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Development and Evaluation of Automated Virtual Refrigerant Charge Sensor Training Kit

Akash Patil
Purdue University

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DEVELOPMENT AND EVALUATION OF AUTOMATED VIRTUAL REFRIGERANT CHARGE SENSOR TRAINING KIT

by

Akash Patil

A Thesis

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THE PURDUE UNIVERSITY GRADUATE SCHOOL
STATEMENT OF COMMITTEE APPROVAL

Prof. James E. Braun
    Department of Mechanical Engineering
Prof. W. Travis Horton
    Department of Mechanical Engineering
Prof. Eckhard Groll
    Department of Mechanical Engineering

Approved by:
    Prof. Jay Gore
        Head of the Graduate Program

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NOMENCLATURE

Symbol

h	Enthalpy [J/kg]
h_{cro}	Refrigerant enthalpy at condenser outlet [J/kg]
h_{eri}	Refrigerant enthalpy at evaporator outlet [J/kg]
k_{SC}	Empirical coefficient for condenser subcooling in VRC sensor [-]
k_{SH}	Empirical coefficient for suction superheat in VRC sensor [-]
k_x	Empirical coefficient for evaporator inlet quality in VRC sensor [-]
m_{actual}	Actual refrigerant charge [lbs]
m_{normal}	Normal refrigerant charge [lbs]
T_{cro}	Refrigerant temperature at condenser outlet [°C]
T_{crs}	Refrigerant saturation temperature in the condenser [°C]
T_{eri}	Refrigerant temperature at evaporator inlet [°C]
T_{suc}	Refrigerant temperature at compressor suction [°C]
ΔT_{SC}	Subcooling at condenser outlet [°C]
$\Delta T_{SC,rated}$	Subcooling at condenser outlet for rated condition [°C]
ΔT_{SH}	Superheat at compressor suction [°C]
$\Delta T_{SH,rated}$	Superheat at compressor suction for rated condition [°C]
x_{eri}	Evaporator inlet quality [-]
$x_{eri,rated}$	Evaporator inlet quality for rated condition [°C]

Abbreviations

COP	Coefficient of Performance
FDD	Fault Detection and Diagnostics
FXO	Fixed Orifice Expansion Device
HVAC	Heating, Ventilation and Air Conditioning
RMSE	Root Mean Square Error
RTU	Rooftop Unit
TXV	Thermal Expansion Valve
VRC	Virtual Refrigerant Charg

ABSTRACT

Author: Patil, Akash, M. MSME
Institution: Purdue University
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Major Professor: James E. Braun

In a vapor compression system, the amount of refrigerant charge significantly affects the performance of the unit. Improperly charged systems run sub-optimally and thus result in higher operating costs due to increased energy usage. The unit can be undercharged due to a small leakage over the years. Similarly, the unit can be overcharged due to improper maintenance practices. Currently, there is no direct way to measure the amount of refrigerant in the system. In this thesis, virtual refrigerant charge sensors were developed and implemented for a rooftop unit using a previously developed approach. An open lab methodology with low cost electrical hardware was implemented for training the virtual refrigerant charge sensor which can be used as a substitute to expensive psychrometric chamber testing. The entire test methodology was automated which significantly reduced the need for human intervention. The open lab training results were validated by testing the RTU inside psychrometric chambers at different ambient conditions and charge levels. The accuracy of the virtual refrigerant charge sensor model trained using open lab methodology was within ±10% of the actual charge measurement. The concept of an automated charging kit was extended further to facilitate adding as well as removing refrigerant charge in the system. This apparatus was used to test the RTU at different charge levels in an attempt to locate an optimal operating charge for coefficient of performance as well as cooling capacity. The results indicate a relatively flat variation of

COP and cooling capacity with charge around the optimal. The automated open lab training methodology can significantly lower testing costs for VRC sensor tuning as it eliminates the need for psychrometric chambers as well as human interference.

CHAPTER 1. INTRODUCTION

1.1 Background and Motivation

Previous studies [1,2] indicate that more than 50% of the packaged air conditioning systems in the field (also called rooftop units, RTUs) have problems due to improper airflow or are improperly charged. According to a commercial building energy consumption survey [3], about 43% of the commercial buildings in the US are cooled using RTUs. This accounts for about 31% of the annual electricity usage. As the amount of refrigerant charge in a vapor compression system has a significant impact on its performance, improperly charged systems have higher energy usage and operating costs. Systems over time tend to become undercharged due to slow refrigerant leaks that may go unnoticed with infrequent inspection or scheduled maintenance. Conversely, systems may become overcharged because of imperfect maintenance practices or unskilled technicians. This has helped fuel the motivation to develop fault detection and diagnostics (FDD) tools for RTUs in order to reduce annual energy consumption in commercial buildings.

Automated FDD systems can potentially lead to lower service and energy utility costs, thus lowering the total operating costs [4]. In order to make it convenient for the manufacturers to incorporate automated FDD system in their equipment, the FDD system should use low cost sensors and have low installation costs. Online monitoring of the data obtained from FDD systems can be used to detect system faults and take appropriate action.

Recently, the use of virtual sensors is gaining interest in Heating, Ventilation and Air Conditioning (HVAC) applications. Virtual sensors use low cost measurements and simple mathematical models to estimate physical quantities that are otherwise difficult or impossible to measure directly. Previously, a number of virtual sensors have been developed to measure refrigerant mass flow rate, power, refrigerant charge, condenser and evaporator fouling etc. across a wide variety of units including variable refrigerant flow multi split heat pumps, split type residential heat pumps and rooftop units.

In a previous work [5], virtual sensors were developed and evaluated for detecting and diagnosing multiple simultaneous faults in vapor compression air conditioning equipment. The sensors were based on physical understanding of the system, cost considerations and heuristics based on experimental data and modeling results. These virtual sensors were evaluated experimentally on different air conditioners.

Considering that the refrigerant charge affects the system performance, a virtual refrigerant charge (VRC) sensor can be used to monitor the system charge for efficient operation. In one previously developed methodology, virtual sensors have been demonstrated that can provide a low cost and relatively accurate estimation of the amount of refrigerant charge contained in RTUs [6]. One particular virtual refrigerant charge (VRC) sensor approach uses four surface-mounted temperature measurements to determine suction superheat, liquid-line subcooling and evaporator inlet quality that are inputs to an empirical model for charge. The empirical parameters of the model are determined using linear regression applied to laboratory data collected from the system.

In another study [7], the VRC sensor was further extended with different approaches for determining the refrigerant charge for equipment with variable speed fans and compressor. This work also developed virtual sensors for refrigerant mass flow measurement, compressor power for variable speed compressor and condenser and evaporator flow rates.

In previous studies, extensive psychrometric chamber testing at different refrigerant charge levels and ambient conditions has been used to obtain sufficient data for determining the empirical parameters of the VRC model. This testing is expensive for equipment manufacturers and it can be difficult to find available test facilities. This, along with additional sensor and instrumentation costs, is a major hurdle for equipment manufacturers looking to incorporate FDD technologies in new equipment.

Vasudevan [8] previously worked on training and evaluation of virtual sensors for RTUs, including a VRC sensor. In that work, a virtual refrigerant charge sensor model was evaluated for a rooftop unit with microchannel condenser and a fixed orifice device. Furthermore, guidelines were established for specifying a minimum set of tests for training the VRC sensor.

Laughman [9] showed through simulation that the refrigerant charge can be used as an additional control variable to enhance the efficiency of a split type vapor compression system. Also, a split system running in heating mode may have a different optimal charge as compared to cooling mode. The work suggests installing a receiver between the liquid line and the evaporator inlet and using two expansion valves to control the level of refrigerant in the tank. This work is relevant to the current study because it presents a method for automatically adjusting refrigerant charge level that could be used for automating the process of generating data for training a VRC sensor and for determining optimal refrigerant charge.

1.2 Objective of the Current Work

Despite the promising results obtained by previous work on FDD, manufacturers have been slow to incorporate FDD technologies for a few reasons:

- FDD systems must be low-cost and easy to install,
- uncertainty with respect to economic benefit/savings potential still exists,
- and lack of integration and interoperability with other building technologies.

In order to address these issues for refrigerant charge faults, previous work has been done to develop and validate a virtual refrigerant charge sensor that uses low-cost measurements. However, collecting data for training the sensor can be costly if psychrometric chamber test facilities are required for testing. To reduce this cost, the primary objective of the current work was to develop and validate an automated methodology for calibrating empirical parameters of the VRC sensor with automated testing performed in an open laboratory space instead of using psychrometric chamber facilities. Accuracy of the VRC sensor tuned using the open laboratory methodology was examined by extensive psychrometric chamber testing at various conditions.

As the automated methodology includes automatic addition and removal of refrigerant charge from the system, a secondary objective was to demonstrate use of automated charging hardware/software as a means of determining optimal refrigerant charge and to study sensitivity of RTU performance to refrigerant charge levels.

1.3 Thesis Organization

This chapter presented some background and objectives for this thesis that is focused on development and use of a virtual refrigerant charge sensor. Chapter 2 starts with a discussion of the VRC sensor model followed by a description of the open laboratory methodology used. Further, the implementation details of the automated training kit are described in this chapter. The experimental goals for this work are split in two parts, which are described in Chapters 3 and 4 and cover the following:

- Automated Training Kit for Virtual Refrigerant Charge Sensor Tuning
- Automated Charging Kit for Refrigerant Charge Optimization

For the automated training kit for VRC sensors, the aim was to develop a low-cost approach for calibrating VRC sensors that would improve the cost effectiveness of embedding them in manufactured units. The training kit was developed and applied to an RTU where the testing occurred in an open laboratory area to collect data for tuning the VRC sensor. Accuracy of the VRC sensor was examined by testing the RTU in psychrometric chambers over a range of operating conditions at various known refrigerant charge levels. Chapter 3 describes the test unit setup and results for VRC accuracy. Chapter 4 describes a modified automated charge variation system that is based on the training kit approach and its application to a different RTU. Results are presented for the effect of charge on performance for a range of different ambient conditions.

Finally, Chapter 5 summarizes the important findings of this work and provides some recommendations for future work.

CHAPTER 2. AUTOMATED VIRTUAL REFRIGERANT CHARGE SENSOR TRAINING KIT

2.1 Virtual Refrigerant Charge Sensor Model

Previous work has shown that the amount of refrigerant charge contained in a system can be estimated using measurements of the compressor suction superheat and liquid-line subcooling. The compressor suction superheat, ΔT_{sh}, is equal to the temperature difference defined by Equation (3.1)

$$\Delta T_{sh} = T_{suc} - T_{eri} \tag{3.1}$$

where T_{suc} is the refrigerant temperature at the compressor inlet (suction) and T_{eri} is the temperature of the refrigerant entering the evaporator (a measure of saturation temperature). The liquid-line subcooling, ΔT_{sc}, is calculated using a similar temperature difference, given by Equation (3.2),

$$\Delta T_{sc} = T_{crs} - T_{cro} \tag{3.2}$$

where T_{crs} is the refrigerant saturation temperature in the condenser and T_{cro} is the refrigerant temperature at the condenser outlet. The amount of refrigerant charge in a DX system relative to the normal amount can be estimated using a virtual refrigerant charge sensor. The functional form of this sensor is given by Equation (3.3)

$$\frac{m_{\text{actual}} - m_{\text{normal}}}{m_{\text{normal}}} = k_{sh}\left(\Delta T_{sh} - \Delta T_{sh,rated}\right) + k_{sc}\left(\Delta T_{sc} - \Delta T_{sc,rated}\right) + k_x\left(x_{eri} - x_{eri,rated}\right) \tag{3.3}$$

where $\Delta T_{sh,rated}$, $\Delta T_{sc,rated}$, and $x_{eri,rated}$ are the superheat, subcooling, and evaporator refrigerant inlet quality of a properly charged system at the rating condition, respectively. Equation (3.3) also requires three empirical parameters: k_{sh}, k_{sc}, k_x.

The correlation defined by Equation (3.3) requires the thermodynamic quality of the refrigerant entering the evaporator. Since it is impossible to measure the thermodynamic quality directly, the use of thermodynamic property relations and a commonly used vapor-compression cycle assumption is used to estimate this quantity. Commonly, the expansion process of the vapor compression cycle is assumed to be isenthalpic; the enthalpy at the inlet and outlet of the expansion valve is constant,

$$h_{cro} = h_{eri}. \tag{3.4}$$

With this assumption, the thermodynamic quality at the evaporator inlet, x_{eri}, can be calculated using thermodynamic property relations if the condenser outlet enthalpy is known and the evaporator inlet temperature is measured,

$$x_{eri} = f(T_{eri}, h_{eri} = h_{cro}). \tag{3.5}$$

To calculate the enthalpy of the enthalpy of the refrigerant exiting the condenser, thermodynamic property relations can be used when nonzero subcooling exists using the outlet temperature and the condenser saturation temperature.

2.2 Open Laboratory Training

In order to reduce the psychrometric chamber testing requirements, an open laboratory testing methodology to determine the empirical parameters of the VRC sensor model was proposed [8]. The methodology involves reducing airflow across each of the heat exchangers in the RTU in order to artificially vary the condensing, evaporating, subcooling and superheat temperatures as depicted in Figure 1. At a given ambient temperature, reducing the airflow across the condenser causes the high-side refrigerant pressure to increase. Similarly, reducing the evaporator airflow causes the low-side refrigerant pressure to decrease. Overall, the effect of reducing the airflow, and manipulating the low- and high-side pressure, changes how the refrigerant charge is distributed in the RTU in a manner that is similar to the effect of changing the ambient conditions. This results in different combinations of superheat, subcooling and evaporator inlet quality that are used as inputs to tune the empirical VRC parameters.

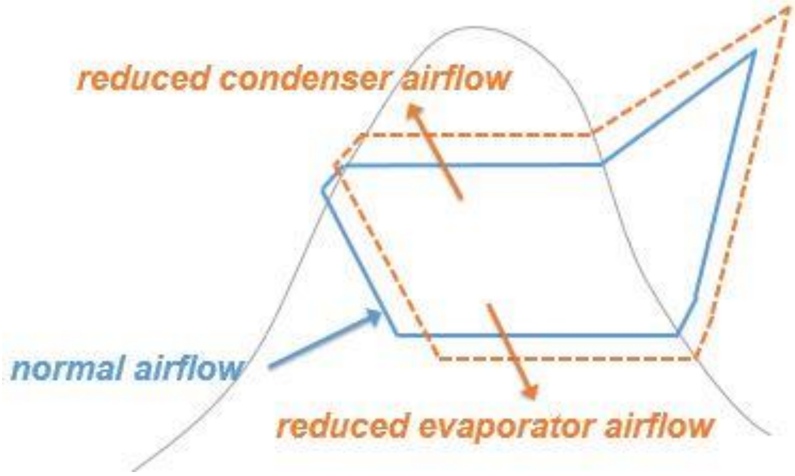


Figure 1: By reducing airflow across the condenser and evaporator coil, the charge distribution in the RTU at different ambient conditions can be simulated in an open laboratory space.

Based on previous testing results, test conditions were selected by determining the optimal fan settings in open laboratory to train a model that minimizes the error using psychrometric chamber data. The charge is incremented in levels of 10%. At each charge level, the evaporator and condenser fans are subject to different combinations of high and low speed settings. At extreme charge levels, more combinations of fan speed settings are tested as compared to intermediate fan levels. Table 1 shows an optimal sequence of tests for one of the RTU configurations. The total number of tests is about 36 and the entire test sequence is expected to finish within 8-12 hours, or approximately 15 minutes per test.

Table 1: Optimal set of test conditions in automated VRC sensor training algorithm.

Test	**Charge Level[1] [%]**	**Compressor Stage [-]**	**Indoor Fan Torque[2] [%]**	**Outdoor Fan Torque[3] [%]**
1	60	LOW	60	70
2	60	LOW	60	40
3	60	LOW	30	40
4	60	LOW	30	70
5	60	HIGH	90	100
6	60	HIGH	90	70
7	60	HIGH	50	70
8	60	HIGH	50	100
9	70	LOW	60	70
10	70	LOW	30	40
11	70	HIGH	90	100
12	70	HIGH	50	70
13	80	LOW	60	70
14	80	LOW	30	40
15	80	HIGH	90	100
16	80	HIGH	50	70
17	90	LOW	60	70
18	90	LOW	30	40
19	90	HIGH	90	100
20	90	HIGH	50	70
21	100	LOW	60	70
22	100	LOW	60	40
23	100	LOW	30	40
24	100	LOW	30	70
25	100	HIGH	90	100
26	100	HIGH	90	70
27	100	HIGH	50	70
28	100	HIGH	50	100
29	110	LOW	60	70
30	110	LOW	30	40
31	110	HIGH	90	100
32	110	HIGH	50	70
33	120	LOW	60	70
34	120	LOW	30	40
35	120	HIGH	90	100
36	120	HIGH	50	70

[1] Charge is measured relative to the recommended charge according to the manufacturer's nameplate data.

[2] Indoor fan torque is set according to a nominal flow rate of 1350 CFM for low stage operation and 2000 CFM for high stage operation.

[3] Outdoor fan torque is set using the manufacturer's default values for low and high stage operation.

2.3 Automated Virtual Refrigerant Charge Sensor Training Kit

While the open laboratory training approach yielded a methodology that eliminated the need for psychrometric chambers, it still required significant human involvement. In the current work, the open lab training methodology was automated through development of a “training kit” that uses hardware and software to reduce human intervention. An overall schematic of the RTU components, the sensor measurements, the control variables, and the information flow of the system design is shown in Figure 2. The hardware selected for the training kit is generally considered to be typical and relatively low-cost when compared to similar data acquisition applications within the HVAC market.

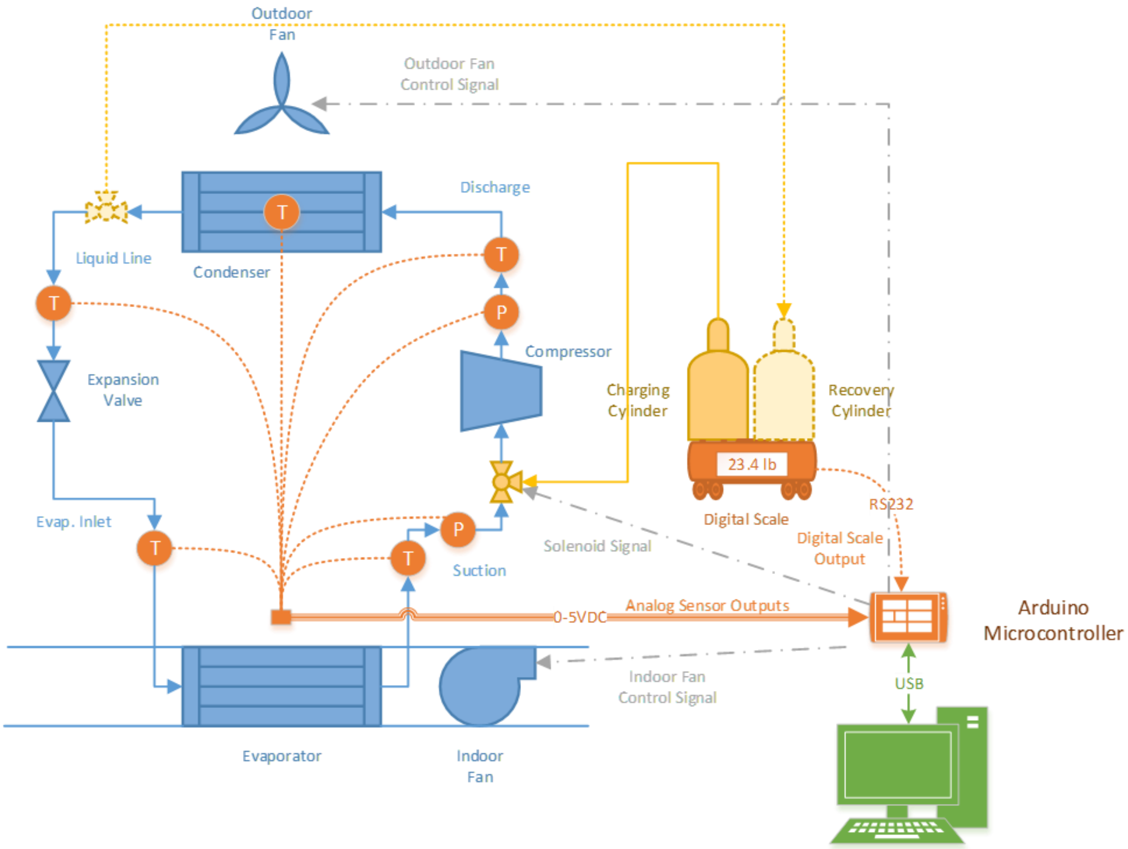


Figure 2: Schematic of automated virtual refrigerant charge sensor training kit.

2.4 Hardware Implementation

An Arduino Mega2560 microcontroller was used to interface with the sensors and control interfaces required to implement the automated training algorithm. Compared to other microcontrollers, the Arduino development environment makes interfacing with sensors and digital outputs relatively easy. To enable this, the Arduino designers have developed an extension of the C++ programming language with built-in functions that can be used to easily read and write to the digital and analog input and outputs found on the microcontroller.

In order to implement the VRC training algorithm, several refrigerant-side temperature and pressure measurements are required. Using these sensors, the empirical parameters used in the VRC sensor can be tuned using the training algorithm. It should also be noted that pressure measurements can be used to calculate the evaporator refrigerant inlet temperature and condenser refrigerant saturation temperature since the refrigerant at these points is a two-phase fluid. Systems that already have these pressure sensors installed for control purposes do not need to install additional temperature sensors which reduces instrumentation costs. Pressure sensors may be required for systems with microchannel condensers since locating a reliable saturation temperature point is not trivial. Table 2 enlists all the necessary measurements for training the virtual refrigerant charge sensor.

Table 2: Description of required refrigerant-side temperature measurements used for training the virtual refrigerant charge sensor.

Symbol	Type	Description
$T_{eri}{}^{1}$	10 kΩ Thermistor	Evaporator Refrigerant Inlet Temperature
T_{suc}	10 kΩ Thermistor	Compressor Refrigerant Suction Temperature
T_{dis}	10 kΩ Thermistor	Compressor Refrigerant Discharge Temperature
$T_{crs}{}^{2}$	10 kΩ Thermistor	Condenser Refrigerant Saturation Temperature
T_{cro}	10 kΩ Thermistor	Condenser Refrigerant Outlet Temperature
P_{suc}	0-300 PSIG Pressure Transducer	Compressor Refrigerant Suction Gauge Pressure
P_{dis}	0-500 PSIG Pressure Transducer	Compressor Refrigerant Discharge Gauge Pressure

[1] The evaporator refrigerant inlet temperature measurement can be replaced by the compressor suction pressure measurement when it is difficult or impossible to measure the evaporator inlet temperature accurately.

[2] The condenser refrigerant saturation temperature measurement can be replaced by the compressor discharge pressure measurement when it is difficult or impossible to measure the condenser saturation temperature accurately (due to a microchannel condenser, for example).

To measure these refrigerant-side temperatures, low-cost thermistor circuits were designed. The thermistors selected for the application have to be surface-mounted to the RTU refrigerant circuit in the locations required. Compared to other types of temperature sensor types (thermocouples, RTDs, etc.) thermistors offer the best combination of accuracy, reliability, and cost. Pressure transducers have also been installed on the system considered in this study to measure the low- and high-side pressures. The high-side pressure is important for the RTU being tested with a microchannel condenser. This makes measuring the condenser saturation temperature nearly impossible or unreliable with surface-mounted temperature sensors.

The hardware implementation also incorporated components used to control the operational mode of the RTU and the control set-points of the indoor fan and outdoor fan. The operational mode of the unit (controlling the system to stand-by, fan-only, low-stage cooling, or high-stage cooling mode) is controlled using three relays. The relays were connected to the G, Y1, Y2 thermostat signals and are sequenced using the software implementation. Conventional control of the indoor and outdoor fans has been overridden using electronically commutated (EC) motor controllers producing a 0-10 VDC pulse-width-modulated output. The duty cycle was controlled via the software implementation for each fan. The motor controlling the indoor fan provides a constant torque output so the PWM output provides the torque set-point of the motor. The outdoor fan was driven by a constant speed motor, thus the PWM output provides the speed setting to the motor.

Refrigerant charge addition was automatically controlled using a suction-side solenoid valve and an electronic weighing scale with a digital output. A relay was used to control the solenoid valve position from the microcontroller using a digital 5 VDC output. When the solenoid is open, refrigerant charge is able to enter the refrigerant circuit of the RTU. The refrigerant charging bottle is placed on the electronic scale in order to measure the mass of refrigerant that has left the cylinder and entered the refrigerant circuit. The personal computer interfaces with the digital output of the scale via a USB serial data connection.

The last component of the automated VRC sensor training kit is a personal computer that is used to run the Python software implementation of the automated training algorithm. A USB serial data connection is used to interface the personal computer and the microcontroller. The software on the personal computer uses logic to determine the control outputs and collects the required sensor outputs used for tuning the empirical VRC parameters.

2.5 Microcontroller Implementation

An implementation of the VRC sensor training algorithm has been created using open-source software packages. As previously noted, the training kit is comprised of one microcontroller and one personal computer each performing different functions. The software embedded on the microcontroller is implemented using the Arduino variant of the C++ programming language. The software used on the personal computer is implemented using the Python programming language. These two systems communicate between one another via a USB data connection.

On the microcontroller side, the software is implemented so that when a control input sequence is received, the following sequence is performed:

1. Receive control input sequence.

The last process performed by the microcontroller is to send the measured sensor values back to the personal computer via USB serial connection. The output string takes the following form:

```
        MODE     IDF     ODF    ADD_CHRG  REM_CHRG
    [   {-},     {%},    {%},     {-},      {-},     ]
```

where

`MODE`: RTU Operating Mode, [-1, 0, 1, 2]

`IDF`: Indoor Fan Torque Setting, [0, 1, …, 100]

`ODF`: Outdoor Fan Speed Setting, [0, 1, …, 100]

`ADD_CHRG`: Low-side Solenoid Valve Position, [0, 1]

`REM_CHRG`: High-side Solenoid Valve Position, [0, 1].

2. Update cooling mode.

This routine is used to set the desired cooling state of the RTU by activating relays connected to the RTU thermostat signal input. There are four possible states:

`-1`: System OFF (`G: 0, Y1: 0, Y2: 0`)

`0`: Fan Only Mode (`G: 1, Y1: 0, Y2: 0`)

`1`: Low Cooling Mode (`G: 1, Y1: 1, Y2: 0`)

`2`: High Cooling Mode (`G: 1, Y1: 1, Y2: 1`).

Each thermostat signal has a dedicated relay with an input controlled by a digital output on the microcontroller.

3. Update fan control set-points.

This routine is used to control the two RTU fans to the desired torque and speed settings. The indoor fan of the RTU is driven by an electronically commutated (EC) motor designed to maintain a constant torque. The outdoor fan of the RTU is driven by an EC motor designed to maintain a constant speed. Both these fan controllers are driven by a pulse-width-modulated (PWM) signal with integer values from 0-100.

