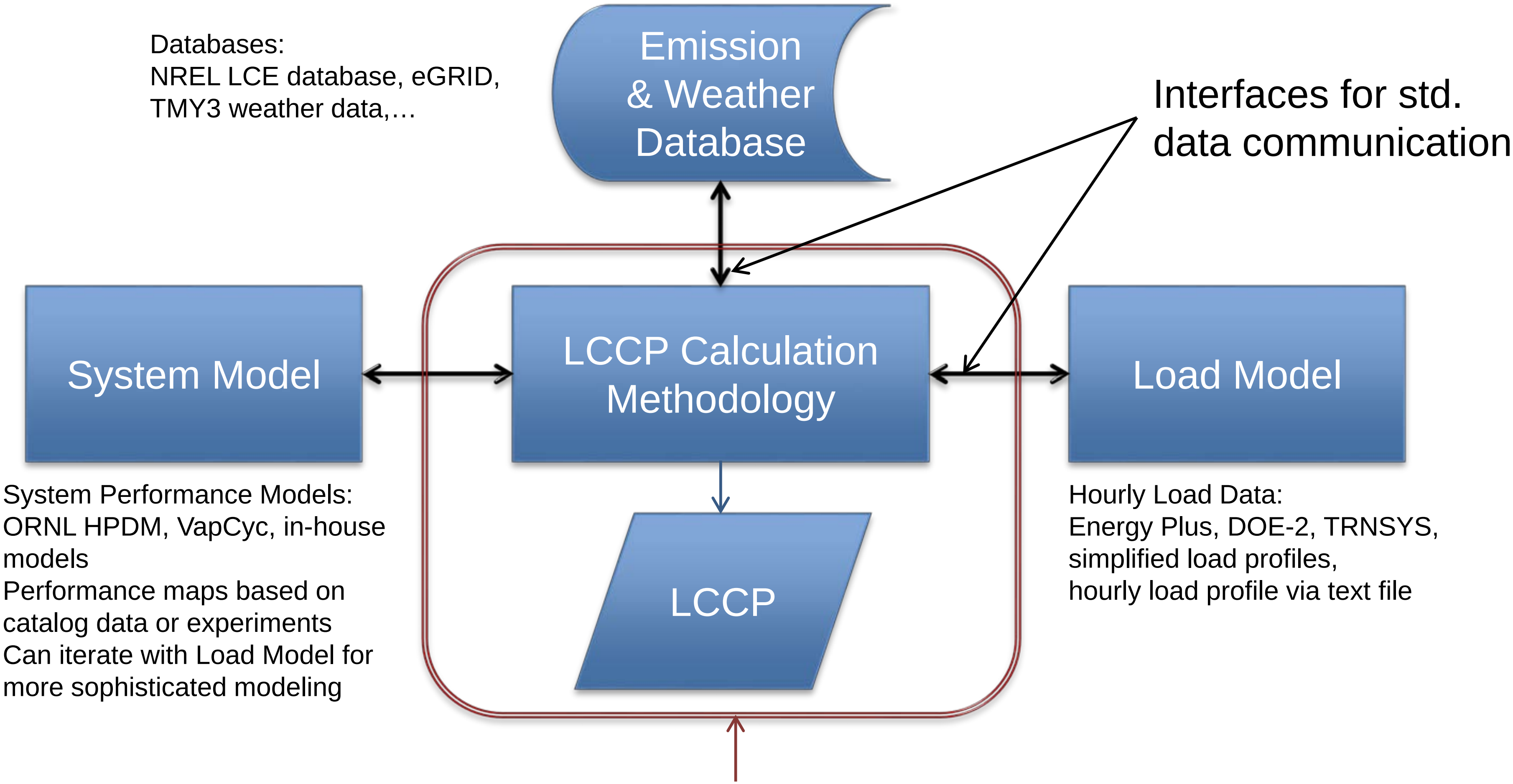
$$Em_{sys,man} = \text{Mass of each material} * CO_2 \text{ equivalent}$$

$$Em_{ref,man} = \text{Charge} * (1 + \text{System lifetime} * \text{Annual leak rate} - \text{Percent of reused refrigerant}) * CO_2 \text{equivalent emissions for virgin refrigerant}$$

$$Em_{sys,EOL} = \text{Energy of recycling of metals} * \text{Mass of metals} * CO_2 \text{ equivalent of metals} + \text{Energy of recycling of plastics} * \text{Mass of plastics} * CO_2 \text{ equivalent of plastics}$$

$$Em_{sys,elec} = \text{System lifetime} * \sum_{n=0}^{8760} \text{Hourly energy consumed} * \text{Emission rate for location}$$

ORNL LCCP Framework



Components will be developed as “Open Source”.
Other components can be open-source or proprietary

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LCCP Inputs

- System
  - Lifetime, leak rates, service intervals, power consumption, charge,..
- Refrigerant
  - GWP, manufacturing, transport, leakage, recycling energy
- Components
  - Manufacturing, transport, recycling
- Application
  - Weather, power-plant emissions, renewable factor

* Also included are place-holders for user-defined inputs

Role of System Simulation Tool

- Indirect emissions: 40%-80% of total
- LCCP approach involves hourly energy consumption calculations, 8760 evaluations
- Robust system simulation tool
  - For novel systems
  - Fast & flexible
  - Allow system design/optimization with LCCP as one of the criterion

