Low GWP R-410A Alternatives in Heat Pumps: "Drop-in" LCCP Evaluation

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Outline

- Introduction
- Experimental Apparatus
- Heat Pump Performance
- LCCP Assumptions
- LCCP Evaluation under Different US Cities
- LCCP Sensitivity Analysis
- Conclusions

Motivation

- **Low GWP replacements needed in HVAC applications**

ODP=0 → **ODP=0 Low GWP**

R-410A GWP: 2,088

R-32	GWP: 675
L-41a	GWP: 494
D2Y60	GWP: 272

- AHRI supports AREP program
- LCCP analysis needed to evaluate the environmental impact (GHG emissions)
- Currently limited LCCP evaluation for low GWP refrigerants in HPs

Refrigerant Properties

Table 1: Comparison of Thermophysical Properties of Refrigerants

Parameter	Unit	R-410A		R-32		L-41a		D2Y60	
Temperature	° C	44	10	44	10	44	10	44	10
Sat. Vapor Pressure	kPa	2,653	1,081	2,73	1,107	2,490	1,016	2,217	924.7
Temperature Glide	K	0.1	0.1	0	0	2.2	2.5	5	5.8
Sat. Liquid Density	kg/m^3	953.2	1133	872	1,020	896.3	1,044	928.2	1,074.3
Sat. Vapor Density	kg/m^3	115.6	41.9	82.4	30.2	81.17	29.68	81.9	30.3
Latent Heat	kJ/kg	151.7	209.9	226	298.9	197.4	258.0	158.6	204.6
Sat. Liq. Spec. Heat	kJ/(kg-K)	2.04	1.57	2.25	1.8	2.07	1.68	1.83	1.5
Sat. Vap. Spec. Heat	kJ/(kg-K)	2.02	1.227	2.06	1.344	1.83	1.23	1.5	1.1
Sat. Liq. Therm. Conductivity	mW/(m-K)	75.1	98.1	105	136.4	95.29	117.5	74.2	91.5
Sat. Vap. Therm. Conductivity	mW/(m-K)	18.7	13.6	21.4	15.3	18.93	12.7	17.8	12.7
Sat. Liquid Viscosity	µPa-s	92	147.3	92.6	139.5	92.3	138.7	96.6	145.4
Sat. Vapor Viscosity	µPa-s	15.7	12.7	14	12	14.4	12.3	14.4	12.3
Vol. Cooling Capacity	kJ/m^3	-	8,804	-	9,039	-	7,656	-	6,202
GWP	-	2,088		675		494		272	

Experimental Apparatus

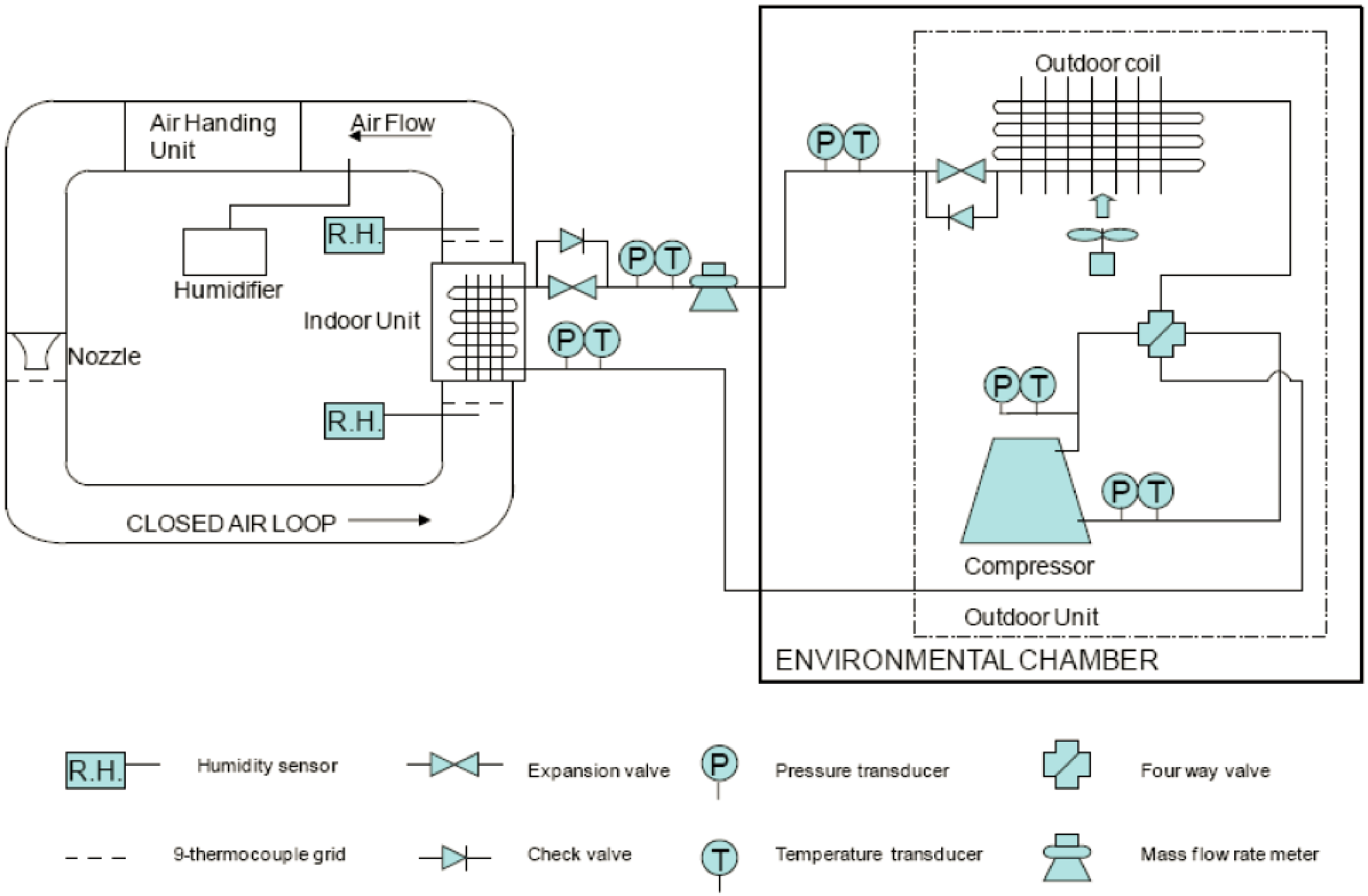


Figure 1: Schematic of Test Facility setup.

Test Matrix

Table 2: ASHRAE Standard 116 (2010) Test Matrix

Test	Indoor Db (°C)	Indoor Wb (°C)	Outdoor Db (°C)	Outdoor Wb (°C)	Operation
Extended Conditions			46.1		Steady State Cooling
A		19.4	35		Steady State Cooling
B	26.7			NA	Steady State Cooling
C		≤13.9	27.8		Steady State Cooling, Dry Coil
D					Cyclic Cooling, Dry Coil
High Temp. 2			8.3	6.1	Steady State Heating
High Temp. 1			16.7	14.7	Steady State Heating
Low Temp.			-8.3	-9.4	Steady State Heating
Extended Conditions	21.1	≤15.6	17.8	NA	Steady State Heating
High Temp. Cyclic			8.3	6.1	Cyclic Heating
Frost Acc.			1.7	0.6	Steady State Defrost