4. Update charging valve positions.

The amount of charge in the system is controlled using this routine. Charge is added or removed using two solenoid valves located on the suction line and liquid line of the RTU, respectively. When charge needs to be added, the low-side solenoid valve is set open; when charge needs to be removed, the high-side solenoid valve is set open.

5. Read analog temperature and pressure sensor outputs.

After the system control set-points have been set to the desired values, the microcontroller reads the current outputs of the thermistors and pressure transducers. The thermistors and pressure transducers output an analog voltage so the built-in analog-to-digital converter (ADC) is used to convert these values to digital inputs.

6. Read digital weighing scale output.

The amount of refrigerant that has entered the system is measured using a weighing scale with a digital output (via RS-232 serial connection). This routine receives the current output of the weighing scale.

7. Send updated measurement values via serial connection.

The last process performed by the microcontroller is to send the measured sensor values back to the personal computer via USB serial connection. The output string takes the following form:

```
     ERI_T    SUC_T    DIS_T    CRS_T    CRO_T    SUC_P    DIS_P     CHRG
[    {K},     {K},     {K},     {K},     {K},    {kPa},   {kPa},    {kg},    ]
```

where

`ERI_T`: Evaporator Refrigerant Inlet Temperature, in Kelvin

`SUC_T`: Compressor Refrigerant Suction Temperature, in Kelvin

`DIS_T`: Compressor Refrigerant Discharge Temperature, in Kelvin

`CRS_T`: Condenser Refrigerant Saturation Temperature, in Kelvin

`CRO_T`: Condenser Refrigerant Outlet Temperature, in Kelvin

`SUC_P`: Compressor Refrigerant Suction Pressure, in kilopascals

`DIS_P`: Compressor Refrigerant Discharge Pressure, in kilopascals

`CHRG`: Net mass of refrigerant charge, in kilograms.

This procedure is repeated by the microcontroller indefinitely while the training algorithm is being executed. Whenever the control input message is sent from the training kit algorithm (which is once per second) the procedure on the microcontroller is executed and the measurements are sent back in response.

2.6 Software Implementation

An object-oriented implementation of the VRC sensor training algorithm has been implemented and tested. At a high level, the algorithm controls the state of the RTU to a sequence of tests and collects steady-state data that can be used to tune the empirical parameters used by the VRC sensor.

On initialization, the training algorithm receives some configuration parameters as inputs and sets up some data connections between the microcontroller and SQLite database used to store the sensor measurements. The serial data connection is initialized by designating the port the microcontroller is connected to and setting the baud rate between the devices. The database connection is simply created by specifying a file path. The schema for storing the data is automatically generated by the training kit object on creation.

Also during initialization, the test sequence is loaded from the configuration file. The test sequence is stored as a list where each element is a list of the desired set-points used for each test. These set-points include the refrigerant charge level, the cooling mode, the indoor fan torque setting, and outdoor fan speed setting. As the algorithm progresses, test scenarios are popped off the list until all the scenarios have been exhausted. At this point, the algorithm has finished testing the system and the RTU is shutdown.

After executing the training algorithm, the software transitions from test scenario to test scenario by applying this sequence of steps. First, the system determines whether the current charge level is at the desired set-point value. If the current charge level is not at the set-point level, the system enters a charge adjustment sequence. In this sequence, the low-side and high-side valves are open or closed in order to add or remove charge, respectively. In the initial hardware implementation, only the low-side solenoid valve to add charge was installed. This means that only the addition of charge can be performed, though the logic in the software implementation is the same. This process continues until the charge level reaches the set-point level.

Once the refrigerant charge level has reached the set-point value, the system enters into a steady-state detection state. In this state, the system applies a steady state filter to a fixed length first in, first out (FIFO) buffer of data points. The steady state detector consists of fitting a simple linear regression model to determine the current slope of the sensor measurements in the FIFO buffer. The data contained in this buffer are the sensor outputs and the steady state detector filters each sensor individually. Thus, a total of 8 simple linear regression models are determined and the 8 slope estimations are each compared to a threshold value. When the absolute values of the slopes are less than the threshold, and the variance of each sensor data is lower than another threshold, the data are deemed to be steady-state. When the data are not determined to be steady, the process simply waits for more data to enter the FIFO buffer.

When the samples are determined to be steady, the algorithm enters into the steady-state data collection process. This process simply collects steady state data points for a fixed amount of time in order to be used later in the parameter tuning procedure. Currently, 5 minutes’ worth of data is collected at a sampling interval of 1 second. Once 300 samples have been collected, the algorithm exits the current test scenario and begins the process again for the next test scenario.

CHAPTER 3. EVALUATION OF VRC SENSOR TRAINING KIT

3.1 Rooftop Unit (RTU) Description

In order to test the performance of the automated VRC sensor training algorithm and virtual sensor implementation, a series of tests were performed on a Lennox 5-ton packaged rooftop unit with a SEER rating of 17.0. The rooftop unit also has a dual stage scroll compressor for varying load operations. The outdoor fan and the indoor blower are driven by variable speed direct drive ECM motors. Figure 3 shows the rooftop unit placed inside the psychrometric chambers for testing. This particular model unit comes with alternative options for the condenser and expansion device. We originally received this unit with a microchannel condenser and a thermal expansion valve (TXV). In order to fully evaluate the accuracy of the VRC sensor for different systems, the unit was retrofit and tested with the following combinations of condenser and expansion devices: 1) microchannel condenser and TXV, 2) microchannel condenser and fixed expansion orifice (FXO), 3) finned-tube condenser with FXO, and 4) finned-tube condenser with TXV.

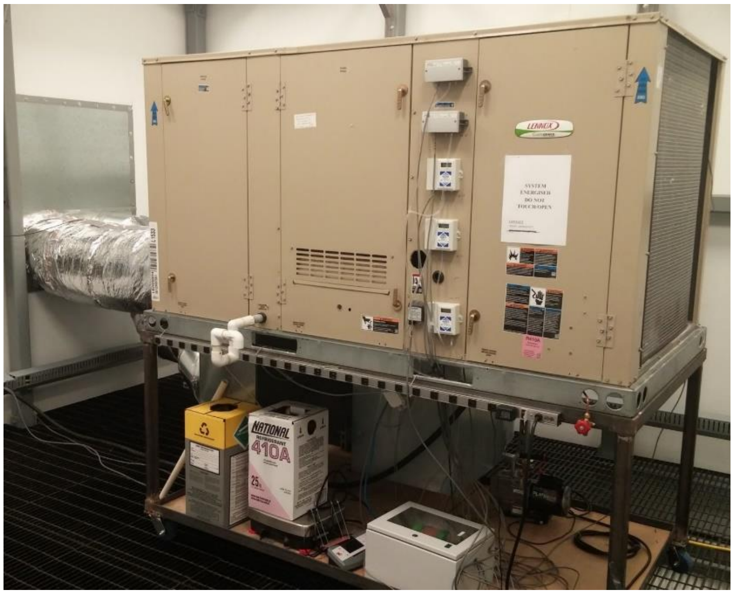


Figure 3: Lennox Rooftop Unit with 2-Stage Operation used for VRC Assessment

Figure 4 shows the setup of the rooftop unit installed in the psychrometric chambers. The room on the left simulates an indoor environment while the right room is the outdoor condition. Both the rooms are controlled to appropriate temperature and humidity depending on the test conditions. The RTU takes in air from indoor room through the return duct, cools it and sends it out the supply duct which is connected to the nozzle box for air measurement and the reconditioning apparatus for the indoor room. This configuration was used for all the psychrometric chamber tests.

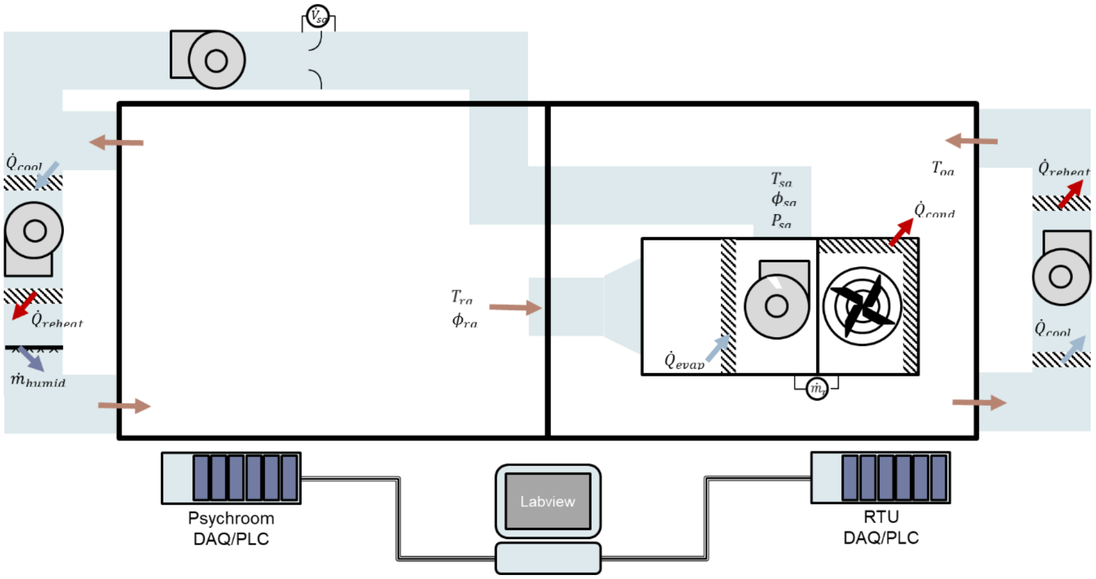


Figure 4: RTU arrangement in the Psychrometric Chambers.

3.2 Overview of RTU Testing

In order to test the performance of the automated VRC sensor training algorithm and virtual sensor implementation, a series of tests were performed on the Lennox 5-ton packaged rooftop unit.

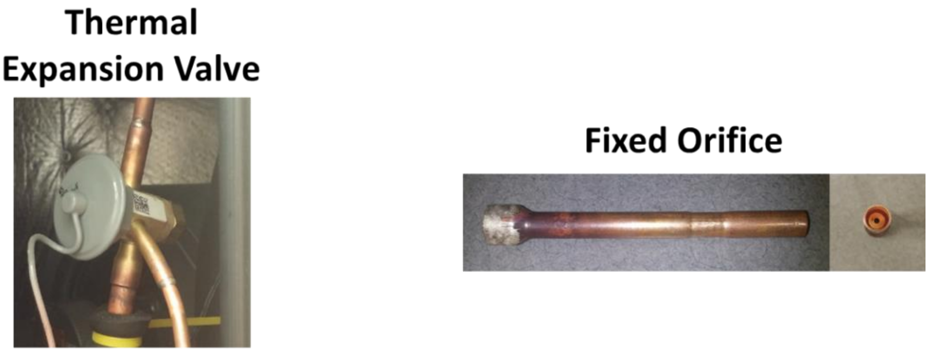
The test plan had two primary considerations in mind: evaluate how well the open laboratory training algorithm tunes the empirical VRC parameters and how well the VRC sensor performs for different types of systems. To do this, combinations of different expansion valves and condenser coils were used in a 5-ton RTU as described in Table 3. Figure 5 shows all the different system components mounted on the rooftop unit over the course of experiments.

Table 3: System configurations and testing environments planned to evaluate automated virtual sensor training algorithm and virtual charge sensor performance.

ID	**Expansion Device**[2]	**Condenser Coil**	**Test Environment**
A2	TXV	Microchannel	Psychrometric Chamber Testing
A1	TXV	Microchannel	Automated Open Lab Training
B1	FXO	Microchannel	Automated Open Lab Training
B2	FXO	Microchannel	Psychrometric Chamber Testing
C1[1]	FXO	Finned-Tube	Automated Open Lab Training
C2	FXO	Finned-Tube	Psychrometric Chamber Testing
D1[1]	TXV	Finned-Tube	Automated Open Lab Training
D2	TXV	Finned-Tube	Psychrometric Chamber Testing

[1] Testing for C1 and D1 was performed inside the psychrometric chambers simulating an open laboratory space. This was done in order to accelerate the tests by not having to remove the RTU from the psychrometric chamber facility once it has been installed.

[2] TXV = thermostatic expansion valve; FXO = fixed orifice expansion device



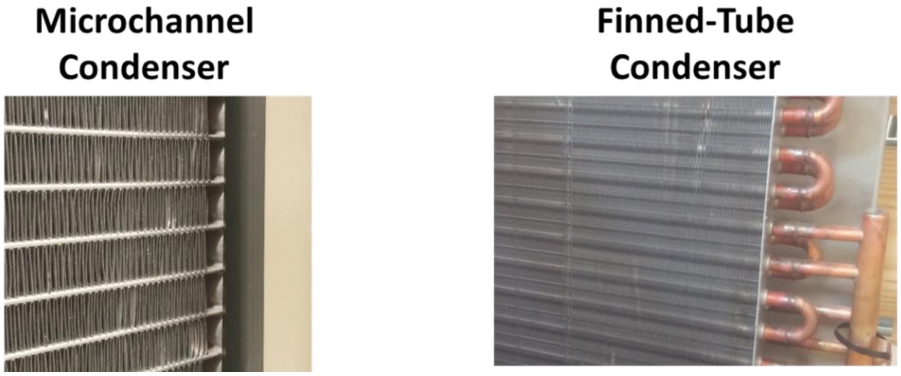


Figure 5: Different components mounted on the rooftop unit during the testing.

3.3 RTU with Microchannel Condenser and Thermostatic Expansion Valve

The first system tested in the psychrometric chamber test facilities was System A (microchannel condenser, thermostatic expansion valve). The empirical parameters of the VRC model were determined using the automated open laboratory training algorithm, as described previously. It should be noted that superheat can either be calculated as a difference between the compressor suction and evaporator inlet temperature or the difference between compressor suction pressure and saturation temperature as calculated from suction pressure. For this unit, superheat was calculated based on the second method. The RTU was then installed in the psychrometric chamber test facilities and was tested for both stages of cooling in order to evaluate VRC accuracy. The test conditions are described in Table 4 for low stage and Table 5 for high stage. Different combinations of charge level, indoor and outdoor fan speeds and outdoor temperatures were tested. The resulting test matrix had over 100 test conditions which provided a large data set for validating the accuracy of VRC sensor. For the psychrometric room testing, the charge level was manually added to the prescribed level .

Table 4: Test conditions for RTU with microchannel condenser and thermostatic expansion valve (System A) for low stage cooling operation in psychrometric test chambers.

Test Variable		Test Values
Compressor Stage	[-]	LOW
Indoor Dry Bulb	[°F]	80
Indoor Wet Bulb	[°F]	67
Outdoor Dry Bulb	[°F]	69, 82, 95
Charge Level[1]	[%]	60, 70, 80, 90, 100, 110, 120
Indoor Fan Torque[2]	[%]	40, 60
Outdoor Fan Torque[3]	[%]	40, 70

[1] Charge is measured relative to the recommended charge according to the manufacturer's nameplate data.
[2] Indoor fan torque is set according to a nominal flow rate of 1350 CFM for low stage operation.
[3] Outdoor fan torque is set using the manufacturer's default value for low stage operation.

Table 5: Test conditions for RTU with microchannel condenser and thermostatic expansion valve (System A) for high stage cooling operation in psychrometric test chambers.

Test Variable		Test Values
Compressor Stage	[-]	HIGH
Indoor Dry Bulb	[°F]	80
Indoor Wet Bulb	[°F]	67
Outdoor Dry Bulb	[°F]	82, 95, 108
Charge Level[1]	[%]	60, 70, 80, 90, 100, 110, 120
Indoor Fan Torque[2]	[%]	60, 90
Outdoor Fan Torque[3]	[%]	70, 100

[1] Charge is measured relative to the recommended charge according to the manufacturer's nameplate data.
[2] Indoor fan torque is set according to a nominal flow rate of 2000 CFM for high stage operation.
[3] Outdoor fan torque is set using the manufacturer's default value for high stage operation.

The resulting accuracy of the VRC sensor models trained in the open laboratory space and applied to the psychrometric chamber test data collected over the range of ambient conditions is shown for both cooling stages in Figure 6. The “training” data refers to the open laboratory results whereas the “testing” data is the psychrometric room evaluation data. The results show that the VRC sensor accuracy is somewhat worse for the low-stage cooling tests than for high-stage cooling operation. This result was observed for the other systems as well. Also, the accuracy is worse at lower charge levels in low stage, even for the training data. This was not the case for high stage cooling operation; the accuracy was relatively the same at all charge levels tested. It should be noted that the root-mean-squared error (RMSE) was less than 10% for both stages of operation. This indicates that the predictions from the VRC sensor could be used as part of an automated FDD system with relative confidence.

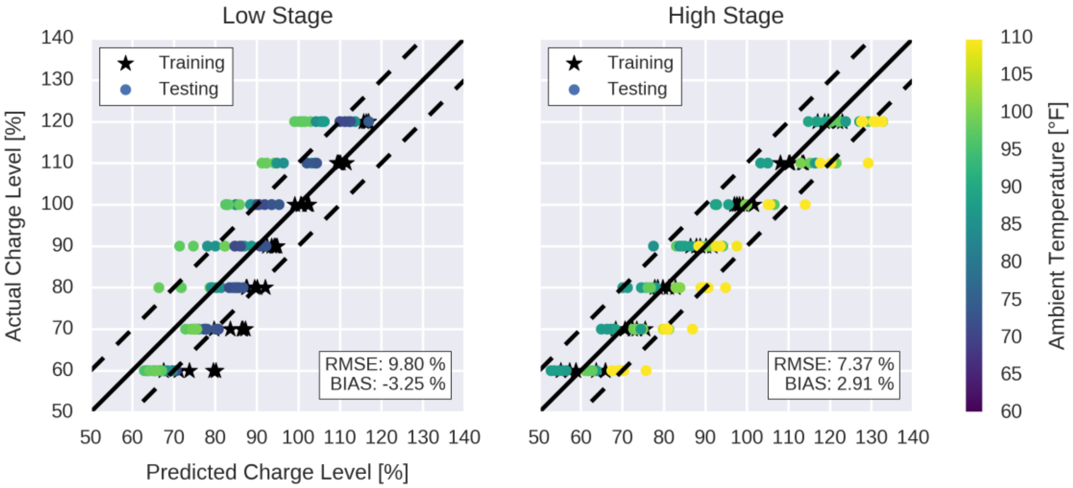


Figure 6: VRC sensor prediction accuracy for RTU with microchannel condenser and thermostatic expansion valve (System A) applied to both stages of operation under different ambient conditions.

3.4 RTU with Microchannel Condenser and Fixed Orifice

After the completion of testing and evaluating the data collected from System A, the thermostatic expansion valve (TXV) was replaced by a fixed orifice expansion device. The orifice size and design was selected with the help of the original equipment manufacturer to ensure that the performance of the unit was representative of actual units. After the replacement of the expansion device, the RTU was referenced as System B.

The automated open laboratory training kit was applied to System B in an open laboratory space in order to collect data used to determine the empirical parameters of the VRC sensor model. Superheat used for the VRC sensor for this unit was calculated as a difference between compressor suction and evaporator inlet temperature. At the conclusion of this process, the RTU was installed in the psychrometric chambers and tested over a range of ambient conditions. The test conditions for low-stage and high-stage operation are described in Table 6 and Table 7 respectively. These conditions were similar to those tested for System A, but extended to include a high temperature condition during low stage operation and a cool temperature condition during high stage operation.

Table 6: Test conditions for RTU with microchannel condenser and fixed orifice expansion device (System B) for low stage cooling operation in psychrometric test chambers.

Test Variable		Test Values
Compressor Stage	[-]	LOW
Indoor Dry Bulb	[°F]	80
Indoor Wet Bulb	[°F]	67
Outdoor Dry Bulb	[°F]	69, 82, 95, 108
Charge Level[1]	[%]	60, 70, 80, 90, 100, 110, 120
Indoor Fan Torque[2]	[%]	40, 60
Outdoor Fan Torque[3]	[%]	40, 70

[1] Charge is measured relative to the recommended charge according to the manufacturer's nameplate data.
[2] Indoor fan torque is set according to a nominal flow rate of 1350 CFM for low stage operation.
[3] Outdoor fan torque is set using the manufacturer's default value for low stage operation.

Table 7: Test conditions for RTU with microchannel condenser and fixed orifice expansion device (System B) for high stage cooling operation in psychrometric test chambers

Test Variable		Test Values
Compressor Stage	[-]	HIGH
Indoor Dry Bulb	[°F]	80
Indoor Wet Bulb	[°F]	67
Outdoor Dry Bulb	[°F]	69, 82, 95, 108
Charge Level[1]	[%]	60, 70, 80, 90, 100, 110, 120
Indoor Fan Torque[2]	[%]	60, 90
Outdoor Fan Torque[3]	[%]	70, 100

[1] Charge is measured relative to the recommended charge according to the manufacturer's nameplate data.
[2] Indoor fan torque is set according to a nominal flow rate of 2000 CFM for high stage operation.
[3] Outdoor fan torque is set using the manufacturer's default value for high stage operation.

The accuracy of the VRC sensor models for System B trained using open laboratory data and applied to the psychrometric chamber test data collected over the range of ambient conditions is shown for both cooling stages in Figure 7. Again, the low-stage cooling tests were less accurate than during high-stage cooling operation. This is especially true when the amount of refrigerant charge contained was above 90%. After analysis of the experimental data, it was determined that for these cases, the system operated with zero superheat or subcooling. One explanation for this is the diameter of the fixed orifice was too large for the low-stage operation. This is understandable since the orifice must be designed for the high stage operation in order to maximize design point performance. Because there was no superheat or subcooling for these data points, the VRC model must rely entirely on the evaporator refrigerant quality term (which is essentially a function of condensing pressure). With this in mind, the performance of the VRC sensor is rather respectable considering the system performance information available. The RMSE error for the low stage operation was on par with the results obtained for System A. The accuracy during high stage operation was actually better than System A at 6.68%.

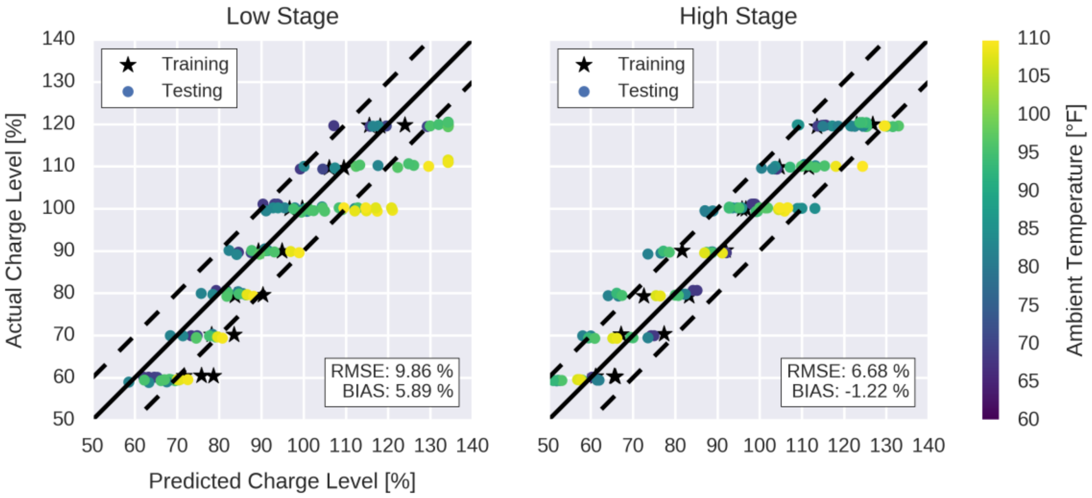


Figure 7: VRC sensor prediction accuracy for RTU with microchannel condenser and fixed orifice expansion device (System B) applied to both stages of operation under different ambient conditions.

3.5 RTU with Finned Tube Condenser and Fixed Orifice

Following the testing and evaluation of the data collected from System B, the microchannel condenser coil originally installed on the unit was replaced by a finned tube condenser coil. The new coil was received from the original equipment manufacturer. This coil was designed for the RTU and can be ordered as a lower efficiency option. After the replacement of the condenser coil, the RTU was referenced as System C.

Because the system was already installed in the psychrometric chambers at this point, the open laboratory training kit was applied with the system installed in the psychrometric chambers rather than the open laboratory space. Open laboratory space conditions were simulated by controlling the air entering the evaporator and condenser coils to be equal at typical indoor conditions. One advantage of this was that the environmental conditions used to train the VRC sensor could be analyzed and its impact on the accuracy of the VRC model assessed. For this system, the superheat is calculated as the difference between compressor suction temperature and the saturation temperature at compressor suction pressure.

Following the training tests, System C was tested in the psychrometric chambers over a wide range of ambient conditions. The conditions tested for low and high stage operation are described Table 8 and Table 9 in respectively. These test conditions were expanded from System B, including testing at both wet and dry coil conditions for a subset of tests.

Table 8: Test conditions for RTU with finned tube condenser and fixed orifice expansion device (System C) for low stage cooling operation in psychrometric test chambers.

Test Variable		**Test Values**
Compressor Stage	[-]	LOW
Indoor Dry Bulb	[°F]	80
Indoor Wet Bulb	[°F]	57, 67
Outdoor Dry Bulb	[°F]	67, 82, 95, 108
Charge Level[1]	[%]	60, 70, 80, 90, 100, 110, 120
Indoor Fan Torque[2]	[%]	30, 60
Outdoor Fan Torque[3]	[%]	40, 70

[1] Charge is measured relative to the recommended charge according to the manufacturer's nameplate data.
[2] Indoor fan torque is set according to a nominal flow rate of 1350 CFM for low stage operation.
[3] Outdoor fan torque is set using the manufacturer's default value for low stage operation.

Table 9: Test conditions for RTU with finned tube condenser and fixed orifice expansion device (System C) for high stage cooling operation in psychrometric test chambers.

Test Variable		**Test Values**
Compressor Stage	[-]	HIGH
Indoor Dry Bulb	[°F]	80
Indoor Wet Bulb	[°F]	57, 67
Outdoor Dry Bulb	[°F]	69, 82, 95, 108
Charge Level[1]	[%]	60, 70, 80, 90, 100, 110, 120
Indoor Fan Torque[2]	[%]	50, 90
Outdoor Fan Torque[3]	[%]	70, 100

[1] Charge is measured relative to the recommended charge according to the manufacturer's nameplate data.
[2] Indoor fan torque is set according to a nominal flow rate of 2000 CFM for high stage operation.
[3] Outdoor fan torque is set using the manufacturer's default value for high stage operation.

The accuracy of the VRC model designed for System C for each stage of operation is shown in Figure 8 over the range of ambient conditions tested. The performance of the VRC sensor applied to System C was better than System A or System B. In both stages of operation, the RMSE was approximately 6.20%. Additionally, the accuracy observed over the range of charge levels was relatively constant. The better accuracy of the VRC sensor for the RTU with a finned-tube condenser may be due to the fact that the refrigerant charge is significantly greater for finned-tube than microchannel heat exchangers. As a result, the sensitivity of RTU performance (including subcooling and superheat) is greater for systems with microchannel than finned-tube heat exchangers.

