ORNL/TM-2018/520

Low-GWP Refrigerant Evaluation in AC Systems for High Ambient Temperature Applications -Design and Simulation Practice to Identify Charge Reduction Opportunities for Residential AC/HP Units– FY18 3rd Quarter Milestone Report

Bo Shen
06/30/2018

Approved for public release. Distribution is unlimited.

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ORNL/TM-2018/520

BTO Project 3.2.2.19
FY18 3rd Quarter Milestone Report

Low-GWP Refrigerant Evaluation in AC Systems for High Ambient Temperature Applications - design and simulation practice to identify charge reduction opportunities for residential AC/HP units

Author
Bo Shen

Date: 06/30/2018

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

Design and simulation practice to identify charge reduction opportunities for residential AC/HP units (Regular Milestone)

Executive Summary

Based on three 5-ton, single-speed heat pumps (HPs), using R-410A, which use the same compressor, indoor blower and outdoor fan, the DOE/ORNL Heat Pump Design Model was used to conduct comparative modelling study. Regarding charge reduction opportunities, in general, we recommend: 1. Downsizing the outdoor condenser will reduce the required system charge, i.e. using smaller tube diameters or fewer tubes; reducing the evaporator inner volume is less important; to offset the reduced condenser tube side surface area, one can increase the air side surface area (fin density) or condenser air flow rate via using a more efficient fan. 2. microchannel heat exchangers are most effective in reducing the required charge, by up to 60% in the condenser and evaporator. To develop low charge systems, one should at least use a microchannel heat exchanger as the outdoor condenser. 3. TXV systems are less sensitive to charge reduction. For the drop-in application, one can decrease the charge to minimize the liquid section in the condenser, at the expense of minor performance degradation; for example, when reducing the system charge by 15% (decrease the subcooling degree to 2R), the simulation results prove that the decrease is less than 3% in the EER and less than 6% in the capacity.

Smaller condenser size, tube diameters and microchannel heat exchangers lead to charge reduction

We obtained unit information and heat exchanger geometries for three 5-ton, single-speed heat pumps, using R-410A. The three heat pumps have the same compressor, indoor blower and outdoor fan. They use different heat exchangers. The evaporator and condenser of Unit A (3/8"Coils) use 3/8-inch (9.5 mm outside diameter) tubes; and Unit B (7mmCoils) uses 7 mm tubes; Unit C (MHXs) uses all microchannel heat exchangers. They have the same rated cooling capacity and similar sensible heat ratio at the AHRI A condition, i.e. 95°F outdoor dry bulb temperature, indoor 80°F dry bulb/67°F wet bulb temperature. The figure below presents the rated EERs and calculated refrigerant charges (sum of the evaporator and condenser) as a function of the ratio of condenser inner volume to evaporator, of the three units.

