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Impact of Charge Degradation on the Life Cycle Climate Performance of a Residential Air-Conditioning System

Paper 2277

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INTRODUCTION

Introduction

- Every vapor compression system has an optimum refrigerant charge
- A portion of this charge leaks out of the system annually
  - Performance degradation
  - System is charged during servicing

LITERATURE REVIEW

Literature Review

- Limited number of studies reporting the effect of charge degradation on vapor compression system performance
- Systems investigated include:
  - Residential and mobile air conditioning
  - Heat pumps (including air-to-air and water-to-water)
  - Water chiller systems
  - Walk-in coolers and freezers

Literature Review

- Primary refrigerants tested include R-22 (most common), R-134a, R-32, R-404A, R-1234yf, and R-410A
- General trends observed with a drop in the system's charge include:
  - Decrease in system capacity, COP, and energy consumption
  - Increase in the suction superheat

Literature Review

- Ambient temperature affects all systems for all expansion devices used
- Accumulator helps to maintain the system performance at its rated value for a charge reduction of up to 20%
- Systems with a capillary tube are very sensitive to a decrease in refrigerant charge, as opposed to orifice, TXV, and EEV

CORRELATION DEVELOPMENT

Correlation Development

- Predict system capacity and power fractions in terms of the charge fraction and the ambient dry bulb temperature
- The general trends fit well to a second degree polynomial

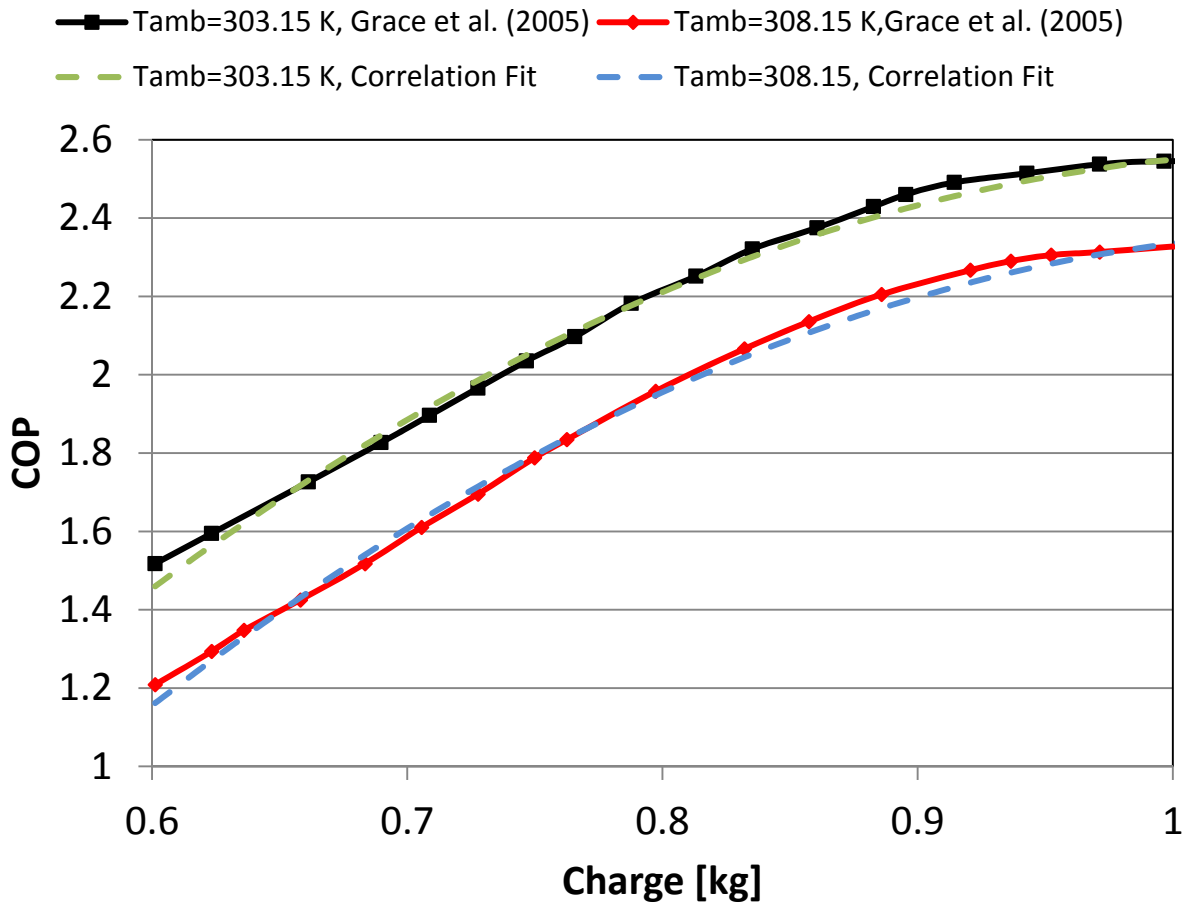
$$z = a + b \times x + c \times y + d \times x^2 + f \times y^2 + g \times x \times y$$