ORNL LCCP Web App

- Supermarket refrigeration
  - Design capability
- Residential air source heat pump
  - Evaluation and design capability
  - ANSI/AHRI Standard 210/240

ORNL LCCP tools can be found at:

http://lccp.umd.edu/

ORNL LCCP Web App

Life Cycle Climate Performance - Supermarket Refrigeration

OAK RIDGE NATIONAL LABORATORY ETSD

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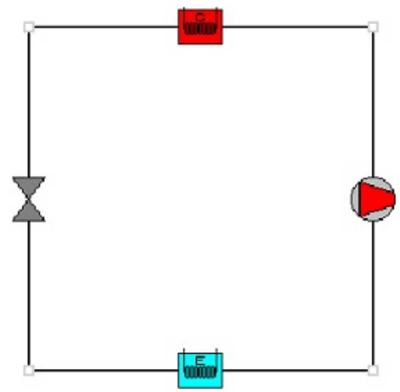
LCCP INPUT PARAMETERS

RUN

Select System Type: Medium Temp DX System | Select Load Profile: Load Profile 1 | Select City: Miami, Florida [1]

Load-profile curve



SYSTEM INPUTS

Load sample values

Refrigerant [-]	R404A	Subcooling at Expansion Device [F]	50.4
System Charge [lb]	4409.25	Superheat at Evaporator Outlet [F]	65.0
Annual Leak Rate [%]	5	Suction Line Temperature Increase [F]	50.0
Refrigerant Loss-EOL [%]	15	Cut-off Temperature [F]	55.0
System Lifetime [yrs]	15	Nominal Load [Btu/hr]	300023.5
Service Leakage Rate [%]	0.05	Service Interval [year]	5
Liquid Line Temperature Decrease [F]	50.0		

COMPONENT INPUTS

Load HTC values

COMPRESSOR

Isentropic Efficiency [%]	65	RPM [-]	3600
Volumetric Efficiency [%]	80	Displacement [in³]	8.54
Number of compressors [-]	10		

CONDENSER

Air Side HTC [Btu/hrft²F]	17.61	Diameter [in]	1.13
Ref Liquid HTC [Btu/hrft²F]	176.11	Tube Length [in]	1200.00
Number of circuits [-]	1	Number of tubes [tubes/circuit]	12
Ref Two Phase HTC [Btu/hrft²F]	874.22	Fin Ratio [-]	15
Ref Vapor HTC [Btu/hrft²F]	105.67	Air Flow Rate(per circuit) [CFM]	42377.60

EVAPORATOR

Air Side HTC [Btu/hrft²F]	17.61	Diameter [in]	0.38
Ref Liquid HTC [Btu/hrft²F]	176.11	Tube Length [in]	2400.00
Number of circuits [-]	1	Number of tubes [tubes/circuit]	10
Ref Two Phase HTC [Btu/hrft²F]	1322.78	Fin Ratio [-]	15
Ref Vapor HTC [Btu/hrft²F]	105.67	Air Flow Rate(per circuit) [CFM]	25426.56