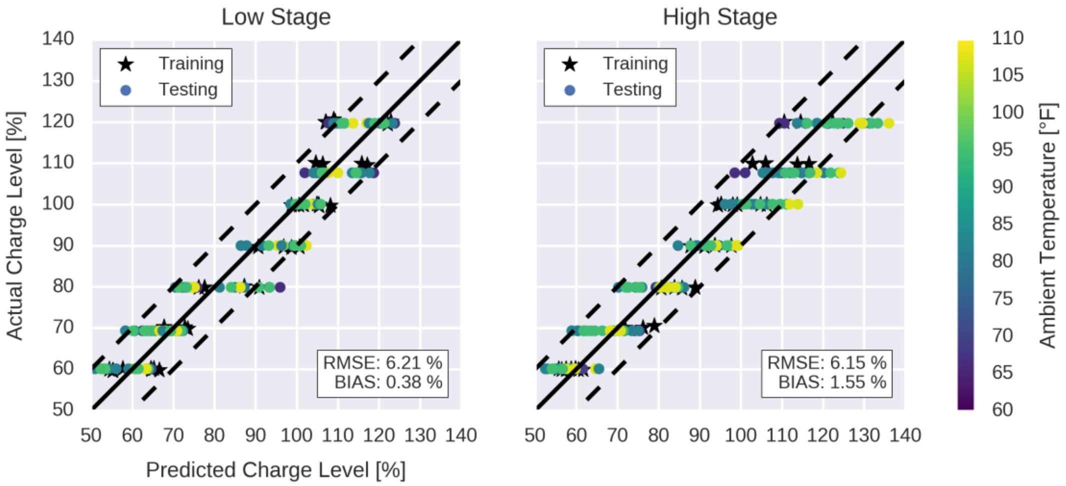


Figure 8: VRC sensor prediction accuracy for RTU with finned tube condenser and fixed orifice expansion device (System C) applied to both stages of operation under different ambient conditions.

3.6 RTU with Finned Tube Condenser and Thermostatic Expansion Valve

After testing and evaluating the data for System C, the fixed orifice valve was replaced by a thermostatic expansion valve (TXV) and referenced as System D.

Again, as the unit was already inside the Psychrometric chamber, open laboratory space conditions were simulated by controlling the air entering the evaporator and condenser coils to be equal at typical indoor conditions. For VRC sensor, the superheat is calculated as the difference between compressor suction temperature and the saturation temperature at compressor suction pressure.

After the training, System D was tested and data was collected at all conditions similar to those of System C. Table 10 and Table 11 summarize all the test conditions for System D which includes dry-coil as well as wet-coil conditions.

Table 10: Test conditions for RTU with finned tube condenser and thermal expansion valve (System D) for low stage cooling operation in psychrometric test chambers.

Test Variable		**Test Values**
Compressor Stage	[-]	LOW
Indoor Dry Bulb	[°F]	80
Indoor Wet Bulb	[°F]	57, 67
Outdoor Dry Bulb	[°F]	67, 82, 95, 108
Charge Level[1]	[%]	60, 70, 80, 90, 100, 110, 120
Indoor Fan Torque[2]	[%]	30, 60
Outdoor Fan Torque[3]	[%]	40, 70

[1] Charge is measured relative to the recommended charge according to the manufacturer’s nameplate data.

[2] Indoor fan torque is set according to a nominal flow rate of 1350 CFM for low stage operation.

[3] Outdoor fan torque is set using the manufacturer’s default value for low stage operation.

Table 11: Test conditions for RTU with finned tube condenser and thermal expansion valve (System D) for high stage cooling operation in psychrometric test chambers.

Test Variable		**Test Values**
Compressor Stage	[-]	HIGH
Indoor Dry Bulb	[°F]	80
Indoor Wet Bulb	[°F]	57, 67
Outdoor Dry Bulb	[°F]	69, 82, 95, 108
Charge Level[1]	[%]	60, 70, 80, 90, 100, 110, 120
Indoor Fan Torque[2]	[%]	50, 90
Outdoor Fan Torque[3]	[%]	70, 100

[1] Charge is measured relative to the recommended charge according to the manufacturer’s nameplate data.

[2] Indoor fan torque is set according to a nominal flow rate of 2000 CFM for high stage operation.

[3] Outdoor fan torque is set using the manufacturer’s default value for high stage operation.

The accuracy of the VRC model designed for System D for each stage of operation is shown in Figure 9 over the range of ambient conditions tested. The RMSE was approximately 6.66% for low stage operation, while for the high stage it was around 5.71%. Again, the performance of the VRC sensor for the RTU with a finned-tube condenser is significantly better than for the RTU with a microchannel condenser.

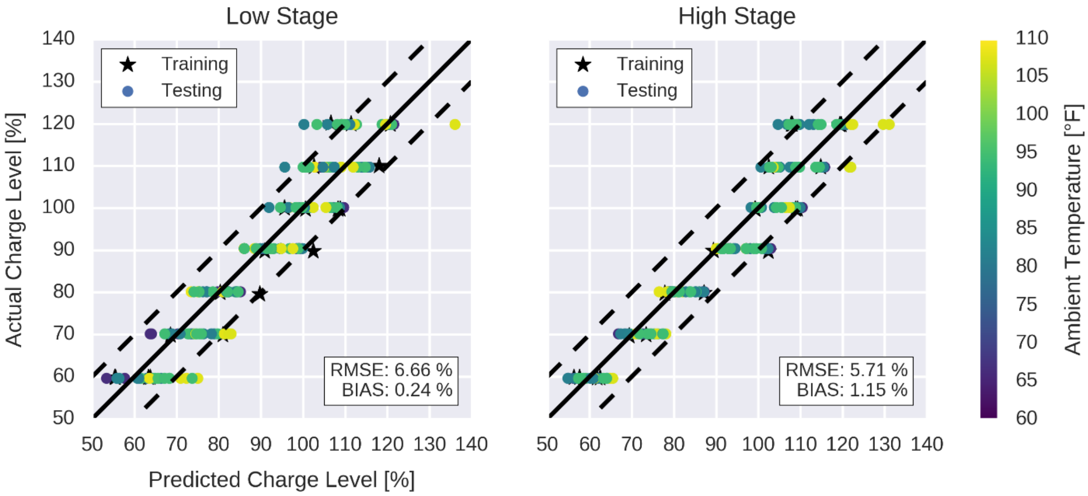


Figure 9: VRC sensor prediction accuracy for RTU with finned tube condenser and thermostatic expansion valve (System D) applied to both stages of operation under different ambient conditions.

3.7 Discussion

The accuracy of the VRC models developed for the four systems tested are shown together in Table 12. For all systems, both the RMSE at each stage and the overall accuracy is better than 10%. For the microchannel units, the VRC sensor is less accurate during low stage operation. For these systems, the subcooling was very sensitive to the charge level. This often led to zero subcooling at many test conditions. Furthermore, when these systems were overcharged, superheat was driven to zero. This made estimating the refrigerant charge level more difficult using the proposed model. The results also show that the open laboratory training algorithm provides experimental data that can be used to design VRC models without extensive testing in psychrometric chamber test facilities.

Table 12: Summary of the prediction accuracy of the VRC sensor applied to different systems.

				RMSE (%)	
System	**Expansion Device**	**Condenser Coil**	**Low Stage**	**High Stage**	**Overall**
A	TXV	Microchannel	9.80	7.37	8.56
B	FXO	Microchannel	9.86	6.68	8.27
C	FXO	Finned-Tube	6.21	6.15	6.18
D	TXV	Finned-Tube	6.66	5.71	6.19

3.8 Uncertainty analysis

For the VRC sensor, the three main quantities of superheat, subcooling and evaporator inlet quality are not measured directly but are the results of functional relationships among other directly measured quantities. Thus, the uncertainty temperature and pressure measurements which are directly measured using sensors will influence the uncertainty of these derived quantities and ultimately on the estimated value of refrigerant charge. The temperature sensors have an accuracy of ±0.5 °C. Pressure sensors have an accuracy within ±0.25 %. An uncertainty propagation was performed in EES and Table 13 below shows the average uncertainties associated with the derived quantities.

Table 13: Uncertainties of derived quantities.

Derived quantity	Uncertainty
Condenser outlet subcooling	±0.51 °C
Suction superheat (Difference between compressor suction and evaporator inlet temperature)	±0.707 °C
Suction superheat (Difference between suction temperature and saturation temperature for compressor suction pressure)	±0.51 °C
Evaporator Inlet quality	±0.004
Predicted refrigerant charge (System A low stage)	±0.194 lb
Predicted refrigerant charge (System A high stage)	±0.303 lb
Predicted refrigerant charge (System B low stage)	±0.201 lb
Predicted refrigerant charge (System B high stage)	±0.150 lb
Predicted refrigerant charge (System C low stage)	±0.251 lb
Predicted refrigerant charge (System C high stage)	±0.495lb
Predicted refrigerant charge (System D low stage)	±0.469 lb
Predicted refrigerant charge (System D high stage)	±0.289 lb

3.9 Cost benefits

While it is important to show that automated open laboratory VRC sensor training methodology it is important to show that automated open laboratory VRC sensor training methodology can be used develop accurate models, the savings in both time and development cost are significant as well. Table 14 shows a comparison between the testing requirements and estimated costs for training the VRC sensor using psychrometric chambers and with the automated open laboratory methodology. In previous studies, psychrometric chambers were used to collect data representing different operational states and ambient conditions for RTUs at different charge levels. To do this, approximately 110 test combinations were used lasting about 160 total hours. It is estimated that this testing could be performed by a third-party laboratory ratings agency, costing $1,100 USD per 8-hour shift. Therefore, the total cost of testing the RTU to determine the empirical parameters of the VRC sensor is approximately $22,000 USD.

In comparison, the automated open laboratory system was able to reduce the total test combinations from 110 to 34. Moreover, control of the ambient conditions was no longer needed, eliminating the need for psychrometric chambers. The total time requirement to complete the entire VRC sensor training was approximately 14 hours, or approximately two 8-hour shifts. Using the same facility and labor costs, the total cost to train the VRC sensor using the automated system is approximately $2,200 USD. The true cost could be even less since the same facility and labor cost for both training methodologies was used in the calculation. Using the automated open laboratory methodology, facility costs should be greatly reduced since psychrometric chambers are not needed. Labor costs should be reduced as well since the system is automated and little human labor is required once the system is installed and configured on the RTU.

Table 14: Comparison of testing requirements and cost of the traditional methodology using psychrometric chambers and the automated open-laboratory methodology to tune the empirical parameters of the VRC sensor.

	Psychrometric Chamber Methodology	**Automated Open Laboratory Methodology**
Total Test Combinations	110	34
Test Variables	• Charge Level • Indoor Fan Speed • Compressor Stage • Ambient Temperature	• Charge Level • Indoor Fan Speed • Outdoor Fan Speed • Compressor Stage
Approximate Test Duration	160 hours (4 weeks, 8 hours/day)	14 hours
Approximate Training Cost	$22,000 USD	$2,200 USD

CHAPTER 4. REFRIGERANT CHARGE OPTIMIZATION

4.1 Rooftop Unit (RTU) Description

For automated charge optimization, a very similar but more advanced RTU from Lennox was used that is shown in Figure 10. The second RTU had a rated capacity of 5 ton and a SEER rating of 20.0. This unit features a variable speed compressor instead of a staged compressor. The unit can be operated in single stage mode, staged mode or in variable mode unit depending on the controller settings. When the controller is set to a wired thermostat mode, the indoor fan, low stage and high stage of cooling can be enabled by activating the G, Y1 and Y2 terminals on the RTU respectively. Figure 10 shows the RTU installed in the psychrometric chambers. All the testing for charge optimization was done by setting the unit to a wired thermostat mode and running the system as a fixed speed system wherein the compressor and the indoor blower run at full capacity.

Figure 10: Lennox Rooftop Unit with Variable Speed Operation used for Charge Optimization.

4.2 RTU Instrumentation

The rooftop unit was instrumented on the refrigerant side as well the air side for all the measurements. The following subsections describe the sensors used.

4.2.1 Refrigerant Side Temperature Measurement

T-type thermocouples with an accuracy of ±0.5 °C from Omega Engineering were used for all the temperature measurements. The thermocouples were mounted on the surface of the refrigerant tubes and insulated with foam tape. Temperature was measured at the following locations –

- Compressor Suction
- Compressor Discharge

- Condenser Outlet
- Liquid Line Outlet (TXV Inlet)
- Evaporator Inlet
- Evaporator Outlet

4.2.2 Refrigerant Side Pressure Measurement

Honeywell pressure transducers with voltage output were used for measuring refrigerant side pressures. These sensors had an accuracy of ±0.25% of the full-scale reading. Refrigerant pressure was measured at the following locations –

- Compressor Suction
- Compressor Discharge
- Condenser Outlet
- Liquid Line Outlet

A Setra M206 pressure sensor was installed later to monitor pressure of the refrigerant tank.

4.2.3 Refrigerant Mass Flow Measurement

A Coriolis mass flow meter from Micromotion with an accuracy of ±0.5% of the reading was used to measure the refrigerant mass flow rate. The mass flow meter was installed after the condenser outlet and before the inlet of the expansion valve.

4.2.4 Air Side Temperature Measurement

T-type thermocouples with an accuracy of ±0.5 °C from Omega Engineering were used for all the temperature measurements. For return air and supply air temperature measurements, a two-by-two grid was spaced equally in a rectangular grid before the evaporator and after the supply fan respectively. This RTU has an L-shaped rectangular condenser and 8 thermocouples were mounted in a four-by-two grid on the face of the condenser. These thermocouples were spaced equally horizontally as well as vertically.

The condenser fan discharges the air through a circular opening on top of the RTU. Four thermocouples were mounted on the condenser outlet in a radially symmetric manner. For every air stream, data was collected from all the thermocouples of the grid and an average value was used in all the calculations.

4.2.5 Air Side Pressure Measurement

Differential air pressure transducers from Setra (model M260) were used to measure the static pressure of the return air, supply air and the differential pressure across the RTU. These sensors have an accuracy of ±1.0 % of the full-scale reading.

4.2.6 Humidity Measurement

For return air as well as supply air, relative humidity and the dew point were measured. Relative humidity was measured using Vaisala HMD112 probes with an accuracy of ±2.0 %. To measure the relative humidity, the probe was inserted at locations with good airflow in the return and supply air streams. Dew point temperature was measured using a General Eastern dew point hygrometer with chilled mirror probe. The rated accuracy for dew point measurement is ±0.15 °C. Air pumps were used to sample small amounts air out of both the air streams for dew point temperature measurements.

4.2.7 Electrical Power Measurement

Electrical power consumption was monitored for the compressor, indoor blower and the condenser fan by means of Ohio Semitronics AC Watt transducers. These transducers have an accuracy of ±0.5 % of the full-scale reading. Thus, based on the individual full-scale readings, the accuracies were ±40 W, ±15 W and ±5 W respectively for the compressor power, indoor fan power and the condenser fan power.

4.2.8 Airflow Measurement (BACnet)

The RTU had an option of using BACnet (A Data Communication Protocol for Building Automation and Control Networks) to communicate with a personal computer. Airflow of the air stream across the evaporator was available from the RTU via this communication.

4.2.9 Data Acquisition System

CompactRIO (NI-cRIO 9024), a real-time controller from National Instruments was used for data acquisition and control. Besides the thermocouple input and the analog input modules, analog and digital output modules were also used to provide control outputs for controlling the RTU. A relay output module was used to control the G, Y1 and Y2 terminals for controlling the staging of the RTU. Digital output module was used to control solenoid valves. Table 15 lists all the National Instruments modules used while testing.

Table 15: National Instruments Modules.

National Instruments Module	Functionality
NI 9213	16-channel thermocouple input
.NI 9205	16-channel differential analog input
NI 9482	4-channel SPST relay output
NI 9474	8-channel digital output

4.3 Automated Refrigerant Charging/Discharging

The approach described in Chapter 2 for automated refrigerant charging was modified to accommodate both charging and discharging. In addition, control of refrigerant charge was accomplished using the CompactRIO system rather than the Arduino system presented in Chapter 2. Figure 11 shows a schematic of the automated charging/discharging apparatus. Solenoid valves are installed at the compressor suction and the liquid line. The valves open and close to let refrigerant into or out of the system from or to a refrigerant tank. Check valves are installed to avoid any backflow. The refrigerant tank is placed on a digital weighing scale from Ohaus Ranger that has an accuracy of ±0.001 lb. Output from the digital scale is an input to the controller and the controller opens/closes the solenoid valves to adjust the charge in response to a charge setpoint. Initially, the RTU is evacuated. By starting with a known mass of refrigerant in the tank and continuously monitoring the change in the weighing scale reading, charge inside the RTU is determined. Finally, a pressure sensor continuously monitors pressure of the refrigerant tank.

When the RTU charge setpoint is increased, the suction side solenoid valve opens and liquid refrigerant from the bottom of the tank is fed to the compressor suction. A manual valve is installed in the refrigerant supply line and adjusted in order to ensure a low refrigerant flow rate to avoid liquid entering the compressor. Similarly, in order to remove refrigerant from the RTU, the liquid line solenoid valve is opened and high-pressure liquid refrigerant discharges into the refrigerant tank. The valves close automatically when the setpoint is reached. Since the working fluid for this demonstration was R410A which is a two-component mixture, it was necessary to deal with liquid refrigerant while charging and discharging to avoid any change in composition of the refrigerant.

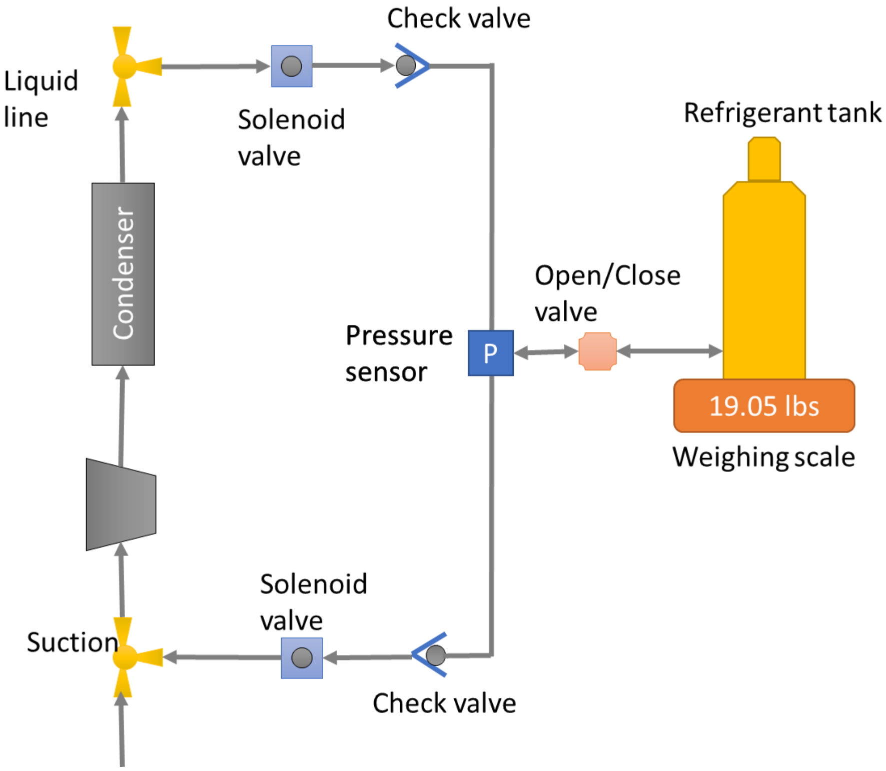


Figure 11: Schematic of the automated charging/discharging apparatus.

4.4 Charge Optimization Testing

As discussed in Chapter 1, the amount of refrigerant in the system can have a significant impact on the performance of vapor compression equipment. As the charge is increased, power consumption of the compressor is increased. At the same time, the condenser exit subcooling increases. Higher subcooling causes a higher refrigerant quality at the evaporator inlet which should contribute to an increase in the cooling capacity. On increasing the charge further, the evaporator exit superheat should decrease and thus, the thermal expansion valve should reduce its opening and thus, reduce the mass flow rate of the refrigerant. These two opposing factors indicate that there must be an optimal for capacity. Similarly, there will be another optimal point for COP which may or may not be the same as that for capacity. With this hypothesis, the RTU was tested as a fixed speed unit at different ambient conditions and charge levels. Refrigerant charge was adjusted using the automated charging/discharging apparatus. Table 16 shows the different test conditions at which the RTU was tested.

Table 16: Test conditions for charge optimization.

Test Condition	**Indoor Drybulb Temperature [°F]**	**Indoor Wetbulb Temperature [°F]**	**Outdoor Drybulb Temperature [°F]**	**Coil Condition**
A	80	56	82	Dry
B	80	56	95	Dry
C	80	56	104	Dry
D	80	67	95	Wet
E	70	50	95	Dry

Figure 12 shows variation of COP with charge level across different ambient conditions. Figure 13 shows the same results normalized to maximum COP at each ambient condition. From these results, it can be seen that there is an optimal for COP around 14-16 lbs. However, the region around the maximum is relatively flat. The COP drops as the charge is increased, mainly due to an increase in the compressor power consumption.

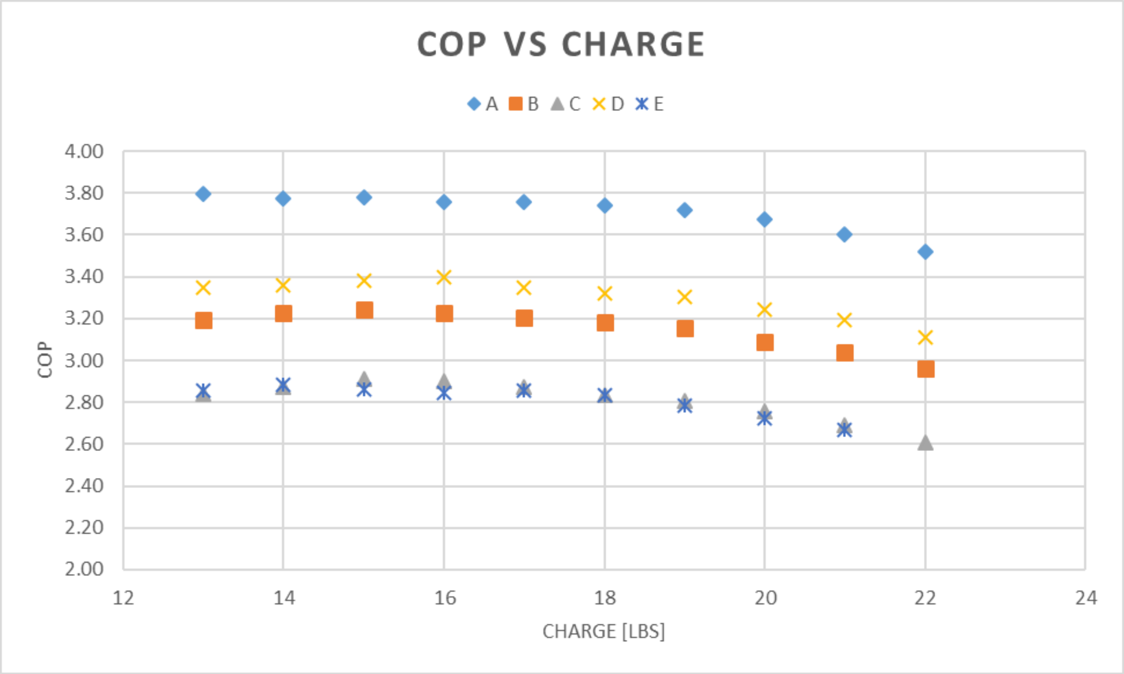


Figure 12: Variation of COP with refrigerant charge for different ambient test conditions.

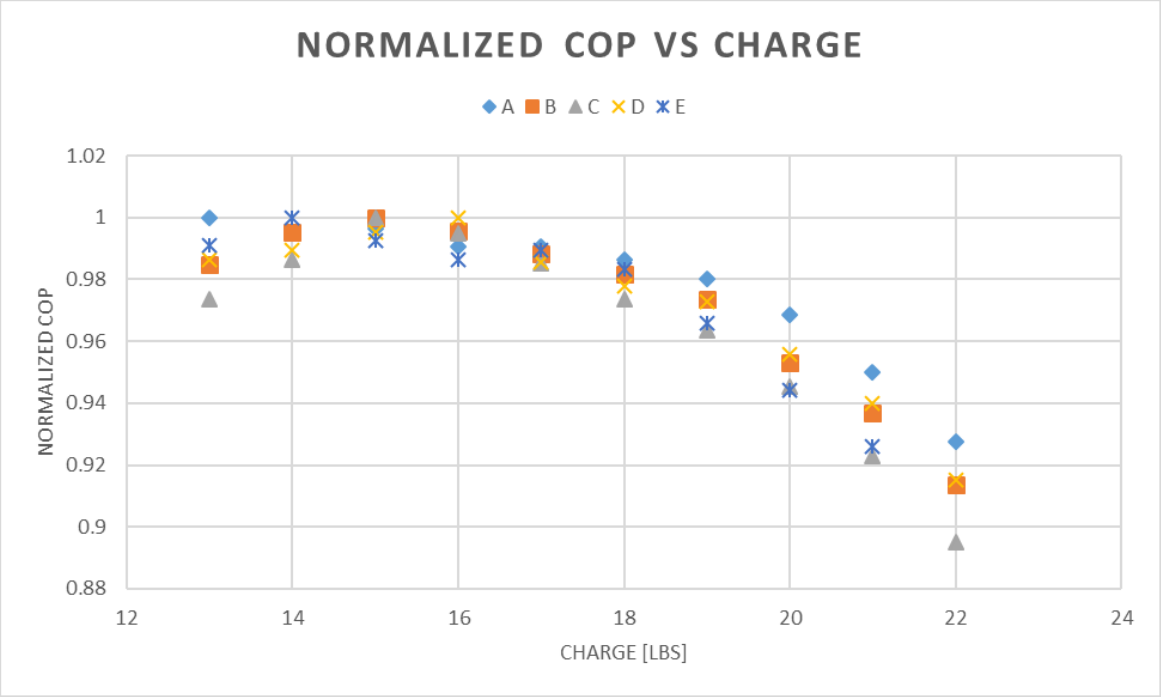


Figure 13: Variation of normalized COP with refrigerant charge at different ambient test conditions.

Figure 14 shows variation of cooling capacity with charge level at different ambient conditions. Figure 1Figure 15shows the same cooling capacity normalized to the maximum at each ambient test condition. From this plot, it can be seen that the cooling capacity first increases with increasing charge levels and tends to fall on further charge addition, indicating the presence of an optimal around higher charge levels. More charge was not added beyond 22 lbs to avoid reaching extreme pressures. Like COP, the cooling capacity does not vary significantly over the charge level variation near the optimum. In this case, the optimum occurs at a somewhat larger charge of 18 lbs compare to the optimal charge for COP.