Cooling

Heating

LCCP Assumptions

System Lifetime [yr]: 15

Number of Cycles: 1

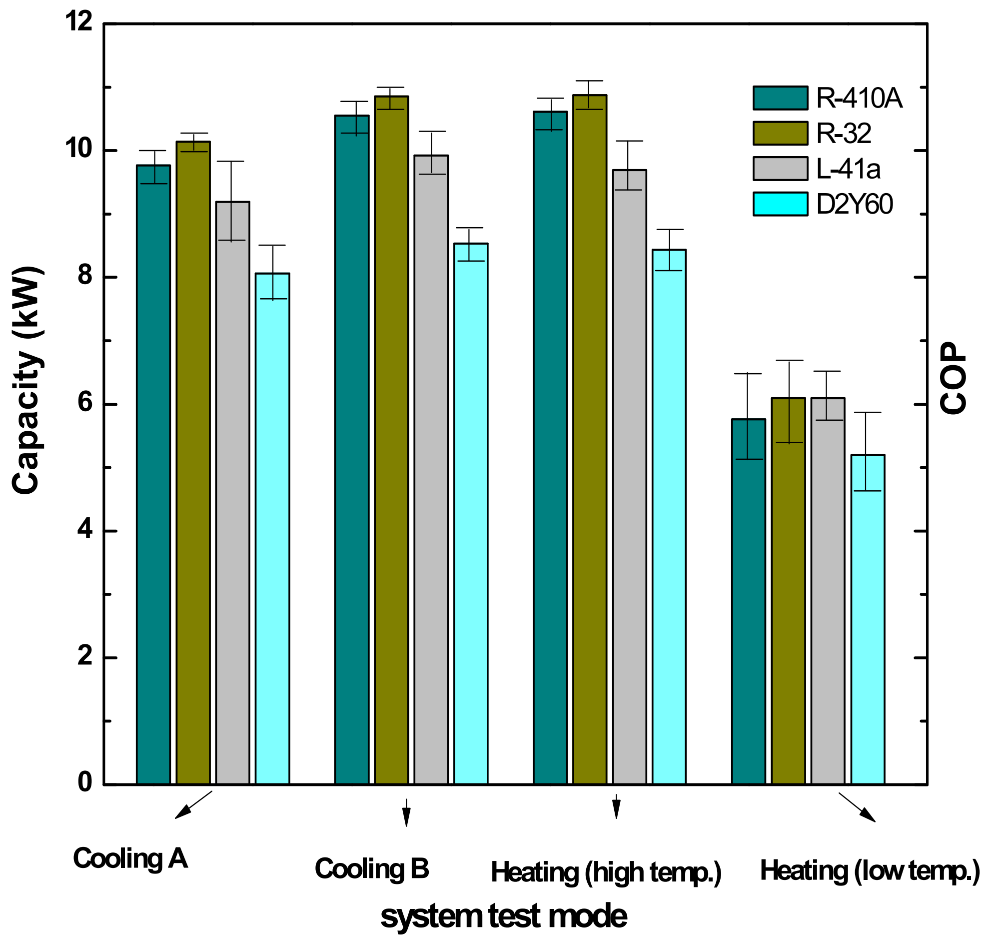
System Property	Cycle 1
System Type [-]	ASHP
Refrigerant [-]	R410A
System Charge [lb]	11.7
Nominal Load [Btu/hr]	36000
Annual Leakage Rate [%]	5
Ref Loss EOL [%]	15
Service Interval [yr]	5
Service Leakage Rate [%]	5
Ref Disposal Energy [lbCO2-Eq]	0
Reused Refrigerant [%]	85
Accident Leakage [%]	0.3
Ref Production & Transportation[%]	0
Equipment Transport [lbCO2-Eq]	0
Aluminum Castings [lb]	15
Aluminum Forgings [lb]	10
Steel Forgings [lb]	10
Wrought Aluminum [lb]	25
Rubber [lb]	5
Copper [lb]	30
Plastics [lb]	5
Brass [lb]	0

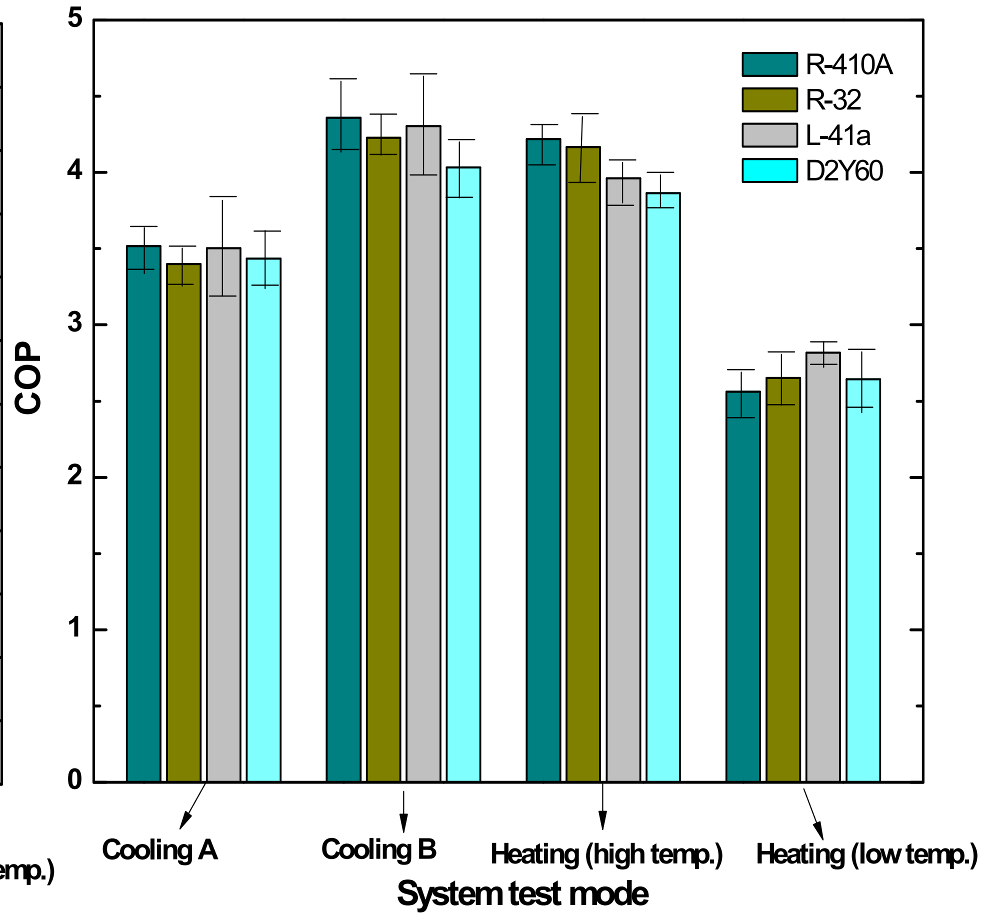
Refrigerant

Charge amount

- **Unit temp. switch:**
  - **T_off: 0 F**
  - **T_on: 10 F**
- **Back up heat combustion data: Combustion efficiency 80%**

