Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP)

TEST REPORT #23

System Soft-Optimized Test Of Refrigerant L-41a in Air Source Heat Pump

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List of Tested Refrigerants' Compositions (Mass%)

L-41a	R-32/R-1234yf/R-1234ze(E) (73/15/12)

1. Background

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) announced an industry-wide cooperative research program to evaluate alternative refrigerants that have low global warming potential (GWP). The program aims at testing several refrigerants for major product categories such as air conditioners, heat pumps, chillers and refrigeration equipment. The program consists of three testing: compressor calorimeter testing, system drop-in testing and soft-optimized system testing

2. Objective

The main objective of this report is to compare the baseline refrigerant, R410A, against the drop-in test refrigerant L41A as well as the soft-optimized L41A refrigerant. The soft-optimized refrigerant has a TXV for heating instead of an orifice as the case for the drop-in and the baseline refrigerants.

3. Approach

The tests to be performed are drop-in test using the environmental chamber at the heat pump laboratory of the CEEE. The test unit itself is a residential split heat pump manufactured by Goodman. The nominal capacity of the unit is 3 tons. The testing followed ASHRAE standard 116-1995 shown in Table 1.

Table 1: ASHRAE Standard 116-1995 Test Matrix

<table>
<tr><th rowspan="2">Test</th><th colspan="2">Indoor</th><th colspan="2">Outdoor</th><th rowspan="2">Operation</th></tr>
<tr><th>DB</th><th>WB</th><th>DB</th><th>WB</th></tr>
<tr><td>Extended condition</td><td rowspan="5">26.7°C</td><td rowspan="3">19.4°C</td><td>46.1°C</td><td rowspan="5">NA</td><td>Steady State Cooling</td></tr>
<tr><td>A</td><td>35.0°C</td><td>Steady State Cooling</td></tr>
<tr><td>B</td><td>27.8°C</td><td>Steady State Cooling</td></tr>
<tr><td>C</td><td rowspan="2">≤13.9°C</td><td rowspan="2">27.8°C</td><td>Steady State Cooling, dry coil</td></tr>
<tr><td>D</td><td>Cyclic Cooling, dry coil</td></tr>
<tr><td>High Temp2</td><td rowspan="6">21.1°C</td><td rowspan="6">≤15.6°C</td><td>8.3°C</td><td>6.1°C</td><td>Steady State Heating</td></tr>
<tr><td>High Temp1</td><td>16.7°C</td><td>14.7°C</td><td>Steady State Heating</td></tr>
<tr><td>Low Temp</td><td>-8.3°C</td><td>-9.4°C</td><td>Steady State Heating</td></tr>
<tr><td>Extended condition</td><td>-17.8°C</td><td>NA</td><td>Steady State Heating</td></tr>
<tr><td>High Temp Cyclic</td><td>8.3°C</td><td>6.1°C</td><td>Cyclic Heating</td></tr>
<tr><td>Frost Acc.</td><td>1.7°C</td><td>0.6°C</td><td>Steady State Defrost</td></tr>
</table>

4. R410A Baseline and L41A Drop In Performance Evaluation

The heat pump unit that was tested is a 3 Tons Goodman heat pump. The specifications of the unit are shown in Table 2.

Table 2: Heat Pump Unit Specifications

Manufacturer	Goodman
Outdoor Unit Model Number	SSZ140361BA
Indoor Unit Model Number	ARUF374316
Compressor	Single Speed, Scroll Compressor
Nominal Cooling Capacity	3 Tons
Rated SEER	14
Rated HSPF	8.7
Expansion Device	TXV for Cooling/ Orifice for Heating

4.1 Instrumentation and Measurement

Figure 1 shows the test facility used in this study. To calculate the capacity and COP of the heat pump system, pressures, temperatures and mass flow rates were measured for both the refrigerant side and the air side of the system. A power meter and a line voltage transducer were installed to measure the power consumption and line voltage of the outdoor unit, respectively. In addition, relative humidity sensors were applied to measure the air relative humidity in the closed air loop, and dew point sensors were applied to measure the outdoor unit inlet and outlet air dew point.

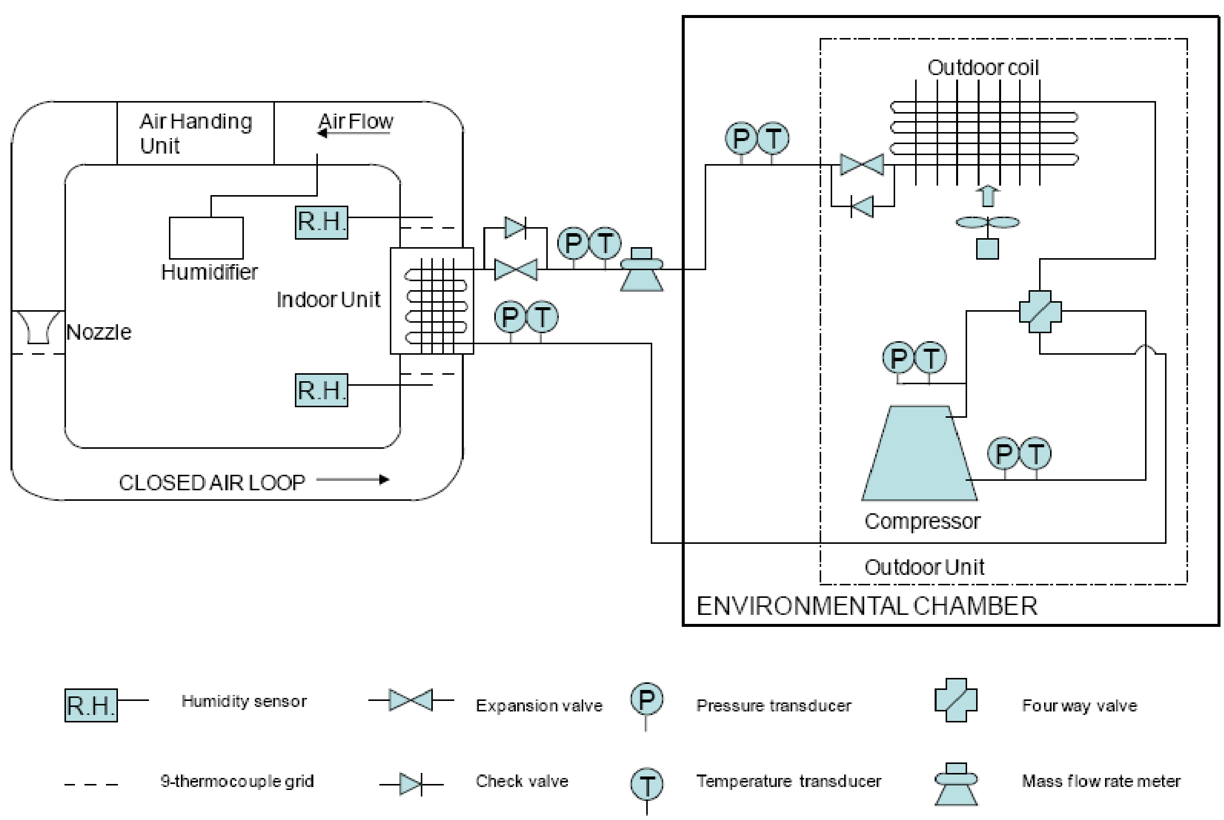


Figure 1: Schematic of Test Facility setup.