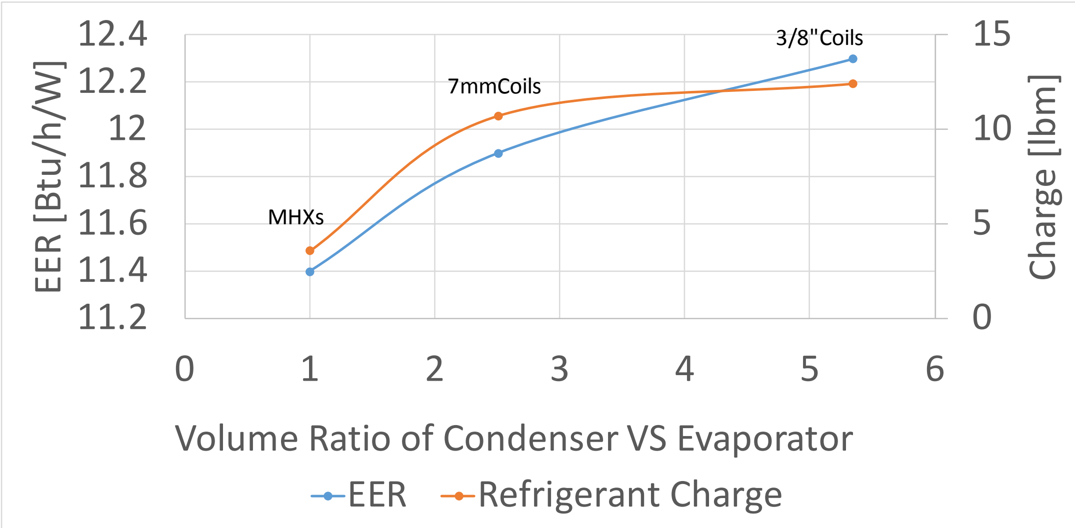

Figure 1: Rated EERs and Refrigerant Charges VS Inner Volume Ratio of Condenser Relative to Evaporator

Figure 1 indicates that the refrigerant charge increases with the tube diameter and relative condenser inner volume. At the same rated capacity, SHR and indoor air flow rate, the indoor evaporator size is relatively fixed. Enlarging the condenser surface area enhances the efficiency while increasing the refrigerant charge. The microchannel heat exchangers can decrease the system charge by 67% in comparison to the unit using 7 mm tubes.

Figure 2 illustrates charge mass distribution in evaporator (M_evap) and condenser (M_cond) when setting the condenser exit subcooling degree at 10R. Additionally, the charge in the condenser splits to four parts, i.e. the charge in the vapor-phase region (M_Vcond), the two-phase region (M_TPcond), the liquid-phase region (M_LIQcond), and in the outlet header (M_Header). In the three units, it can be seen, that more than 70% of refrigerant charge is in the condenser, primarily in the two-phase and liquid-phase regions. Charge in the liquid header of the microchannel-channel heat exchanger is also noticeable, which takes 20% of the total charge. For charge reduction, it is most important to control the charge in the condenser, i.e. downsizing the outdoor condenser inner volume.

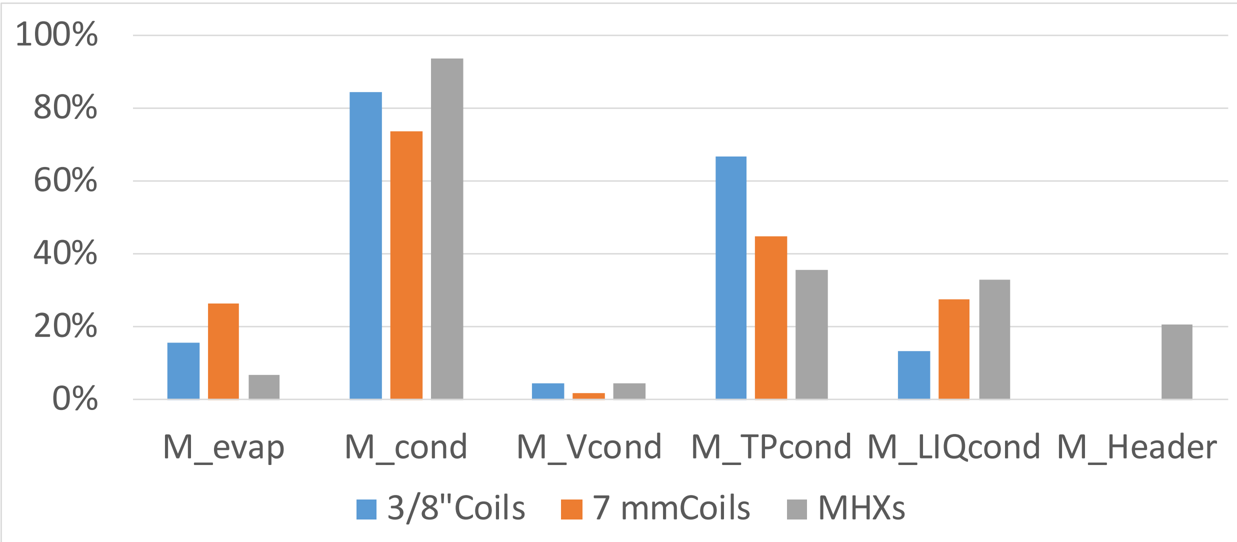

Figure 2: Charge Mass Distribution in Evaporator and Condenser

However, reducing the outdoor condenser inner volume elevates the condensing pressure and degrades the energy efficiency. One can increase the condenser air flow rate or the condenser air side surface area, i.e. fin density, to balance the degradation. On the other hand, these will cause higher air side pressure drop and larger fan power. Hence, it is necessary to use a more efficient condenser fan.