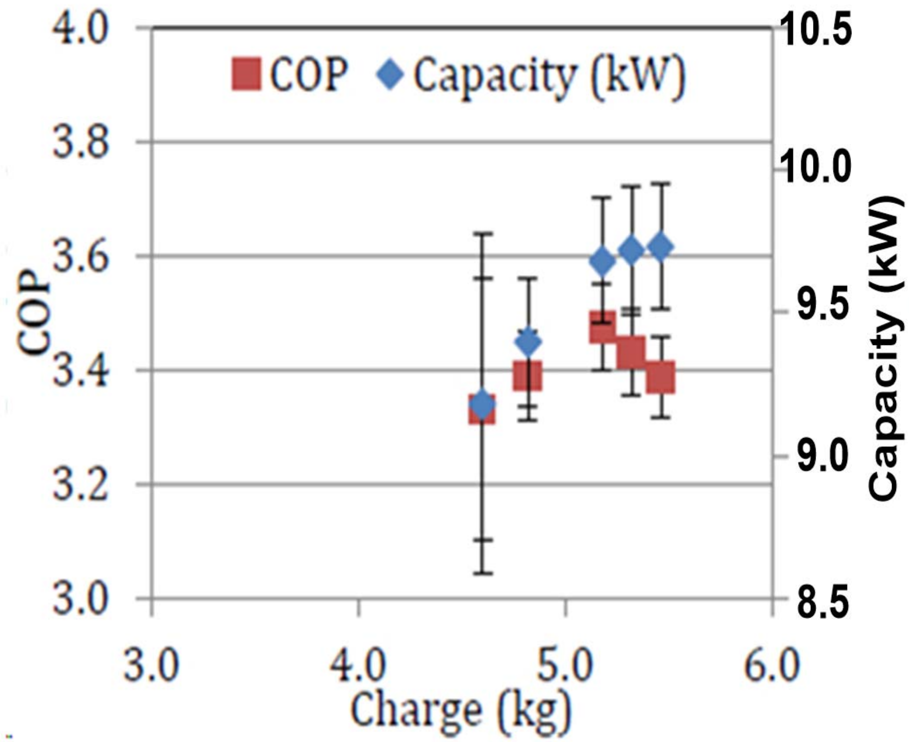
Heat Pump Performance



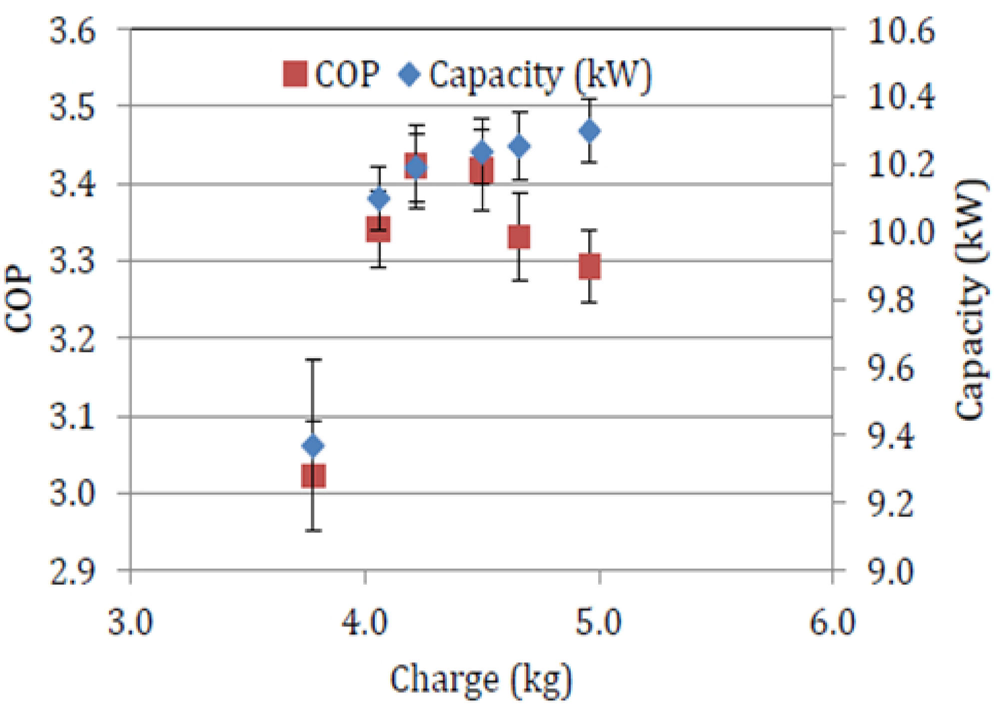


Heat Pump Performance- Charge Effects

Cooling A



R-410A

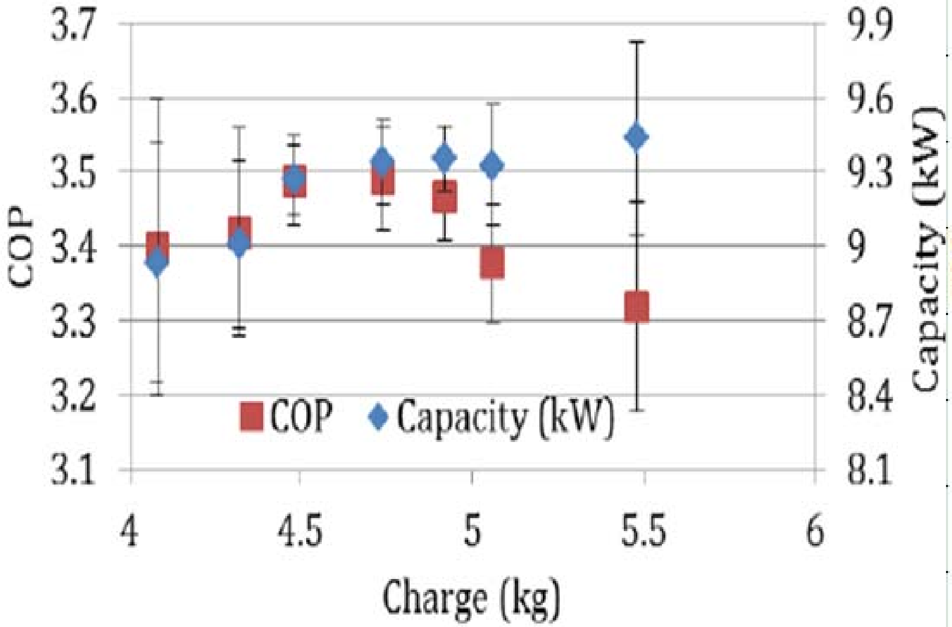


R-32

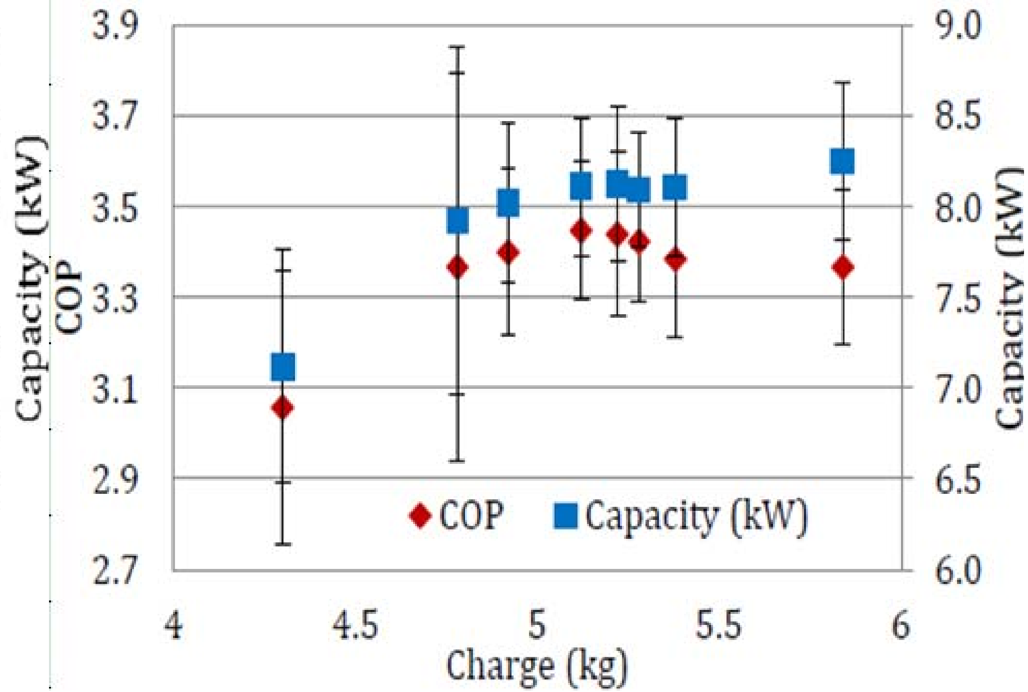
- As the refrigerant charge amount is increased, the cooling capacity is increased and COP is increased first and then decreased