4.1.1 Temperature Measurement

The temperatures of the refrigerant at different locations were measured by T-type in-stream thermocouples. The locations of those thermocouples are illustrated in Figure 1. Thermocouples were inserted into the refrigerant tube line, and contacted the refrigerant flow directly to measure the temperature accurately. In the case of the airside temperature measurements, two thermocouple grids were installed at the upstream and the downstream of the indoor unit, which is shown in Figure 1. Each thermocouple grid consisted of nine T-type thermocouples. The thermocouples were distributed evenly in a particular cross-section area, and connected in parallel to measure the average temperature of the air flowing through the cross-section area (ASHRAE Handbook, 2001). Mesh sheets were installed in front of the thermocouple grids to ensure a uniform air flow profile. Two thermocouple grids were installed at the inlet and outlet of the outdoor unit, respectively, to measure the air temperature entering and leaving the outdoor unit. The specifications of the thermocouples are shown in Table 3.

Table 3: Specifications of Thermocouples

Manufacturer	Omega Engineering, Inc.
Model No.	T Type Thermocouple
Temperature range	−270°C to 400°C
Accuracy	0.5°C

4.1.2 Pressure Measurement

Pressure transducers were installed in the refrigerant tube lines to measure the pressures of the refrigerant. The locations of the pressure transducers are illustrated in Figure 1. A differential pressure transducer was installed to measure the pressure drop across the nozzle in the closed air loop. The specifications of the pressure transducers and the differential pressure transducer are listed in Table 4.

Table 4: Specifications of Pressure Transducers

Item	Pressure Transducers	Pressure Transducers	Differential Pressure Transducers
Manufacturer	Setra Systems, Inc	WIKA, Inc	Setra System, Inc
Model No.	280E	S-10	264
Range	0 ~ 3,447 kPa	0 ~ 6,894 kPa	0 ~ 1.245 kPa
Accuracy	±0.11% Full Scale	±0.125% Full Scale	±1% Full Scale

4.1.3 Relative Humidity Measurement

The relative humidity of the air in the closed loop was measured by two humidity sensors, located at the upstream and downstream of the indoor unit. The relative humidity together with the temperature of the air was used to calculate the air properties in the closed loop. The specifications of the humidity sensors are shown in Table 5.

Table 5: Specifications of Humidity Sensors

Manufacturer	Vaisala
Model No.	HMP233
Range	−40°C to 80°C 0 to 100%
RH accuracy	±1% Measured
Temperature accuracy	±0.2°C
Stability	±0.5% Annual

4.1.4 Dew Point Measurement

Two dew point sensors were used to measure the dew points of the outdoor unit inlet and outlet air. Specifications of the dew point sensors are shown in Table 6.

Table 6: Specifications of Dew Point Sensors

Manufacturer	General Eastern
Model No.	Hygro-M2
Range	−80°C to 95°C
Dew point accuracy	±0.2 °C

4.1.5 Power Consumption and Line Voltage Measurements

The power consumption and line voltage of the heat pump system were measured by an AC watt transducer and a voltage transducer, respectively. The specification of the watt transducer and line voltage transducer are shown in Table 7.

Table 7: Specifications of AC Watt Transducer

Manufacturer	Ohio Semitronics	
Model No.	PC5	VT-240A
Range	0 to 5 kW	0 to 300 V
Accuracy	±0.5% Full Scale	±0.25% Full Scale

4.1.6 Mass Flow Rate and Volume Flow Rate Measurements

The refrigerant mass flow rates were measured by a Coriolis mass flow meter. The location of the mass flow rate meter is shown in Figure 1. The mass flow meter was installed in the liquid lines of the system to avoid the reading fluctuation caused by the two-phase flow. The specification of the mass flow meter is shown in Table 8.

Table 8: Specifications of Mass Flow Meter

Item	Mass flow meter
Manufacturer	Micro Motion, Inc.
Model No.	DS 025
Range	0 ~ 100 g/s
Zero stability	0.038g/s
Accuracy	±0.15%± [(ZeroStability / Flowrate)100%]% of flow rate

The air volume flow rate in the closed loop was measured by a standard 6-inch nozzle. The nozzle was installed in the closed loop, which is shown in Figure 1. The air volume flow rate was calculated by Equation 1 (ASHRAE Standard, 41.2-1987).

$$V = \left[(C_d A_6) Y \left(\frac{2\Delta P}{\rho}\right)^{0.5}\right] / (1 - E\beta^4)^{0.5} \qquad (1)$$

where

C_d is the discharge coefficient
A_6 is the area measured at the plane of nozzle exit
Y=1-(0.548+0.71β^4) (1-α)
α =1-ΔP/(ρR(t_o+273.2))
β=D_6/D_x
ΔP is the pressure drop across the nozzle
t_o is the inlet air temperature
ρ is the inlet air density
D_6 is the nozzle exit diameter
D_x is the duct diameter
E=1.043 for duct approach
The discharge coefficient has been determined as 0.986 according to the nozzle calibration.

4.2 Calibration

The calibration of the instrumentation was conducted before the experimental study. Thermocouples were tested in ice/water bath. Pressure transducers were calibrated by using a digital pressure calibrator having a resolution of 0.1 kPa. The refrigerant mass flow meter was calibrated by weighing water in a specific time period.

4.3 Data Acquisition

Instruments in the air side and the refrigerant side were connected to FieldPoint data acquisition modules supplied National Instruments (National Instruments). The modules were connected to a data acquisition computer, and communicated with a data acquisition program. The data acquisition program was developed by using the LabView software package (National Instruments). The program visualized the measured parameters (pressure, temperature, relative humidity, dew point, mass flow rate, and power consumption) in the form of numbers and graphs on the computer screen. The data was measured with a two-second interval. The data in steady state condition was recorded for 30 minutes, and averaged for the system performance analysis. The steady state operation was defined as follows: the variations of the airside temperatures are within ±1K of the average values. The saturated refrigerant temperatures corresponding to the measured refrigerant-side pressures have maximum variations of ±1.7 K of the average values. The refrigerant mass flow rate fluctuations were within 2% of the readings (ASHRAE Standard, 37-2005).

4.4 Performance Evaluation

4.4.1 Air Side Capacity

Air side capacity was calculated by multiplying the air mass flow rate and the inlet and outlet air enthalpy difference in the closed air loop, as described by the Equation 2:

$$Q_{air}=\dot{m}_{air}\Delta h_{air} \qquad (2)$$

where $\dot{m}_{air}$ is the air mass flow rate in the closed air loop, and Δh_{air} is the inlet and outlet air enthalpy difference of the indoor coil.

When there was condensation occurring in the indoor coil (ASHRAE Extended cooling condition, ASHRAE A cooling condition and ASHRAE B cooling condition), Equation 2 was used. When the relative humidity was low and there was no condensation occurring, Equation 3 was used:

$$Q_{air}=\dot{m}_{air}C_p\Delta t_{air} \qquad (3)$$

where C_p is the specific heat of air and Δt_{air} is the inlet and outlet air temperature difference.