RUN

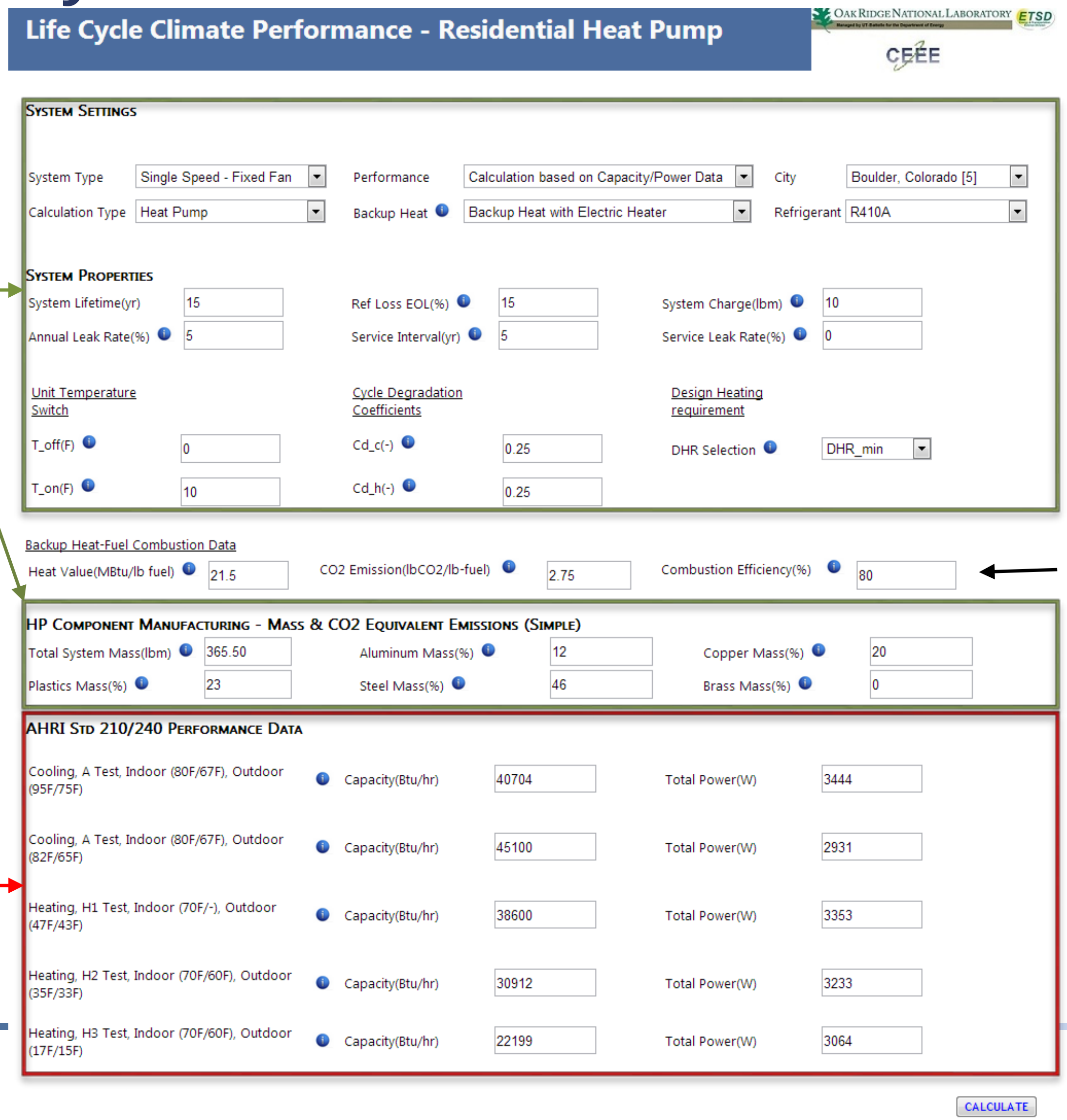
ORNL LCCP Web App

- ASHP system evaluation tool

General system inputs

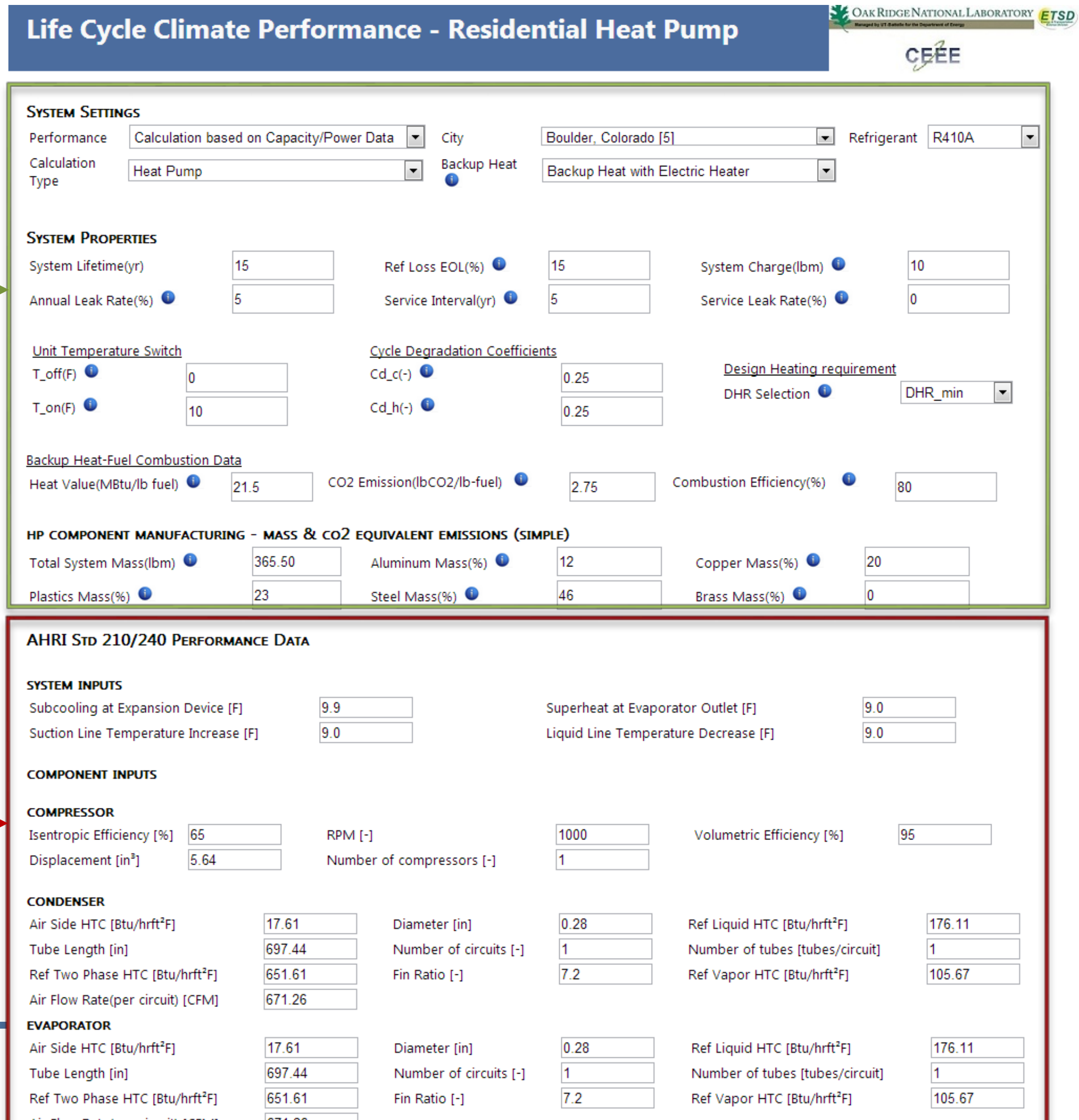
Required for backup heat with gas/oil

- Test data inputs according to AHRI std 210/240
- Required for LCCP evaluation



ORNL LCCP Web App

- ASHP system design tool

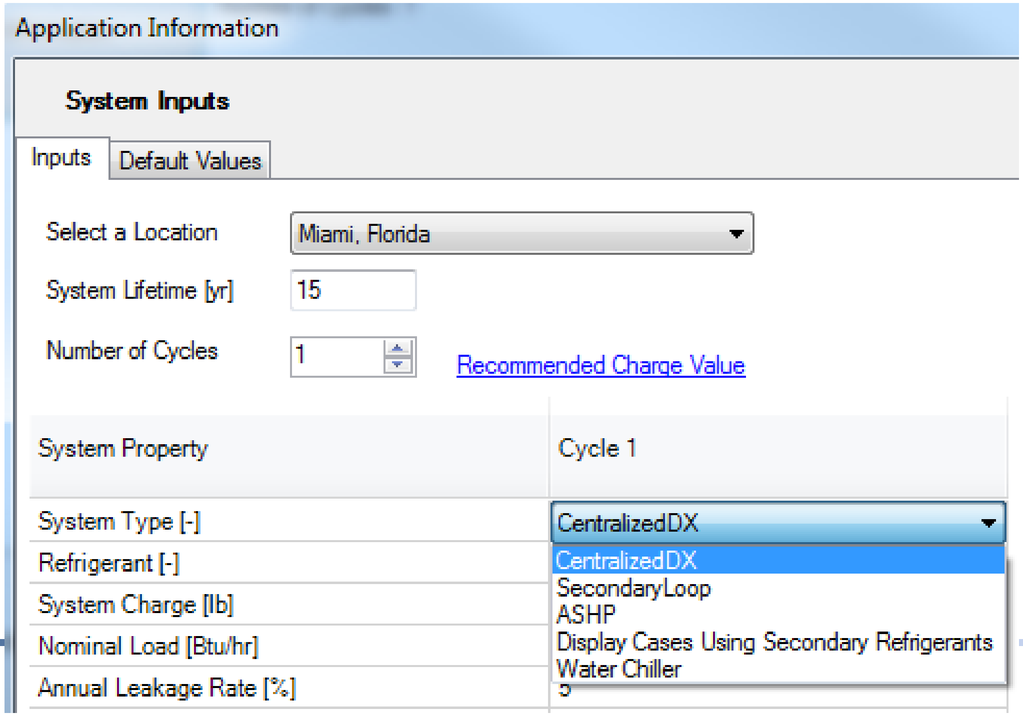


Similar to evaluation tool

- System sizing details
- Required for design based on LCCP

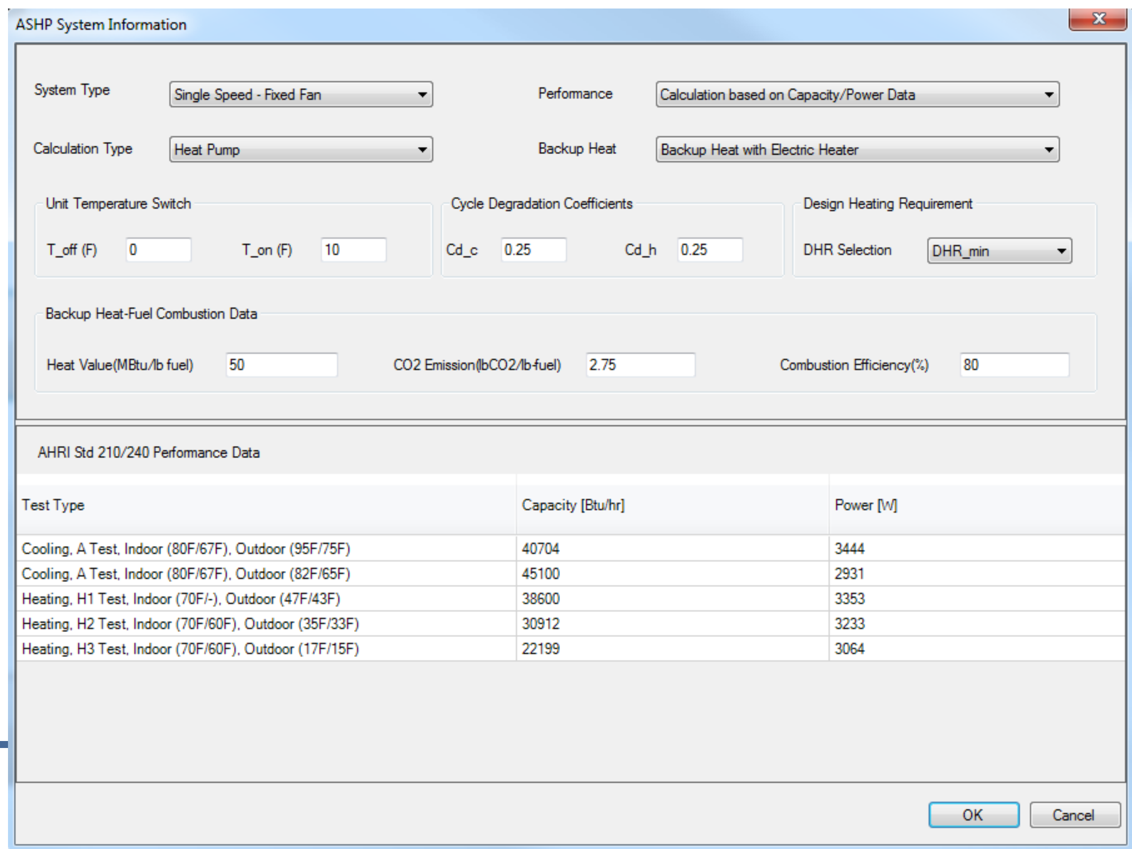
ORNL LCCP Desktop App

- Supermarket refrigeration
- Residential air source heat pump
- Display cases using secondary refrigerants
- Water chiller



ORNL LCCP Desktop App

- Residential air-source heat pump
  - ANSI/AHRI Standard 210/240