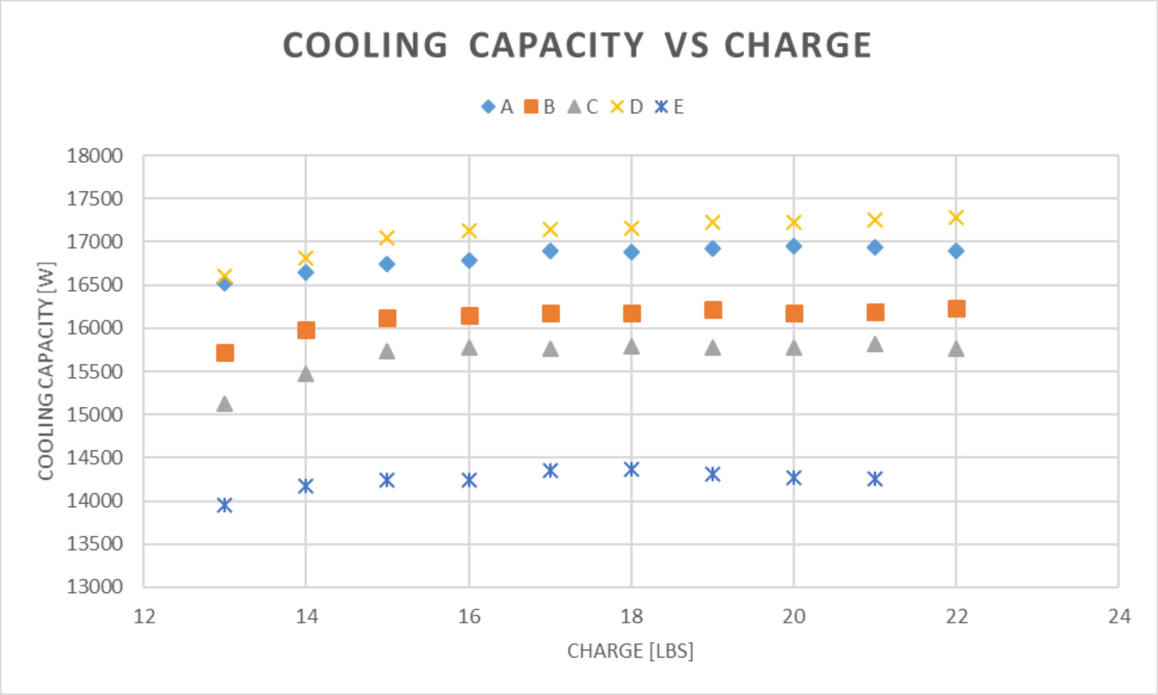


Figure 14: Variation of cooling capacity with refrigerant charge at different ambient test conditions.

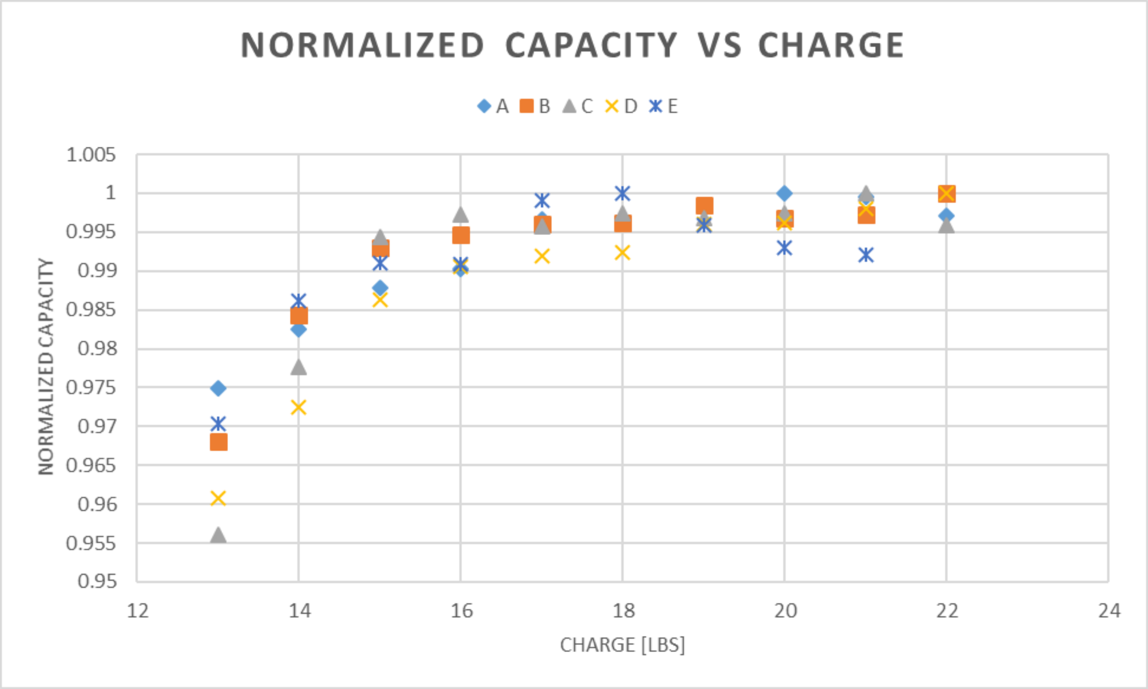


Figure 15: Variation of normalized cooling capacity with refrigerant charge at different ambient test conditions.

CHAPTER 5. SUMMARY AND RECOMMENDATIONS

5.1 Summary

A methodology and system have been implemented for rooftop units to automatically tune the empirical parameters of a virtual sensor for estimating the amount of refrigerant in a system. This system reduces engineering time and costs associated with the virtual sensor by reducing the number of tests required for training and eliminating the need for use of a psychrometric chamber test facility and testing the system in an open laboratory space instead. In order to assess the accuracy of this methodology, the system was applied to four different RTUs (with varying types of components) to tune the model. This model was then compared with data collected for the units collected using psychrometric chamber test facilities over a wide range of ambient conditions. The results showed that the virtual refrigerant charge sensor performed better with a finned tube condenser as compared to a microchannel condenser. This was mainly due to zero subcooling at low charge conditions and zero superheat at higher charge levels. However, the overall accuracy of each of the virtual refrigerant charge sensor models still had root-mean-square errors less than 10%. This shows that the automated open laboratory training system results in accurate sensors for many types of RTUs. In addition, it was found that the time and cost associated with training a VRC sensor using the automated approach can be reduced by about a factor of 10.

The automated training kit was further extended to have the functionality of removing charge from a running system. With this apparatus, a RTU was tested at different charge levels and ambient conditions to study the impact of refrigerant charge on the unit performance. The results show that there exists an optimal charge level for COP as well as cooling capacity which varies with ambient conditions. However, the variation in COP or cooling capacity around the optimal is not significant for cooling-only RTUs, providing little value to the ability to modulate refrigerant charge while the unit is running. However, this system could still be useful for one-time optimization of refrigerant charge for new unit designs or possibly for online charge variation in heat pumps.

5.2 Recommendations

After analyzing the data, it was observed that the VRC sensor tends to be less accurate when applied to systems with microchannel condensers. This is most likely caused by the much smaller condenser volume in comparison to systems with conventional finned tube condensers leading to greater sensitivity of performance to charge. The systems that were tested with microchannel condensers tended to have lower levels of subcooling as well, especially for low charge levels. Since subcooling is an essential input to the VRC sensor, accurate prediction of charge levels is much more difficult when subcooling is zero at undercharged conditions. Further investigation of systems with microchannel heat exchangers would provide more evidence and possibilities for improvement in the VRC sensor model.

Similarly, with overcharged systems, the superheat reduces, especially for units with a fixed orifice device. Again, as superheat is one of the essential inputs to the VRC sensor model, accurate prediction of refrigerant charge becomes more difficult a low superheat with this model. An improved VRC sensor model which handles conditions of zero superheat and zero subcooling conditions could lead to more accurate charge level predictions.

It is known that the optimal charge amount for a heat pump in heating mode is different than cooling mode due to different volumes of the heat exchangers. The automated charging/discharging setup can be used for testing the impact of charge levels across heating and cooling modes to quantify the performance benefits with an active charge control. If there are significant energy savings, the apparatus could be implemented as small add-on component consisting of a small receiver with two valves used to modulate the charge while the system is running.

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APPENDIX A. EXPERIMENTAL DATA

Training Data for System A (Microchannel Condenser and Thermal Expansion Valve)

Test number	Compressor Stage	Indoor Fan Speed [%]	Outdoor Fan Speed [%]	Evaporator Refrigerant Inlet Temperature [^{o}C]	Compressor Suction Temperature [^{o}C]	Compressor Discharge Temperature [^{o}C]	Condenser Refrigerant Outlet Temperature [^{o}C]	Compressor Suction Pressure [kPa]	Compressor Discharge Pressure [kPa]	Liquid Line Pressure [kPa]	Actual Charge [lbs]
0	2	50	100	2.83	20.09	67.59	27.90	809.94	1889.61	1758.02	4.24
1	2	70	100	3.64	20.54	66.86	28.16	835.96	1906.09	1773.84	4.24
2	2	90	60	5.94	21.26	68.68	31.32	885.95	2066.96	1910.63	4.24
3	2	90	80	5.47	21.17	66.70	29.38	874.86	1968.25	1817.22	4.24
4	2	90	100	4.24	20.85	66.51	28.46	853.38	1923.60	1791.59	4.24
5	2	50	100	5.32	20.15	65.67	28.76	877.60	1954.59	1802.89	4.94
6	2	70	100	6.19	20.60	64.94	28.95	900.86	1969.70	1814.19	4.94
7	2	90	100	6.78	20.85	64.47	29.17	918.71	1982.15	1826.04	4.94
8	2	90	60	7.21	20.73	66.76	31.50	919.13	2085.68	1928.09	4.94
9	2	90	80	6.96	20.84	64.81	29.59	917.59	1997.41	1840.59	4.94
10	2	50	100	5.85	18.92	64.00	28.91	893.77	1973.42	1818.87	5.65
11	2	70	100	6.93	19.64	63.39	29.10	923.36	1992.60	1833.83	5.65
12	2	90	60	7.67	19.86	66.23	32.00	932.06	2124.51	1960.11	5.65
13	2	90	80	6.48	19.44	64.18	29.42	905.47	1998.00	1839.56	5.65
14	2	90	100	7.69	20.15	63.04	29.34	955.24	2014.05	1852.21	5.65
15	2	50	100	6.20	17.67	62.32	28.71	902.72	1979.10	1821.97	6.36
16	2	70	100	7.38	18.59	61.68	28.83	936.04	1995.65	1838.11	6.36

17	2	90	60	8.17	18.75	64.20	31.66	955.72	2133.38	1976.94	6.36
18	2	90	80	8.05	19.11	62.34	29.62	956.76	2045.12	1885.55	6.36
19	2	90	100	8.41	19.17	61.07	28.85	970.77	2016.60	1851.87	6.36
20	2	50	100	6.35	15.44	59.88	28.43	910.30	1995.03	1842.78	7.06
21	2	70	100	7.55	16.99	59.81	28.20	944.69	2005.10	1844.12	7.06
22	2	90	60	9.05	17.96	63.06	31.15	988.99	2184.93	2017.84	7.06
23	2	90	80	9.13	18.72	61.22	28.85	996.73	2088.91	1918.58	7.06
24	2	90	100	8.22	18.11	60.27	27.60	967.51	2031.13	1868.40	7.06
25	2	50	100	6.62	13.90	58.78	26.04	932.12	2044.55	1887.81	7.77
26	2	70	100	7.90	15.81	58.71	25.83	969.81	2053.59	1888.32	7.77
27	2	90	60	10.46	18.46	62.76	27.91	1048.46	2284.91	2106.39	7.77
28	2	90	80	10.05	18.48	60.31	25.89	1035.68	2148.20	1971.00	7.77
29	2	90	100	8.16	16.85	59.72	25.06	980.61	2067.34	1902.73	7.77
30	2	50	100	6.05	12.79	59.48	23.50	923.67	2096.63	1955.17	8.48
31	2	70	100	7.37	14.55	59.47	23.69	961.03	2115.04	1965.41	8.48
32	2	90	60	8.29	15.49	63.35	25.37	985.72	2307.48	2158.34	8.48
33	2	90	80	8.21	15.75	60.47	24.16	986.63	2171.25	2017.93	8.48
34	2	90	100	8.40	16.13	59.80	23.78	991.39	2134.46	1978.25	8.48
35	1	20	73	3.77	19.28	62.41	26.71	862.97	1809.40	1682.20	4.24
36	1	40	73	5.43	20.47	60.68	26.91	906.40	1822.83	1695.66	4.24
37	1	60	30	8.81	21.12	66.08	33.45	989.56	2164.61	2001.71	4.24
38	1	60	50	7.77	21.07	61.18	29.35	966.05	1947.80	1795.17	4.24
39	1	60	73	6.61	21.26	59.89	27.40	940.65	1851.06	1722.23	4.24
40	1	20	73	5.41	18.73	60.34	27.31	901.83	1844.68	1697.96	4.94
41	1	40	73	7.51	20.37	58.96	27.73	967.37	1881.74	1734.08	4.94
42	1	60	73	8.41	20.90	58.00	27.92	999.08	1898.65	1750.47	4.94
43	1	60	50	8.98	20.90	59.87	29.86	1008.59	1988.51	1836.29	4.94
44	1	60	30	9.74	20.79	65.35	34.15	1022.94	2214.89	2056.84	4.94

45	1	20	73	5.72	17.50	58.93	27.58	915.95	1867.23	1725.53	5.65
46	1	40	73	7.90	19.55	57.72	27.92	987.18	1901.62	1757.02	5.65
47	1	60	30	8.51	19.18	65.50	33.88	987.41	2199.25	2058.13	5.65
48	1	60	50	7.80	19.24	59.56	29.28	977.83	1962.90	1817.15	5.65
49	1	60	73	9.10	20.46	56.64	28.10	1014.83	1915.70	1771.84	5.65
50	1	20	73	4.87	15.16	57.07	26.97	893.91	1843.89	1714.41	6.36
51	1	40	73	7.83	18.46	57.23	28.29	980.75	1918.99	1788.06	6.36
52	1	60	30	9.51	18.97	65.43	35.13	1018.67	2276.11	2151.23	6.36
53	1	60	50	8.79	19.21	59.45	30.46	1006.17	2021.35	1894.80	6.36
54	1	60	73	8.98	19.68	56.67	28.51	1018.32	1938.49	1805.68	6.36
55	1	20	73	6.11	14.76	56.49	28.02	930.04	1903.33	1782.34	7.06
56	1	40	73	8.97	18.47	55.71	28.49	1018.52	1944.60	1823.71	7.06
57	1	60	30	11.44	19.58	65.23	36.72	1092.82	2395.90	2275.62	7.06
58	1	60	50	10.73	19.83	58.41	31.41	1072.35	2096.53	1972.22	7.06
59	1	60	73	9.99	19.37	54.80	28.48	1050.01	1952.93	1829.52	7.06
60	1	20	73	5.13	11.87	54.98	27.53	914.48	1903.95	1801.70	7.77
61	1	40	73	7.85	15.61	54.19	27.62	996.52	1928.46	1814.53	7.77
62	1	60	30	9.96	16.97	63.94	33.44	1061.40	2369.39	2253.26	7.77
63	1	60	50	9.59	17.28	56.48	29.48	1044.72	2061.83	1943.51	7.77
64	1	60	73	9.48	17.71	53.57	26.91	1044.33	1939.91	1820.97	7.77
65	1	40	73	8.08	15.20	55.29	25.79	1004.09	1991.99	1882.06	8.48
66	1	60	30	9.96	16.68	67.26	30.92	1058.49	2503.06	2395.38	8.48
67	1	60	50	9.63	17.04	58.34	27.22	1050.23	2146.58	2032.38	8.48
68	1	60	73	9.79	17.38	54.83	26.14	1053.40	2016.03	1898.91	8.48
69	1	20	73	5.14	11.60	55.74	25.69	917.73	1950.84	1852.16	8.48

Training Data for System B (Microchannel Condenser and Fixed Orifice Device)

Test number	Compressor Stage	Indoor Fan Speed [%]	Outdoor Fan Speed [%]	Evaporator Refrigerant Inlet Temperature [^{o}C]	Compressor Suction Temperature [^{o}C]	Compressor Discharge Temperature [^{o}C]	Condenser Refrigerant Outlet Temperature [^{o}C]	Compressor Suction Pressure [kPa]	Compressor Discharge Pressure [kPa]	Liquid Line Pressure [kPa]	Actual Charge [lbs]
0	1	100	100	4.90	21.78	65.63	27.61	880.78	1802.58	1806.23	4.27
1	1	50	70	3.60	21.41	71.06	29.18	847.71	1871.77	1875.45	4.27
2	1	100	70	5.00	20.93	68.59	29.22	885.88	1879.65	1883.33	4.27
3	2	100	100	3.57	21.94	73.80	29.44	823.12	1936.15	1939.85	4.26
4	2	50	70	1.40	20.87	78.80	30.97	766.34	1993.75	1997.46	4.26
5	2	100	70	4.01	21.93	77.50	32.00	835.47	2058.23	2061.97	4.26
6	2	100	100	4.91	21.07	72.71	28.14	863.11	1983.56	1987.28	4.97
7	2	50	70	2.72	20.11	76.61	31.37	800.06	2024.99	2028.71	4.96
8	1	100	100	7.62	22.36	66.25	29.37	969.29	1893.67	1897.35	4.96
9	1	50	70	5.53	21.55	69.31	30.20	900.16	1927.35	1931.04	4.96
10	1	100	100	8.96	21.86	62.65	29.52	1005.59	1908.19	1911.88	5.62
11	1	50	70	6.28	20.78	67.15	30.37	921.76	1936.70	1940.40	5.61
12	2	100	100	5.69	21.20	71.19	27.04	887.17	2007.33	2011.05	5.61
13	2	50	70	3.31	18.80	74.43	31.38	815.37	2034.13	2037.86	5.60
14	2	100	100	6.09	19.76	69.75	25.94	902.13	2023.76	2027.49	6.37
15	2	50	70	3.86	15.95	71.54	31.64	829.65	2050.51	2054.24	6.36
16	1	100	100	9.21	20.88	61.65	29.51	1018.13	1909.25	1912.94	6.36
17	1	50	70	6.70	19.67	65.31	30.40	934.60	1940.06	1943.76	6.36
18	1	100	100	9.99	20.34	59.10	29.49	1039.13	1914.89	1918.58	7.07
19	1	50	70	7.02	17.92	63.29	30.43	944.41	1943.76	1947.46	7.06
20	2	100	100	6.54	19.24	67.98	25.44	916.80	2039.80	2043.53	7.06
21	2	50	70	3.95	11.95	67.74	30.45	833.10	2057.61	2061.35	7.05

22	2	100	100	6.68	17.34	66.06	24.63	922.30	2048.65	2052.38	7.76
23	2	50	70	4.19	7.79	63.89	29.38	840.35	2086.90	2090.64	7.75
24	1	100	100	9.92	18.49	56.63	29.41	1041.03	1916.67	1920.36	7.75
25	1	50	70	7.32	14.62	59.78	30.57	952.41	1951.68	1955.39	7.74
26	1	100	100	10.54	16.48	54.11	29.47	1054.56	1920.24	1923.93	8.45
27	1	50	70	7.32	10.58	54.25	30.11	951.54	1938.93	1942.63	8.46
28	1	100	70	10.41	15.44	55.39	31.28	1051.71	2005.98	2009.70	8.44
29	2	100	100	6.94	14.65	63.11	24.54	927.35	2067.85	2071.59	8.44
30	2	50	70	4.37	3.12	57.31	27.39	847.17	2095.90	2099.65	8.47
32	2	100	70	6.20	9.65	61.10	26.53	904.95	2149.11	2152.88	8.47

Training Data for System C (Finned Tube Condenser and Fixed Orifice Device)

Test number	Compressor Stage	Indoor Fan Speed [%]	Outdoor Fan Speed [%]	Evaporator Refrigerant Inlet Temperature [°C]	Compressor Suction Temperature [°C]	Compressor Discharge Temperature [°C]	Condenser Refrigerant Outlet Temperature [°C]	Compressor Suction Pressure [kPa]	Compressor Discharge Pressure [kPa]	Liquid Line Pressure [kPa]	Actual Charge [lbs]
1	1	60	70	6.20	25.95	70.90	30.85	923.63	1953.30	1991.18	9.26
2	1	40	70	5.75	25.65	74.45	30.85	916.03	1949.10	1986.99	9.25
3	1	40	40	9.35	25.25	76.95	36.15	1019.40	2235.50	2277.59	9.33
4	1	60	40	10.15	25.75	75.95	36.35	1047.09	2243.90	2290.29	9.32
5	2	90	100	4.65	25.95	81.05	31.85	858.15	2050.16	2104.95	9.32
6	2	50	100	4.45	25.55	80.15	31.35	850.56	2029.07	2079.66	9.29
7	2	50	70	4.95	25.45	81.05	31.85	865.65	2066.96	2125.94	9.28
8	2	90	70	5.25	25.75	80.75	31.65	873.25	2075.46	2130.14	9.28
9	2	90	70	6.95	25.25	78.35	29.65	923.63	2138.64	2189.12	10.94

11	1	60	70	10.55	24.55	66.05	31.55	1064.69	1999.58	2050.16	10.90
12	1	60	40	11.75	23.75	71.75	37.35	1097.48	2302.88	2353.47	10.88
13	1	60	40	12.75	17.55	65.35	37.75	1125.17	2323.98	2382.96	12.42
14	1	60	70	11.55	21.35	62.35	32.55	1094.98	2045.97	2100.65	12.38
15	2	90	100	6.95	24.15	75.25	28.35	929.88	2113.34	2163.93	12.38
16	2	90	70	8.05	24.45	77.45	29.15	956.42	2193.32	2248.10	12.38
17	2	90	70	8.85	23.25	75.85	28.75	981.61	2243.90	2298.68	13.95
18	2	90	100	8.05	24.05	76.05	28.35	961.42	2176.52	2227.11	13.92
19	1	60	70	11.95	15.95	57.75	31.25	1107.57	2048.07	2104.95	13.91
20	1	60	40	12.85	12.25	57.55	37.05	1127.67	2349.27	2408.15	13.91
21	1	60	40	13.05	12.25	54.35	35.95	1130.26	2395.55	2454.53	15.52
22	1	60	70	11.95	11.95	51.65	31.05	1105.07	2113.34	2163.93	15.49
23	1	40	70	10.75	10.35	48.85	30.55	1067.29	2058.56	2109.15	15.49
24	1	40	40	11.65	10.85	51.55	34.85	1082.38	2344.97	2403.95	15.50
25	2	90	100	8.55	22.25	72.75	28.65	974.02	2243.90	2298.68	15.49
26	2	50	70	8.65	17.55	72.25	29.35	976.51	2294.49	2353.47	15.49
27	2	60	100	8.45	21.45	73.75	28.95	971.52	2243.90	2294.49	15.49
28	2	90	100	9.35	20.85	73.25	28.65	996.71	2294.49	2349.27	17.05
29	2	90	70	9.95	16.75	71.55	29.05	1014.30	2370.26	2429.24	17.03
30	1	60	70	12.25	11.85	49.45	30.05	1117.67	2159.63	2201.82	17.03
31	1	60	40	13.05	12.05	47.45	29.55	1106.32	2361.86	2425.04	17.05
32	1	60	40	13.65	12.25	48.10	28.75	1107.57	2500.82	2568.30	18.63
33	1	60	70	12.25	11.75	47.05	28.15	1107.57	2134.44	2189.12	18.62
34	1	40	70	10.85	10.55	44.75	26.75	1059.69	2071.26	2121.74	18.70
37	1	60	70	4.25	23.05	68.95	27.65	875.75	1810.04	1847.93	9.32
38	1	30	70	2.05	22.55	72.75	27.45	820.27	1793.15	1826.94	9.31
39	1	30	40	5.75	21.65	74.25	32.65	916.03	2054.36	2092.25	9.29
40	1	60	40	7.65	22.65	72.45	33.25	974.02	2088.05	2130.14	9.27

41	2	90	100	2.65	22.95	75.05	27.75	810.27	1843.73	1898.51	9.29
42	2	50	100	2.25	22.55	75.25	27.85	800.17	1835.33	1894.32	9.31
43	2	50	70	2.95	22.25	75.55	28.45	812.77	1881.62	1940.60	9.32
44	2	90	70	3.25	22.75	75.25	28.15	822.86	1885.82	1940.60	9.32
45	2	90	70	4.65	22.15	72.95	26.15	860.65	1932.20	1986.99	10.87
46	2	90	100	4.05	22.45	72.95	25.65	850.56	1877.42	1932.20	10.86
47	1	60	70	7.85	21.75	63.25	28.05	981.61	1831.14	1881.62	10.87
48	1	60	40	9.15	20.75	68.75	33.95	1014.30	2125.94	2176.52	10.83
49	1	60	40	9.95	12.95	60.85	34.45	1036.99	2151.23	2206.01	12.38
50	1	60	70	8.55	17.65	56.85	28.25	1004.21	1839.53	1894.32	12.37
51	2	90	100	4.65	20.85	69.45	24.75	868.15	1906.91	1953.30	12.35
52	2	90	70	5.55	20.85	71.25	25.25	888.34	1965.89	2016.48	12.36
53	2	90	70	6.05	19.45	69.15	24.55	903.44	1986.99	2041.77	13.96
54	2	90	100	5.55	20.45	69.65	24.25	893.34	1932.20	1986.99	13.93
55	1	60	70	9.25	9.35	50.25	28.25	1024.40	1856.43	1919.61	13.90
56	1	60	40	10.25	9.55	51.55	34.35	1041.99	2155.43	2214.41	13.88
57	1	60	40	10.35	9.55	48.85	32.15	1039.49	2210.21	2269.19	15.44
58	1	60	70	9.05	8.75	44.05	27.05	1016.80	1869.02	1928.00	15.48
59	1	30	70	6.85	6.25	41.25	27.65	941.23	1847.93	1902.71	15.48
60	1	30	40	8.05	7.45	43.55	29.55	953.82	2176.52	2227.11	15.46
61	2	90	100	5.75	18.75	64.45	23.75	895.94	1957.50	2007.98	15.48
62	2	50	70	5.55	10.95	61.75	24.35	888.34	1999.58	2054.36	15.50
63	2	60	100	5.55	17.05	65.75	23.85	893.34	1953.30	2003.78	15.51
64	2	90	100	6.35	15.95	64.65	23.35	913.54	1982.79	2037.47	17.03
65	2	90	70	6.85	11.45	61.55	23.65	926.13	2045.97	2104.95	17.01
66	1	60	70	9.35	8.95	42.25	25.55	1024.40	1894.32	1949.10	17.07
67	1	60	40	10.65	9.45	43.65	26.55	1024.40	2218.61	2290.29	16.99
68	1	60	40	10.95	9.35	43.45	25.55	1019.40	2294.49	2361.86	18.52