z: the fraction of capacity, rated energy consumption, or COP
x: is the ambient temperature in K
y: is the charge fraction
a, *b*, *c*, *d*, *f* and *g:* regression coefficients

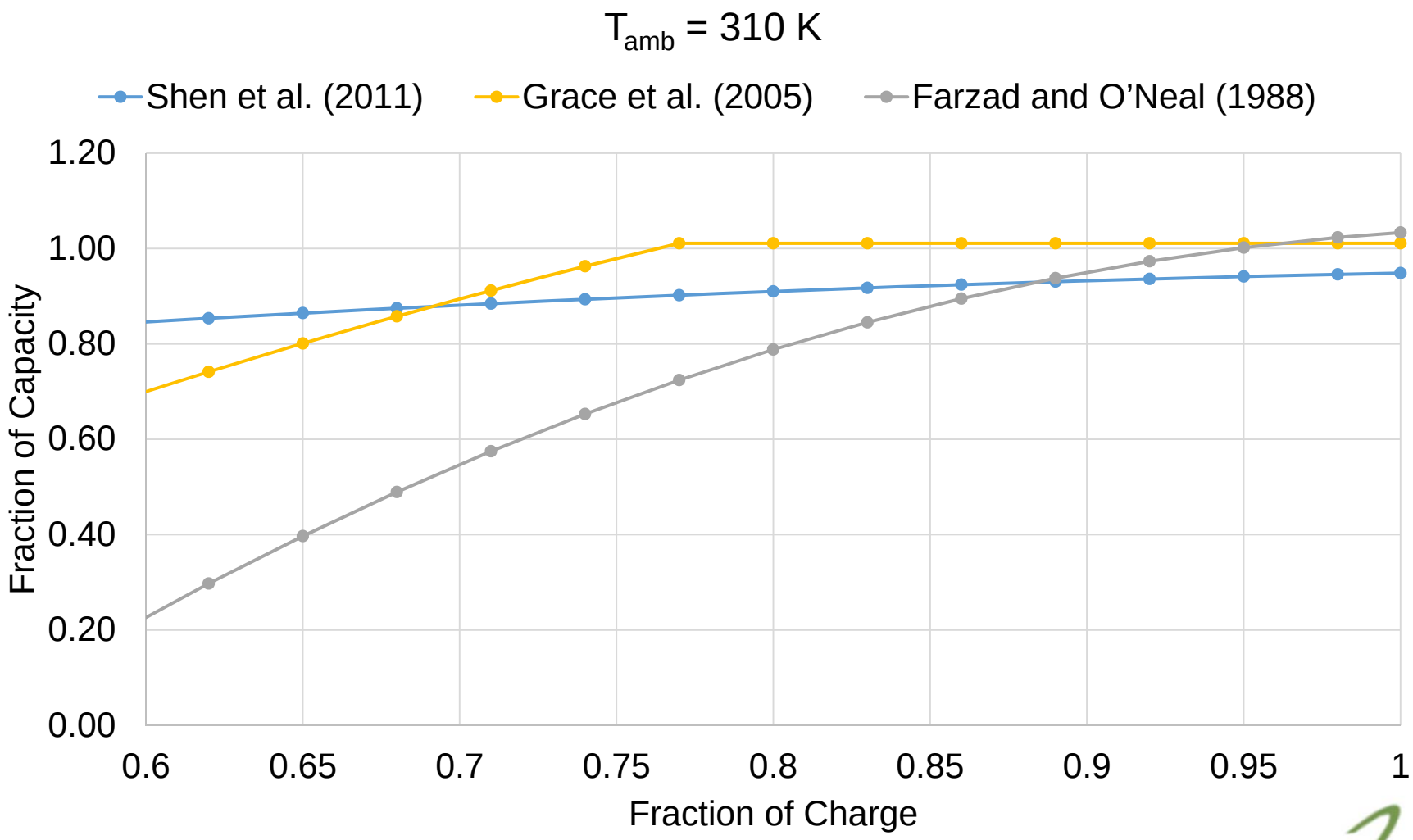
Correlation Development