Heat Pump Performance- Charge Effects

Cooling A



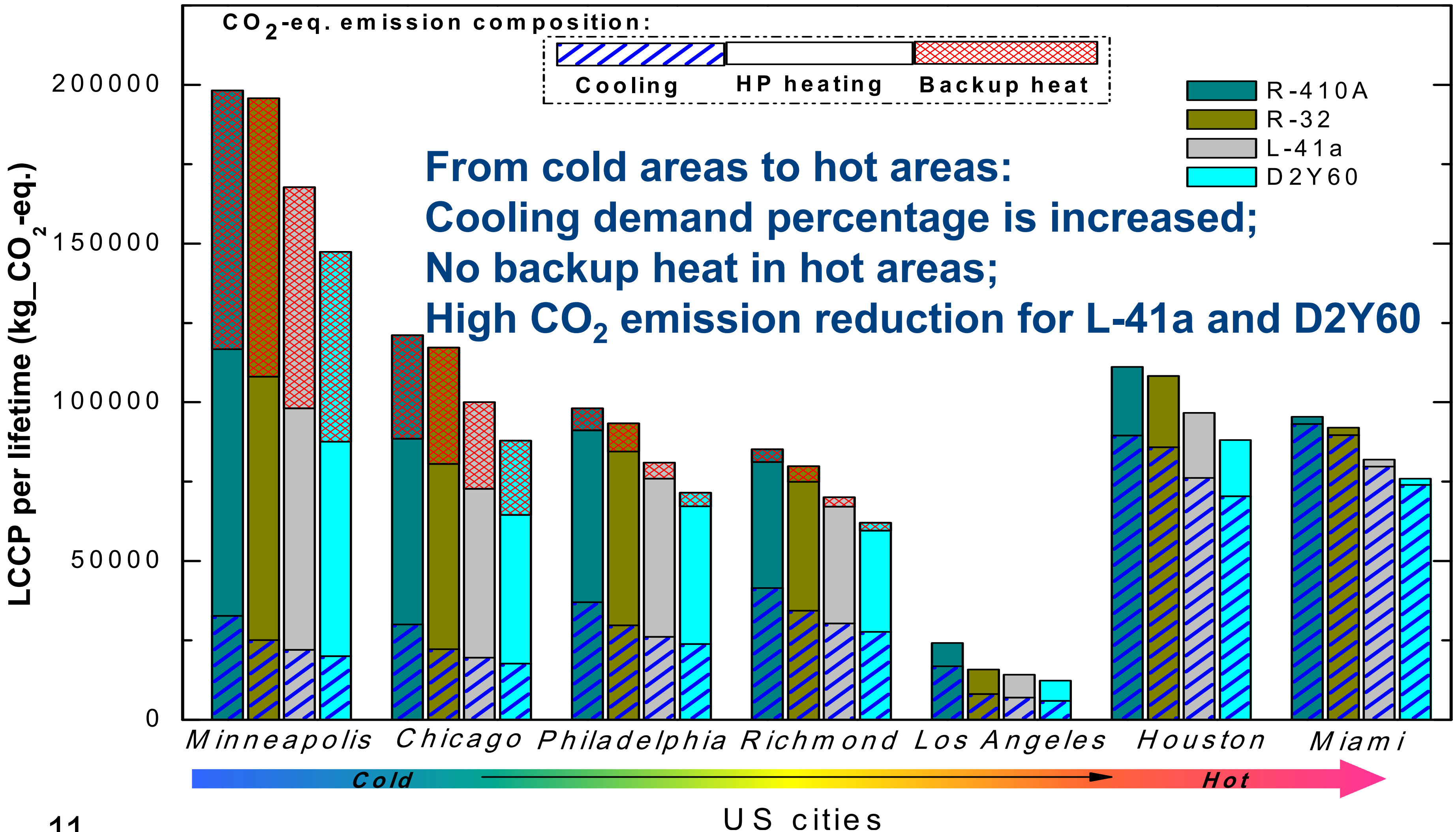
L-41a



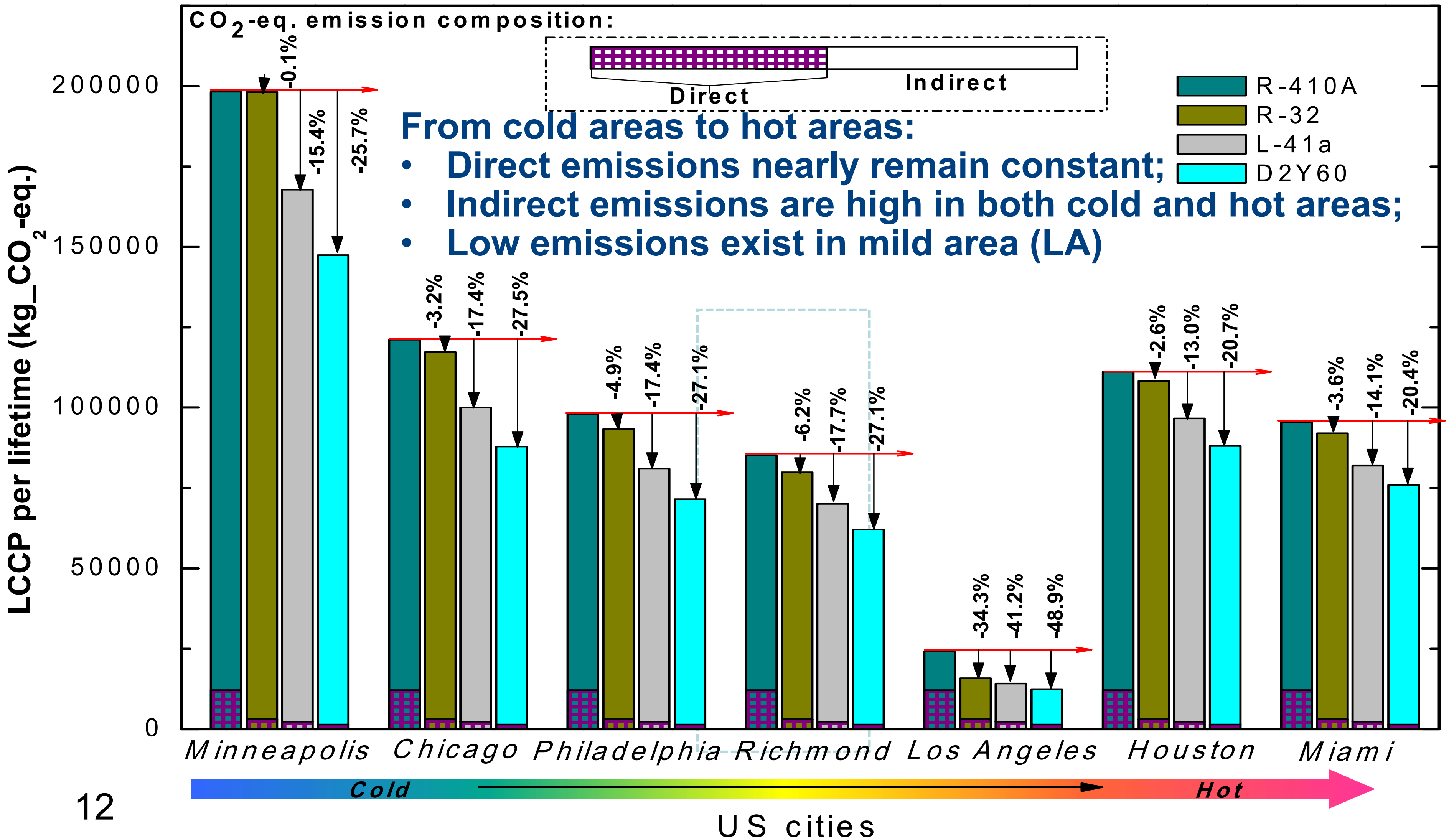
D2Y60

- As the refrigerant charge amount is increased, the cooling capacity is increased and COP is increased first and then decreased

LCCP Evaluation under Different US Cities

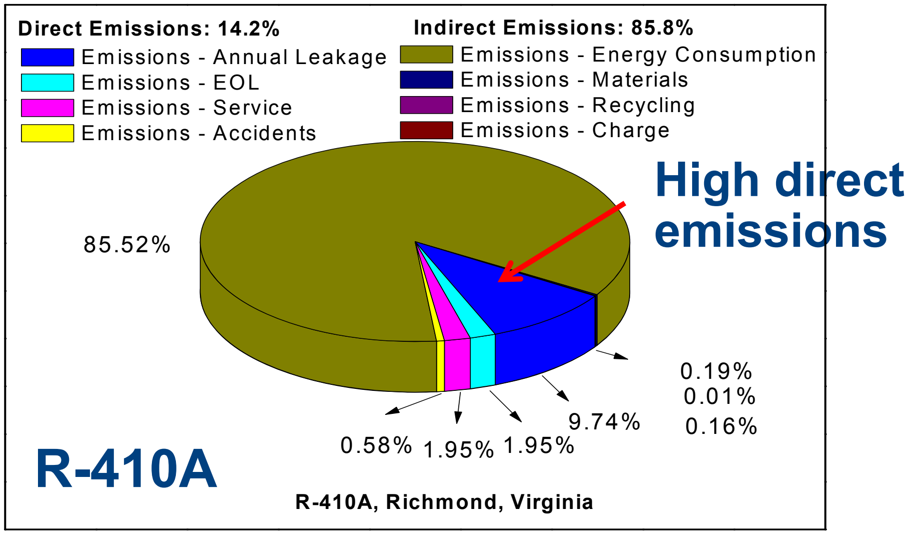


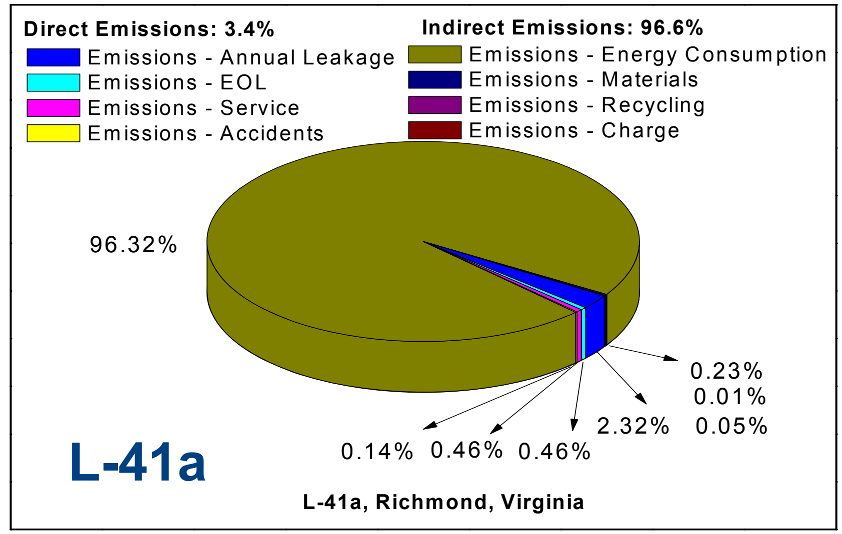
LCCP Evaluation under Different US Cities