  - Can be coupled with EnergyPlus for load calculation


ASHP System Information

System Type: Single Speed - Fixed Fan

Performance: Calculation based on Capacity/Power Data

Calculation Type: Heat Pump

Backup Heat: Backup Heat with Electric Heater

Unit Temperature Switch

T_off (F): 0 T_on (F): 10

Cycle Degradation Coefficients

Cd_c: 0.25 Cd_h: 0.25

Design Heating Requirement

DHR Selection: DHR_min

Backup Heat-Fuel Combustion Data

Heat Value(MBtu/lb fuel): 50 CO2 Emission(lbCO2/lb-fuel): 2.75 Combustion Efficiency(%): 80

AHRI Std 210/240 Performance Data

Test Type	Capacity [Btu/hr]	Power [W]
Cooling, A Test, Indoor (80F/67F), Outdoor (95F/75F)	40704	3444
Cooling, A Test, Indoor (80F/67F), Outdoor (82F/65F)	45100	2931
Heating, H1 Test, Indoor (70F/-), Outdoor (47F/43F)	38600	3353
Heating, H2 Test, Indoor (70F/60F), Outdoor (35F/33F)	30912	3233
Heating, H3 Test, Indoor (70F/60F), Outdoor (17F/15F)	22199	3064

OK Cancel

ORNL LCCP Desktop App

- Display cases using secondary refrigerants (ANSI/AHRI Standard 1320)

Input Values for Typical Secondary Coolant Display Case Parameters

Typical Secondary Coolant Display Case Parameters

Parameter	MT Multideck	MT Reach-in	LT Reach-in	LT Island
Secondary Coolant Flow Rate (GPM/ft)	0.50	0.40	0.65	0.35
Secondary Coolant Pressure Drop (psi/ft)	0.75	0.75	0.75	0.75
Fans (W/ft)	7.0	4.0	10	3.0
Lights (W/ft)	3.0	8.0	7.0	0.0
Anti-Sweat Heater (W/ft)	0.0	24	50	10
Defrost Heater (W/ft)	100	135	300	300
Refrigeration Load (BTUH/ft)	1400	800	550	510