69	1	60	70	9.55	9.25	40.75	24.25	1016.80	1911.11	1965.89	18.60
70	1	30	70	7.25	6.85	40.35	23.95	946.32	1890.12	1936.40	18.61
71	2	90	70	6.95	7.75	57.35	23.45	928.63	2079.66	2138.64	18.61
72	2	90	100	6.55	13.25	61.55	23.25	923.63	2016.48	2075.46	18.61
73	2	50	100	5.65	6.35	57.95	23.45	890.84	2003.78	2058.56	18.60

Training Data for System D (Finned Tube Condenser and Thermal Expansion Valve)

Test number	Compressor Stage	Indoor Fan Speed [%]	Outdoor Fan Speed [%]	Evaporator Refrigerant Inlet Temperature [^{o}C]	Compressor Suction Temperature [^{o}C]	Compressor Discharge Temperature [^{o}C]	Condenser Refrigerant Outlet Temperature [^{o}C]	Compressor Suction Pressure [kPa]	Compressor Discharge Pressure [kPa]	Liquid Line Pressure [kPa]	Actual Charge [lbs]
0	1	60	70	12.00	24.78	66.60	33.95	1098.29	2096.33	2180.99	9.27
1	1	30	70	10.57	23.38	68.47	33.32	1051.61	2063.71	2147.64	9.27
2	1	30	40	11.25	22.28	70.50	35.84	1068.51	2195.30	2284.39	9.27
3	1	60	40	12.76	23.77	70.42	36.82	1121.34	2247.29	2336.24	9.27
4	2	90	100	8.68	24.98	76.95	35.31	962.14	2175.94	2261.68	9.27
5	2	50	100	8.11	24.95	78.51	35.02	945.85	2161.41	2246.71	9.26
6	2	50	50	9.45	24.09	80.61	38.12	978.59	2330.73	2423.39	9.26
7	2	90	50	10.13	24.57	80.42	38.55	1000.59	2353.76	2447.84	9.26
8	1	60	70	12.69	22.83	65.41	34.30	1126.44	2114.50	2198.09	10.82
9	1	30	40	11.07	18.40	68.20	36.95	1069.05	2258.43	2331.78	10.84
10	2	90	100	10.07	22.17	72.58	36.00	1007.45	2216.64	2307.02	10.80
11	2	50	50	10.59	20.90	76.23	38.88	1013.19	2374.64	2470.35	10.85
12	1	60	70	12.36	20.04	63.40	35.04	1120.60	2158.68	2225.16	12.39
13	1	30	40	10.66	16.34	66.94	37.72	1062.52	2316.85	2372.24	12.33

14	2	90	100	10.86	20.25	70.19	36.08	1033.65	2249.70	2338.36	12.37
15	2	50	50	10.91	16.76	72.36	38.94	1025.15	2427.49	2515.71	12.39
16	1	60	70	12.27	18.42	62.12	34.46	1121.65	2192.40	2247.57	13.93
17	1	30	40	10.27	15.01	66.33	35.74	1054.87	2364.00	2408.33	13.93
18	2	90	100	10.73	18.29	68.97	33.95	1034.92	2291.40	2365.11	13.93
19	2	50	50	10.40	14.55	71.19	35.44	1016.62	2488.19	2559.78	13.91
20	1	60	70	11.81	19.13	63.40	31.69	1110.98	2230.79	2275.39	15.50
21	1	30	70	9.83	15.15	62.31	32.46	1044.81	2194.39	2236.28	15.46
22	1	30	40	9.70	15.46	68.39	32.55	1042.79	2393.83	2429.93	15.46
23	1	60	40	11.83	18.82	70.08	32.06	1112.94	2462.31	2503.64	15.46
24	2	90	100	10.79	16.70	68.32	32.31	1038.89	2331.13	2401.02	15.46
25	2	50	100	9.75	15.33	68.25	32.23	1005.33	2307.64	2373.66	15.46
26	2	50	50	9.77	14.91	73.05	32.40	1006.22	2536.35	2599.26	15.46
27	2	90	50	10.72	16.64	74.22	32.38	1037.51	2569.62	2635.80	15.46
28	1	60	70	11.84	18.66	64.03	30.70	1113.42	2262.22	2303.61	17.03
29	1	30	40	9.66	14.98	68.24	30.90	1042.77	2438.48	2471.87	17.05
30	2	50	100	9.51	15.58	69.38	31.13	1001.96	2352.28	2413.00	17.01
31	2	50	50	9.55	14.87	74.22	30.77	1003.93	2585.51	2643.61	17.01
32	1	60	70	11.69	18.67	65.34	29.79	1109.33	2303.14	2342.36	18.62
33	1	30	70	9.60	14.80	63.16	30.07	1040.61	2255.64	2290.00	18.60
34	1	30	40	9.33	15.33	70.46	29.42	1034.73	2464.30	2495.83	18.59
35	1	60	40	11.61	18.58	72.27	29.29	1109.78	2541.67	2578.34	18.58
36	2	90	100	10.54	16.21	70.11	30.60	1035.37	2418.59	2482.61	18.58
37	2	50	100	9.48	14.71	69.69	30.42	1001.54	2391.13	2450.88	18.57
38	2	50	50	9.34	14.53	75.15	29.69	999.90	2631.70	2686.67	18.57
39	2	90	50	10.30	16.36	76.55	29.64	1031.26	2671.60	2731.38	18.57

Testing Data for System A (Microchannel Condenser and Thermal Expansion Valve)

Test number	Compressor Stage	Indoor Fan Speed [%]	Outdoor Fan Speed [%]	Evaporator Refrigerant Inlet Temperature [°C]	Compressor Suction Temperature [°C]	Compressor Discharge Temperature [°C]	Condenser Refrigerant Outlet Temperature [°C]	Compressor Suction Pressure [kPa]	Compressor Discharge Pressure [kPa]	Liquid Line Pressure [kPa]	Actual Charge [lbs]
0	2	80	27	8.67	25.59	75.17	35.75	961.71	2301.63	2125.82	4.24
1	2	80	60	10.15	25.74	80.55	40.84	996.38	2613.80	2423.95	4.24
2	2	60	27	8.13	25.23	75.38	35.60	951.64	2293.21	2119.31	4.24
3	2	59	100	7.13	24.75	76.25	35.31	927.62	2283.45	2103.80	4.24
4	2	60	35	7.94	25.42	76.41	35.66	949.42	2301.64	2120.21	4.24
5	2	80	45	8.50	25.78	76.22	35.83	968.50	2314.92	2131.86	4.24
6	2	80	27	10.36	26.11	82.07	41.93	1001.04	2661.94	2471.08	4.24
7	2	80	60	11.76	26.24	87.55	46.71	1037.41	2989.67	2783.23	4.24
8	2	60	27	9.99	25.71	82.25	41.82	983.99	2647.31	2455.61	4.24
9	2	59	100	8.98	25.07	83.52	41.70	971.12	2653.01	2458.34	4.24
10	2	60	35	9.92	25.90	83.71	42.10	990.44	2679.11	2483.93	4.24
11	2	80	45	10.34	26.31	83.47	41.99	1004.17	2684.71	2489.48	4.24
12	2	60	27	11.28	26.10	91.28	48.31	1002.17	3060.44	2852.78	4.24
13	2	80	60	13.54	26.84	96.72	53.31	1060.07	3435.18	3213.31	4.24
14	2	80	27	12.14	26.71	92.27	49.44	1027.80	3154.96	2943.40	4.24
15	2	59	100	11.31	25.93	91.18	47.92	1017.68	3055.41	2846.43	4.24
16	2	60	35	12.06	26.58	91.38	48.32	1036.40	3077.76	2865.80	4.24
17	2	80	45	12.38	26.77	91.08	48.36	1050.09	3091.20	2882.12	4.24
18	2	60	27	11.36	25.30	81.41	43.27	1038.24	2767.20	2579.82	4.94
19	2	80	60	13.33	25.65	86.25	47.85	1086.34	3088.45	2887.51	4.94
20	2	80	27	11.87	25.57	80.62	43.01	1055.24	2752.72	2564.78	4.94

21	2	59	100	10.36	24.20	81.18	42.07	1007.59	2709.91	2512.02	4.94
22	2	60	35	11.38	25.09	81.44	42.59	1035.12	2738.44	2540.14	4.94
23	2	80	45	12.04	25.54	81.23	42.83	1055.50	2752.87	2555.35	4.94
24	2	60	27	9.71	24.65	73.46	36.42	995.92	2357.66	2184.66	4.94
25	2	59	100	8.58	23.95	73.88	35.53	968.03	2315.84	2137.06	4.94
26	2	60	27	13.03	25.48	88.72	49.26	1069.19	3152.45	2948.34	4.94
27	2	80	60	15.36	26.57	95.03	54.66	1136.36	3571.96	3355.98	4.94
28	2	80	27	14.00	26.45	90.26	50.71	1103.73	3272.64	3064.98	4.94
29	2	59	100	12.17	24.82	88.82	48.20	1062.75	3136.33	2921.57	4.94
30	2	60	35	13.21	25.74	89.31	48.91	1086.99	3172.55	2957.61	4.94
31	2	80	45	14.04	26.40	89.34	49.35	1105.52	3186.83	2971.87	4.94
32	2	59	100	9.18	22.68	71.61	35.46	984.41	2320.64	2142.24	5.65
33	2	80	60	12.30	25.24	78.71	42.17	1068.51	2725.33	2540.77	5.65
34	2	80	27	11.03	25.21	72.52	36.41	1038.90	2366.80	2194.02	5.65
35	2	60	35	10.57	23.87	71.85	35.97	1029.29	2357.64	2174.64	5.65
36	2	60	27	10.10	24.50	72.88	36.26	1012.04	2351.88	2182.89	5.65
37	2	80	45	11.55	24.67	71.49	36.10	1056.67	2377.45	2195.98	5.65
38	2	60	27	11.67	24.96	80.78	43.31	1050.09	2774.51	2590.84	5.65
39	2	80	60	13.60	25.52	85.58	47.87	1101.02	3094.79	2899.07	5.65
40	2	80	27	12.38	25.52	79.90	43.01	1069.95	2753.25	2570.37	5.65
41	2	59	100	11.05	22.75	79.46	42.37	1022.04	2721.54	2525.45	5.65
42	2	60	35	12.07	24.04	79.43	42.62	1058.22	2746.59	2549.20	5.65
43	2	80	45	12.86	24.69	79.29	42.88	1086.44	2769.55	2572.93	5.65
44	2	60	27	13.35	23.97	87.55	49.96	1088.21	3225.87	3030.81	5.65
45	2	80	60	15.09	24.81	94.04	55.03	1137.42	3607.99	3414.75	5.65
46	2	80	27	13.91	24.74	87.24	49.92	1106.83	3217.62	3025.62	5.65
47	2	59	100	12.91	23.34	87.60	49.03	1067.63	3165.87	2958.44	5.65
48	2	60	35	13.97	24.68	87.86	49.47	1108.98	3200.95	2992.29	5.65

49	2	80	45	14.57	25.35	87.80	49.71	1127.77	3221.49	3012.28	5.65
50	2	80	60	13.61	24.52	84.89	48.16	1106.65	3123.36	2939.96	6.36
51	2	80	27	12.40	24.40	78.17	42.57	1079.34	2740.13	2561.61	6.36
52	2	60	35	12.54	23.00	77.88	42.87	1078.88	2776.85	2587.65	6.36
53	2	59	100	11.83	21.67	76.55	42.17	1055.71	2721.14	2544.56	6.36
54	2	80	45	13.41	24.02	78.01	43.08	1110.76	2800.84	2612.78	6.36
55	2	59	100	10.38	21.63	69.64	35.92	1021.22	2350.10	2175.69	6.36
56	2	80	60	12.32	24.17	75.91	41.13	1078.10	2672.87	2489.39	6.36
57	2	80	27	11.21	24.23	69.66	35.24	1054.22	2325.72	2149.25	6.36
58	2	60	35	11.08	22.77	70.25	36.15	1049.41	2382.71	2197.34	6.36
59	2	80	45	12.11	23.69	70.08	36.25	1081.38	2406.65	2216.87	6.36
60	2	80	27	14.24	25.27	88.70	50.95	1131.28	3311.94	3126.69	6.36
61	2	60	35	13.73	23.75	86.69	49.41	1115.30	3214.06	3036.02	6.36
62	2	80	45	14.39	24.71	86.42	49.18	1148.36	3238.78	3056.10	6.36
63	2	59	100	13.54	22.73	85.50	49.12	1097.79	3173.12	3001.49	6.36
64	2	59	100	9.79	19.33	68.00	35.57	1009.37	2372.85	2201.58	7.06
65	2	60	35	11.29	21.64	69.16	35.52	1056.13	2414.56	2236.74	7.06
66	2	80	45	12.18	22.72	69.55	35.11	1086.39	2444.50	2260.43	7.06
67	2	59	100	11.40	19.01	74.66	41.75	1042.47	2728.79	2553.75	7.06
68	2	80	45	13.86	22.96	76.78	41.88	1121.09	2822.21	2638.29	7.06
69	2	60	35	12.80	21.69	76.29	42.06	1091.67	2795.31	2617.88	7.06
70	2	59	100	13.17	19.72	85.46	48.65	1079.59	3284.30	3111.51	7.06
71	2	80	45	14.58	22.96	85.62	47.83	1137.83	3273.53	3095.05	7.06
72	2	60	35	13.94	21.97	85.22	48.39	1117.49	3250.73	3075.35	7.06
73	2	60	35	12.63	19.68	74.80	39.25	1098.01	2851.14	2673.86	7.77
74	2	80	45	13.16	20.90	75.89	38.91	1119.28	2879.29	2702.65	7.77
75	2	59	100	11.01	16.86	74.46	38.84	1039.32	2817.69	2657.97	7.77
76	2	59	100	9.75	16.03	64.88	33.01	1007.67	2377.23	2211.96	7.77

77	2	60	35	11.13	19.85	67.42	33.03	1061.27	2425.35	2250.41	7.77
78	2	80	45	12.10	21.45	68.04	32.54	1095.90	2457.23	2275.90	7.77
79	2	59	100	12.25	17.28	84.89	44.48	1062.66	3333.49	3182.66	7.77
80	2	60	35	13.60	20.25	85.47	44.92	1115.43	3340.62	3174.00	7.77
81	2	80	45	14.10	21.51	85.82	44.39	1139.84	3365.51	3198.54	7.77
82	2	59	100	10.39	16.18	76.40	35.80	1029.92	2922.79	2774.29	8.48
83	2	60	35	11.81	19.10	74.76	35.68	1082.33	2846.95	2694.08	8.48
84	2	60	27	12.03	19.06	76.07	36.44	1085.78	2929.93	2773.29	8.48
85	2	80	60	13.76	19.91	86.80	41.15	1134.37	3527.09	3368.18	8.48
86	2	80	45	12.88	20.00	73.75	35.79	1115.46	2844.51	2679.42	8.48
87	2	80	27	13.40	20.19	77.44	37.89	1126.86	3036.68	2869.98	8.48
88	2	80	60	12.82	19.68	78.25	36.03	1120.37	3085.19	2922.66	8.48
89	2	59	100	9.24	15.65	66.41	29.37	1002.68	2454.01	2300.93	8.48
90	2	60	27	11.30	18.73	68.59	31.23	1071.53	2572.56	2409.74	8.48
91	2	60	35	11.20	18.88	67.27	30.49	1068.30	2509.03	2346.60	8.48
92	2	80	27	12.26	20.30	69.25	31.21	1107.35	2610.96	2442.75	8.48
93	2	80	45	12.23	20.47	68.08	30.45	1104.29	2543.73	2373.30	8.48
94	2	60	35	13.09	19.80	90.78	43.45	1104.36	3577.02	3428.11	8.48
95	2	59	100	11.24	16.47	85.77	42.48	1044.08	3392.74	3252.78	8.48
96	2	60	27	12.93	18.73	88.10	43.35	1097.46	3531.33	3380.74	8.48
97	2	80	27	14.00	20.04	88.40	43.67	1142.46	3576.01	3421.38	8.48
98	2	80	45	13.84	20.12	86.45	43.07	1141.19	3473.61	3319.26	8.48
99	1	40	30	7.61	24.62	59.72	25.80	982.81	1780.63	1631.50	4.24
100	1	60	37	8.44	25.06	59.25	26.11	1001.24	1793.35	1643.81	4.24
101	1	36	100	6.66	23.80	59.84	25.72	956.87	1781.27	1631.12	4.24
102	1	40	50	8.26	24.61	60.03	26.77	991.11	1818.20	1669.26	4.24
103	1	60	70	10.14	25.00	64.08	31.23	1041.44	2053.79	1891.12	4.24
104	1	60	50	8.93	24.95	59.56	26.98	1013.31	1839.45	1690.25	4.24

105	1	40	50	10.51	25.47	68.74	34.52	1053.48	2215.77	2041.72	4.24
106	1	60	70	12.30	25.72	72.74	38.49	1098.61	2459.34	2273.18	4.24
107	1	36	100	8.98	24.60	68.92	33.33	1013.18	2153.40	1978.37	4.24
108	1	60	50	11.08	25.75	68.06	34.49	1068.46	2215.50	2041.54	4.24
109	1	40	30	10.03	25.43	68.65	33.64	1040.76	2172.11	1995.47	4.24
110	1	60	37	10.57	25.77	68.09	33.84	1063.23	2184.11	2007.53	4.24
111	1	60	50	13.06	26.38	76.55	41.36	1117.06	2602.59	2410.39	4.24
112	1	60	70	13.93	26.50	82.17	45.54	1146.69	2893.25	2700.07	4.24
113	1	40	50	12.48	26.03	76.96	41.09	1104.33	2586.06	2396.10	4.24
114	1	36	100	11.08	25.45	76.53	39.64	1075.64	2532.32	2336.23	4.24
115	1	40	30	12.01	26.15	76.79	40.17	1097.32	2552.81	2357.39	4.24
116	1	60	37	12.41	26.25	76.25	40.36	1108.71	2560.32	2364.59	4.24
117	1	36	100	9.99	23.47	66.51	33.47	1037.95	2168.79	1997.54	4.94
118	1	40	50	11.54	24.89	67.03	35.01	1091.23	2252.29	2084.82	4.94
119	1	60	70	13.21	25.14	71.48	39.25	1138.11	2519.02	2340.37	4.94
120	1	60	50	12.09	25.10	66.33	34.99	1107.16	2249.87	2084.19	4.94
121	1	40	30	11.14	24.68	66.28	33.73	1089.23	2203.11	2028.12	4.94
122	1	60	37	11.90	25.06	65.85	34.13	1102.61	2212.48	2039.90	4.94
123	1	80	60	11.47	25.08	78.80	41.65	1044.44	2683.41	2496.49	4.94
124	1	80	27	10.20	25.03	72.99	36.30	1015.12	2348.37	2175.83	4.94
125	1	80	45	10.36	25.09	73.53	36.30	1017.88	2358.53	2176.93	4.94
126	1	60	35	9.60	24.75	73.85	35.93	995.50	2344.18	2163.16	4.94
127	1	40	50	9.56	24.22	57.69	26.98	1040.21	1843.16	1702.07	4.94
128	1	60	70	11.57	24.65	61.19	31.08	1083.75	2053.86	1899.06	4.94
129	1	60	50	10.39	24.67	56.81	26.99	1063.63	1846.25	1704.95	4.94
130	1	36	100	7.99	22.95	57.70	25.93	992.40	1795.03	1647.67	4.94
131	1	40	30	9.43	24.12	57.62	26.37	1036.36	1822.27	1673.91	4.94
132	1	60	37	10.23	24.58	57.02	26.58	1060.52	1833.31	1685.78	4.94

133	1	40	50	13.05	25.01	75.37	41.45	1131.57	2622.25	2440.59	4.94
134	1	60	70	14.73	25.75	80.52	45.93	1179.57	2930.30	2746.66	4.94
135	1	60	50	13.76	25.69	75.06	41.75	1152.14	2644.26	2463.54	4.94
136	1	36	100	12.09	24.02	74.66	40.12	1091.05	2542.82	2350.57	4.94
137	1	40	30	13.00	25.06	74.66	40.45	1121.11	2569.84	2379.84	4.94
138	1	60	37	13.64	25.60	74.27	40.72	1149.10	2589.84	2402.54	4.94
139	1	36	100	12.12	23.04	73.43	40.29	1102.13	2567.18	2388.74	5.65
140	1	40	30	13.28	24.58	73.53	40.58	1143.94	2595.86	2415.76	5.65
141	1	40	50	12.97	25.17	76.11	41.82	1126.14	2639.76	2471.04	5.65
142	1	60	70	14.38	25.97	84.39	48.00	1175.90	3075.86	2918.91	5.65
143	1	60	50	13.66	25.85	76.41	42.52	1150.54	2682.97	2517.72	5.65
144	1	60	37	13.72	25.14	72.94	40.59	1170.24	2615.11	2439.41	5.65
145	1	60	70	13.71	24.99	72.04	40.15	1152.84	2579.97	2414.80	5.65
146	1	36	100	10.88	22.40	64.24	33.64	1068.62	2185.78	2019.12	5.65
147	1	40	50	11.61	23.88	66.06	35.25	1102.26	2273.00	2112.32	5.65
148	1	60	50	12.47	24.64	65.46	35.35	1129.38	2281.12	2125.26	5.65
149	1	40	30	11.90	23.90	64.56	33.86	1102.01	2206.12	2035.53	5.65
150	1	60	37	12.46	24.47	64.14	34.14	1130.02	2228.10	2058.78	5.65
151	1	40	50	10.24	23.79	57.02	27.52	1068.01	1878.92	1736.14	5.65
152	1	60	70	12.13	24.27	61.88	32.61	1120.21	2153.45	2001.77	5.65
153	1	60	50	11.16	24.40	56.55	27.85	1096.60	1897.78	1756.75	5.65
154	1	36	100	8.87	22.08	55.35	25.90	1024.70	1802.89	1658.79	5.65
155	1	40	30	10.25	23.76	55.89	26.31	1063.27	1828.93	1682.84	5.65
156	1	60	37	11.12	24.35	55.44	26.59	1090.31	1843.09	1697.00	5.65
157	1	60	70	13.19	24.50	72.23	40.44	1147.09	2594.53	2448.57	6.36
158	1	40	30	11.97	23.28	64.22	34.22	1116.95	2240.01	2082.06	6.36
159	1	60	50	12.48	24.56	67.02	36.58	1132.32	2351.75	2208.24	6.36
160	1	60	37	12.74	24.08	63.74	34.46	1143.49	2253.94	2099.64	6.36

161	1	36	100	10.87	21.50	63.70	33.93	1073.25	2204.85	2058.33	6.36
162	1	60	70	14.12	24.84	82.35	47.28	1175.66	3029.43	2889.38	6.36
163	1	60	50	13.38	24.81	75.84	42.67	1151.08	2703.01	2560.00	6.36
164	1	36	100	11.91	21.37	72.33	40.55	1101.62	2590.84	2430.57	6.36
165	1	40	30	12.95	23.18	73.15	41.07	1136.17	2623.12	2472.76	6.36
166	1	60	37	13.85	24.17	72.86	41.38	1165.67	2642.06	2489.56	6.36
167	1	36	100	9.42	21.30	54.26	26.27	1037.15	1815.13	1678.19	6.36
168	1	60	70	12.13	24.21	61.76	32.48	1116.37	2145.93	2005.91	6.36
169	1	60	50	11.22	24.29	56.47	27.91	1097.65	1903.56	1770.10	6.36
170	1	40	30	10.50	22.86	54.82	26.48	1078.59	1847.35	1702.38	6.36
171	1	60	37	11.52	23.68	54.60	26.84	1108.88	1866.13	1722.81	6.36
172	1	36	100	10.07	20.29	63.73	34.12	1057.91	2224.70	2093.07	7.06
173	1	40	30	11.67	22.31	64.08	34.65	1110.30	2262.76	2133.26	7.06
174	1	40	50	11.61	22.57	66.36	36.46	1109.18	2353.09	2214.19	7.06
175	1	60	70	13.14	23.40	71.62	40.81	1153.66	2630.14	2497.08	7.06
176	1	60	50	12.46	23.69	65.34	36.10	1138.18	2332.89	2197.85	7.06
177	1	60	37	12.65	23.43	63.75	34.87	1145.55	2284.44	2156.12	7.06
178	1	36	100	11.28	20.46	72.60	40.88	1092.06	2613.49	2490.81	7.06
179	1	40	30	12.67	22.59	73.03	41.27	1137.31	2643.95	2523.65	7.06
180	1	60	37	13.53	23.84	72.76	41.08	1171.06	2661.32	2538.24	7.06
181	1	40	50	10.29	22.40	55.52	27.54	1074.35	1889.50	1755.65	7.06
182	1	60	70	12.23	23.07	61.05	32.93	1120.81	2174.70	2040.71	7.06
183	1	60	50	11.33	23.25	55.11	27.83	1104.12	1905.36	1774.40	7.06
184	1	36	100	8.96	20.33	54.11	26.39	1028.25	1836.56	1706.43	7.06
185	1	40	30	10.61	22.18	54.40	26.82	1081.31	1863.85	1735.57	7.06
186	1	60	37	11.73	23.14	54.08	27.00	1119.14	1886.38	1759.10	7.06
187	1	36	100	11.25	18.64	71.37	40.95	1093.05	2636.17	2522.30	7.77
188	1	40	30	12.93	21.04	71.63	41.16	1146.48	2667.20	2548.09	7.77

189	1	60	37	13.92	22.85	71.84	40.45	1179.68	2690.91	2566.51	7.77
190	1	36	100	10.07	17.46	60.98	34.14	1054.83	2231.85	2117.41	7.77
191	1	40	30	11.76	21.17	62.79	34.28	1116.41	2269.95	2147.89	7.77
192	1	60	37	12.65	22.43	62.60	33.25	1150.46	2289.28	2164.84	7.77
193	1	36	100	9.21	18.50	51.89	26.36	1034.00	1831.10	1707.91	7.77
194	1	40	30	10.89	20.94	53.14	26.20	1092.34	1874.77	1751.84	7.77
195	1	60	37	11.70	22.01	53.26	25.10	1122.84	1894.08	1769.18	7.77
196	1	36	100	10.90	17.68	69.61	38.08	1088.16	2616.36	2511.71	8.48
197	1	40	30	12.55	20.48	72.28	37.85	1143.99	2723.07	2612.96	8.48
198	1	40	50	12.72	20.02	73.76	39.51	1143.63	2796.76	2689.26	8.48
199	1	60	70	13.94	22.12	85.10	41.42	1185.21	3315.34	3211.15	8.48
200	1	60	50	13.50	21.94	74.58	38.26	1173.48	2851.25	2742.83	8.48
201	1	60	37	13.33	22.03	70.98	36.20	1168.67	2665.36	2556.74	8.48
202	1	36	100	9.74	16.13	60.61	30.99	1045.93	2251.45	2139.66	8.48
203	1	40	50	11.89	19.87	63.71	33.25	1124.76	2377.43	2266.73	8.48
204	1	40	30	11.79	19.88	61.98	32.14	1118.70	2301.10	2188.43	8.48
205	1	60	70	13.38	21.78	72.23	35.61	1171.68	2762.92	2651.05	8.48
206	1	60	50	12.90	21.71	64.61	32.35	1158.46	2414.24	2300.89	8.48
207	1	60	37	12.85	21.69	62.26	31.29	1156.17	2332.67	2216.64	8.48
208	1	36	100	8.90	15.55	50.33	25.69	1018.52	1859.51	1747.04	8.48
209	1	40	30	11.06	19.48	50.41	25.00	1096.91	1867.96	1750.58	8.48
210	1	40	50	11.07	19.67	52.37	26.51	1103.14	1929.43	1809.73	8.48
211	1	60	70	12.69	20.25	58.57	30.46	1151.05	2254.70	2136.83	8.48
212	1	60	37	11.99	21.06	50.99	24.49	1134.77	1891.53	1771.23	8.48
213	1	60	50	12.09	21.20	53.18	25.66	1140.34	1978.03	1856.39	8.48