TXV Systems less sensitive to charge variation

Performance of an Air conditioner using a thermo-expansion valve tends to be insensitive to variation of the system charge. Figures 3 and 4 predict variations of cooling EER and capacity as a function of the system charge relative to the nominal value in the systems using 3/8 inch tubes and microchannel heat exchangers. With reducing the system charge by 15% (decrease the subcooling degree to 2R), the degradation in the EER is less than 3%, and the capacity reduction is less than 6%.

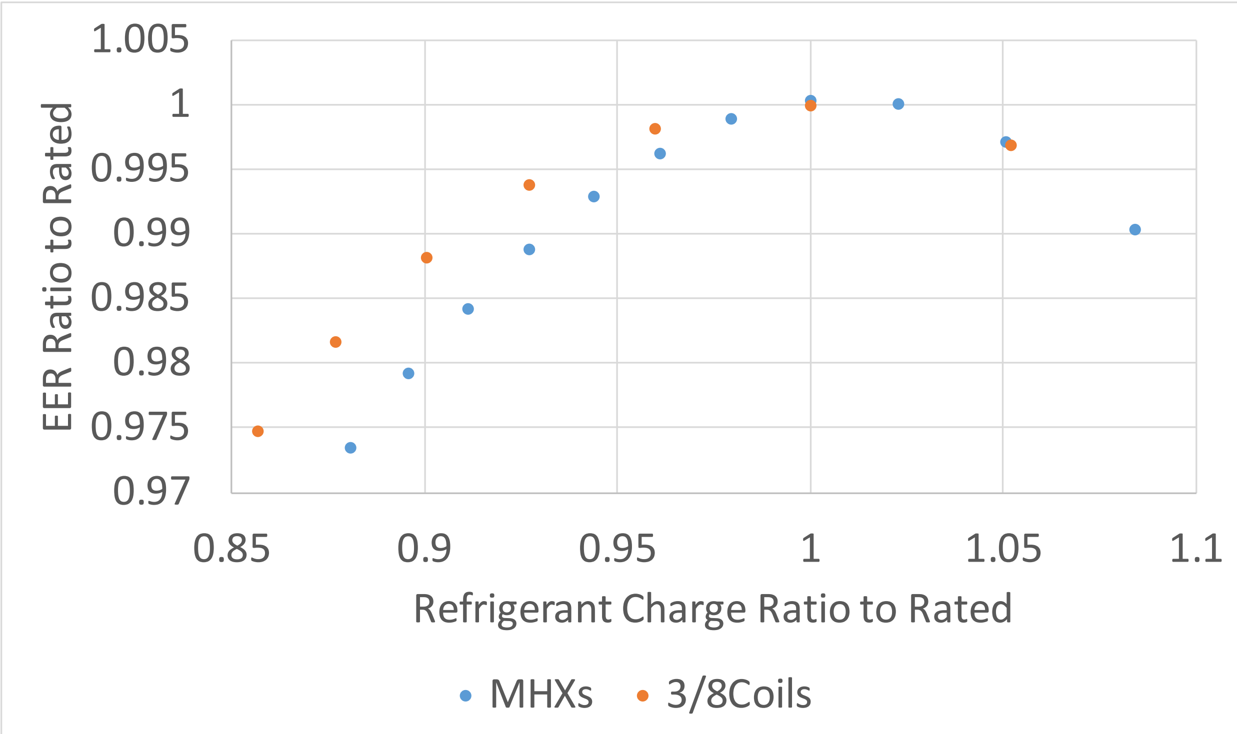

Figure 3: EERs change with the system charge

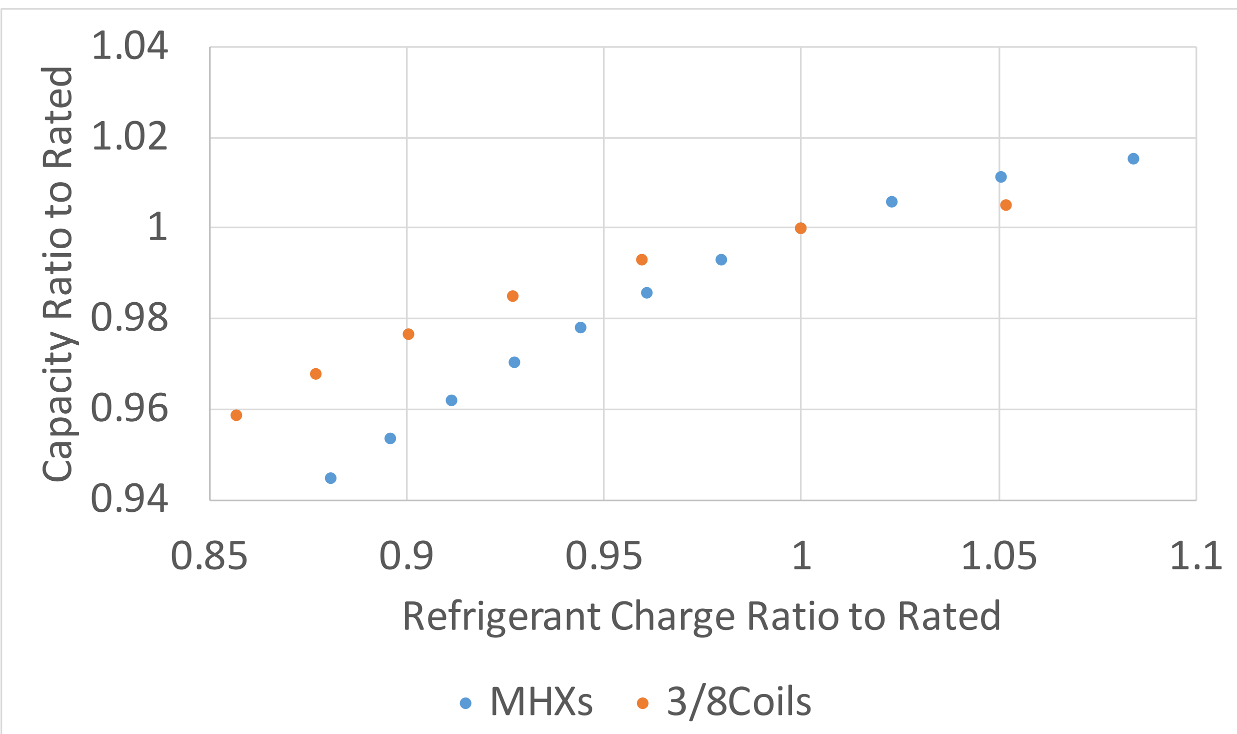

Figure 4: Cooling capacities change with the system charge

Summary

Regarding charge reduction opportunities, in general, it is recommended:

1. Downsizing the outdoor condenser will reduce the required system charge, i.e. using smaller tube diameters or fewer tubes; reducing the evaporator inner volume is less important; to offset the reduced condenser tube side surface area, one can increase the air side surface area (fin density) or condenser air flow rate via using a more efficient fan.
2. microchannel heat exchangers are most effective in reducing the required charge, by up to 60% in the condenser and evaporator. To develop low charge systems, one should at least use a microchannel heat exchanger as the outdoor condenser.
3. TXV systems are less sensitive to charge reduction. For the drop-in application, one can decrease the charge to minimize the liquid section in the condenser, at the expense of minor performance degradation; for example, when reducing the system charge by 15% (decrease the subcooling degree to 2R), the simulation results prove that the decrease is less than 3% in the EER and less than 6% in the capacity.