OK

These values are given per foot of display case width

Display Case with Secondary Refrigerants Input

Cycle Defrost Inputs

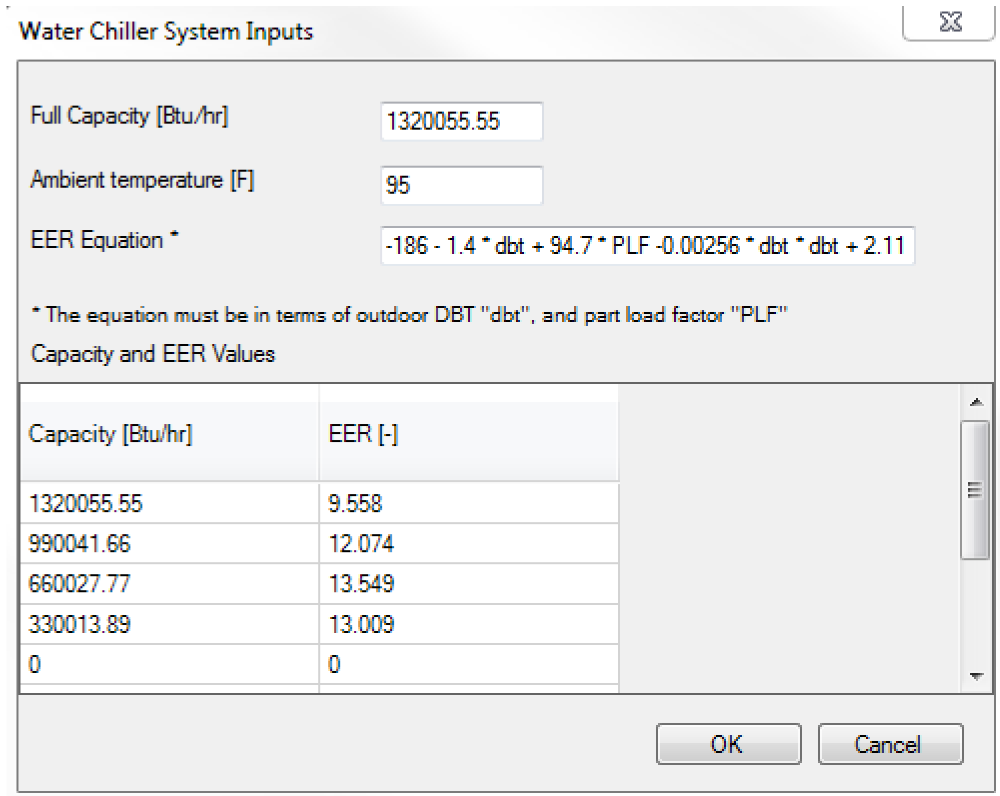
Recommended Input Values

Cut off temperature [K]	298.15	Condensate evaporator pan heaters time [h]	0.25
Secondary coolant pressure drop [psi]	7.5	Condensate evaporator pan heaters power [W]	0
Secondary coolant flow rate [gpm]	5.9	Anti-condensate heaters time [h]	0.25
Defrost heaters time [h]	0.25	Anti-condensate heaters power [W]	0
Defrost heaters power [W]	0	Average refrigerator load [Btu/hr]	16400
Fan motor efficiency [-]	1	Number of fan motors [-]	1
Lights time [h]	24	Defrost time [h]	2.4
Lights power [W]	294	Fan power [W]	60
Time fans [h]	24	Test unit time [h]	24
EER equation as function of ambient dbt	dbt*1/20	**The equation must be in terms of outdoor DBT "dbt"	

OK Cancel

ORNL LCCP Desktop App

- Water chiller system (ANSI/AHRI Standard 550/590)



ORNL LCCP Desktop App

- System
  - VapCyc based
    - Interchange component models
    - Refrigerant mixtures
    - User-defined components and fluids
  - User-defined
- Loads
  - Text file
  - EnergyPlus
  - User defined

ORNL LCCP Desktop App

- TMY3 weather data (predefined cities)
- Multiple cycles system
- Comparison of different systems
- Multi-dimensional parametric analysis
- Sensitivity analysis
- Uncertainty analysis
- Consider effect of charge degradation on system performance

LCCP Applications Comparison

- Supermarket refrigeration system

LCCP Application	Web-based	Desktop
No. of cycles	Single	Multi
Cycles	LT, MT, MT-LT	Any
Simulation software	VapCyc	Any
No. of cities	47	47 + User defined
Load profile	Built-in	Built-in, file-based, EnergyPlus
Parametric Analysis	N/A	Multi parameters
GWP, CO_2 Eq. values	Fixed	User modified

LCCP Applications Comparison

- ASHP system

LCCP Application	AHRI	ORNL-LCCP	
	MS Excel based	Web	Desktop
Design Capability	No	Yes	Yes
System Type	3 + custom	3	3 + custom
Units	English/SI	English/SI/Modified	English/SI/Modified
No. of Cities	41 + User defined	41	41 + User defined
Refrigerants	13 + User defined	13	13 + User defined
Performance Calculation	AHRI std/Simple SEER	AHRI std/Simple SEER	AHRI std/Simple SEER
CO2 from Manufacturing/EOL	Simple/Detailed	Simple	Simple

AHRI tool: http://www.ahrinet.org/technical+results.aspx

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LCCP Desktop Version Demo

ASHP System Information

System Type: Two-Capacity Compressor

Performance: Calculation based on Capacity/Power Data

Calculation Type: Heat Pump

Backup Heat: Backup Heat with Electric Heater

Unit Temperature Switch

T_off (F): 0 T_on (F): 10

Cycle Degradation Coefficients

Cd_c: 0.25 Cd_h: 0.25

Design Heating Requirement

DHR Selection: DHR_min

Backup Heat-Fuel Combustion Data

Heat Value(MBtu/lb fuel): 50 CO2 Emission(lbCO2/lb-fuel): 2.75 Combustion Efficiency(%): 80

AHRI Std 210/240 Performance Data

Test Type	Capacity [Btu/hr]	Power [W]
Cooling(high), A2 Test, Indoor (80F/67F), Outdoor (95F/75F)	36526	2971
Cooling(high), B2 Test, Indoor (80F/67F), Outdoor (82F/65F)	39214	2656
Cooling(Low), B1 Test, Indoor (80F/67F), Outdoor (82F/65F)	28077	1572
Cooling(low), F1 Test, Indoor (80F/67F), Outdoor (67F/53.5F)	31000	1400
Heating(High), H12 Test, Indoor (70F/60F), Outdoor (47F/43F)	37585	2993
Heating(High), H22 Test, Indoor (70F/60F), Outdoor (35F/33F)	31105	2732
Heating(High), H32 Test, Indoor (70F/60F), Outdoor (17F/15F)	23968	2531
Heating(Low), H01 Test, Indoor (70F/60F), Outdoor (62F/56.5F)	32000	2232
Heating(Low), H11 Test, Indoor (70F/60F), Outdoor (47F/43F)	25255	2054
Heating(Low), H21 Test, Indoor (70F/60F), Outdoor (35F/33F)	21190	1959