Charge degradation correlations

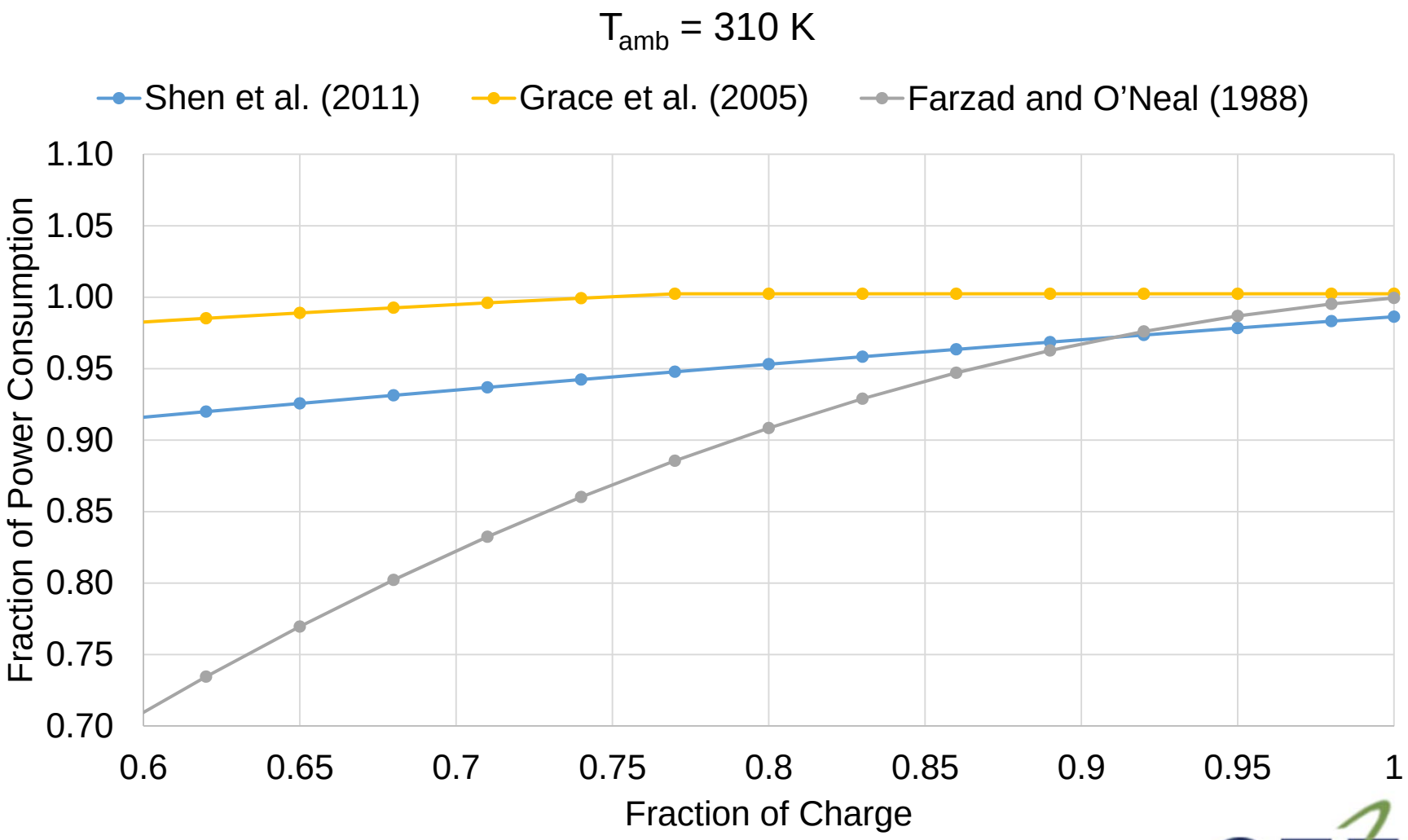
Correlation	System/ Exp. Device
Shen et al. (2011)	Heat Pump/ TXV
Grace et al. (2005)	Water to water chiller/ TXV
Farzad and O'Neal (1988)	Air Conditioning/ Capillary Tube