4.4.2 Refrigerant Side Capacity

Refrigerant side capacity was calculated by multiplying the refrigerant mass flow by the inlet and outlet enthalpy difference, which is shown in Equation 4:

$$Q_{ref}=\dot{m}_{ref}\Delta h_{ref} \qquad (4)$$

where $\dot{m}_{ref}$ is the refrigerant mass flow rate and Δh_{ref} is the refrigerant enthalpy difference of the inlet and outlet of the indoor coil.

4.4.3 Energy Balance

Energy balance was defined as the capacity difference between the refrigerant side and air side divided by refrigerant side capacity, described by Equation 5:

$$\text{Energy Balance}= (Q_{ref} - Q_{air})/ Q_{ref} \qquad (5)$$

4.4.4 Power Consumption

Outdoor power consumption was directly measured by a watt meter, which included the compressor power and fan power. Power consumption of the control board was neglected because all controls were disconnected, except for the relay, which consumed negligible power. The original blower matching the indoor unit was disassembled and the indoor air was driven by a blower of the air handling unit in the closed air loop. Therefore, the realistic power consumption by the Original Equipment Manufacturer (OEM) blower could not be measured directly. To consider the effect of indoor blower on the system performance, power consumption data from the OEM was used. The average power consumption of the original blower matching the indoor coil was 373 W with air volume flow rate set at 1,200 CFM.

4.4.5 Coefficient of Performance

The Coefficient of Performance (COP) was defined as the net refrigerant side capacity divided by total power consumption, described by Equation 6:

$$COP = \dot{Q}_{ref} / P_{total} \qquad (6)$$

where $\dot{Q}_{ref}$ is the net refrigerant side capacity, including the indoor blower effect on the capacity. For the cooling mode, $\dot{Q}_{ref}$ equals the refrigerant side capacity minus the indoor blower power consumption. For the heating mode, $\dot{Q}_{ref}$ equals the refrigerant side capacity plus the indoor blower power consumption. P_{total} is the total power consumption, including the compressor, the outdoor fan and the indoor blower power consumption.

4.4.6 Compressor Efficiencies

The compressor isentropic efficiency and volumetric efficiency are described by Equation 7 and Equation 8, respectively:

$$\text{Isentropic efficiency, } \eta_{Isen} = (h_{out,s} - h_{in})/(h_{out} - h_{in}) \qquad (7)$$

$$\text{Volumetric efficiency, } \eta_{Vol} = \dot{m}_{Ref}/(\rho \ V \ RPM) \qquad (8)$$

4.5 L41A Refrigerant Soft Optimized System Test Results

The original heat pump unit came with a TXV for cooling and an orifice for heating. L41A had no suction superheating during the drop-in heating tests which could damage the compressor. To prevent compressor damage, an R410A TXV was installed for heating during the soft optimization testing. The TXV was adjusted to maintain a superheating around 2 K for High Temperature test 2, and this adjustment was kept the same throughout the tests. The installation of the TXV resulted in little improvement in the steady state tests but large improvement in the cyclic testing, which in turn resulted in HSPF improvement.

4.5.1 Charge Optimization

This section re-presents the results from the drop-in tests. Charge optimization was conducted for cooling mode. The charge for the soft-optimized test was not changed from the drop-in test. ASHRAE A cooling condition was used for charge optimization. R410A refrigerant charge was varied from 4.6 kg to 5.5 kg. Capacity and COP (for cooling) variations with the increase of refrigerant charge are shown in Figure 2. Superheat and subcooling (for cooling) variations with the increase of refrigerant charge are shown in Figure 3. Maximum COP occurred at 5.19 kg (11.44 lb) charge where subcooling was 2.9 K.

L41A refrigerant charge was varied from 4.08 kg to 5.48 kg. Capacity and COP variations with the increase of refrigerant charge are shown in Figure 4. The TXV opening was too large for L41A because no superheating was observed. Therefore, the TXV was adjusted by rotating the stem 3.25 turns clockwise. Superheat and subcooling variations with the increase of refrigerant charge are shown in Figure 5. Maximum COP occurred at 4.74 kg (10.45 lb) charge.

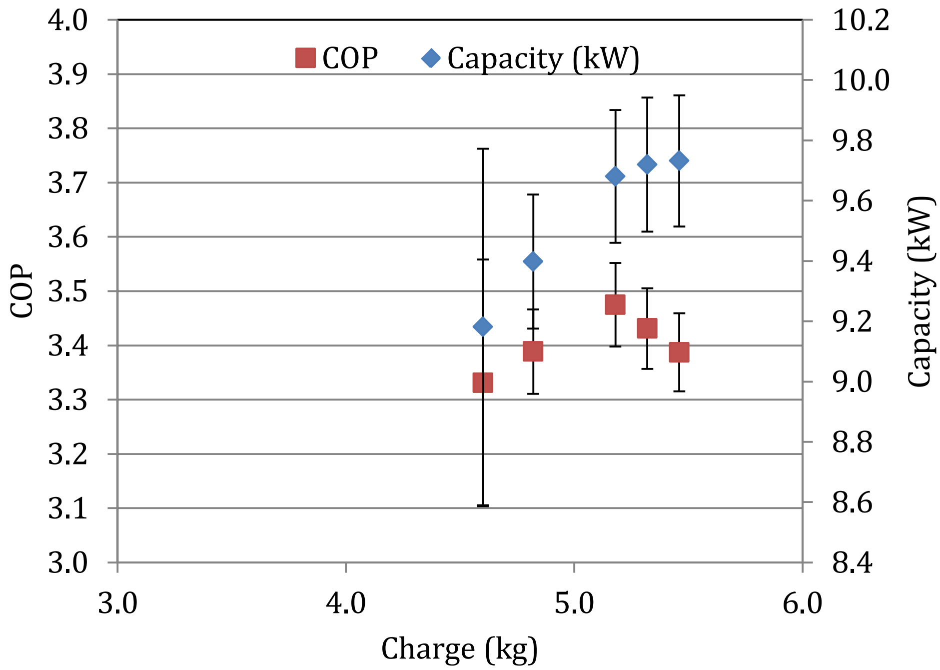


Figure 2: COP and Capacity vs. R410A Refrigerant Charge
Q(kBtu/hr)=3.412*Q(kW), EER=3.412*COP, m(lb)=0.45*m(kg)