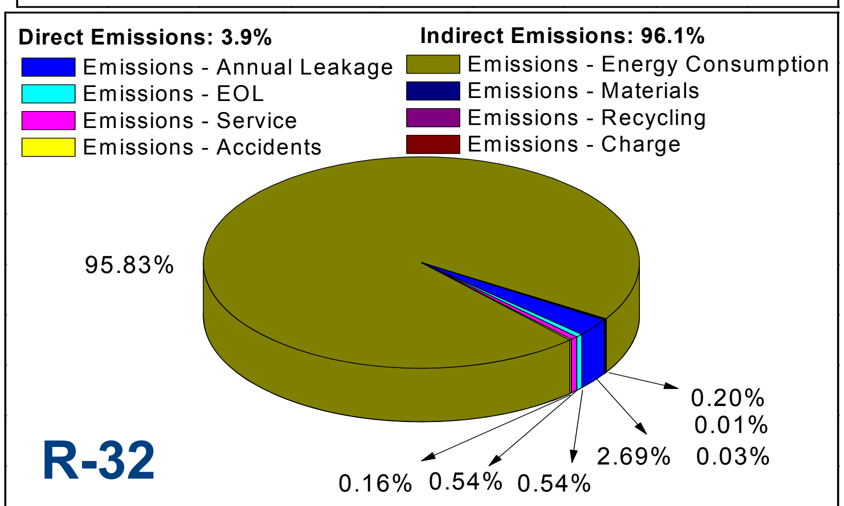


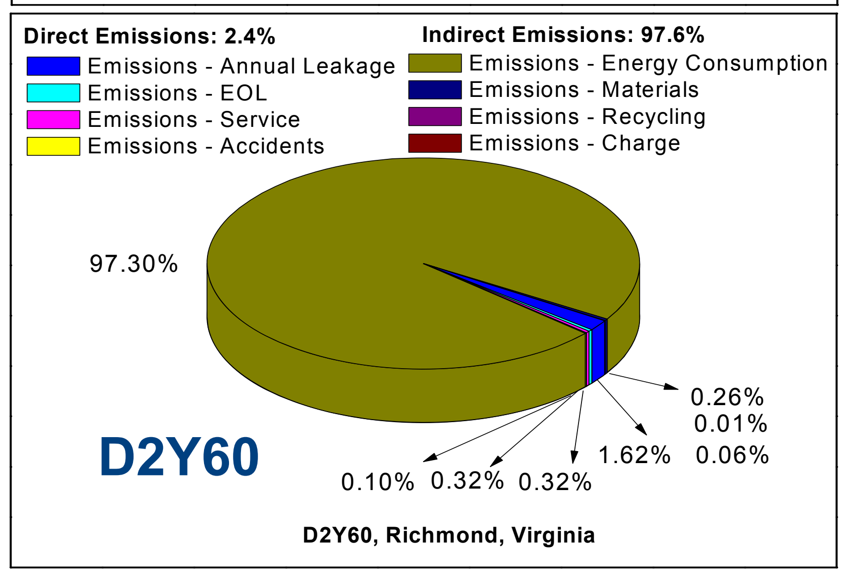
From cold areas to hot areas:
- **Direct emissions nearly remain constant;**
- **Indirect emissions are high in both cold and hot areas;**
- **Low emissions exist in mild area (LA)**