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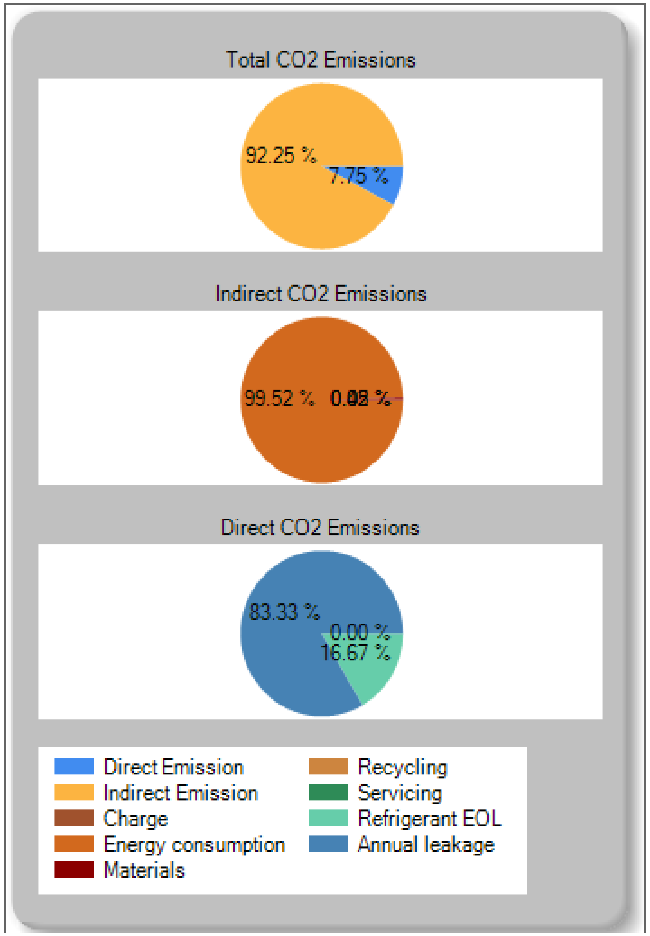
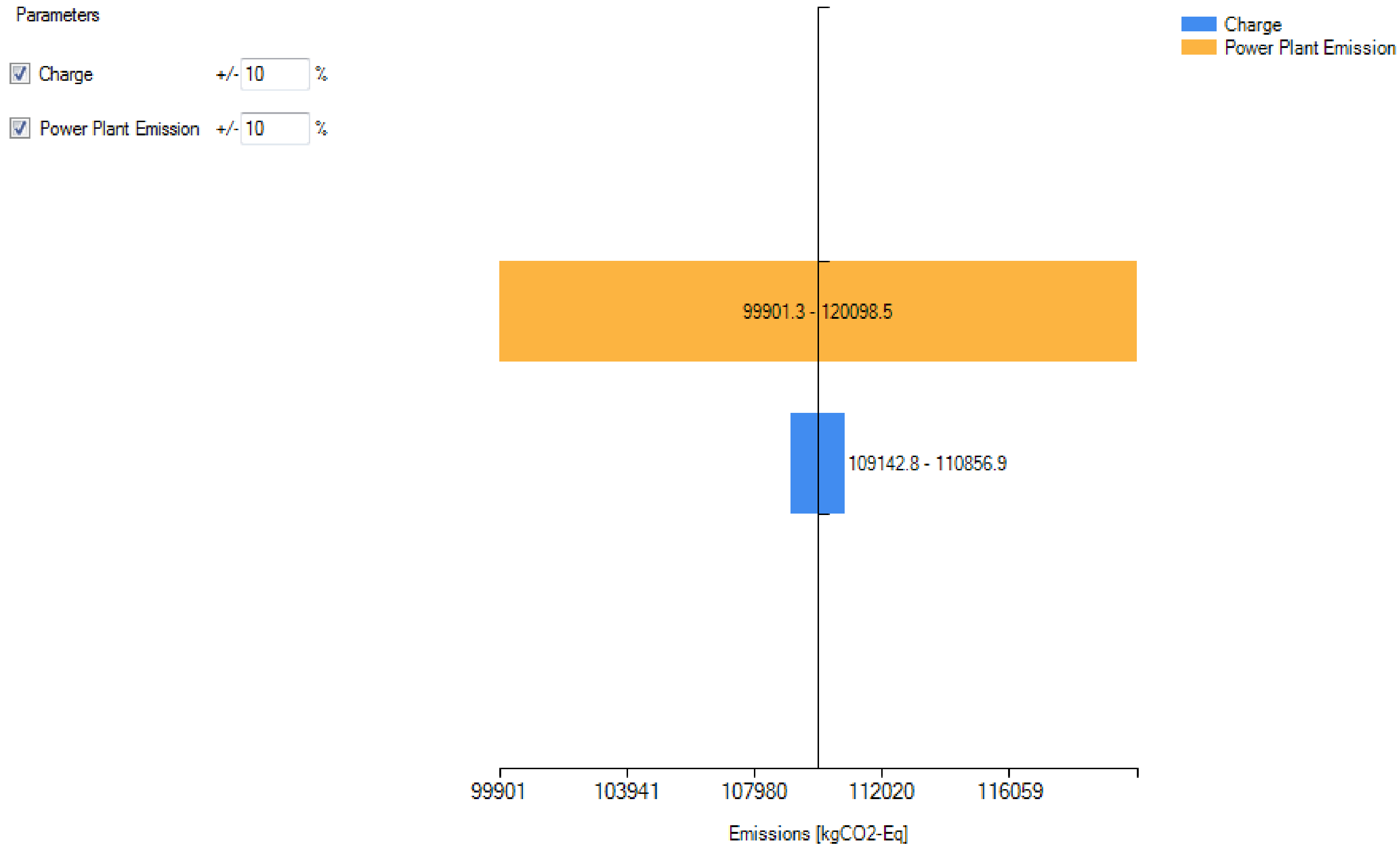
LCCP Desktop Version Demo