Correlation Development



Correlation Development



LCCP ANALYSIS

LCCP Analysis - System

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

http://www.ahrinet.org/App_Content/ahri/files/RESEARCH/AREP_Final_Reports/AHRI%20Low-GWP%20AREP-Rpt-020.pdf

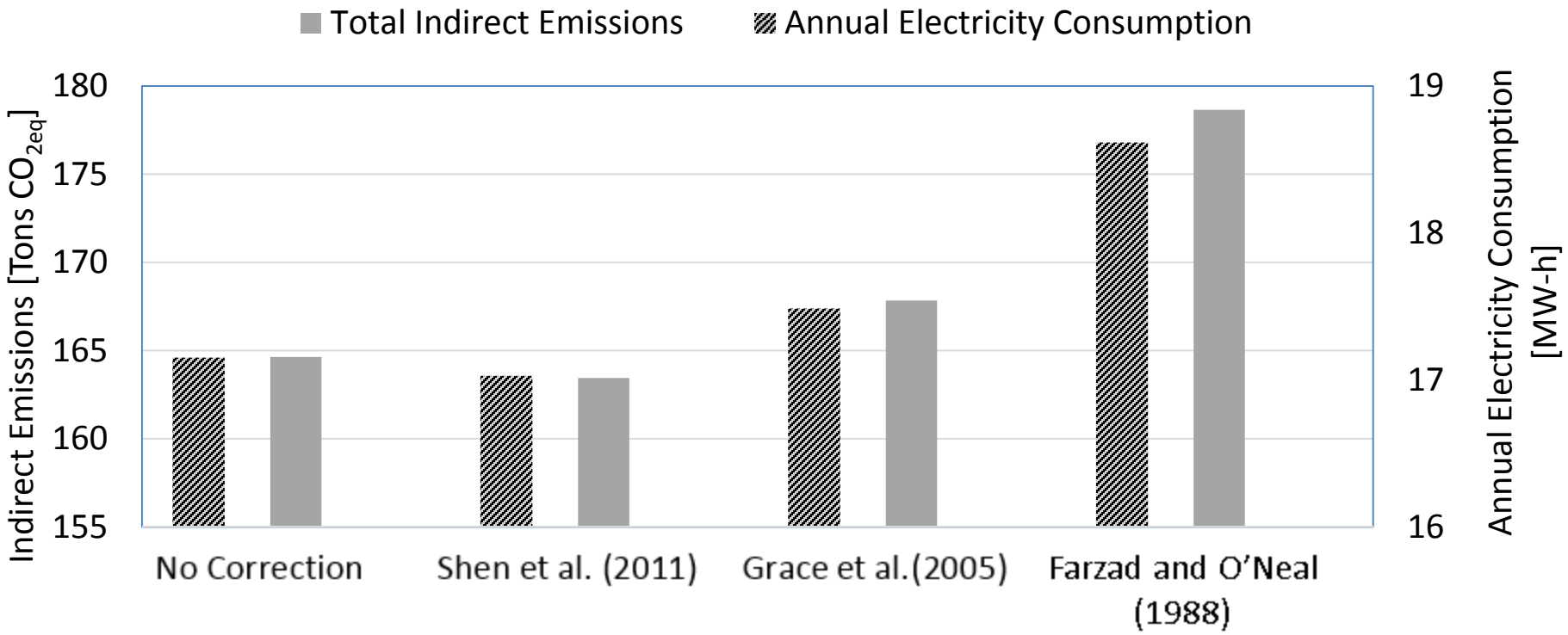
LCCP Analysis - Inputs

- ASHP* located in Chicago, IL
- Refrigerant: R410A with charge of 4.54 kg
- AHRI standard 210/240 for load calculations
- An in house vapor compression system simulation tool for system simulation

System Property	Value
Annual Leak Rate (%)	5
Ref Loss EOL (%)	15
System Lifetime (years)	15
Service Interval (years)	5
Reused Refrigerant (%)	85
Aluminum (kg)	19.1
Steel (kg)	75.9
Copper (kg)	31.2
Plastics (kg)	37.8

http://www.ahrinet.org/App_Content/ahri/files/RESEARCH/AREP_Final_Reports/AHRI%20Low-GWP%20AREP-Rpt-020.pdf