LCCP Evaluation under Different US Cities



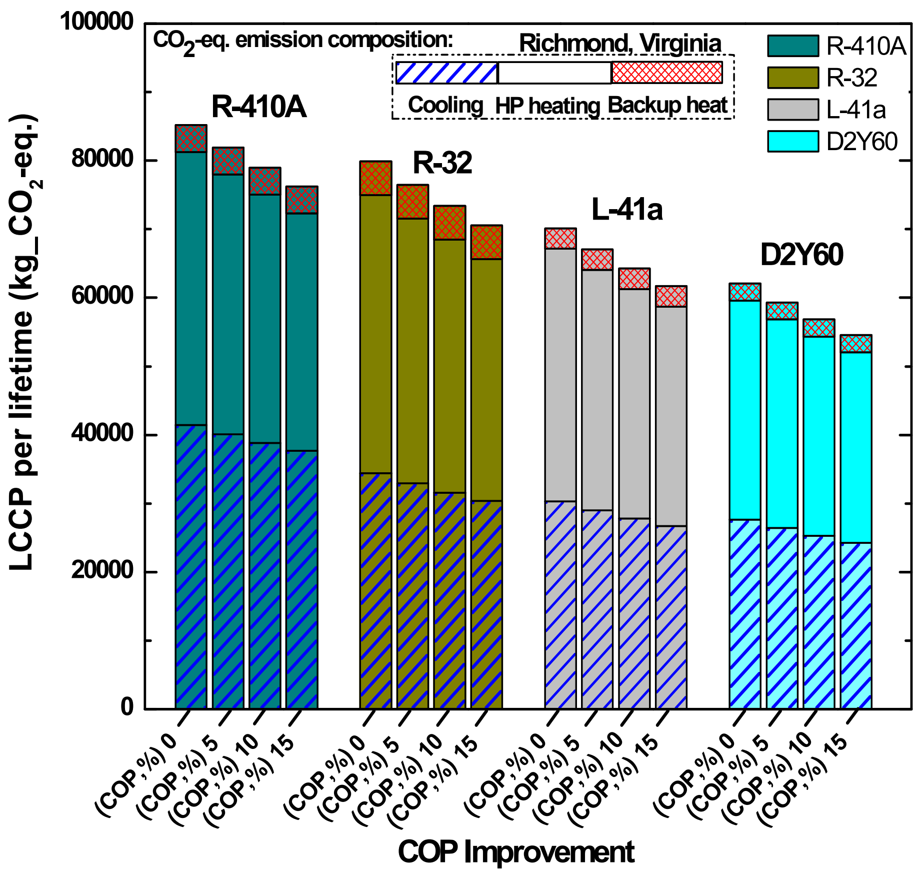


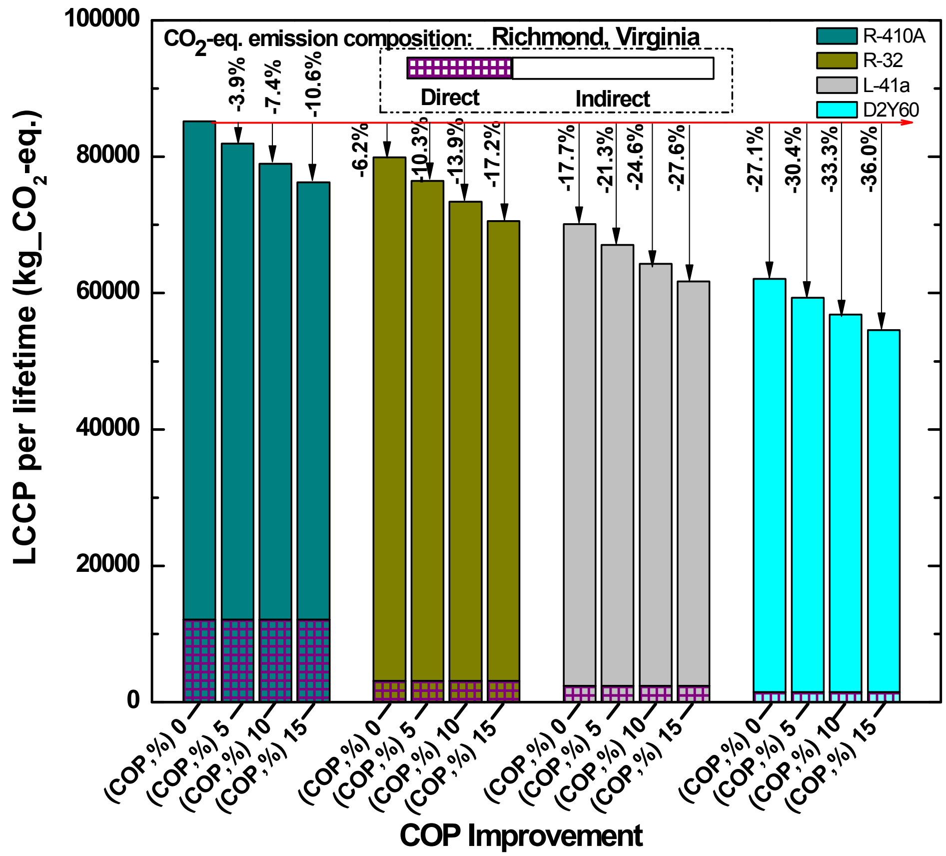




LCCP Sensitivity Analysis

Effect of COP Improvements

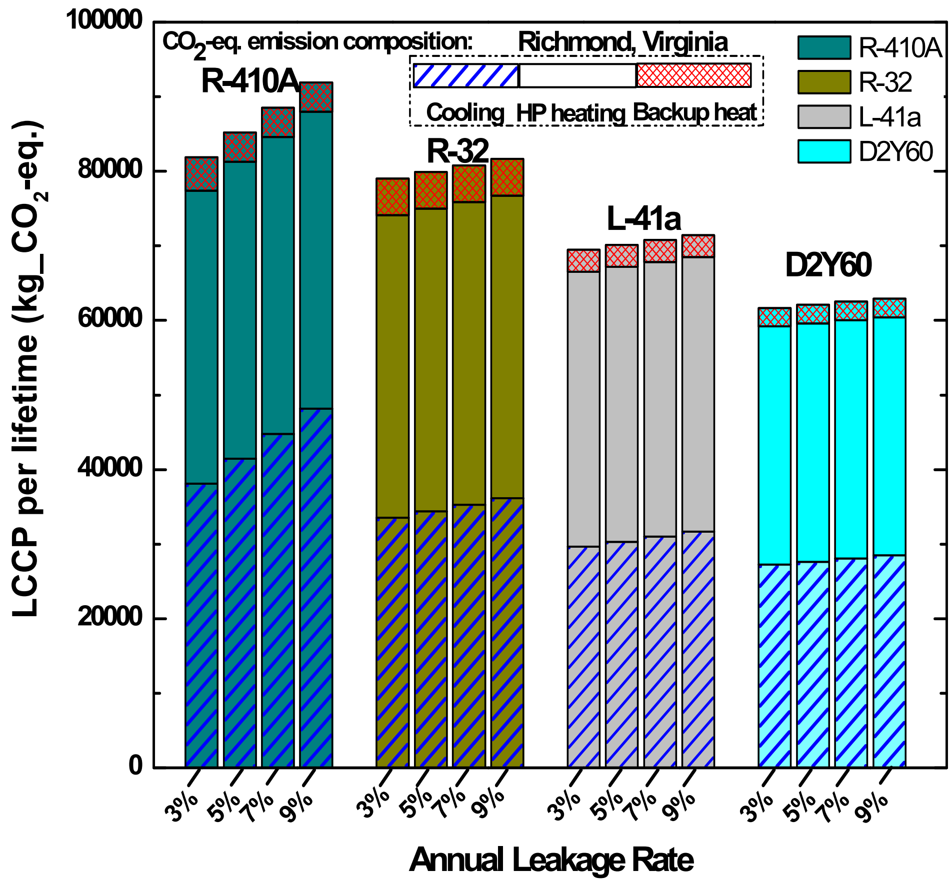


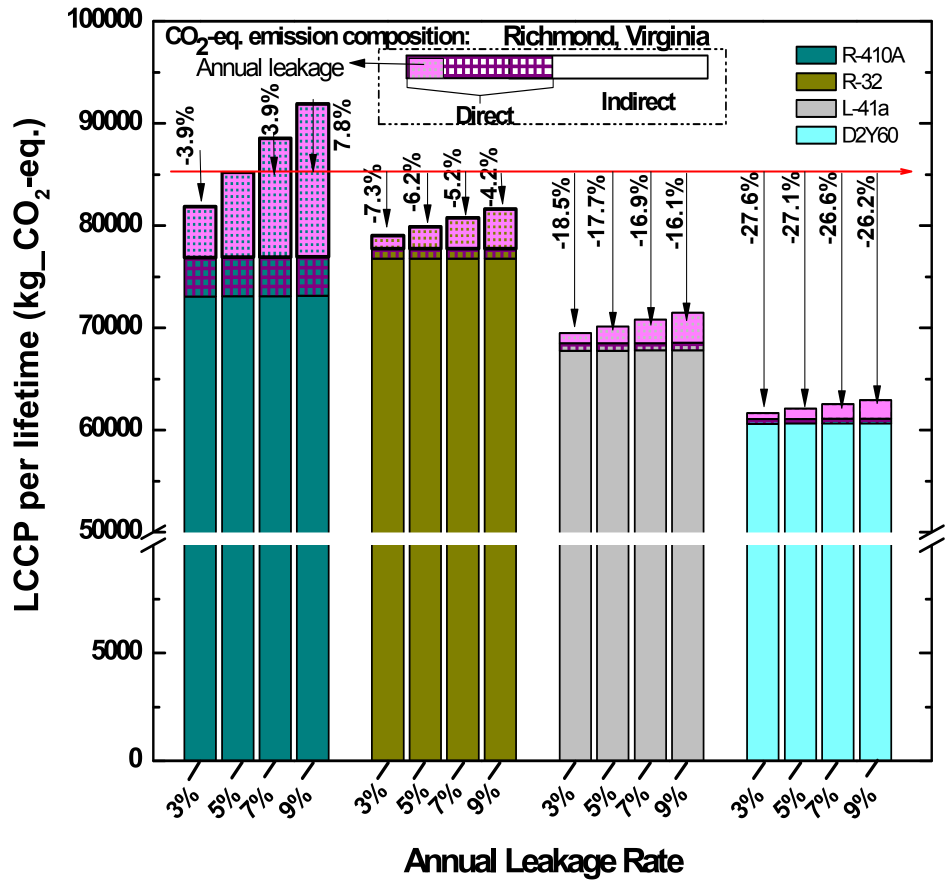


- It has high influence on CO_2 emissions
- Direct emissions remain constant

LCCP Sensitivity Analysis

Effect of Annual Leakage Rates

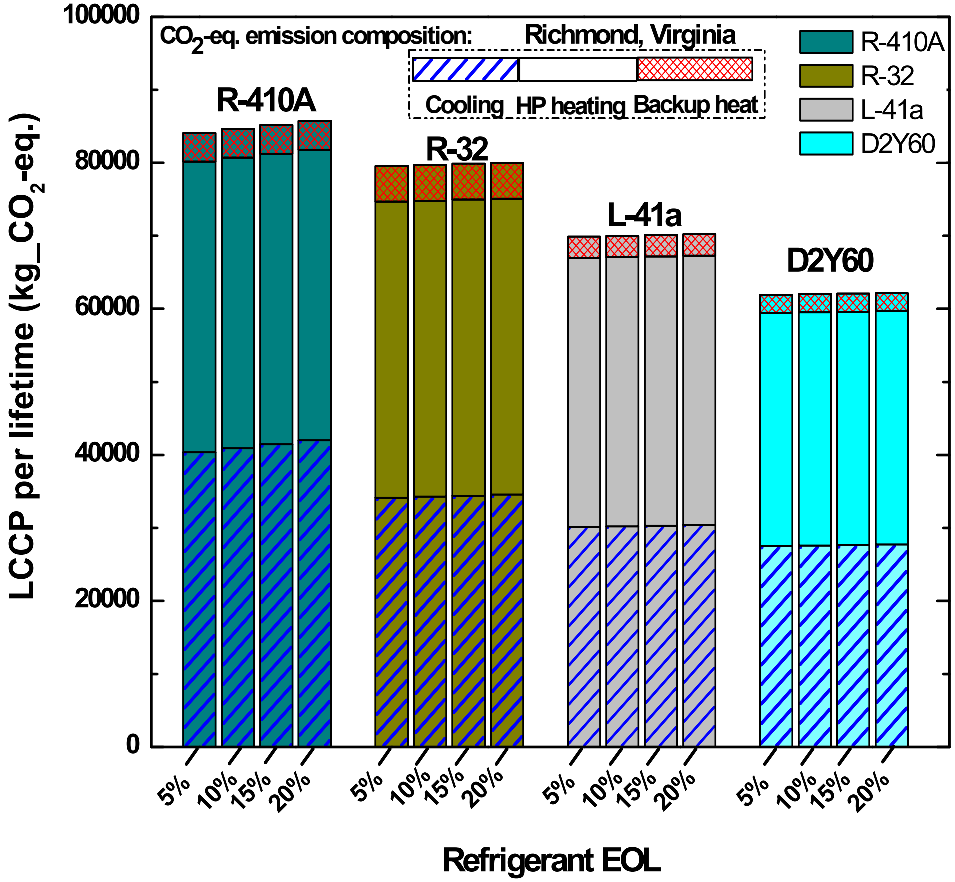