Testing Data for System B (Microchannel Condenser and Fixed Orifice Device)

Test number	Compressor Stage	Indoor Fan Speed [%]	Outdoor Fan Speed [%]	Evaporator Refrigerant Inlet Temperature [^{o}C]	Compressor Suction Temperature [^{o}C]	Compressor Discharge Temperature [^{o}C]	Condenser Refrigerant Outlet Temperature [^{o}C]	Compressor Suction Pressure [kPa]	Compressor Discharge Pressure [kPa]	Liquid Line Pressure [kPa]	Actual Charge [lbs]
0	1	60	70	10.34	21.90	56.16	26.83	1067.54	1768.77	1842.67	7.14
1	1	60	40	10.69	22.06	62.68	31.85	1076.76	2008.02	2069.67	7.14
2	2	70	70	7.46	21.84	68.18	21.85	962.64	1956.74	2034.64	7.14
3	2	70	100	7.34	21.86	68.11	21.08	961.72	1930.33	2007.92	7.14
4	2	90	100	7.40	21.93	68.33	21.21	964.34	1940.16	2018.38	7.14
5	2	90	70	7.50	21.93	68.54	21.40	965.71	1950.72	2029.26	7.14
6	1	40	70	9.13	18.98	55.84	26.52	1030.85	1750.62	1821.88	7.72
7	1	60	40	10.98	19.33	60.36	32.14	1084.77	2023.41	2087.20	7.72
8	2	70	100	7.59	20.38	66.35	21.34	968.72	1963.84	2040.96	7.72
9	2	90	70	7.70	20.56	67.18	21.30	971.62	1965.36	2044.02	7.72
10	1	40	40	10.25	11.63	55.97	32.09	1057.65	2020.33	2082.98	8.43
11	1	40	70	9.25	14.45	50.64	26.65	1033.12	1765.72	1839.76	8.44
12	1	60	70	10.35	17.97	52.12	25.24	1070.37	1777.96	1854.77	8.45
13	1	60	40	11.37	15.49	56.61	32.23	1094.75	2043.73	2109.19	8.44
14	2	70	70	8.02	17.91	63.99	21.34	979.09	2006.65	2083.79	8.44
15	2	70	100	7.95	17.62	64.59	21.14	978.93	2003.51	2081.18	8.45
16	2	90	100	7.91	17.34	64.49	21.23	977.48	2006.25	2083.87	8.46
17	2	90	70	7.90	17.06	64.50	21.52	975.68	2016.04	2093.69	8.46
18	1	40	40	5.43	24.82	73.49	30.31	915.21	1923.94	1963.96	4.24
19	1	40	70	4.84	25.14	67.87	26.01	903.44	1714.21	1762.08	4.25
20	1	60	70	5.42	25.38	66.80	26.01	919.11	1715.47	1765.46	4.25
21	1	60	40	5.94	25.51	72.10	30.17	931.80	1917.20	1959.38	4.25

22	2	70	70	3.73	25.30	74.74	26.01	847.40	1815.05	1886.10	4.25
23	2	70	100	3.51	25.26	74.16	24.92	845.20	1777.10	1850.05	4.25
24	2	90	100	3.57	25.29	74.31	25.13	846.57	1786.73	1859.23	4.24
25	2	90	70	3.71	25.30	74.90	25.78	847.57	1810.70	1882.00	4.24
26	1	40	70	6.98	24.10	63.91	26.16	964.28	1724.17	1782.61	4.94
27	1	60	40	8.48	25.20	68.88	31.08	1005.98	1964.63	2015.74	4.94
28	2	70	100	5.13	24.89	72.13	22.97	891.36	1830.96	1906.13	4.94
29	2	90	70	5.32	24.85	72.99	23.50	895.58	1859.59	1933.92	4.94
30	1	40	70	8.08	23.54	61.66	26.33	998.67	1734.98	1799.79	5.70
31	1	60	40	9.70	24.48	66.47	31.51	1045.55	1986.32	2042.93	5.70
32	2	70	100	6.24	24.26	70.72	21.91	926.87	1875.91	1951.86	5.70
33	2	90	70	6.44	24.21	71.56	22.25	931.39	1899.26	1976.64	5.70
34	1	40	70	8.59	22.56	59.96	26.49	1014.63	1743.54	1811.19	6.33
35	1	60	40	10.37	23.50	64.78	31.68	1065.00	1997.96	2057.53	6.33
36	2	70	100	6.96	23.30	69.29	21.70	947.28	1911.65	1987.63	6.33
37	2	90	70	7.09	23.22	70.18	21.78	950.32	1925.05	2003.52	6.33
38	1	40	40	9.70	21.03	63.88	31.47	1044.24	1985.63	2044.57	7.13
39	1	40	70	8.79	21.13	58.07	26.62	1021.88	1753.05	1822.51	7.14
40	1	60	70	11.65	16.31	58.02	33.44	1103.48	2106.58	2170.54	8.44
41	1	60	40	12.50	12.44	63.97	39.87	1123.01	2452.44	2512.49	8.44
42	2	90	100	8.98	16.25	68.17	27.14	999.86	2266.42	2341.76	8.44
43	2	90	70	9.28	14.89	69.00	28.20	1004.51	2330.86	2408.84	8.44
45	1	40	40	7.22	25.69	77.01	37.36	950.79	2291.92	2330.97	4.20
46	1	40	70	6.93	25.90	77.43	33.80	958.75	2098.39	2139.98	4.20
47	1	60	70	7.49	26.10	76.20	33.70	977.89	2096.25	2140.23	4.20
48	1	60	40	8.22	26.29	81.29	37.70	993.38	2308.90	2351.29	4.20
49	2	70	70	6.07	25.93	83.29	34.48	901.76	2219.08	2286.56	4.20
50	2	70	100	5.86	25.81	83.31	34.24	899.86	2205.98	2274.81	4.20

51	2	90	100	5.88	25.79	83.56	34.53	899.92	2214.73	2283.53	4.20
52	2	90	70	5.96	25.76	83.75	34.69	899.87	2218.86	2288.01	4.20
53	1	40	70	8.63	24.33	73.81	33.87	1009.61	2104.79	2153.58	4.96
54	1	60	40	10.15	25.69	78.48	38.38	1053.11	2348.49	2397.40	4.93
55	2	70	100	7.51	25.25	82.14	33.72	944.45	2303.97	2375.33	4.90
56	2	90	70	7.34	25.09	82.31	33.44	939.96	2288.12	2359.93	4.91
57	1	40	70	9.57	23.56	72.08	34.37	1036.78	2129.53	2181.52	5.67
58	1	60	40	11.05	24.73	76.33	38.81	1082.19	2372.27	2423.87	5.64
59	2	70	100	8.30	24.04	81.00	33.42	968.48	2360.21	2433.74	5.63
60	2	90	70	8.12	23.74	81.15	33.22	963.37	2346.47	2420.38	5.63
61	1	40	70	9.97	22.17	70.62	34.78	1050.21	2150.08	2204.24	6.39
62	1	60	40	11.40	23.41	74.65	38.96	1093.59	2379.86	2433.02	6.36
63	2	70	100	8.63	22.39	80.03	33.77	977.24	2410.22	2484.80	6.34
64	2	90	70	8.46	22.00	80.25	33.84	971.41	2406.82	2482.51	6.34
65	1	40	40	10.88	19.27	72.93	39.03	1074.18	2380.89	2433.97	7.09
66	1	40	70	10.24	19.81	68.57	35.80	1056.85	2206.03	2259.41	7.06
67	1	60	70	12.77	19.90	65.20	37.69	1095.44	2278.76	2328.96	7.06
68	1	60	40	10.50	16.71	74.55	41.76	1056.80	2537.77	2585.89	7.07
69	2	70	70	9.63	7.90	83.83	47.99	965.09	3120.82	3183.33	7.07
70	2	70	100	9.84	6.81	86.43	51.56	961.92	3318.05	3377.71	7.07
71	2	90	100	9.97	6.87	87.61	52.40	963.78	3370.86	3429.23	7.07
72	2	90	70	10.15	6.93	89.33	53.55	964.89	3450.78	3512.54	7.07
73	1	40	70	10.92	9.74	78.23	50.08	1052.81	3076.59	3115.49	7.84
74	1	60	40	11.97	16.64	72.55	42.92	1101.20	2634.72	2686.19	7.78
75	2	70	100	10.74	7.11	89.90	55.86	973.14	3705.26	3786.43	7.80
76	2	90	70	9.76	15.55	79.94	37.97	993.20	2785.84	2862.14	7.78
77	1	40	40	11.21	9.71	78.41	52.26	1056.60	3228.71	3267.50	8.51
78	1	40	70	11.12	9.65	78.42	52.44	1052.82	3245.65	3283.34	8.48

79	1	60	70	11.02	9.62	78.35	52.37	1049.84	3239.77	3275.58	8.47
80	1	60	40	11.07	9.63	78.92	52.80	1051.07	3272.21	3308.76	8.46
81	2	70	70	11.28	7.34	90.70	57.35	982.22	3796.34	3810.04	8.46
82	2	70	100	10.98	6.94	92.10	57.72	972.57	3820.01	3827.94	8.46
83	2	90	100	10.94	6.90	91.93	57.70	972.04	3820.15	3827.98	8.46
84	2	90	70	10.96	6.89	91.91	57.72	971.81	3819.86	3827.72	8.46
85	1	60	70	9.92	21.58	66.29	33.48	1038.29	2081.25	2134.84	7.07
86	1	60	40	10.12	21.01	73.77	38.36	1047.87	2354.87	2404.89	7.08
87	1	40	40	9.14	19.35	75.35	38.62	1013.12	2362.75	2408.71	7.08
88	1	40	70	8.24	19.57	69.45	33.79	992.35	2102.78	2151.26	7.07
89	2	90	100	7.34	19.86	74.79	30.14	940.92	2217.31	2292.08	7.07
90	2	90	70	7.45	19.62	75.86	30.69	942.84	2244.10	2319.37	7.07
91	2	60	70	6.95	18.18	74.96	30.96	927.13	2232.37	2306.51	7.07
92	2	60	100	6.56	17.58	73.73	30.21	921.41	2200.70	2274.68	7.08
93	1	60	70	11.72	21.31	61.28	33.26	1103.03	2090.99	2152.36	7.77
94	2	90	100	9.21	20.77	72.78	27.85	1004.29	2255.85	2330.06	7.77
95	1	60	70	13.00	14.19	65.26	40.69	1138.68	2495.04	2553.71	8.44
96	1	60	40	13.93	13.12	72.52	47.50	1160.57	2918.17	2971.98	8.44
97	2	90	100	10.46	13.53	73.53	34.17	1030.56	2642.39	2715.90	8.44
98	2	90	70	10.85	10.72	74.35	35.90	1037.09	2754.70	2829.80	8.44
99	1	40	40	8.23	26.42	90.99	43.80	984.87	2655.17	2693.03	4.19
100	1	40	70	8.15	26.72	88.86	40.84	987.54	2473.39	2514.47	4.21
101	1	60	70	8.67	27.11	87.88	40.95	1005.38	2480.24	2523.73	4.20
102	1	60	40	9.29	27.24	92.58	44.28	1018.94	2686.53	2726.62	4.20
103	2	70	70	7.62	26.87	93.26	42.66	932.59	2603.37	2668.86	4.20
104	2	70	100	7.28	26.81	91.59	41.05	926.74	2510.11	2578.61	4.20
105	2	90	100	7.34	26.85	91.20	41.08	929.93	2508.90	2579.23	4.20
106	2	90	70	7.65	26.90	93.07	42.54	934.34	2595.77	2663.00	4.20

107	1	40	70	9.82	25.73	85.05	41.02	1039.68	2484.61	2531.49	4.94
108	1	60	40	11.25	26.74	89.14	44.99	1080.98	2729.06	2774.81	4.92
109	2	70	100	8.74	26.36	88.96	39.37	973.62	2557.09	2629.65	4.91
110	2	90	70	9.23	26.34	90.50	40.92	982.73	2641.41	2713.17	4.90
111	1	40	70	10.75	24.68	82.28	41.22	1068.85	2497.02	2548.39	5.64
112	1	60	40	12.30	25.77	86.72	45.53	1116.56	2766.53	2815.53	5.62
113	2	70	100	9.73	25.39	86.90	38.01	1004.13	2596.16	2669.19	5.62
114	2	90	70	10.11	25.24	88.38	39.49	1012.20	2680.57	2754.28	5.61
115	1	40	70	11.27	23.43	80.26	41.38	1083.56	2507.65	2559.55	6.36
116	1	60	40	12.88	24.46	84.66	45.78	1133.49	2782.71	2834.39	6.34
117	2	70	100	10.20	24.06	85.19	37.41	1020.02	2622.89	2697.40	6.33
118	2	90	70	10.58	23.82	86.74	38.89	1028.38	2714.54	2790.62	6.33
119	1	40	40	12.30	19.35	82.14	45.79	1111.30	2779.10	2829.89	7.05
120	1	40	70	11.52	20.48	77.47	41.99	1091.79	2540.15	2592.83	7.03
121	1	60	70	12.58	21.92	76.01	41.96	1127.24	2540.80	2598.52	7.02
122	1	60	40	13.30	21.52	80.82	45.97	1145.93	2798.05	2852.31	7.02
123	2	70	70	10.85	20.81	83.56	38.52	1035.35	2745.50	2820.45	7.02
124	2	70	100	10.29	20.98	81.93	36.21	1023.76	2626.34	2701.47	7.01
125	2	90	100	10.43	21.31	81.79	35.94	1028.36	2623.48	2699.29	7.01
126	2	90	70	10.91	20.57	83.38	38.05	1038.47	2738.89	2815.07	7.08
127	1	40	70	11.96	14.59	70.69	41.90	1102.50	2536.70	2594.06	7.81
128	1	60	40	13.66	15.95	75.78	46.50	1154.36	2835.34	2891.06	7.79
129	2	70	100	10.85	17.81	78.24	36.31	1039.54	2698.44	2773.07	7.79
130	2	90	70	10.97	16.49	79.16	36.95	1040.67	2746.52	2822.54	7.78
131	1	40	40	13.24	12.41	70.69	46.51	1134.62	2825.69	2885.02	8.47
132	1	40	70	12.20	11.72	66.31	42.08	1106.79	2556.13	2615.17	8.45
133	1	60	70	13.20	13.00	65.89	42.04	1143.15	2559.57	2621.54	8.45
134	1	60	40	14.11	13.42	71.03	46.72	1165.83	2844.26	2903.90	8.44

135	2	70	70	11.51	12.28	75.75	37.36	1051.39	2835.68	2912.41	8.44
136	2	70	100	10.96	13.89	74.84	35.31	1042.12	2715.16	2791.70	8.44
137	2	90	100	11.11	14.34	75.04	35.10	1047.17	2712.98	2789.51	8.43
138	2	90	70	11.54	12.19	75.87	36.87	1055.36	2829.37	2906.70	8.43
139	1	60	70	12.56	21.91	74.10	41.54	1123.79	2526.87	2581.74	7.07
140	1	60	40	13.05	20.31	81.24	46.16	1136.57	2821.56	2873.54	7.07
141	1	40	40	12.08	18.09	81.95	46.24	1101.65	2822.88	2870.26	7.07
142	1	40	70	10.95	19.32	75.42	40.80	1074.21	2486.80	2538.06	7.07
143	2	90	100	10.07	19.97	81.58	36.69	1015.62	2630.81	2705.81	7.07
144	2	90	70	10.36	19.58	82.71	37.46	1020.57	2676.59	2752.48	7.07
145	2	60	70	10.01	18.73	82.21	37.73	1009.62	2671.59	2746.50	7.07
146	2	60	100	9.81	18.85	81.68	37.23	1006.77	2644.65	2719.67	7.07
147	1	60	70	13.08	19.22	70.79	41.61	1141.27	2534.38	2589.64	7.77
148	2	90	100	10.40	18.12	77.70	34.84	1029.55	2609.26	2682.84	7.77
149	1	60	70	14.59	14.21	74.40	48.80	1179.69	3001.14	3053.08	8.44
150	1	60	40	15.18	14.14	80.46	53.68	1194.81	3345.33	3390.11	8.44
151	2	90	100	12.29	10.95	80.95	42.31	1070.54	3132.53	3200.48	8.44
152	2	90	70	12.60	10.51	80.96	43.56	1072.34	3237.19	3306.18	8.44
153	1	30	40	9.04	26.92	101.48	51.03	1004.99	3135.86	3163.70	4.21
154	1	40	70	9.55	27.58	100.57	47.68	1026.16	2906.97	2939.87	4.21
155	1	60	70	9.98	27.86	99.09	47.49	1041.69	2896.27	2931.11	4.21
156	1	60	40	10.64	27.98	103.98	51.13	1059.00	3142.62	3174.53	4.21
157	2	60	60	8.73	27.33	105.68	50.42	956.22	3106.60	3157.25	4.20
158	2	60	100	8.13	27.25	102.06	47.48	944.06	2907.16	2963.86	4.21
159	2	90	100	8.32	27.33	101.40	47.49	949.19	2907.33	2964.38	4.20
160	2	90	60	8.86	27.38	105.05	50.28	959.59	3095.98	3149.08	4.20
161	1	40	70	10.84	26.20	96.90	47.66	1067.55	2905.58	2943.80	4.92
162	1	60	40	12.29	27.33	101.83	51.99	1112.15	3200.97	3235.94	4.90

163	2	60	100	10.06	26.42	98.16	47.76	1000.01	2951.39	3015.76	4.90
164	2	90	60	10.88	26.39	101.43	50.67	1017.82	3139.90	3203.14	4.90
165	1	40	70	11.46	24.86	93.93	48.10	1086.42	2932.77	2972.56	5.63
166	1	60	40	13.08	26.04	98.93	52.30	1137.56	3227.83	3264.78	5.60
167	2	60	100	10.64	24.97	95.38	46.21	1022.42	2968.91	3035.87	5.61
168	2	90	60	11.62	24.93	98.99	49.57	1043.62	3179.62	3243.32	5.60
169	1	40	70	11.92	22.41	90.81	48.23	1101.05	2940.30	2981.28	6.35
170	1	60	40	13.61	23.54	95.59	52.58	1152.45	3249.12	3287.15	6.33
171	2	60	100	11.00	22.15	92.54	45.52	1032.08	3004.61	3070.78	6.32
172	2	90	60	12.06	21.28	95.45	48.64	1055.01	3222.12	3287.33	6.32
173	1	30	50	12.59	16.29	86.08	50.40	1117.45	3087.65	3128.22	7.04
174	1	40	70	13.43	18.87	83.81	48.80	1148.97	2982.18	3029.06	7.03
175	1	60	70	13.75	19.97	83.79	48.70	1159.95	2977.12	3025.18	7.02
176	1	60	40	13.96	18.69	89.59	52.81	1161.93	3264.53	3305.22	7.02
177	2	60	60	12.21	16.89	91.45	48.23	1057.37	3273.75	3338.96	7.02
178	2	60	100	11.07	17.33	87.11	43.91	1034.18	3014.95	3082.34	7.05
179	2	90	100	11.44	18.15	87.56	43.74	1046.68	3032.71	3100.96	7.06
180	2	90	60	12.39	17.97	91.60	47.53	1066.61	3262.16	3327.86	7.06
181	1	40	70	12.84	12.26	77.39	48.66	1123.84	2972.88	3020.63	7.87
182	1	60	40	14.63	13.86	83.53	53.33	1178.50	3307.89	3351.36	7.83
183	1	60	70	14.15	21.10	82.67	48.81	1168.09	2977.62	3024.13	7.07
184	1	60	40	14.45	19.27	90.75	53.20	1176.19	3298.90	3339.89	7.07
185	1	40	40	13.65	17.42	91.64	53.33	1146.94	3302.64	3340.57	7.08
186	1	40	70	12.49	17.98	84.83	48.30	1118.19	2955.09	2998.11	7.07
187	2	90	100	12.06	18.31	89.67	45.33	1061.14	3127.05	3194.58	7.07
188	2	90	70	12.23	17.85	90.30	45.70	1063.57	3161.00	3228.93	7.07
189	2	60	70	11.95	17.18	89.90	45.91	1054.14	3151.44	3218.09	7.07
190	2	60	100	11.42	17.77	88.11	43.98	1043.62	3030.99	3098.98	7.07

191	1	60	70	14.24	15.54	78.38	48.61	1174.03	2974.68	3024.72	7.77
192	2	90	100	12.12	15.34	84.56	42.62	1067.52	3070.46	3137.78	7.77
193	2	90	70	12.63	13.19	86.09	44.85	1075.70	3226.38	3293.26	7.77
194	1	40	70	6.12	24.63	77.81	33.40	928.11	2070.92	2111.08	4.94
195	1	60	40	7.59	25.26	81.27	37.20	975.87	2278.76	2321.59	4.94
196	2	60	100	4.00	24.25	82.30	33.13	845.12	2085.40	2151.41	4.94
197	2	90	60	5.20	24.47	84.89	35.87	872.45	2228.06	2294.49	4.94
198	1	40	70	6.13	22.58	76.64	33.50	932.00	2080.70	2122.93	5.65
199	1	60	40	8.45	24.13	79.38	37.62	1000.42	2299.86	2345.09	5.63
200	2	60	100	4.62	22.72	79.85	33.12	860.20	2092.58	2161.37	5.61
201	2	90	60	5.71	22.95	82.38	35.64	887.52	2240.60	2309.83	5.60
202	1	40	70	6.52	21.12	74.11	33.61	942.46	2085.41	2129.55	6.36
203	1	60	40	8.86	22.95	77.32	37.76	1012.53	2307.86	2353.81	6.30
204	2	60	100	4.85	20.63	77.46	32.05	867.95	2101.89	2170.01	6.30
205	2	90	60	6.02	20.81	79.95	34.59	897.25	2258.33	2326.95	6.32
206	1	30	40	5.79	15.19	75.97	37.23	917.91	2273.07	2312.63	7.02
207	1	60	70	8.50	20.63	69.84	34.31	1005.01	2120.60	2170.24	7.02
208	2	60	60	5.89	16.47	76.06	34.45	889.20	2278.29	2346.51	7.02
209	2	60	100	4.96	16.90	73.73	31.15	871.70	2123.78	2192.84	7.03
210	2	90	100	5.46	18.47	73.66	29.93	888.35	2113.56	2184.10	7.01
211	2	90	60	6.39	17.90	76.69	33.61	906.86	2282.96	2353.72	7.02
212	1	40	70	7.15	14.69	66.60	34.00	959.56	2105.76	2152.12	7.74
213	1	60	40	9.89	17.43	70.73	38.73	1040.31	2363.39	2413.28	7.74
214	2	60	100	5.31	13.57	69.92	29.98	880.58	2137.39	2206.51	7.74
215	2	90	60	6.61	14.01	72.63	32.79	913.01	2309.30	2380.50	7.73
216	1	30	40	6.50	6.00	63.78	37.82	935.79	2315.69	2358.97	8.44
217	1	60	70	9.24	14.25	60.92	34.39	1024.18	2139.76	2193.79	8.44
218	2	60	60	6.33	5.55	66.67	32.52	902.31	2343.21	2412.90	8.44

219	2	60	100	5.15	7.99	64.22	28.77	877.94	2154.41	2224.08	8.44
220	2	90	100	5.84	10.83	65.60	28.24	901.83	2162.80	2234.19	8.44
221	2	90	60	6.90	8.47	67.94	31.91	920.46	2352.15	2424.22	8.44
222	1	60	70	5.69	24.43	70.49	32.51	891.64	2013.94	2051.30	4.17
223	1	60	40	6.01	25.95	83.55	36.84	927.09	2262.29	2301.38	4.16
224	1	40	70	4.23	25.50	82.05	33.20	878.76	2068.59	2105.54	4.16
225	2	90	100	2.97	25.42	84.60	33.07	819.12	2075.57	2138.13	4.19
226	2	90	60	3.54	25.45	87.87	35.55	829.61	2205.92	2266.64	4.19
227	2	60	100	2.43	25.26	85.69	32.85	806.75	2065.41	2126.87	4.20
228	1	60	70	8.32	27.45	86.88	40.82	984.56	2471.91	2506.42	4.19
229	1	60	40	8.03	26.93	94.99	43.99	982.25	2671.43	2708.02	4.20
230	1	40	70	6.20	26.45	92.63	40.32	930.10	2450.59	2486.19	4.20
231	2	90	100	4.54	26.18	93.62	39.49	853.04	2417.39	2475.86	4.20
232	2	90	60	5.33	26.27	99.28	43.39	866.97	2651.67	2704.29	4.19
233	2	60	100	3.96	25.96	94.76	39.27	838.69	2401.60	2458.20	4.19
234	1	60	70	8.91	25.68	88.08	41.43	1010.50	2518.99	2560.85	4.91
235	1	60	40	9.52	26.30	92.13	44.45	1026.66	2706.12	2745.62	4.90
236	2	90	100	6.13	25.20	90.48	39.82	895.79	2446.80	2511.89	4.90
237	2	90	60	7.03	25.11	95.43	43.72	913.89	2677.72	2739.16	4.90
238	1	60	70	9.64	24.33	84.86	41.00	1031.61	2492.51	2538.56	5.66
239	1	60	40	10.27	25.01	89.52	44.64	1049.93	2718.00	2760.36	5.60
240	2	90	100	6.83	23.50	87.68	39.88	914.75	2458.31	2528.28	5.65
241	2	90	60	7.61	23.39	91.74	43.29	931.29	2657.44	2723.60	5.61
242	1	60	70	10.05	23.13	82.60	41.19	1045.61	2505.87	2553.87	6.36
243	1	60	40	10.89	23.45	88.37	45.58	1069.41	2777.38	2820.55	6.30
244	2	90	100	7.20	20.81	84.66	38.98	925.11	2472.16	2543.20	6.35
245	2	90	60	8.16	20.24	88.05	43.16	945.49	2686.18	2755.19	6.33
246	1	60	70	10.41	20.71	79.01	41.17	1055.77	2504.43	2554.44	7.06