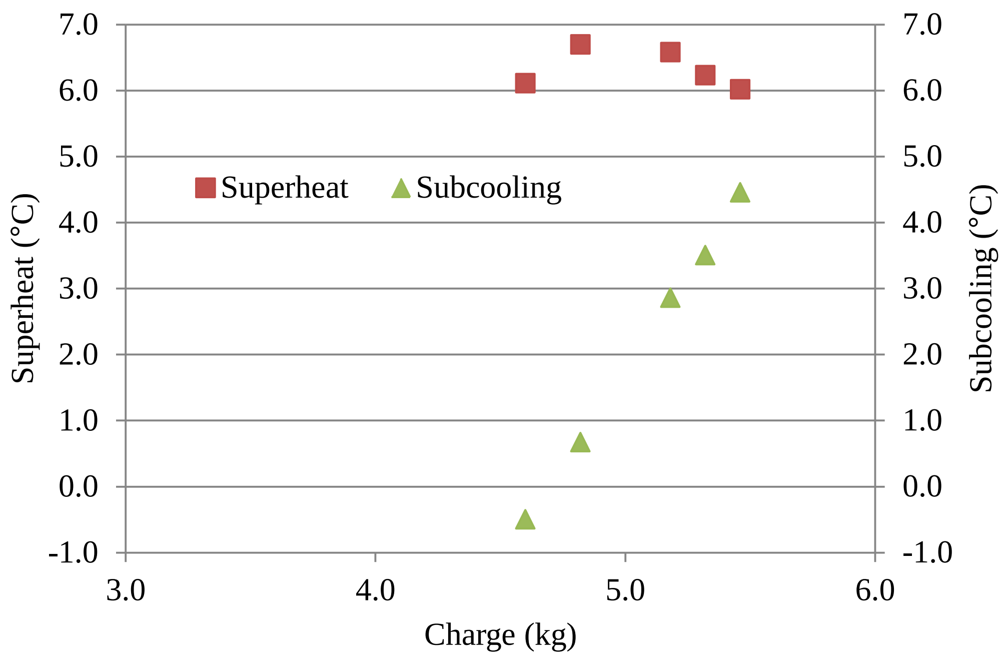


Figure 3: Superheat and Subcooling vs. R410A Refrigerant Charge
ΔT(F)=1.8*ΔT(°C), m(lb)=0.45*m(kg)

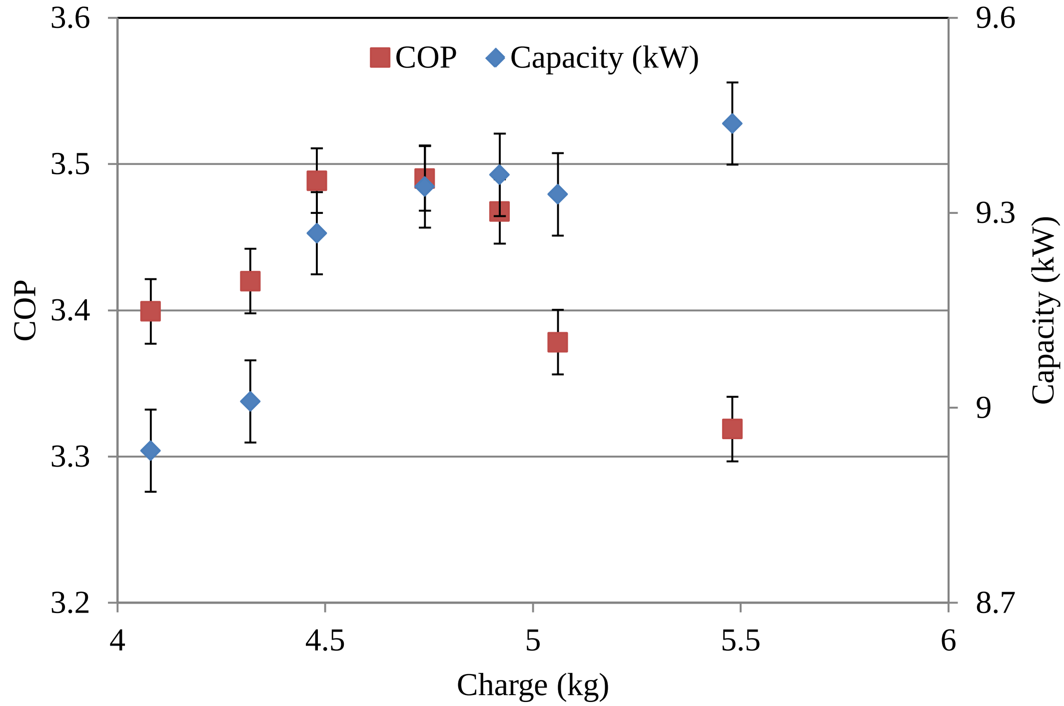


Figure 4: COP and Capacity vs. L41A Refrigerant Charge
Q(kBtu/hr)=3.412*Q(kW), EER=3.412*COP, m(lb)=0.45*m(kg)

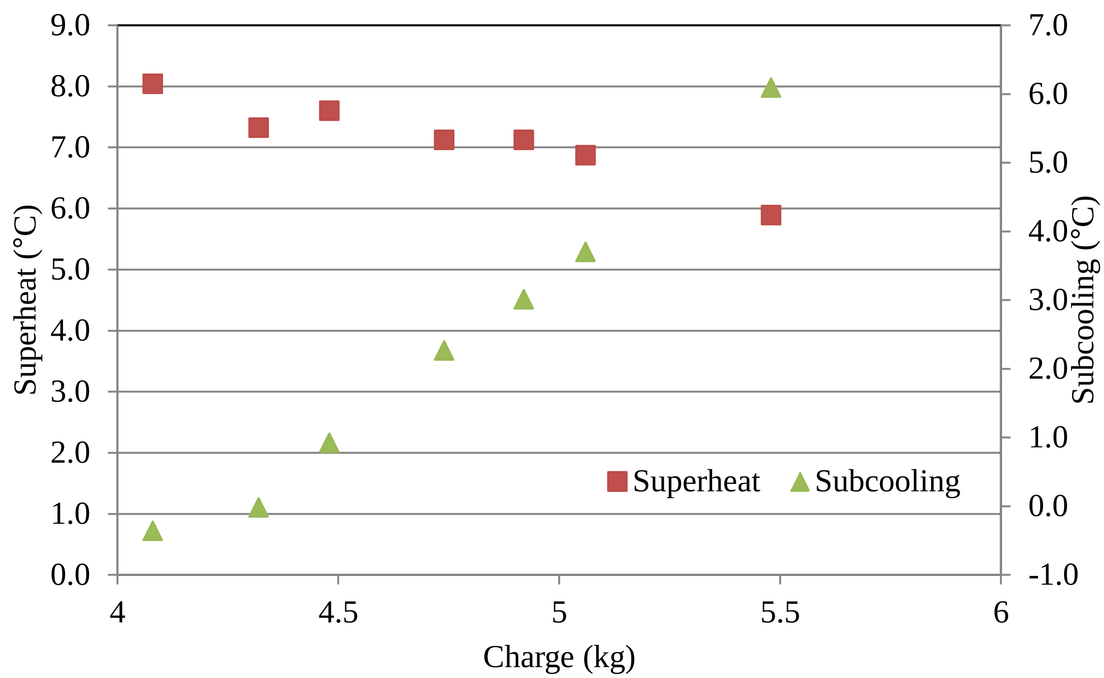


Figure 5: Superheat and Subcooling vs. L41A Refrigerant Charge.
ΔT(F)=1.8*ΔT(°C), m(lb)=0.45*m(kg)

4.6.1 Steady State Heating Test Results Comparison

The comparisons of the steady state heating test results are shown in Figure 6 and Figure 7. The results of L41A show that it has lower capacity than R410A in two test conditions but higher capacity in two other test conditions. Furthermore, L41A has lower COP than R410A in two test conditions whereas it has higher COP in two other test conditions. Adding the TXV resulted in slight change where slight increase in the capacity for Low Temperature and Extended Conditions tests as well as a slight improvement in the COP for the High Temperature 2 test were observed. Such variation in the trend is due to variation of the suction superheat. The detailed test conditions and results are provided in Section 5.