LCCP Analysis - Results



$$energy\ consumption = \frac{load}{capacity} \times power$$

CONCLUSIONS

Conclusions

- Three main factors affect the sensitivity of system performance relative to refrigerant charge:
  - Ambient temperature
  - Use of an accumulator
  - Type of expansion device
- Three correlations for the capacity and rated energy consumption fractions as a function of charge fraction and ambient temperature are presented

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Conclusions

- Applying these correlations to an ASHP tends to give much higher total emissions of the system
- Farzad and O'Neal (1988) correlation gives the highest energy consumption as it is developed for systems with a capillary tube

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Literature Review

Study	System	Charge	Conclusion
Trane Co.	A/C	90%	Efficiency is 20% lower
Domingorena	3-ton air-to-air heat pump, capillary tube, no accumulator	63-127%	• Highly sensitive to undercharging • Almost insensitive to overcharging • COP and capacity decrease almost linearly
Domingorena and Ball	3-ton air-to-air heat pump, orifice, suction line accumulator	63-127%	Using the accumulator helped to maintain the COP of the system at its rated value for more charge reduction (around 20%)
Houcek and Thedford	1.5 ton split A/C	77-123%	For the undercharging conditions, the capacity dropped by 23% at 301 K and 34% at 308 K
Farzad and O'Neal	3-ton A/C, capillary tube, no accumulator	75-125%	Total capacity, EER, and SEER are more sensitive to undercharging than overcharging conditions
Farzad	3-ton A/C, no accumulator, three expansion devices: a short-tube orifice, a thermostatic expansion valve, and a capillary tube	80-120%	• System using a capillary tube is more sensitive to the off-design charging than the system using either the TXV or the short-tube orifice • The performance of the system with the TXV and the short tube orifice is strongly dependent on the outdoor air temperature
Robinson	3-ton A/C, orifice	80-120%	

Literature Review

Study	System	Charge	Conclusion
Rodriguez	3-ton A/C, no accumulator, a short-tube orifice 3.5-ton A/C, no accumulator, a thermostatic expansion valve	60-130%	• Charge reduction more than 20% causes a sharp decrease in capacity and EER • Overcharging the system more than 20% did not have much impact on performance
Bailey	70-ton dual circuit, air-cooled chiller	40-115%	Chiller power per ton of refrigerating capacity is directly proportional to the outdoor air temperature and the refrigerant charge level
Goswami et al.	3-ton A/C	50%	For a 10% reduction in charge, the capacity decreases by 3.5% while the COP increases by 2%
Choi and Kim	3.5 ton water-to-water heat pump, electronic expansion valve (EEV) and a capillary tube	80-120%	• The system using the EEV was almost insensitive to the change in charge while it was sensitive to the outdoor conditions • The system using the capillary tube was sensitive to both the charge and outdoor conditions with the capacity and COP decreasing for both undercharging and overcharging

Literature Review

Study	System	Charge	Conclusion
Grace et al.	1.1 ton water-to-water chiller, a thermostatic expansion valve	50-140%	• Charge degradation has a slight effect on the system performance in the charge range from 75% to 125% • Further reduction in the charge caused a sharp drop in the system performance
Kruse and Palmiter	3-ton heat pump, suction-line accumulator, a short-tube orifice and a thermostatic expansion valve	70-130%	Heat pump without a suction-line accumulator would be much more sensitive to variations in charge level
Shen et al.		60-150%	
Wichman and Braun	Walk-in coolers and freezers, a thermostatic expansion valve and a liquid line receiver	50-240%	• TXV helped to maintain system performance until the charge reached 80% • Further decrease in charge caused a sharp decrease in the capacity

Literature Review

Study	System	Charge	Conclusion
Kim, and Braun	six different residential air conditioning systems with different components	40-130%	for systems with a fixed expansion orifice (FXO), the accumulator had little impact on the charge degradation effect on the capacity. for the systems using the TXV, below a charge limit of 70%, the TXV starts to operate similar to the FXO as the TXV becomes wide open
Huyghe	mobile air conditioning system used in a mid-size sedan, thermostatic expansion valve	25-100%	system performance began to significantly decrease when the refrigerant charge dropped below 70%