247	1	60	40	11.17	20.35	83.30	45.13	1077.80	2753.30	2799.63	7.03
248	1	40	70	8.56	18.34	80.16	41.07	997.60	2498.66	2542.14	7.00
249	2	90	100	7.46	16.67	80.47	38.30	933.85	2525.94	2597.38	7.07
250	2	90	60	8.41	16.02	83.55	41.85	952.50	2718.48	2788.14	7.07
251	2	60	100	6.87	15.26	79.89	38.74	915.46	2506.19	2576.93	7.09
252	1	60	70	10.94	16.83	74.85	42.26	1071.40	2571.19	2622.85	7.79
253	1	60	40	11.63	14.99	78.05	45.75	1090.58	2788.86	2836.21	7.75
254	2	90	100	7.59	12.88	76.01	36.75	938.20	2525.44	2596.92	7.76
255	2	90	60	8.59	10.99	78.88	40.72	956.52	2756.18	2824.99	7.75
256	1	60	70	11.08	11.70	69.02	41.58	1075.39	2533.70	2587.49	8.47
257	1	60	40	12.21	11.51	73.07	46.59	1104.95	2847.03	2897.00	8.43
258	1	40	70	9.14	8.68	67.73	41.47	1010.47	2523.85	2571.31	8.51
259	2	90	100	7.58	6.52	70.07	35.53	937.92	2549.81	2620.35	8.50
260	2	90	60	8.67	6.77	73.05	39.39	958.19	2787.34	2855.83	8.50
261	2	60	100	7.11	5.56	69.54	36.27	919.86	2562.98	2632.08	8.50

Testing Data for System C (Finned Tube Condenser and Fixed Orifice Device)

Test number	Compressor Stage	Indoor Fan Speed [%]	Outdoor Fan Speed [%]	Evaporator Refrigerant Inlet Temperature [^{o}C]	Compressor Suction Temperature [^{o}C]	Compressor Discharge Temperature [^{o}C]	Condenser Refrigerant Outlet Temperature [^{o}C]	Compressor Suction Pressure [kPa]	Compressor Discharge Pressure [kPa]	Liquid Line Pressure [kPa]	Actual Charge [lbs]
0	1	60	70	10.96	10.78	42.06	23.44	1084.87	1885.87	1940.63	18.55
1	1	30	70	8.42	8.32	39.52	22.47	991.65	1843.74	1894.29	18.55

2	1	30	40	9.33	8.14	38.57	21.42	984.09	2054.36	2113.33	18.55
3	1	60	40	12.03	10.69	40.06	21.24	1059.68	2138.61	2206.00	18.55
4	2	90	100	7.86	20.11	64.6	22.3	966.45	2029.08	2083.84	18.55
5	2	50	100	7.02	15.12	63.26	22.3	943.78	1995.38	2050.14	18.55
6	2	50	70	7.21	7.86	58.49	22.39	946.29	2058.57	2113.33	18.55
7	2	90	70	8.32	14.33	61.42	22.47	979.05	2083.84	2138.61	18.55
8	1	60	70	5.99	25.13	59.66	24.6	918.58	1679.46	1725.80	9.31
9	1	40	70	5.61	24.69	61.78	24.33	911.02	1654.18	1704.74	9.31
10	1	40	40	8.14	24.15	66.62	30.15	989.13	1932.20	1982.75	9.31
11	1	60	40	9.33	24.78	66.82	30.62	1024.40	1953.27	2003.81	9.31
12	2	90	100	2.49	25.04	71.74	23.71	812.76	1692.10	1746.85	9.31
13	2	50	100	2.38	24.69	71.98	23.62	807.72	1683.67	1738.44	9.31
14	2	50	70	2.98	24.6	72.96	24.15	822.83	1742.65	1801.62	9.31
15	2	90	70	3.18	24.87	72.72	23.62	827.87	1730.01	1788.98	9.31
16	1	60	70	9.24	24.15	60.36	27.02	1026.92	1991.17	1826.89	10.75
17	1	30	70	6.84	22.91	62.32	26.21	956.37	1986.97	1780.55	10.75
18	1	30	40	7.77	20.54	64.02	29.32	979.05	1978.54	1936.41	10.75
19	1	60	40	10.24	22.56	62.32	30.06	1054.64	1970.11	1986.97	10.75
20	2	90	100	4.36	24.42	71.74	24.15	860.63	1965.90	1873.23	10.75
21	2	50	100	4.16	24.24	72.72	24.24	855.58	1953.27	1864.81	10.75
22	2	50	70	4.84	24.15	73.46	24.78	873.23	1881.65	1927.98	10.75
23	2	90	70	5.23	24.87	73.46	24.69	884.56	1890.08	1940.63	10.75
24	1	60	70	10.33	21.68	56.55	27.21	1062.20	1801.62	1856.38	12.38
25	1	30	70	7.58	17.31	56.55	26.48	976.53	1788.98	1805.83	12.38
26	1	30	40	8.42	8.6	53.37	29.87	994.17	1915.35	1974.32	12.38
27	1	60	40	10.78	16	54.7	30.44	1072.27	1965.90	2020.66	12.38
28	2	90	100	5.03	22.83	69.2	23.27	883.31	1869.01	1915.35	12.38
29	2	50	100	5.03	23.44	71.27	23.27	880.79	1856.38	1902.71	12.38

30	2	50	70	5.8	23.27	71.74	23.89	900.94	1915.35	1965.90	12.38
31	2	90	70	6.37	24.15	72.23	23.8	918.58	1936.41	1982.75	12.38
32	1	60	70	10.96	11.14	45.93	24.07	1084.87	1856.38	1911.14	16.69
33	1	30	70	8.51	8.14	40.72	25.04	1006.76	1805.83	1860.59	16.69
34	1	30	40	9.15	8.42	39.1	22.65	989.13	2008.02	2062.78	16.69
35	1	60	40	11.76	11.05	40.83	22.3	1064.72	2088.06	2151.24	16.69
36	2	90	100	7.3	21.68	65.8	22.47	948.81	1982.75	2033.30	16.69
37	2	50	100	6.65	19.84	67.46	22.56	933.70	1953.27	1999.60	16.69
38	2	50	70	6.93	14.77	63.83	22.65	941.26	2008.02	2062.78	16.69
39	2	90	70	7.86	18.88	65.8	22.56	968.97	2033.30	2088.06	16.69
40	1	60	70	12.48	12.3	50.02	31	1110.07	2311.31	2361.86	18.55
41	1	30	70	10.33	9.69	47.17	30.72	1031.97	2264.97	2311.31	18.55
42	1	30	40	11.23	9.79	47.17	29.97	1029.44	2505.08	2564.05	18.55
43	1	60	40	13.54	12.12	49.62	30.06	1102.51	2580.90	2648.30	18.55
44	2	90	100	9.79	16.7	70.56	30.91	1011.80	2458.74	2513.50	18.55
45	2	50	100	8.87	9.06	67.24	30.81	981.57	2433.47	2488.23	18.55
46	2	50	70	9.24	7.58	63.64	31	984.09	2513.50	2568.27	18.55
47	2	90	70	10.15	9.06	66.41	31	1016.84	2538.78	2597.75	18.55
48	1	60	70	6.27	26.12	73.21	31.86	933.70	2008.02	2045.94	9.31
49	1	40	70	5.32	25.94	76.91	31.95	904.72	2008.02	2041.72	9.31
50	1	40	40	8.97	25.49	78.93	37.31	1006.76	2290.25	2332.37	9.31
51	1	60	40	9.88	26.03	78.93	37.73	1037.00	2315.53	2357.64	9.31
52	2	90	100	4.45	26.03	81.39	32.24	855.58	2045.94	2100.70	9.31
53	2	50	100	4.26	25.67	81.07	31.86	848.03	2029.08	2083.84	9.31
54	2	50	70	4.94	25.49	81.71	32.62	863.15	2083.84	2138.61	9.31
55	2	90	70	5.03	25.76	81.07	32.24	868.19	2075.42	2130.18	9.31
56	1	60	70	10.375	25.76	71.98	35.38	1054.64	2197.58	2239.70	10.75
57	1	30	70	8.32	24.6	74.75	34.78	994.17	2172.31	2193.37	10.75

58	1	30	40	9.33	22.91	76.91	37.83	1024.40	2159.67	2370.28	10.75
59	1	60	40	11.59	24.24	75.28	38.46	1089.92	2147.03	2420.83	10.75
60	2	90	100	6.84	25.49	81.71	33.45	918.58	2134.40	2298.67	10.75
61	2	50	100	6.55	25.22	82.36	33.59	911.02	2130.18	2286.04	10.75
62	2	50	70	7.12	24.96	83.02	34.48	926.14	2121.75	2357.64	10.75
63	2	90	70	7.58	25.67	83.02	34.28	938.74	2117.54	2370.28	10.75
64	1	60	70	11.76	23.18	67.24	35.38	1097.48	2197.58	2243.91	12.38
65	1	30	70	9.33	20.89	70.1	34.98	1021.88	2176.51	2214.43	12.38
66	1	30	40	10.15	15.04	69.2	38.35	1042.04	2357.64	2399.77	12.38
67	1	60	40	12.48	18.53	68.1	39.1	1117.63	2399.77	2450.31	12.38
68	2	90	100	7.77	23.98	78.93	32.24	948.81	2294.47	2340.80	12.38
69	2	50	100	7.49	24.07	80.44	32.33	938.74	2273.40	2319.74	12.38
70	2	50	70	7.95	23.36	80.76	33.3	953.85	2340.80	2391.34	12.38
71	2	90	70	8.6	24.42	81.07	33.11	971.49	2361.86	2408.20	12.38
72	1	60	70	12.3	16.87	61.78	36.28	1117.63	2252.34	2302.88	13.95
73	1	30	70	9.97	12.57	61.6	35.88	1042.04	2218.64	2264.97	13.95
74	1	30	40	10.78	10.06	59.15	39.2	1059.68	2412.41	2462.96	13.95
75	1	60	40	12.92	12.12	59.66	39.96	1130.22	2462.96	2521.93	13.95
76	2	90	100	8.6	22.74	77.2	32.43	971.49	2366.07	2416.62	13.95
77	2	50	100	8.14	22.12	78.93	32.72	961.41	2345.01	2395.56	13.95
78	2	50	70	8.51	20.02	78.34	33.59	968.97	2408.20	2462.96	13.95
79	2	90	70	9.15	22.21	79.23	33.4	991.65	2429.26	2484.01	13.95
80	1	60	70	12.66	12.21	55.61	34.98	1127.71	2273.40	2328.16	15.51
81	1	30	70	10.42	9.69	52.79	35.78	1052.12	2222.85	2273.40	15.51
82	1	30	40	10.96	9.97	53.66	38.14	1057.16	2416.62	2471.38	15.51
83	1	60	40	13.1	12.3	56.23	37.93	1135.26	2484.01	2542.99	15.51
84	2	90	100	9.15	22.03	75.01	31.57	991.65	2382.92	2433.47	15.51
85	2	50	100	8.51	19.76	76.36	31.76	974.02	2357.64	2408.20	15.51

86	2	50	70	8.87	15.65	73.97	32.43	981.57	2433.47	2488.23	15.51
87	2	90	70	9.6	19.23	75.55	32.33	1004.25	2454.53	2513.50	15.51
88	1	60	70	12.21	11.68	51.11	33.01	1112.59	2264.97	2315.53	16.69
89	1	30	70	9.97	9.24	48.18	32.43	1029.44	2235.48	2277.61	16.69
90	1	30	40	10.96	9.88	47.42	31.57	1029.44	2462.96	2521.93	16.69
91	1	60	40	13.19	12.3	49.75	31.57	1102.51	2530.36	2593.54	16.69
92	2	90	100	9.24	20.54	73.21	30.91	994.17	2399.77	2450.31	16.69
93	2	50	100	8.51	15.21	71.74	31	971.49	2374.50	2425.04	16.69
94	2	50	70	8.87	9.15	68.32	31.38	976.53	2450.31	2505.08	16.69
95	2	90	70	9.69	15.3	71.03	31.28	1006.76	2471.38	2526.14	16.69
96	1	60	70	14.07	13.36	57.18	38.46	1147.87	2745.18	2795.73	18.55
97	1	30	70	12.03	10.96	55.15	37.93	1074.79	2690.43	2740.97	18.55
98	1	30	40	12.92	11.23	54.85	38.04	1079.83	2947.37	3002.13	18.55
99	1	60	40	14.815	13.45	58.235	38.46	1147.87	3010.56	3073.74	18.55
100	2	90	100	11.59	13.28	75.82	38.25	1049.60	2892.61	2947.37	18.55
101	2	50	100	10.87	8.97	73.72	38.14	1024.40	2867.34	2922.10	18.55
102	2	50	70	11.23	9.06	71.5	38.57	1029.44	2955.80	3014.77	18.55
103	2	90	70	11.94	9.97	73.21	38.57	1057.16	2981.07	3040.04	18.55
104	1	60	70	5.7	27.39	88.85	39.42	911.02	2391.34	2420.83	9.31
105	1	40	70	5.23	27.12	91.77	38.99	900.94	2366.07	2395.56	9.31
106	1	40	40	9.69	26.84	92.2	44.19	1026.92	2686.21	2724.13	9.31
107	1	60	40	10.42	27.21	91.77	44.37	1047.08	2694.63	2732.54	9.31
108	2	90	100	4.16	26.93	93.55	38.99	837.95	2389.24	2433.47	9.31
109	2	50	100	3.48	26.84	95.43	39.31	817.80	2408.20	2450.31	9.31
110	2	50	70	5.32	26.66	94.48	40.28	863.15	2462.96	2509.30	9.31
111	2	90	70	5.89	26.84	93.09	40.17	880.79	2462.96	2513.50	9.31
112	1	60	70	11.05	27.02	85.09	42.4	1072.27	2576.69	2614.60	10.75
113	1	30	70	9.33	26.03	86.92	41.83	1019.36	2542.99	2576.69	10.75

114	1	30	40	10.51	24.24	88.85	44.84	1052.12	2728.33	2762.03	10.75
115	1	60	40	12.48	25.49	87.3	45.44	1115.11	2770.46	2812.58	10.75
116	2	90	100	8.87	26.3	90.91	42.17	968.97	2648.30	2703.06	10.75
117	2	50	100	8.6	26.03	91.33	42.28	956.37	2631.45	2682.00	10.75
118	2	50	70	9.15	25.67	92.2	43.31	968.97	2703.06	2757.82	10.75
119	2	90	70	9.51	26.39	92.65	42.97	984.09	2719.91	2774.67	10.75
120	1	60	70	12.57	24.15	78.05	43.2	1120.15	2635.66	2677.78	12.38
121	1	30	70	10.51	22.03	81.39	42.51	1054.64	2593.54	2627.24	12.38
122	1	30	40	11.41	15.21	80.44	45.81	1077.31	2799.94	2833.64	12.38
123	1	60	40	13.36	19.58	80.14	46.3	1142.83	2833.64	2879.97	12.38
124	2	90	100	9.79	24.24	87.68	40.83	996.69	2715.70	2762.03	12.38
125	2	50	100	9.42	23.98	88.85	41.05	984.09	2690.43	2740.97	12.38
126	2	50	70	9.88	22.91	89.26	42.28	994.17	2770.46	2821.00	12.38
127	2	90	70	10.51	24.42	89.66	41.94	1014.32	2787.30	2842.07	12.38
128	1	60	70	13.45	13.98	70.33	43.66	1145.35	2665.14	2711.48	13.95
129	1	30	70	11.32	10.78	69.65	43.2	1074.79	2635.66	2677.78	13.95
130	1	30	40	12.21	11.23	68.53	46.42	1094.96	2850.49	2892.61	13.95
131	1	60	40	14.25	13.45	70.33	47.04	1165.50	2896.83	2947.37	13.95
132	2	90	100	10.42	23.44	85.09	40.39	1016.84	2783.10	2829.43	13.95
133	2	50	100	10.06	20.81	86.55	40.61	1001.73	2762.03	2808.37	13.95
134	2	50	70	10.42	18.27	85.45	41.61	1009.28	2850.49	2896.83	13.95
135	2	90	70	11.05	21.59	86.92	41.38	1031.97	2871.56	2917.89	13.95
136	1	60	70	13.72	12.83	62.32	43.78	1150.39	2698.84	2753.61	15.51
137	1	30	70	11.59	10.69	62.14	43.43	1082.35	2656.73	2707.27	15.51
138	1	30	40	12.57	11.14	61.24	45.56	1087.40	2896.83	2947.37	15.51
139	1	60	40	14.42	13.19	64.02	46.3	1160.46	2938.96	2993.71	15.51
140	2	90	100	10.78	20.98	82.69	39.96	1029.44	2821.00	2871.56	15.51
141	2	50	100	10.24	16.09	81.71	39.96	1009.28	2799.94	2850.49	15.51

142	2	50	70	10.6	12.66	80.14	40.72	1014.32	2892.61	2938.96	15.51
143	2	90	70	11.32	17.05	82.36	40.61	1042.04	2913.67	2964.23	15.51
144	1	60	70	13.63	12.74	58.82	40.83	1142.83	2703.06	2753.61	16.69
145	1	30	70	11.76	10.69	56.7	40.06	1069.75	2669.36	2715.70	16.69
146	1	30	40	12.57	11.14	55.92	40.17	1074.79	2922.10	2972.64	16.69
147	1	60	40	14.51	13.19	60.01	41.27	1145.35	2993.71	3048.47	16.69
148	2	90	100	11.05	17.095	79.83	39.2	1037.00	2863.13	2913.67	16.69
149	2	50	100	10.42	11.76	77.76	39.31	1011.80	2837.86	2892.61	16.69
150	2	50	70	10.78	8.78	75.55	39.74	1016.84	2934.74	2985.29	16.69
151	2	90	70	11.59	12.57	78.34	39.85	1044.56	2955.80	3010.56	16.69
152	1	60	70	15.48	13.98	64.8	45.93	1173.06	3238.03	3288.57	18.55
153	1	30	70	13.89	12.12	62.69	45.44	1112.59	3195.90	3238.03	18.55
154	1	60	55	15.74	14.07	64.8	45.81	1175.58	3334.91	3385.46	18.55
155	2	90	100	13.36	11.14	83.02	45.68	1087.40	3381.25	3431.79	18.55
156	2	50	100	12.66	10.24	80.76	45.56	1064.72	3351.76	3406.52	18.55
157	2	90	70	13.81	11.23	81.71	46.05	1097.48	3482.34	3541.32	18.55
158	1	60	70	7.77	28.95	106.18	48.18	961.41	2938.96	2960.01	9.31
159	1	30	70	7.3	28.49	107.53	47.93	951.33	2922.10	2943.16	9.31
160	1	30	40	10.24	28.12	107.53	51.11	1039.52	3136.93	3162.20	9.31
161	1	60	40	10.96	28.58	106.18	51.24	1059.68	3149.57	3174.84	9.31
162	2	90	100	1.47	28.67	119.87	48.18	757.33	2938.96	2964.23	9.31
163	2	50	100	1.17	28.58	120.86	48.05	749.77	2934.74	2960.01	9.31
164	2	50	70	3.18	28.49	119.87	49.35	797.63	3023.20	3048.47	9.31
165	2	90	70	3.08	28.58	118.89	49.35	797.63	3027.41	3048.47	9.31
166	1	60	70	11.85	28.21	96.92	49.49	1092.44	3023.20	3056.90	10.75
167	1	30	70	10.6	27.39	99.55	48.96	1054.64	2989.50	3014.77	10.75
168	1	30	40	11.94	25.85	101.23	51.8	1094.96	3187.47	3216.96	10.75
169	1	60	40	13.54	27.12	100.1	52.36	1147.87	3229.60	3259.09	10.75

170	2	90	100	10.69	27.48	103	50.02	1009.28	3086.39	3136.93	10.75
171	2	50	100	10.06	27.21	103	49.82	989.13	3073.74	3124.29	10.75
172	2	50	70	10.78	26.75	103.62	50.97	1006.76	3157.99	3204.33	10.75
173	2	90	70	11.23	27.21	103	50.97	1021.88	3166.42	3216.96	10.75
174	1	60	70	13.63	25.4	91.77	50.56	1147.87	3103.23	3132.72	12.38
175	1	30	70	11.68	23.09	94.48	49.89	1087.40	3052.69	3082.17	12.38
176	1	30	40	12.66	17.84	93.55	53.08	1115.11	3271.73	3301.21	12.38
177	1	60	40	14.51	21.95	93.55	53.51	1175.58	3309.63	3343.33	12.38
178	2	90	100	11.85	25.13	98.47	49.49	1047.08	3191.69	3238.03	12.38
179	2	50	100	11.5	24.07	99.01	49.62	1031.97	3162.20	3216.96	12.38
180	2	50	70	11.85	23	99.55	50.97	1039.52	3254.87	3305.43	12.38
181	2	90	70	12.39	24.87	100.1	50.56	1059.68	3280.15	3326.49	12.38
182	1	60	70	14.51	16.53	81.39	50.56	1175.58	3120.09	3157.99	13.95
183	1	30	70	12.66	12.03	81.07	50.15	1112.59	3082.17	3115.87	13.95
184	1	30	40	13.54	12.48	80.44	53.37	1135.26	3318.06	3351.76	13.95
185	1	60	40	15.39	14.33	81.07	54.25	1195.73	3360.19	3402.30	13.95
186	2	90	100	12.39	23.18	94.95	48.31	1062.20	3242.24	3284.36	13.95
187	2	50	100	11.94	19.84	94.48	48.44	1047.08	3221.17	3263.30	13.95
188	2	50	70	12.3	17.4	93.55	49.49	1052.12	3313.85	3360.19	13.95
189	2	90	70	12.92	20.72	95.92	49.35	1074.79	3334.91	3385.46	13.95
190	1	60	70	15.04	13.89	72.72	51.24	1185.66	3157.99	3208.54	15.51
191	1	30	70	13.1	12.03	72.72	50.56	1122.67	3120.09	3157.99	15.51
192	1	30	40	14.33	12.48	70.33	52.93	1130.22	3368.61	3414.94	15.51
193	1	60	40	15.91	14.33	72.96	54.25	1195.73	3402.30	3448.64	15.51
194	2	90	100	12.74	20.02	91.77	47.8	1074.79	3297.00	3343.33	15.51
195	2	50	100	12.21	15.21	89.66	47.67	1054.64	3271.73	3318.06	15.51
196	2	50	70	12.66	11.68	89.26	48.7	1062.20	3372.82	3423.37	15.51
197	2	90	70	13.28	16.35	91.33	48.57	1087.40	3402.30	3448.64	15.51

198	1	60	70	15.21	13.98	67.24	48.18	1175.58	3183.27	3229.60	16.69
199	1	30	70	13.54	12.12	64.8	47.54	1110.07	3145.36	3187.47	16.69
200	1	60	55	15.48	13.98	67.46	48.7	1178.10	3288.57	3334.91	16.69
201	2	90	100	13.01	16.18	88.46	47.04	1082.35	3343.33	3389.67	16.69
202	2	50	100	12.48	10.96	86.92	46.92	1062.20	3313.85	3364.40	16.69
203	2	90	70	13.63	11.5	88.07	47.93	1094.96	3452.86	3507.62	16.69
204	1	60	70	9.15	8.6	46.3	30.72	994.17	2260.77	2302.88	18.55
205	1	30	70	6.18	5.13	43.66	30.34	898.42	2210.21	2252.34	18.55
206	1	30	40	7.4	5.8	44.25	30.15	916.06	2403.98	2454.53	18.55
207	1	60	40	11.14	9.69	46.3	30.15	1024.40	2509.30	2568.27	18.55
208	2	90	100	6.74	5.23	60.88	30.53	913.54	2361.86	2412.41	18.55
209	2	50	100	5.42	3.58	57.34	31	873.23	2328.16	2374.50	18.55
210	2	50	70	5.7	3.67	56.39	31.38	873.23	2391.34	2441.90	18.55
211	2	90	70	7.12	5.32	59.49	31.47	921.10	2433.47	2488.23	18.55
212	1	60	70	3.38	25.58	74.75	31.38	848.03	1978.54	2008.02	9.31
213	1	40	70	2.49	25.49	80.76	31.38	827.87	1978.54	2003.81	9.31
214	1	40	40	5.99	24.6	82.03	35.98	921.10	2214.43	2248.13	9.31
215	1	60	40	7.77	25.58	81.39	36.8	974.02	2264.97	2302.88	9.31
216	2	90	100	2.28	25.94	87.68	34.28	792.59	2138.61	2180.73	9.31
217	2	50	100	1.27	25.58	90.07	34.38	764.88	2142.81	2180.73	9.31
218	2	50	70	2.08	25.4	90.49	35.48	782.52	2163.88	2243.91	9.31
219	2	90	70	3.38	25.85	89.26	35.78	820.32	2214.43	2264.97	9.31
220	1	60	70	7.21	25.04	74.1	34.68	958.89	2155.45	2189.15	10.75
221	1	30	70	4.16	23.09	79.83	33.89	873.23	2109.12	2134.40	10.75
222	1	30	40	5.32	20.02	80.76	36.69	903.46	2256.55	2286.04	10.75
223	1	60	40	8.97	23.71	78.34	37.83	1011.80	2323.95	2361.86	10.75
224	2	90	100	5.23	23.8	81.07	34.78	873.23	2189.15	2239.70	10.75
225	2	50	100	4.07	22.91	83.02	34.88	840.47	2180.73	2227.07	10.75

226	2	50	70	4.45	22.39	83.7	35.88	848.03	2235.48	2281.83	10.75
227	2	90	70	5.8	23.44	82.69	36.08	885.82	2256.55	2311.31	10.75
228	1	60	70	8.97	21.86	69.87	34.78	1011.80	2159.67	2201.80	12.38
229	1	30	70	5.13	17.31	72.96	34.18	900.94	2125.97	2151.24	12.38
230	1	30	40	6.37	8.42	69.2	37.31	931.18	2294.47	2328.16	12.38
231	1	60	40	10.15	18.1	70.1	38.35	1044.56	2357.64	2399.77	12.38
232	2	90	100	5.7	20.81	77.48	33.79	888.34	2231.28	2277.61	12.38
233	2	50	100	4.75	16.26	75.82	34.48	858.10	2214.43	2248.13	12.38
234	2	50	70	5.13	14.86	75.28	35.38	863.15	2210.21	2315.53	12.38
235	2	90	70	6.27	20.02	78.05	34.68	900.94	2206.00	2345.01	12.38
236	1	60	70	9.6	14.86	62.88	35.48	1034.49	2197.58	2243.91	13.95
237	1	30	70	5.99	6.27	62.69	34.88	923.62	2163.88	2193.37	13.95
238	1	30	40	6.93	6.18	59.15	37.985	946.29	2336.58	2374.50	13.95
239	1	60	40	10.69	10.06	60.88	39.2	1059.68	2412.41	2462.96	13.95
240	2	90	100	6.46	17.75	73.72	33.3	911.02	2290.25	2340.80	13.95
241	2	50	100	5.23	10.06	70.1	33.59	870.71	2264.97	2311.31	13.95
242	2	50	70	5.42	8.23	69.42	34.58	873.23	2328.16	2374.50	13.95
243	2	90	70	6.65	14.77	73.21	34.28	911.02	2357.64	2403.98	13.95
244	1	60	70	10.15	9.6	53.08	35.58	1047.08	2214.43	2264.97	15.51
245	1	30	70	6.18	5.61	53.22	34.98	928.66	2172.31	2210.21	15.51
246	1	30	40	7.4	6.37	48.44	35.07	936.22	2349.23	2395.56	15.51
247	1	60	40	11.14	10.33	54.55	38.46	1067.24	2425.04	2484.01	15.51
248	2	90	100	6.37	13.01	68.75	32.14	905.98	2302.88	2349.23	15.51
249	2	50	100	5.13	3.87	64.41	32.14	870.71	2277.61	2323.95	15.51
250	2	50	70	5.51	3.77	63.26	33.01	875.75	2353.44	2399.77	15.51
251	2	90	70	6.74	9.74	67.88	33.01	916.06	2378.71	2429.26	15.51
252	1	60	70	10.06	9.42	48.96	32.82	1039.52	2218.64	2264.97	16.69
253	1	30	70	6.65	5.99	45.2	31.66	918.58	2184.94	2227.07	16.69