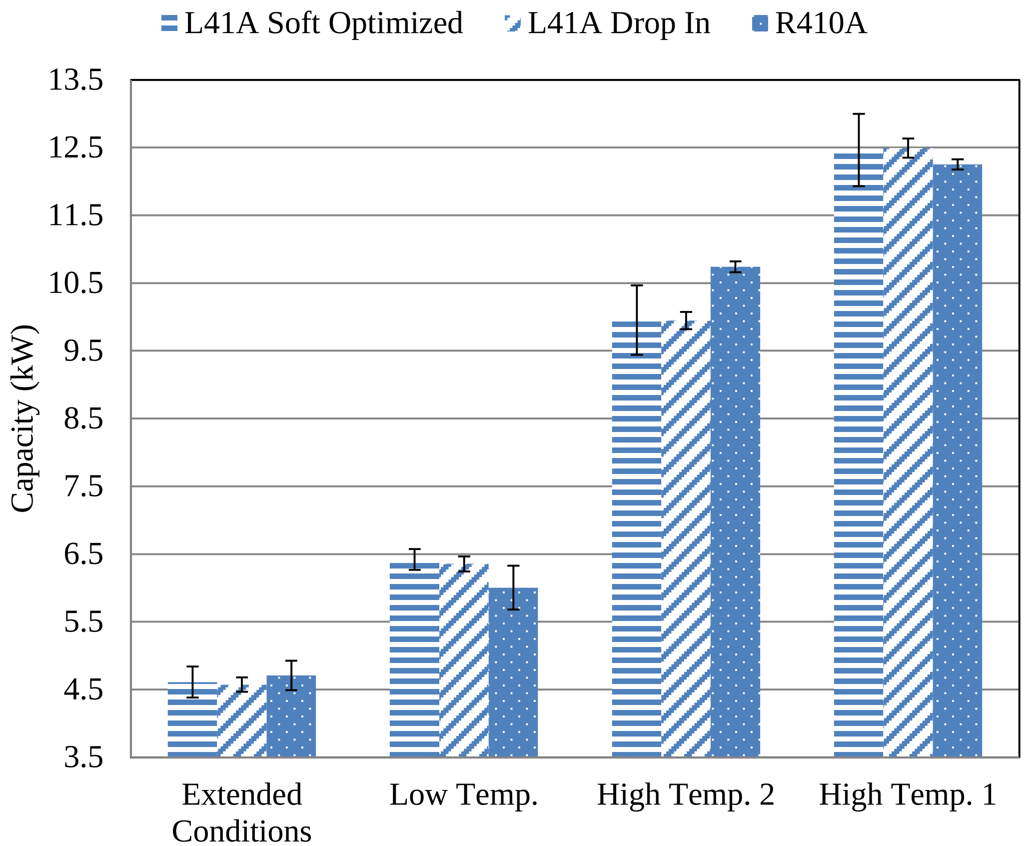


Figure 6: L41A vs. R410A Heating Test Results: Capacity. Q(kBtu/hr)=3.412*Q(kW)

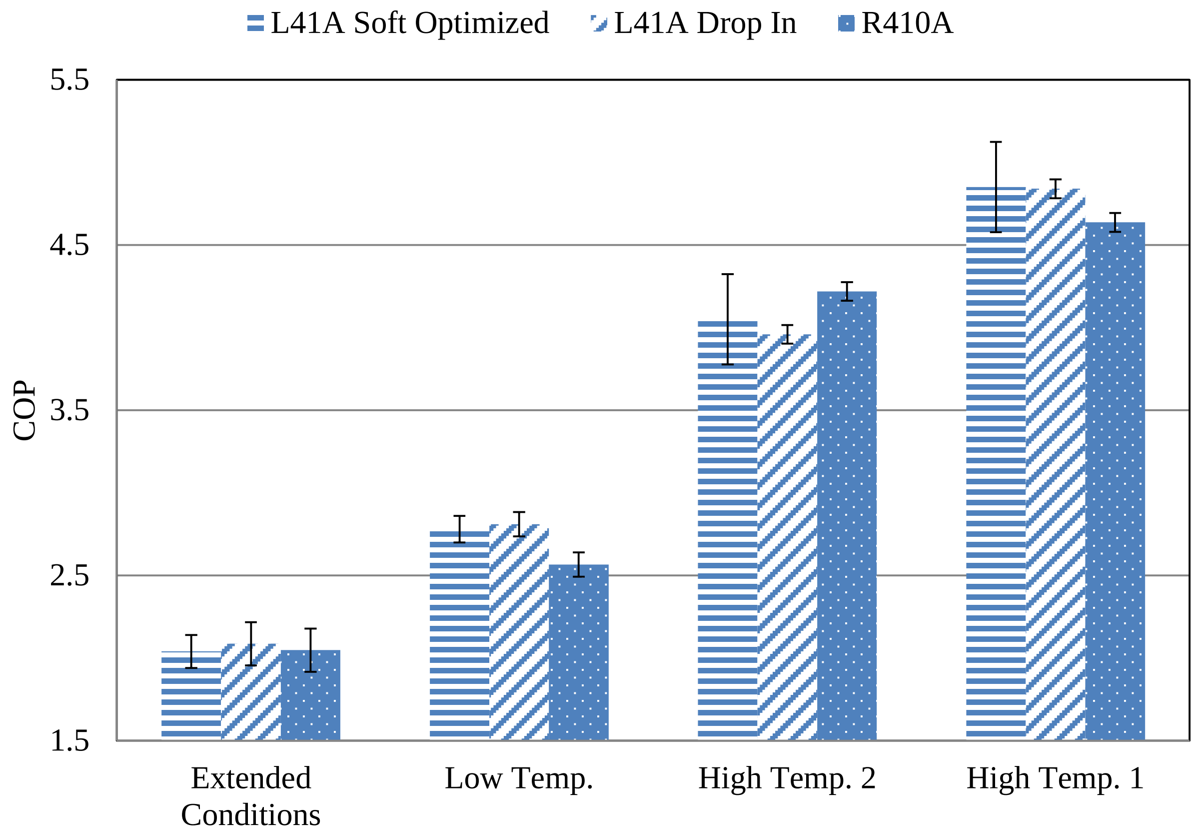


Figure 7: L41A vs. R410A Heating Test Results: COP.
EER=3.412*COP

5 Detailed Heating Test Results for R410A vs. L41A Soft Optimization

Testing Participant: UMD-CEEE **Participant's Notation: Ext. Cond. Test**

Basic Information	
Alternative Refrigerant	L41A
Alternative Lubricant Type and ISO Viscosity	POE
Baseline Refrigerant and Lubricant	R410A
Make and Model of System	SSZ140361BA/ARUF374316
Nominal Capacity and Type of System	36000 Btu/hr , Heat Pump