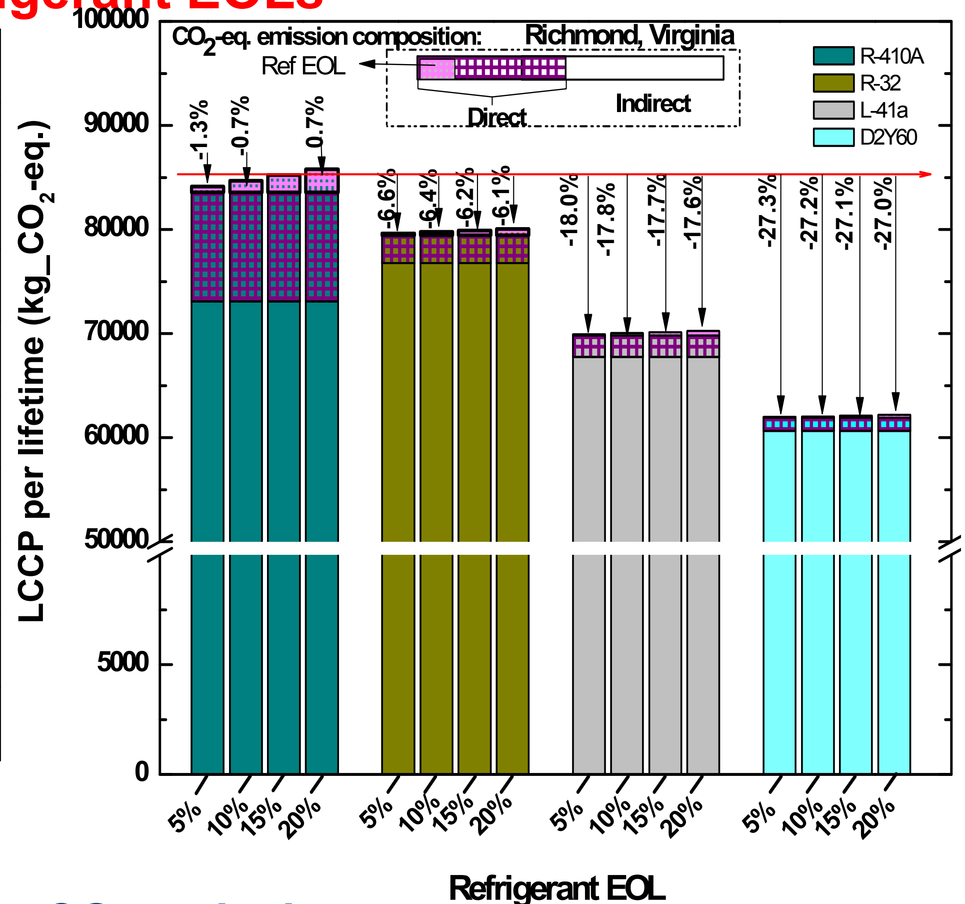


- It has high influence on CO_2 emissions
- Indirect emissions remain constant
- Direct emissions varied (due to annual leakage)

LCCP Sensitivity Analysis

Effect of Refrigerant EOLs

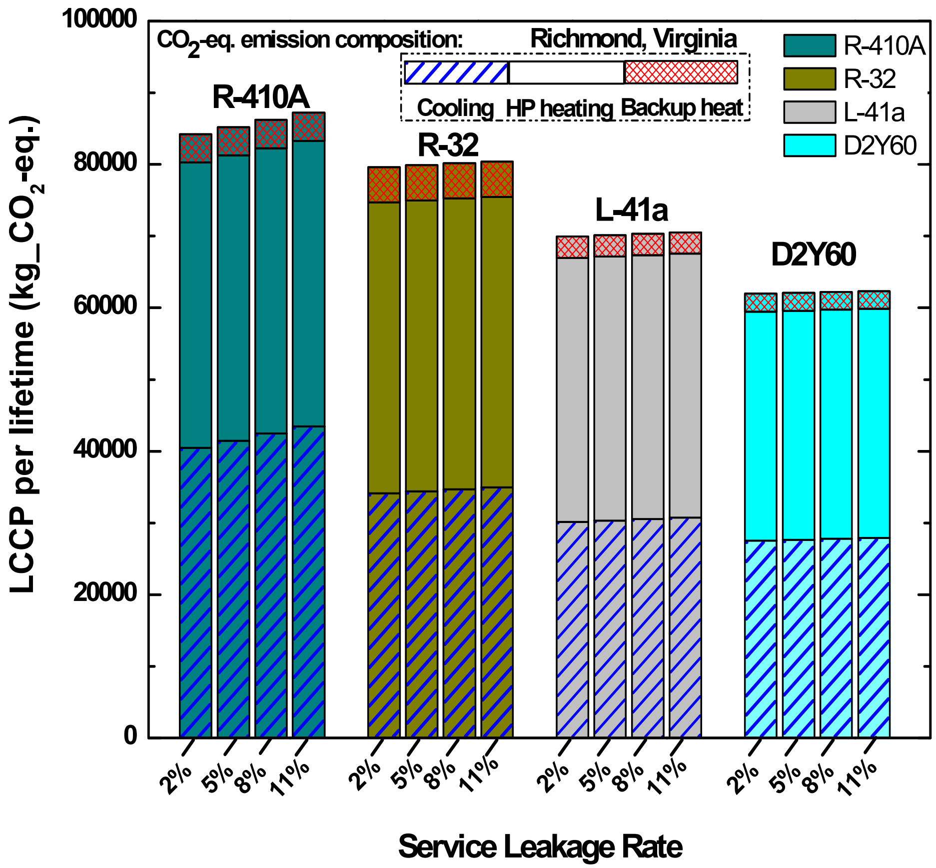


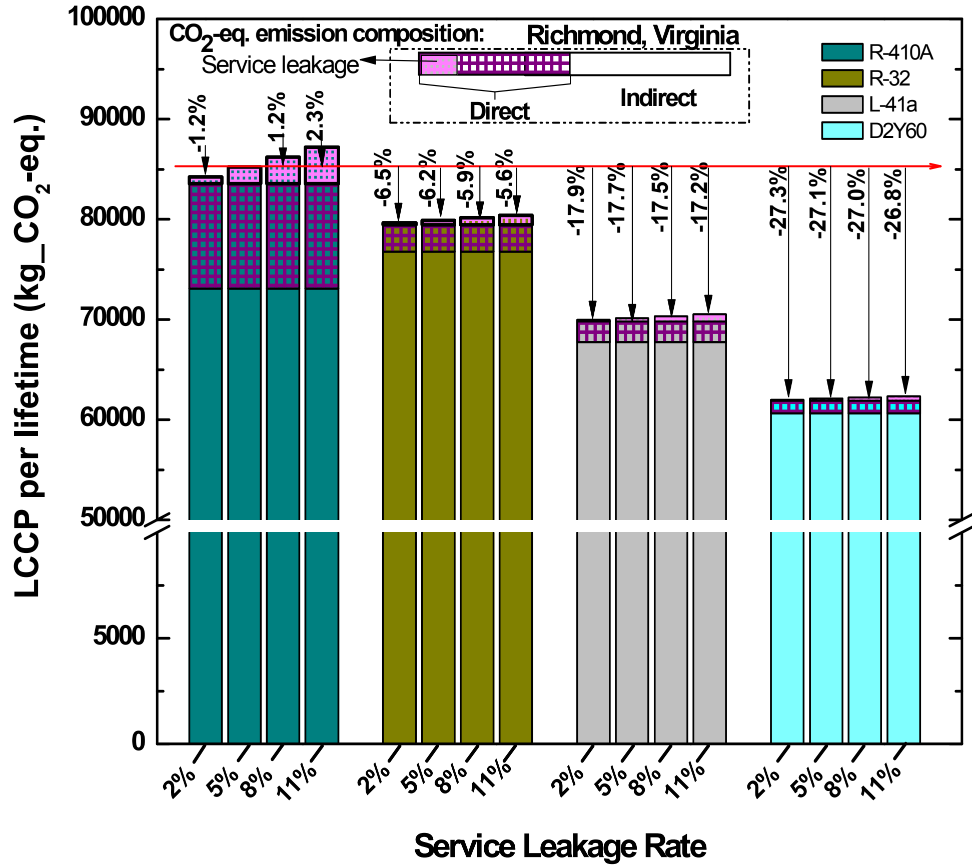


- It has small influence on CO_2 emissions
- Indirect emissions remain constant
- (All these conclusions can be analyzed with emission distributions in slide page 11)