Results

Result Type	Value	% Value
City Name	Chicago, Illi...	
Refrigerant	R410A	
Total Emissions[kgCO2-Eq]	109999.86	
Total Direct Emissions[kgCO2-Eq]	8523.90	
Emissions - Annual Leakage[kgCO2-Eq]	7103.25	6.46
Emissions - EOL[kgCO2-Eq]	1420.65	1.29
Emissions - Service[kgCO2-Eq]	0.00	0.00
Emissions - Accidents	0.00	0.00
Emissions - Ref. Production and Transportation	0.00	0.00
Total Indirect Emissions[kgCO2-Eq]	101475.96	
Emissions - Energy Consumption[kgCO2-Eq]	100986.02	91.81
Emissions - Materials[kgCO2-Eq]	421.39	0.38
Emissions - Recycling[kgCO2-Eq]	22.01	0.02
Emissions - Charge[kgCO2-Eq]	46.54	0.04
Emissions - Refrigerant Disposal	0.00	0.00
Emissions - System Transport	0.00	0.00
Annual Energy Consumption[kgCO2-Eq]	6732.40	

LCCP Desktop Version Demo



LCCP Desktop Version Demo

Inputs | Results | Sensitivity Analysis | Results -ALT | Uncertanity Analysis

Input Parameters	Current Value [SI Units]	Uncertanity(absolute)	Uncertainity(%)
Refrigerant EOL Disposal	0		1
Reused Refrigerant	0.8		1
Service Leakage Rate	0.05		1
Ref Production & Transportation	0		1
Refrigerant Loss EOL	0.1		1
Accidents Leakage Rate	0		1
Annual Leakage Rate	0.1		1
Charge	3299.9		1

Results

Copy results data to clipboard

Parameters	Current Value	Uncertainity Absolute	Uncertainity Percent
Total Emissions	48608192.62	48608192.62 +/- 566763.42	48608192.62 +/- 1.17 %
Total Direct Emission	33649693.45	33649693.45 +/- 545724.74	33649693.45 +/- 1.62 %
Annual Leakage Emission	25884379.58	25884379.58 +/- 448330.61	25884379.58 +/- 1.73 %
Refrigerant EOL Emission	1294218.98	1294218.98 +/- 22416.53	1294218.98 +/- 1.73 %
Production Emission	0	0 +/- 0	0 +/- 0 %
Accidents Emission	0	0 +/- 0	0 +/- 0 %
Servicing Emission	6471094.89	6471094.89 +/- 112082.65	6471094.89 +/- 1.73 %
Total Indirect Emission	14958499.17	14958499.17 +/- 148387.26	14958499.17 +/- 0.992 %
Energy Consumption Emission	14837261.01	14837261.01 +/- 148372.61	14837261.01 +/- 1 %
Materials Emission	0	0 +/- 0	0 +/- 0 %
Recycling Emission	0	0 +/- 0	0 +/- 0 %
Charge Emission	121238.16	121238.16 +/- 2085.39	121238.16 +/- 1.72 %
Refrigerant EOL Emission	0	0 +/- 0	0 +/- 0 %
Equipment Transport	0	0 +/- 0	0 +/- 0 %

Parameters	Current Value	Uncertainity Absolute	Uncertainity Percent	Partial Derivative
Refrigerant EOL Disposal	0	0 +/- 0	0 +/- 1%	0
Reused Refrigerant	0.8	0.8 +/- 0.008	0.8 +/- 1%	-55108.2566
Service Leakage Rate	0.05	0.05 +/- 0.0005	0.05 +/- 1%	129421897.83
Ref Production & Transportation	0	0 +/- 0	0 +/- 1%	0
Refrigerant Loss EOL	0.1	0.1 +/- 0.001	0.1 +/- 1%	12942189.8
Accidents Leakage Rate	0	0 +/- 0	0 +/- 1%	0

Project Team

- Oak Ridge National Labs (ORNL)
  - Omar Abdelaziz (abdelazizoa@ornl.gov)
  - Ed Vineyard
  - Brian Fricke
- University of Maryland (UMD)
  - Vikrant Aute (vikrant@umd.edu)
  - Reinhard Radermacher
  - Lopamudra Vemulapalli
  - Mohamed Beshr

Thank You