Comparison Data		Base.	Alt.	SI Units	Base.	Alt.	IP Units	Ratio
Mode (Heating/Cooling)		Heating						
Compressor Type		Scroll	Scroll					
Compressor Displacement		0.096	0.096	m^3/min	3.4	3.4	ft^3/min	1.0037
Nominal Motor Size		3.8	3.8	hp				1
Motor Speed		3500	3500	rpm				1
Expansion Device Type		R410A orifice	R410A TXV					
Lubricant Charge		0.71	0.71	kg	1.57	1.57	lb	1
Refrigerant Charge		5.19	4.74	kg	11.44	10.45	lb	0.91
Refrigerant Mass Flow Rate		N/A	N/A	kg/min	N/A	N/A	lb/min	
Composition, at compr. Inlet if applicable				%wt				
Ambient Temps.	Indoor, db	21.5	21.11	°C	70.7	69.99	F	
	Indoor, rh	51.3	54.81	%	51.3	54.81	%	
	Outdoor db	-17.82	-17.48	°C	-0.08	0.54	F	
	Outdoor, dew pt	-18.85	-19.87	°C	-1.93	-3.77	F	
Total Capacity		4.71	4.61	kW	16.07	15.73	kBtu/hr	0.98
Sensible Capacity		N/A	N/A	kW	N/A	N/A	kBtu/hr	
Total System Power Input		2.3	2.26	kW	2.3	2.26	kW	0.98
Compressor Power Input		1.93	1.89	kW	1.93	1.89	kW	0.98
Energy Efficiency Ratio (EER)		6.99	6.97	Btu-hr/W		23.77		1.00
Coeff. of Performance (COP)		2.05	2.04					1.00

Other System Changes
Orifice was replaced by TXV with 3 CW turns (10/12)

Type of System: Air-Source Split HP Alternate Refrigerant: L41A

Air/Water Side Data	Base.	Alt.	SI Units	Base.	Alt.	IP Units	Ratio
Evaporator							
Heat Exchange Fluid	Air	Air					
Flow Rate (gas)	N/A	N/A	m^3/min	N/A	N/A	ft^3/min	
Flow Rate (liquid)	N/A	N/A	L/min	N/A	N/A	gal/min	
Inlet Temperature	21.5	21.11	°C	70.7	69.99	F	
Outlet Temperature	27.71	27.37	°C	81.88	81.27	F	
Condenser							
Heat Exchange Fluid	Air	Air					
Flow Rate (gas)	35.11	33.97	m^3/min	1239.78	1199.73	ft^3/min	0.97
Flow Rate (liquid)	N/A	N/A	kg/min	N/A	N/A	lb/min	
Inlet Temperature	21.5	21.11	°C	70.7	69.99	F	
Outlet Temperature	27.71	27.37	°C	81.88	81.27	F	

Refrigerant Side Data Temperatures & Pressures	Baseline		Alternative		Baseline		Alternative	
	T (°C)	P (kPa)	T (°C)	P (kPa)	T (F)	P (psia)	T (F)	P (psia)
Compressor Suction	-20.65	404.71	-19.84	338.65	-5.17	58.7	-3.71	49.12
Compressor Discharge	53.74	1848.76	85.18	1723.12	128.73	268.14	185.33	249.92
Condenser Inlet	38.668	1825.25	49.839	1708.8	101.6	264.73	121.71	247.84
Condenser Outlet	28.35	1809.52	22.48	1700.33	83.03	262.45	72.47	246.61
Expansion Device Inlet	26.89	1828.2	19.81	1734.45	80.4	265.16	67.65	251.56
Subcooling, at expan. device	1.84	N/A	9.53	N/A	3.31	N/A	17.15	N/A
Evaporator Inlet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Evaporator Outlet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Suction Superheat	-1	N/A	0.21	N/A	-1.8	N/A	0.39	N/A

Data Source(s) for Refrigerant Properties
Refrigerant supplier

Additional Notes
Air Side Capacity and COP

Submitted by: Abdullah Alabdulkarem and Dr. Yunho Hwang

Testing Participant: UMD-CEEE **Participant's Notation: High Temp. 1 Test**

Basic Information	
Alternative Refrigerant	L41A
Alternative Lubricant Type and ISO Viscosity	POE
Baseline Refrigerant and Lubricant	R410A
Make and Model of System	SSZ140361BA/ARUF374316
Nominal Capacity and Type of System	36000 Btu/hr , Heat Pump

Comparison Data		Base.	Alt.	SI Units	Base.	Alt.	IP Units	Ratio
Mode (Heating/Cooling)		Heating						
Compressor Type		Scroll	Scroll					
Compressor Displacement		0.096	0.096	m^3/min	3.4	3.4	ft^3/min	1.0037
Nominal Motor Size		3.8	3.8	hp				1
Motor Speed		3500	3500	rpm				1
Expansion Device Type		R410A orifice	R410A TXV					
Lubricant Charge		0.71	0.71	kg	1.57	1.57	lb	1
Refrigerant Charge		5.19	4.74	kg	11.44	10.45	lb	0.91
Refrigerant Mass Flow Rate		3.3	2.94	kg/min	7.28	6.49	lb/min	0.89
Composition, at compr. Inlet if applicable				%wt				
Ambient Temps.	Indoor, db	21.23	20.97	°C	70.21	69.75	F	
	Indoor, rh	58.8	54.82	%	58.8	54.82	%	
	Outdoor db	16.84	16.63	°C	62.31	61.93	F	
	Outdoor, dew pt	13.33	13.08	°C	55.99	55.54	F	
Total Capacity		12.25	12.46	kW	41.8	42.53	kBtu/hr	1.02
Sensible Capacity		N/A	N/A	kW	N/A	N/A	kBtu/hr	
Total System Power Input		2.64	2.57	kW	2.64	2.57	kW	0.97
Compressor Power Input		2.27	2.20	kW	2.27	2.20	kW	0.97
Energy Efficiency Ratio (EER)		15.82	16.54	Btu-hr/W		56.45		1.05
Coeff. of Performance (COP)		4.64	4.85					1.05

Other System Changes
Orifice was replaced by TXV with 3 CW turns (10/12)

Type of System: Air-Source Split HP **Alternate Refrigerant: L41A**

Air/Water Side Data	Base.	Alt.	SI Units	Base.	Alt.	IP Units	Ratio
Evaporator							
Heat Exchange Fluid	Air	Air					
Flow Rate (gas)	N/A	N/A	m^3/min	N/A	N/A	ft^3/min	
Flow Rate (liquid)	N/A	N/A	L/min	N/A	N/A	gal/min	
Inlet Temperature	21.23	20.97	°C	70.21	69.75	F	
Outlet Temperature	37.79	38.90	°C	100.02	102.02	F	
Condenser							
Heat Exchange Fluid	Air	Air					
Flow Rate (gas)	34.96	33.98	m^3/min	1234.6	1200.02	ft^3/min	0.97
Flow Rate (liquid)	N/A	N/A	kg/min	N/A	N/A	lb/min	
Inlet Temperature	21.23	20.97	°C	70.21	69.75	F	
Outlet Temperature	37.79	38.90	°C	100.02	102.02	F	