LCCP Sensitivity Analysis

Effect of Service Leakage Rates

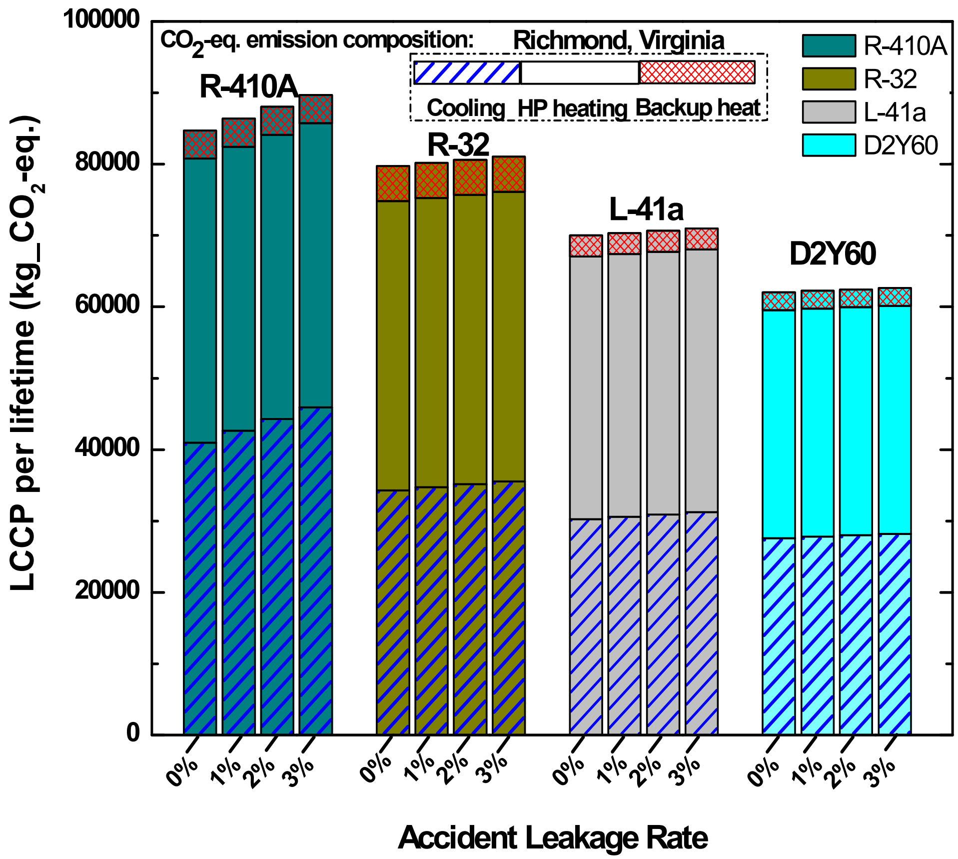


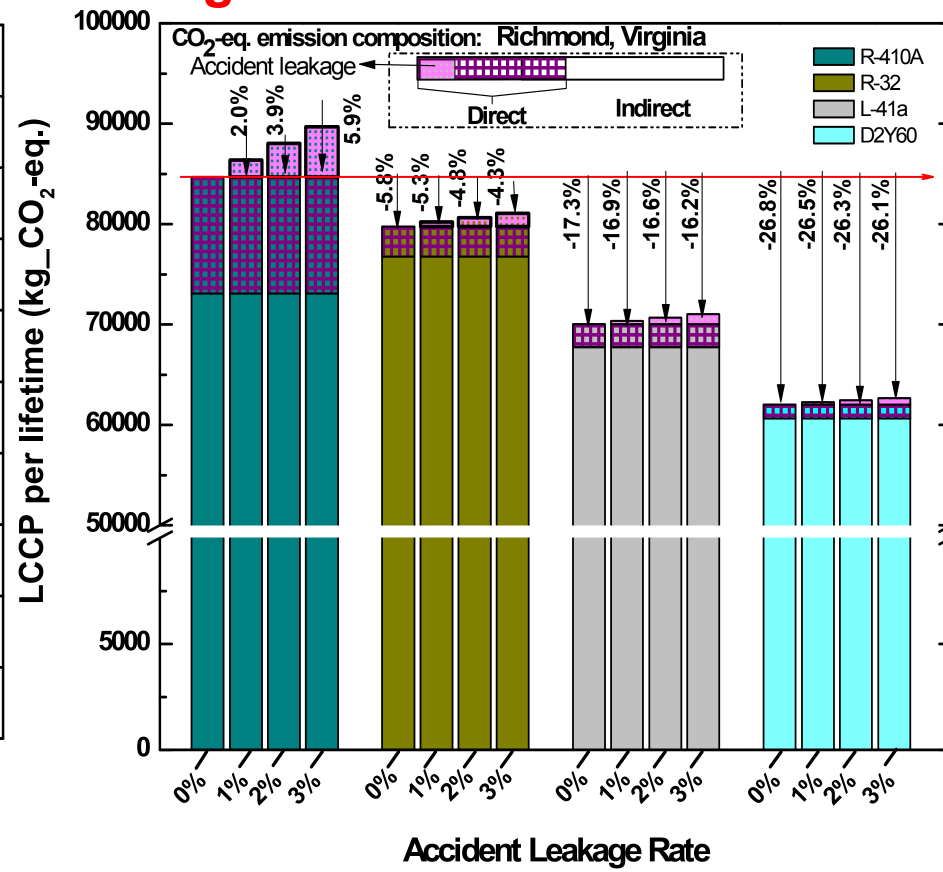


- It has small influence on CO_2 emissions
- Indirect emissions remain constant

LCCP Sensitivity Analysis

Effect of Accident Leakage Rates

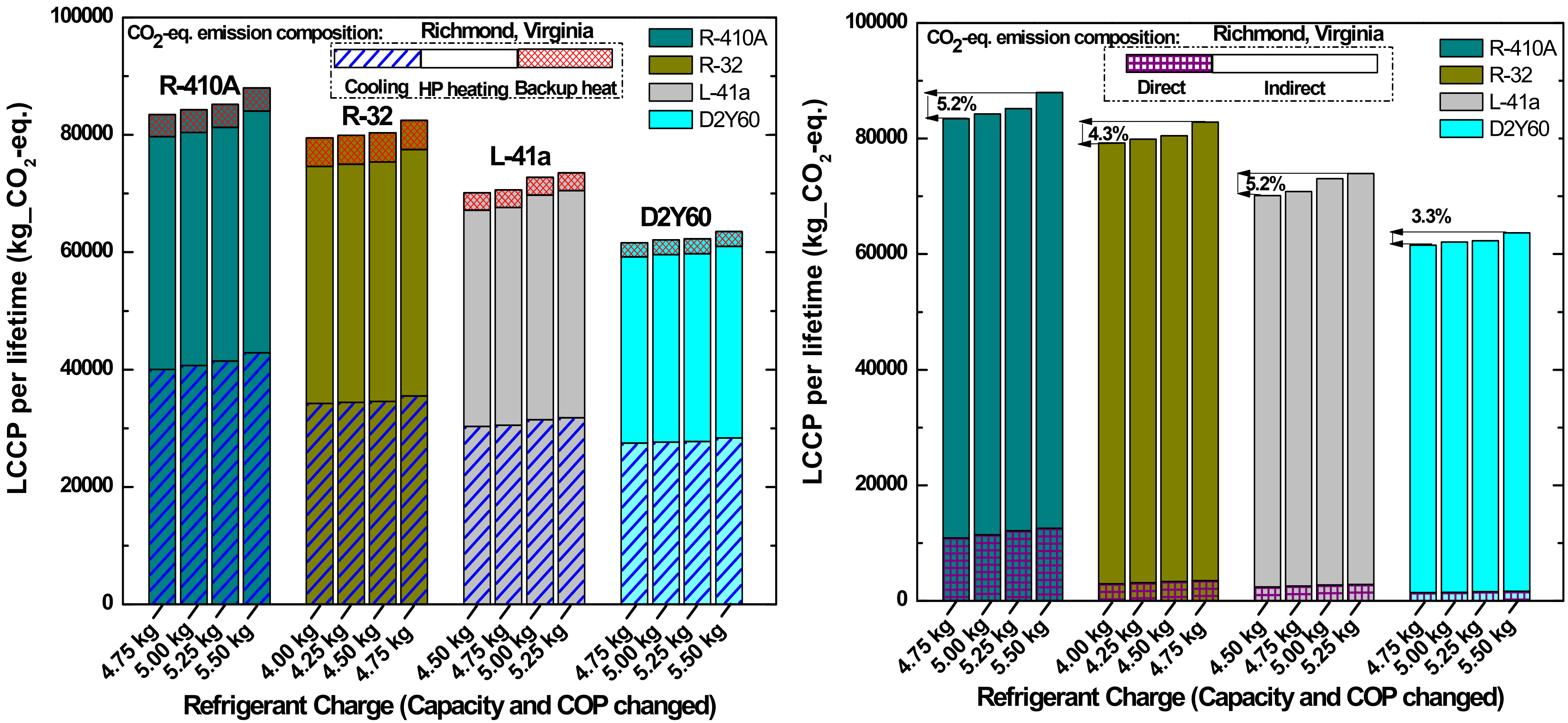




- It has high influence on CO_2 emissions
- Indirect emissions remain constant
- (All these conclusions can be analyzed with emission distributions in slide page 11)

LCCP Sensitivity Analysis

Effect of Refrigerant Charge



- COP and capacity results with different refrigerant charge amount were used for LCCP evaluation
- Both direct and indirect emissions are increased

Conclusions

- **In general, R-32 has about 4% CO_2 emission reduction as compared with R-410A.**
- **Lower capacity refrigerants (L-41a and D2Y60) have the reduction of around 17% and 27%, respectively.**
- **But their proper evaluation should be made after capacity matching.**
- **Mild area has lower CO_2 emissions than that of cold and hot areas.**
- **R-410A has a high direct emission contribution (14.2%) while its alternatives have lower within 4%.**
- **COP improvement has a highest impact on CO_2 emission reduction.**

Thank You!

Any Questions?