Refrigerant Side Data Temperatures & Pressures	Baseline		Alternative		Baseline		Alternative	
	T (°C)	P (kPa)	T (°C)	P (kPa)	T (F)	P (psia)	T (F)	P (psia)
Compressor Suction	15.36	953.88	14.55	1033.44	59.65	138.35	58.19	149.89
Compressor Discharge	71.99	2450.46	69.74	2343.75	161.58	355.41	157.53	339.93
Condenser Inlet	65.07	2432.44	61.577	2327.24	149.13	352.79	142.84	337.54
Condenser Outlet	28.4	2399.23	33.46	2294.07	83.12	347.98	92.22	332.72
Expansion Device Inlet	27.6	2384.9	32.46	2287.20	81.68	345.9	90.42	331.73
Subcooling, at expan. device	11.7	N/A	7.97	N/A	21.06	N/A	14.35	N/A
Evaporator Inlet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Evaporator Outlet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Suction Superheat				N/A	17.35	N/A	2.67	N/A

Data Source(s) for Refrigerant Properties
Refrigerant supplier

Submitted by: Abdullah Alabdulkarem and Dr. Yunho Hwang

Testing Participant: UMD-CEEE **Participant's Notation: High Temp. 2 Test**

Basic Information	
Alternative Refrigerant	L41A
Alternative Lubricant Type and ISO Viscosity	POE
Baseline Refrigerant and Lubricant	R410A
Make and Model of System	SSZ140361BA/ARUF374316
Nominal Capacity and Type of System	36000 Btu/hr, Heat Pump

Comparison Data		Base.	Alt.	SI Units	Base.	Alt.	IP Units	Ratio
Mode (Heating/Cooling)		Heating						
Compressor Type		Scroll	Scroll					
Compressor Displacement		0.096	0.096	m^3/min	3.4	3.4	ft^3/min	1.003714
Nominal Motor Size		3.8	3.8	hp				1
Motor Speed		3500	3500	rpm				1
Expansion Device Type		R410A orifice	R410A TXV					
Lubricant Charge		0.71	0.71	kg	1.57	1.57	lb	1
Refrigerant Charge		5.19	4.74	kg	11.44	10.45	lb	0.91
Refrigerant Mass Flow Rate		2.96	2.21	kg/min	6.53	4.88	lb/min	0.75
Composition at compr. Inlet if applicable				%wt				
Ambient Temps.	Indoor, db	21.24	21.05	°C	70.23	69.89	F	
	Indoor, rh	51.13	51.21	%	51.13	51.21	%	
	Outdoor db	8.3	8.25	°C	46.94	46.85	F	
	Outdoor, dew pt	4.45	3.98	°C	40.01	39.16	F	
Total Capacity		10.74	9.95	kW	36.65	33.96	kBtu/hr	0.93
Sensible Capacity		N/A	N/A	kW	N/A	N/A	kBtu/hr	
Total System Power Input		2.55	2.46	kW	2.55	2.46	kW	0.96
Compressor Power Input		2.17	2.09	kW	2.17	2.09	kW	0.96
Energy Efficiency Ratio (EER)		14.4	13.81	Btu-hr/W		47.13		0.96
Coeff. of Performance (COP)		4.22	4.05					0.96

Other System Changes
Orifice was replaced by TXV with 3 CW turns (10/12)

Type of System: Air-Source Split HP **Alternate Refrigerant: L41A**

Air/Water Side Data	Base.	Alt.	SI Units	Base.	Alt.	IP Units	Ratio
Evaporator							
Heat Exchange Fluid	Air	Air					
Flow Rate (gas)	N/A	N/A	m^3/min	N/A	N/A	ft^3/min	
Flow Rate (liquid)	N/A	N/A	L/min	N/A	N/A	gal/min	
Inlet Temperature	21.24	21.05	°C	70.23	69.89	F	
Outlet Temperature	35.54	35.32	°C	95.97	95.58	F	
Condenser							
Heat Exchange Fluid	Air	Air					
Flow Rate (gas)	33.83	33.99	m^3/min	1194.58	1200.2	ft^3/min	1
Flow Rate (liquid)	N/A	N/A	kg/min	N/A	N/A	lb/min	
Inlet Temperature	21.24	21.05	°C	70.23	69.89	F	
Outlet Temperature	35.54	35.32	°C	95.97	95.58	F	

Refrigerant Side Data Temperatures & Pressures	Baseline		Alternative		Baseline		Alternative	
	T (°C)	P (kPa)	T (°C)	P (kPa)	T (F)	P (psia)	T (F)	P (psia)
Compressor Suction	6.62	835.75	6.19	790.91	43.92	121.21	43.15	114.71
Compressor Discharge	66.35	2304.52	72.78	2151.56	151.43	334.24	163.00	312.06
Condenser Inlet	58.701	2281.86	60.56	2135.52	137.66	330.95	141.01	309.73
Condenser Outlet	28.89	2254.86	27.54	2116.97	84	327.04	81.57	307.04
Expansion Device Inlet	27.81	2252.25	26.14	2123.69	82.06	326.66	79.06	308.01
Subcooling at expan. device	9.16	N/A	11.23	N/A	16.49	N/A	20.22	N/A
Evaporator Inlet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Evaporator Outlet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Suction Superheat	5.16	N/A	1.89	N/A	9.29	N/A	3.40	N/A

Data Source(s) for Refrigerant Properties
Refrigerant supplier

Submitted by: Abdullah Alabdulkarem and Dr. Yunho Hwang

Testing Participant: UMD-CEEE **Participant's Notation: Low Temp. Test**

Basic Information	
Alternative Refrigerant	L41A
Alternative Lubricant Type and ISO Viscosity	POE
Baseline Refrigerant and Lubricant	R410A
Make and Model of System	SSZ140361BA/ARUF374316
Nominal Capacity and Type of System	36000 Btu/hr , Heat Pump

Comparison Data		Base.	Alt.	SI Units	Base.	Alt.	IP Units	Ratio
Mode (Heating/Cooling)		Heating						
Compressor Type		Scroll	Scroll					
Compressor Displacement		0.096	0.096	m^3/min	3.4	3.4	ft^3/min	1.0037
Nominal Motor Size		3.8	3.8	hp				1
Motor Speed		3500	3500	rpm				1
Expansion Device Type		R410A orifice	R410A TXV					
Lubricant Charge		0.71	0.71	kg	1.57	1.57	lb	1
Refrigerant Charge		5.19	4.74	kg	11.44	10.45	lb	0.91
Refrigerant Mass Flow Rate		N/A	N/A	kg/min	N/A	N/A	lb/min	
Composition, at compr. Inlet if applicable				%wt				
Ambient Temps.	Indoor, db	21.27	21.08	°C	70.29	69.94	F	
	Indoor, rh	49.61	54.48	%	49.61	54.48	%	
	Outdoor db	-8.79	-8.35	°C	16.18	16.97	F	
	Outdoor, dew pt	-11.07	-12.47	°C	12.07	9.55	F	
Total Capacity		6	6.42	kW	20.47	21.91	kBtu/hr	1.07
Sensible Capacity		N/A	N/A	kW	N/A	N/A	kBtu/hr	
Total System Power Input		2.34	2.31	kW	2.34	2.31	kW	0.99
Compressor Power Input		1.97	1.94	kW	1.97	1.94	kW	0.98
Energy Efficiency Ratio (EER)		8.76	9.48	Btu-hr/W		32.36		1.08
Coeff. of Performance (COP)		2.57	2.78					1.08

Type of System: Air-Source Split HP **Alternate Refrigerant: L41A**

Air/Water Side Data	Base.	Alt.	SI Units	Base.	Alt.	IP Units	Ratio
Evaporator							
Heat Exchange Fluid	Air	Air					
Flow Rate (gas)	N/A	N/A	m^3/min	N/A	N/A	ft^3/min	
Flow Rate (liquid)	N/A	N/A	L/min	N/A	N/A	gal/min	
Inlet Temperature	21.27	21.08	°C	70.29	69.94	F	
Outlet Temperature	29.55	30.02	°C	85.19	86.04	F	
Condenser							
Heat Exchange Fluid	Air	Air					
Flow Rate (gas)	34.15	33.98	m^3/min	1205.85	1200.02	ft^3/min	1
Flow Rate (liquid)	N/A	N/A	kg/min	N/A	N/A	lb/min	
Inlet Temperature	21.27	21.08	°C	70.29	69.94	F	
Outlet Temperature	29.55	30.02	°C	85.19	86.04	F	

Refrigerant Side Data Temperatures & Pressures	Baseline		Alternative		Baseline		Alternative	
	T (°C)	P (kPa)	T (°C)	P (kPa)	T (F)	P (psia)	T (F)	P (psia)
Compressor Suction	-13.29	521.69	-8.54	475.10	8.08	75.66	16.63	68.91
Compressor Discharge	52.45	1943.28	78.12	1859.44	126.41	281.85	172.62	269.69
Condenser Inlet	41.569	1912.82	54.56	1842.32	106.82	277.43	130.21	267.20
Condenser Outlet	30.08	1894.01	22.92	1829.79	86.14	274.7	73.26	265.39
Expansion Device Inlet	28.96	1910.26	20.99	1859.56	84.13	277.06	69.78	269.71
Subcooling at expan. device	1.46	N/A	11.06	N/A	2.63	N/A	19.91	N/A
Evaporator Inlet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Evaporator Outlet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Suction Superheat	-0.62	N/A	2.37	N/A	-1.12	N/A	4.27	N/A

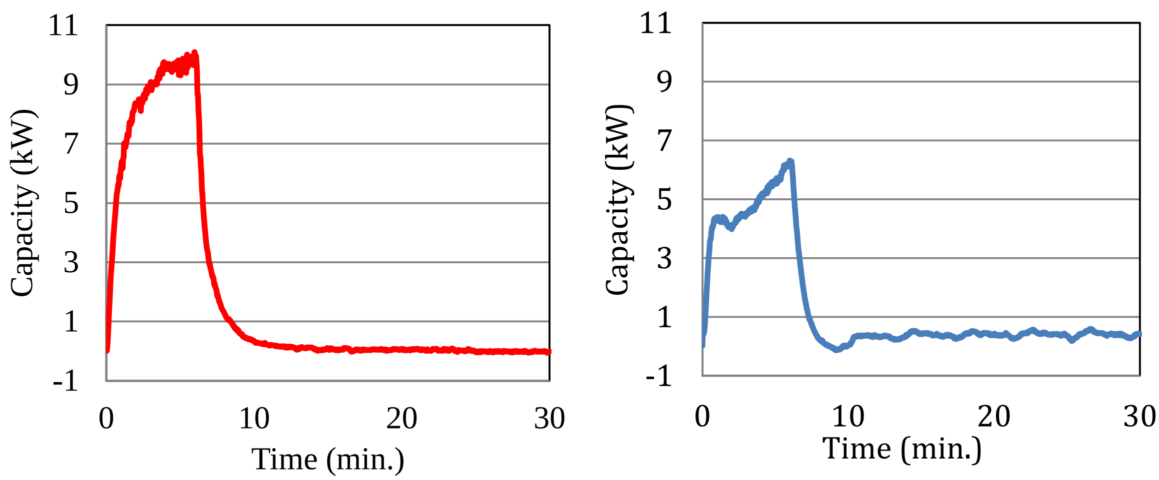
Data Source(s) for Refrigerant Properties
Refrigerant supplier

Additional Notes
Air Side Capacity and COP

Submitted by: Abdullah Alabdulkarem and Dr. Yunho Hwang

- **Cyclic heating tests**

The cyclic condition included two cycles. Each cycle was comprised of 6 minutes "on" time and 24 minutes "off" time (Figure 8). Specific calculation procedure followed ARI standard 210/240 (1995). The summary of the results of the cyclic heating test are shown in Table 9.



(a) L41A (b) R410A

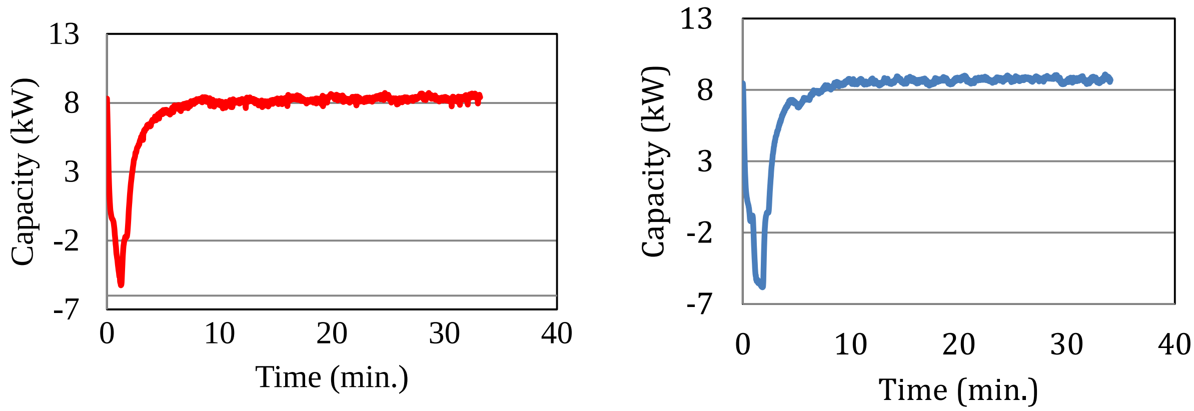
Figure 8: Heating capacity vs. time for cyclic heating test.

Table 9: Cyclic heating results and HSPF.

	Heating-Air Side (kW-hr)	Power Consumption (kW-hr)	COP	Heating Load Factor (HLF)	Degradation Coefficient (CD)	HSPF
R410A	0.53	0.24	2.2	0.11	0.49	7.57
L41A	0.93	0.25	3.67	0.18	0.12	9.00
Difference (%)	74.45	3.28	66.7	-57.8	-84.3	18.9

- **Frost accumulation tests**

The cyclic condition included two cycles. Each cycle was comprised of the start of the defrosting cycle until the start of the next defrosting cycle (Figure 9). Specific calculation procedure followed ARI standard 210/240 (1995). The summary of the results are shown in Table 10.



(a) L41A (b) R410A

Figure 9: Heating capacity vs. time for frost accumulation test.

Table 10: Heating capacity and COP for frost accumulation tests.

	Heating-Air side (kW-hr)	Average Heating Capacity (kW)	COP
R410A	4.31	7.59	3.23
L41A	4.28	7.75	3.36
Difference (%)	-0.71	2.04	4.12