254	1	30	40	7.58	6.27	44.37	31.47	928.66	2374.50	2425.04	16.69
255	1	60	40	11.14	10.24	47.17	31.57	1037.00	2471.38	2526.14	16.69
256	2	90	100	6.65	9.24	65.8	31.38	913.54	2328.16	2374.50	16.69
257	2	50	100	5.32	3.67	60.88	31.38	870.71	2302.88	2349.23	16.69
258	2	50	70	5.61	3.77	59.84	32.24	875.75	2370.28	2420.83	16.69
259	2	90	70	6.93	5.42	63.26	32.05	918.58	2399.77	2450.31	16.69
260	1	60	70	12.3	11.41	55.92	38.25	1082.35	2719.91	2766.24	18.55
261	1	30	70	9.15	7.86	52.22	37.62	971.49	2652.51	2694.63	18.55
262	1	30	40	10.33	8.23	52.5	37.93	991.65	2867.34	2917.89	18.55
263	1	60	40	13.45	11.85	55.46	38.14	1097.48	2972.64	3031.63	18.55
264	2	90	100	8.97	6.84	68.53	38.35	963.93	2808.37	2854.70	18.55
265	2	50	100	7.49	5.23	65.19	38.46	916.06	2745.18	2795.73	18.55
266	2	50	70	7.95	5.42	64.6	38.67	918.58	2833.64	2884.19	18.55
267	2	90	70	9.33	7.02	67.67	38.99	966.45	2879.97	2930.53	18.55
268	1	60	70	5.61	27.48	96.42	41.38	905.98	2509.30	2538.78	9.31
269	1	40	70	4.94	27.21	97.43	40.94	885.82	2479.80	2509.30	9.31
270	1	40	40	7.86	26.39	96.42	44.01	971.49	2673.57	2703.06	9.31
271	1	60	40	9.15	27.12	94.48	44.48	1009.28	2698.84	2728.33	9.31
272	2	90	100	1.17	27.3	104.24	41.38	754.81	2526.14	2551.41	9.31
273	2	50	100	0.55	26.93	105.52	41.16	739.68	2513.50	2542.99	9.31
274	2	50	70	1.98	26.75	104.87	42.28	774.96	2580.90	2614.60	9.31
275	2	90	70	2.78	27.12	104.24	42.51	795.11	2593.54	2627.24	9.31
276	1	60	70	9.15	26.39	86.55	42.06	1014.32	2559.84	2593.54	10.75
277	1	30	70	6.18	24.69	91.33	41.27	926.14	2505.08	2530.36	10.74
278	1	30	40	7.49	21.86	92.2	44.01	961.41	2673.57	2703.06	10.74
279	1	60	40	10.78	25.13	89.26	45.08	1064.72	2740.97	2778.88	10.74
280	2	90	100	6.93	25.49	92.65	42.51	913.54	2606.17	2652.51	10.74
281	2	50	100	5.61	24.6	94.01	42.17	875.75	2580.90	2623.03	10.74

282	2	50	70	6.18	24.15	94.95	43.31	885.82	2648.30	2694.63	10.74
283	2	90	70	7.58	24.96	93.55	43.54	926.14	2669.36	2719.91	10.74
284	1	60	70	10.51	23.71	80.76	42.4	1057.16	2585.11	2623.03	12.38
285	1	30	70	7.02	19.23	84.39	41.5	951.33	2521.93	2551.41	12.38
286	1	30	40	8.32	10.87	80.44	44.6	981.57	2719.91	2749.40	12.38
287	1	60	40	11.76	18.97	80.76	45.56	1092.44	2783.10	2821.00	12.38
288	2	90	100	8.05	21.07	86.18	42.06	938.74	2635.66	2686.21	12.38
289	2	50	100	6.93	17.14	84.74	42.4	905.98	2606.17	2656.73	12.38
290	2	50	70	7.4	16.09	84.74	43.54	916.06	2677.78	2732.54	12.38
291	2	90	70	8.42	20.11	86.55	43.08	948.81	2703.06	2757.82	12.38
292	1	60	70	11.68	14.16	73.21	43.43	1092.44	2648.30	2690.43	13.95
293	1	30	70	7.58	7.02	70.1	42.62	963.93	2593.54	2627.24	13.95
294	1	30	40	8.97	7.95	69.42	46.17	996.69	2821.00	2854.70	13.95
295	1	60	40	12.48	11.68	71.5	47.04	1112.59	2888.40	2930.53	13.95
296	2	90	100	8.42	16.26	80.76	41.5	951.33	2715.70	2766.24	13.95
297	2	50	100	7.3	9.06	77.48	41.72	916.06	2690.43	2740.97	13.95
298	2	50	70	7.68	6.08	77.2	42.74	921.10	2770.46	2816.80	13.95
299	2	90	70	8.87	14.16	81.07	42.51	958.89	2799.94	2850.49	13.95
300	1	60	70	10.96	10.15	63.45	43.31	1059.68	2648.30	2690.43	15.51
301	1	30	70	7.77	6.93	62.69	42.51	963.93	2593.54	2631.45	15.51
302	1	30	40	9.6	7.95	57.02	43.43	984.09	2812.58	2858.91	15.51
303	1	60	40	13.1	11.85	62.69	46.54	1115.11	2884.19	2938.96	15.51
304	2	90	100	8.23	10.69	75.01	39.96	946.29	2724.13	2770.46	15.51
305	2	50	100	7.3	5.32	71.74	39.96	916.06	2703.06	2749.40	15.51
306	2	50	70	7.77	5.42	71.27	40.94	921.10	2795.73	2837.86	15.51
307	2	90	70	8.87	7.21	75.28	40.83	961.41	2821.00	2867.34	15.51
308	1	60	70	12.12	11.05	56.86	40.5	1092.44	2665.14	2711.48	16.69
309	1	30	70	8.78	7.58	52.65	38.88	963.93	2606.17	2648.30	16.69

310	1	30	40	10.06	8.23	52.65	39.42	989.13	2837.86	2884.19	16.69
311	1	60	40	13.1	11.94	57.34	40.5	1097.48	2930.53	2981.07	16.69
312	2	90	100	8.69	7.02	72.23	38.99	958.89	2757.82	2804.16	16.69
313	2	50	100	7.49	5.23	68.53	39.1	918.58	2728.33	2770.46	16.69
314	2	50	70	7.77	5.32	68.32	40.17	923.62	2804.16	2850.49	16.69
315	2	90	70	9.06	6.84	70.79	39.85	963.93	2846.28	2892.61	16.69

Testing Data for System D (Finned Tube Condenser and Thermal Expansion Valve)

Test number	Compressor Stage	Indoor Fan Speed [%]	Outdoor Fan Speed [%]	Evaporator Refrigerant Inlet Temperature [°C]	Compressor Suction Temperature [°C]	Compressor Discharge Temperature [°C]	Condenser Refrigerant Outlet Temperature [°C]	Compressor Suction Pressure [kPa]	Compressor Discharge Pressure [kPa]	Liquid Line Pressure [kPa]	Actual Charge [lbs]
0	1	60	70	10.83	17.10	52.46	22.61	1086.22	1905.63	1950.87	18.57
1	1	30	70	8.08	13.69	53.43	22.37	1001.07	1883.62	1917.99	18.57
2	1	30	40	7.68	14.47	60.38	21.30	993.30	2061.68	2090.19	18.57
3	1	60	40	10.15	17.45	61.25	21.37	1072.83	2126.37	2161.46	18.57
4	2	90	100	8.87	14.76	60.34	22.96	1002.55	2023.78	2086.86	18.57
5	2	50	100	7.71	13.64	60.45	22.79	966.53	1999.35	2058.17	18.57
6	2	50	50	7.47	13.64	65.75	21.83	962.35	2211.21	2265.49	18.57
7	2	90	50	8.51	15.37	66.97	21.83	994.64	2248.44	2305.50	18.57
8	1	60	70	9.94	24.67	56.40	26.88	1032.83	1754.21	1829.97	9.24
9	1	30	70	8.36	23.57	60.69	26.32	993.44	1725.31	1798.74	9.24
10	1	30	40	9.13	22.53	63.01	29.11	1015.30	1859.53	1933.78	9.24
11	1	60	40	11.00	23.66	62.03	29.80	1077.47	1889.84	1975.17	9.24
12	2	90	100	7.00	24.52	68.50	27.97	930.31	1817.15	1901.77	9.24

13	2	50	100	6.30	24.26	70.00	27.56	909.54	1797.45	1880.16	9.24
14	2	50	50	7.55	23.34	71.77	30.67	940.19	1947.54	2036.27	9.24
15	2	90	50	8.40	23.92	71.60	31.10	965.62	1970.77	2060.56	9.24
16	1	60	70	11.69	22.74	56.46	27.24	1096.78	1758.71	1845.03	10.87
17	1	30	70	9.45	20.79	57.29	26.47	1029.83	1729.50	1813.20	10.87
18	1	30	40	9.79	19.11	59.15	29.27	1039.50	1869.74	1948.37	10.87
19	1	60	40	11.37	21.43	59.59	30.43	1093.99	1926.49	2001.37	10.87
20	2	90	100	8.89	22.02	64.70	28.49	983.64	1851.69	1943.25	10.87
21	2	50	100	7.93	21.61	66.09	28.22	955.96	1837.33	1925.62	10.87
22	2	50	50	8.82	20.21	67.93	31.36	977.24	1989.20	2080.91	10.87
23	2	90	50	9.70	20.80	67.75	31.80	1004.21	2011.85	2106.61	10.87
24	1	60	70	11.84	20.36	50.64	27.41	1102.32	1790.50	1869.72	12.42
25	1	30	70	9.09	17.11	54.08	27.02	1022.67	1765.28	1833.35	12.42
26	1	30	40	9.10	16.13	57.58	29.97	1023.57	1927.21	1981.30	12.42
27	1	60	40	11.32	19.43	58.29	30.43	1097.43	1976.06	2036.48	12.42
28	2	90	100	9.75	19.33	61.36	28.74	1012.32	1874.59	1970.85	12.42
29	2	50	100	8.71	17.93	61.68	28.48	979.77	1856.55	1947.82	12.42
30	2	50	50	9.19	15.73	63.26	31.26	989.53	2023.66	2111.58	12.42
31	2	90	50	10.04	17.60	64.09	31.00	1018.51	2053.83	2142.28	12.42
32	1	60	70	11.60	17.70	49.53	27.57	1103.01	1820.36	1889.98	14.01
33	1	30	70	8.99	14.75	52.17	27.15	1022.18	1796.57	1854.22	14.01
34	1	30	40	9.01	14.55	56.57	28.54	1024.06	1963.81	2009.28	14.01
35	1	60	40	11.14	18.09	57.91	27.42	1095.93	2023.50	2072.26	14.01
36	2	90	100	9.73	16.32	58.78	26.82	1016.91	1910.54	1995.21	14.01
37	2	50	100	8.57	14.74	58.75	26.62	980.82	1891.37	1971.04	14.01
38	2	50	50	8.66	13.60	62.12	27.50	981.60	2082.12	2151.24	14.01
39	2	90	50	9.61	15.85	63.48	27.27	1013.14	2114.13	2184.96	14.01
40	1	60	70	11.24	17.41	51.57	23.93	1095.95	1815.32	1872.06	15.52

41	1	30	70	8.63	14.52	52.65	24.23	1015.99	1821.83	1866.78	15.52
42	1	30	40	8.38	15.04	58.47	23.78	1011.03	2003.52	2037.13	15.52
43	1	60	40	10.55	18.13	59.57	23.69	1083.79	2060.60	2100.13	15.52
44	2	90	100	9.22	15.70	59.25	24.55	1009.67	1948.81	2020.64	15.52
45	2	50	100	8.04	14.29	59.17	24.30	973.47	1926.64	1993.21	15.52
46	2	50	50	8.03	14.03	63.62	24.26	973.58	2125.96	2186.76	15.52
47	2	90	50	9.06	16.00	64.89	24.13	1006.28	2156.88	2222.00	15.52
48	1	60	70	10.84	17.41	52.38	22.90	1089.98	1851.74	1901.62	17.00
49	1	30	70	8.22	14.58	53.55	23.02	1008.25	1852.27	1890.30	17.00
50	1	30	40	8.02	14.99	59.71	22.32	1004.55	2036.43	2066.55	17.00
51	1	60	40	10.38	17.93	60.57	22.38	1079.93	2095.28	2132.19	17.00
52	2	90	100	9.07	15.55	60.02	23.66	1006.95	1984.67	2052.76	17.00
53	2	50	100	7.94	14.12	59.93	23.46	971.81	1962.68	2026.38	17.00
54	2	50	50	7.84	14.19	64.79	22.72	971.06	2164.95	2223.80	17.00
55	2	90	50	8.89	15.56	65.62	22.80	1003.92	2197.13	2260.16	17.00
56	1	60	70	12.70	17.59	59.83	31.49	1128.39	2345.82	2390.32	18.57
57	1	30	70	9.79	15.12	64.47	31.00	1046.15	2307.53	2338.51	18.57
58	1	30	40	9.61	15.53	71.99	30.58	1044.31	2512.80	2540.79	18.57
59	1	60	40	11.82	18.73	73.84	30.34	1117.93	2594.06	2627.12	18.57
60	2	90	100	10.81	15.64	70.67	31.53	1042.41	2471.80	2534.68	18.57
61	2	50	100	9.67	14.23	70.56	31.33	1005.92	2443.47	2501.30	18.57
62	2	50	50	9.48	14.13	76.37	30.70	1002.71	2692.73	2745.61	18.57
63	2	90	50	10.47	16.07	77.96	30.73	1034.96	2738.73	2796.18	18.57
64	1	60	70	12.25	24.88	68.29	34.82	1105.02	2140.51	2222.94	9.24
65	1	30	70	10.74	23.39	69.89	34.13	1055.70	2105.35	2189.76	9.24
66	1	30	40	11.40	22.47	72.03	36.75	1073.29	2243.83	2330.85	9.24
67	1	60	40	12.57	24.03	72.44	37.68	1115.45	2296.74	2379.65	9.24
68	2	90	100	8.61	25.05	78.00	35.56	960.92	2188.19	2273.72	9.24

69	2	50	100	8.27	24.93	79.73	35.83	949.15	2202.36	2288.29	9.24
70	2	50	50	9.57	24.18	81.76	38.80	980.57	2366.50	2459.19	9.24
71	2	90	50	10.23	24.62	81.57	39.22	1001.18	2389.93	2483.93	9.24
72	1	60	70	13.09	23.00	67.01	35.44	1133.25	2169.64	2248.66	10.87
73	1	30	70	11.40	20.17	66.56	34.84	1076.88	2142.79	2222.38	10.87
74	1	30	40	11.43	19.14	69.41	37.66	1077.83	2300.40	2372.56	10.87
75	1	60	40	12.87	21.94	70.51	38.71	1130.13	2359.47	2427.72	10.87
76	2	90	100	10.68	22.85	74.85	37.24	1019.33	2280.40	2370.11	10.87
77	2	50	100	9.93	22.44	75.74	36.82	996.63	2256.12	2343.44	10.87
78	2	50	50	10.92	20.88	77.57	39.86	1020.31	2428.56	2523.97	10.87
79	2	90	50	11.69	21.80	77.53	40.35	1045.63	2454.89	2551.56	10.87
80	1	60	70	12.57	20.99	64.40	36.00	1127.59	2225.65	2283.06	12.42
81	1	30	70	10.40	17.91	65.97	35.48	1058.59	2188.99	2242.74	12.42
82	1	30	40	10.57	17.53	69.93	38.53	1064.21	2366.45	2414.90	12.42
83	1	60	40	12.48	20.23	69.74	38.60	1129.04	2390.14	2441.33	12.42
84	2	90	100	11.24	19.82	71.36	37.23	1045.39	2297.96	2386.72	12.42
85	2	50	100	10.29	18.41	71.29	36.85	1014.51	2273.70	2359.60	12.42
86	2	50	50	10.86	16.70	73.75	39.79	1025.74	2475.73	2557.81	12.42
87	2	90	50	11.63	18.49	74.72	39.67	1052.45	2504.32	2587.64	12.42
88	1	60	70	12.59	17.90	62.62	35.53	1127.41	2262.32	2311.19	14.01
89	1	30	70	10.08	15.20	64.37	35.27	1049.67	2228.75	2270.91	14.01
90	1	30	40	10.10	15.60	68.95	35.88	1052.24	2390.45	2428.12	14.01
91	1	60	40	12.23	18.88	70.55	35.89	1123.25	2473.97	2514.93	14.01
92	2	90	100	11.13	16.57	68.72	35.13	1045.16	2341.02	2415.83	14.01
93	2	50	100	10.03	15.14	68.56	34.79	1010.05	2316.70	2386.29	14.01
94	2	50	50	10.27	14.62	73.06	36.14	1014.75	2545.55	2609.33	14.01
95	2	90	50	11.24	16.49	74.23	36.16	1046.62	2578.95	2646.54	14.01
96	1	60	70	13.12	18.09	61.06	34.05	1145.08	2282.11	2329.86	15.52

97	1	30	70	10.30	15.37	63.46	33.68	1058.63	2241.59	2280.10	15.52
98	1	30	40	10.18	15.60	69.53	33.84	1057.40	2437.88	2470.12	15.52
99	1	60	40	12.18	19.09	71.32	33.20	1124.91	2503.72	2540.52	15.52
100	2	90	100	11.15	16.41	69.03	33.23	1049.56	2371.46	2439.42	15.52
101	2	50	100	10.01	14.96	68.85	32.90	1012.68	2348.07	2411.38	15.52
102	2	50	50	10.00	14.62	73.95	33.40	1012.37	2584.82	2642.72	15.52
103	2	90	50	10.93	16.46	75.33	33.31	1043.13	2621.63	2683.79	15.52
104	1	60	70	12.16	18.10	63.81	32.11	1123.70	2319.16	2357.53	17.00
105	1	30	70	9.77	15.21	64.54	31.84	1047.80	2274.09	2307.27	17.00
106	1	30	40	9.53	15.41	71.44	31.68	1042.50	2482.29	2512.24	17.00
107	1	60	40	11.72	18.99	73.21	31.36	1115.04	2552.22	2587.73	17.00
108	2	90	100	10.72	16.08	70.18	32.11	1041.80	2419.20	2483.85	17.00
109	2	50	100	9.61	14.78	69.98	31.82	1006.34	2391.93	2451.90	17.00
110	2	50	50	9.52	14.61	75.52	31.65	1005.01	2638.89	2693.57	17.00
111	2	90	50	10.49	16.36	76.79	31.62	1035.85	2675.33	2735.01	17.00
112	1	60	70	13.11	18.71	77.08	39.14	1150.07	2844.99	2877.25	18.57
113	1	30	70	10.79	15.77	77.18	38.35	1076.66	2749.09	2777.30	18.57
114	1	30	40	10.68	16.26	84.78	38.30	1075.72	2990.72	3011.65	18.57
115	1	60	40	12.72	19.72	86.74	38.03	1143.90	3069.39	3095.99	18.57
116	2	90	100	11.89	16.73	81.98	38.67	1067.34	2921.62	2976.01	18.57
117	2	50	100	10.82	15.43	81.63	38.41	1032.79	2888.11	2938.77	18.57
118	2	50	50	10.74	15.45	88.31	38.20	1032.13	3174.65	3221.93	18.57
119	2	90	50	11.72	17.27	89.75	38.28	1064.25	3224.27	3272.10	18.57
120	1	60	70	13.88	25.88	78.05	41.48	1147.64	2509.88	2596.20	9.24
121	1	30	70	12.76	23.99	78.78	40.86	1108.18	2471.51	2563.97	9.24
122	1	30	40	13.11	23.37	81.58	43.39	1118.26	2626.28	2715.98	9.24
123	1	60	40	14.08	24.94	82.21	44.21	1154.97	2677.28	2764.23	9.24
124	2	90	100	10.65	25.91	87.57	42.91	1002.62	2600.78	2694.22	9.24

125	2	50	100	10.21	25.75	88.61	42.58	988.99	2580.28	2673.74	9.24
126	2	50	50	11.57	25.10	90.96	45.59	1022.13	2768.30	2866.31	9.24
127	2	90	50	12.11	25.61	91.09	45.95	1040.15	2789.67	2888.98	9.24
128	1	60	70	14.50	23.62	76.82	42.29	1170.72	2554.66	2633.69	10.87
129	1	30	70	12.70	20.27	76.12	41.73	1110.53	2528.15	2606.58	10.87
130	1	30	40	12.68	19.70	79.76	44.60	1111.40	2709.40	2776.74	10.87
131	1	60	40	14.08	22.67	81.07	45.47	1161.81	2765.01	2831.36	10.87
132	2	90	100	12.31	23.60	83.38	43.49	1054.54	2640.60	2736.25	10.87
133	2	50	100	11.88	23.07	84.56	43.66	1038.66	2649.55	2745.06	10.87
134	2	50	50	12.87	21.40	86.47	46.70	1061.34	2846.66	2944.97	10.87
135	2	90	50	13.51	22.50	86.88	47.17	1083.19	2876.62	2975.61	10.87
136	1	60	70	13.71	22.27	75.97	43.10	1158.98	2626.87	2680.35	12.42
137	1	30	70	11.84	19.16	77.04	42.55	1097.89	2587.00	2640.06	12.42
138	1	30	40	12.00	18.86	81.08	45.51	1103.68	2781.63	2826.62	12.42
139	1	60	40	13.64	21.86	82.06	46.05	1160.90	2834.20	2881.28	12.42
140	2	90	100	12.74	20.88	81.26	44.32	1078.13	2701.76	2787.84	12.42
141	2	50	100	11.89	19.56	81.00	43.93	1049.84	2676.35	2760.15	12.42
142	2	50	50	12.53	18.14	83.97	47.18	1063.04	2908.20	2984.10	12.42
143	2	90	50	13.31	19.85	85.05	47.31	1089.46	2939.59	3015.61	12.42
144	1	60	70	13.74	19.51	75.35	43.38	1160.01	2708.95	2753.78	14.01
145	1	30	70	11.46	16.61	75.54	42.71	1088.26	2633.92	2674.24	14.01
146	1	30	40	11.51	16.78	80.86	43.97	1091.54	2849.70	2882.08	14.01
147	1	60	40	13.42	20.00	82.14	43.53	1156.56	2908.49	2944.83	14.01
148	2	90	100	12.62	17.65	78.77	42.56	1077.69	2757.67	2828.82	14.01
149	2	50	100	11.65	16.33	78.42	42.29	1046.31	2732.35	2801.83	14.01
150	2	50	50	11.91	15.76	83.47	43.84	1050.83	2993.66	3051.42	14.01
151	2	90	50	12.80	17.57	84.59	43.90	1080.46	3029.10	3087.98	14.01
152	1	60	70	13.34	18.77	71.60	40.56	1152.23	2691.38	2730.39	15.52

153	1	30	70	11.11	16.15	75.06	40.55	1082.98	2659.73	2693.14	15.52
154	1	30	40	11.06	16.65	82.01	41.06	1083.33	2890.46	2916.01	15.52
155	1	60	40	12.99	19.80	83.63	40.66	1147.97	2956.21	2984.69	15.52
156	2	90	100	12.20	17.11	79.42	40.48	1071.62	2802.64	2864.38	15.52
157	2	50	100	11.17	15.87	79.21	40.19	1038.64	2775.35	2831.73	15.52
158	2	50	50	11.21	15.67	85.20	40.86	1039.61	3051.61	3101.12	15.52
159	2	90	50	12.14	17.35	86.40	40.92	1069.44	3088.56	3143.12	15.52
160	1	60	70	13.25	18.86	74.36	39.55	1149.66	2762.99	2797.48	17.00
161	1	30	70	10.97	16.10	76.31	39.25	1079.15	2703.18	2732.68	17.00
162	1	30	40	10.87	16.50	83.74	39.60	1078.57	2947.98	2970.23	17.00
163	1	60	40	12.79	19.66	85.35	39.24	1142.64	3013.65	3040.69	17.00
164	2	90	100	11.98	16.85	80.61	39.42	1066.70	2858.24	2915.37	17.00
165	2	50	100	10.98	15.74	80.44	39.10	1034.61	2828.56	2882.45	17.00
166	2	50	50	10.93	15.62	87.03	39.29	1034.00	3118.45	3166.11	17.00
167	2	90	50	11.82	17.32	88.36	39.40	1063.23	3160.21	3209.95	17.00
168	1	60	70	14.23	19.98	88.39	45.78	1182.29	3281.32	3305.12	18.57
169	1	30	70	12.02	17.02	90.03	45.50	1111.79	3230.06	3250.92	18.57
170	1	30	40	11.88	17.63	98.59	45.41	1110.89	3484.17	3504.26	18.57
171	1	60	40	18.35	15.88	66.64	47.33	1213.99	3401.99	3496.49	18.57
172	2	90	100	17.80	12.21	59.62	46.27	1122.53	3271.83	3396.78	18.57
173	2	50	100	17.11	11.21	57.58	45.88	1094.72	3243.58	3367.45	18.57
174	2	50	50	18.81	11.61	59.78	46.72	1112.68	3495.44	3645.49	18.57
175	2	90	50	19.43	12.32	60.41	46.73	1135.06	3538.57	3697.94	18.57
176	1	60	70	16.76	26.56	85.84	47.73	1221.43	2899.29	3000.41	9.24
177	1	30	70	15.14	24.51	87.32	47.30	1172.11	2870.27	2971.74	9.24
178	1	30	40	15.37	23.95	89.96	49.64	1179.61	3025.67	3121.48	9.24
179	1	60	40	16.36	25.64	90.84	50.45	1216.23	3081.29	3175.54	9.24
180	2	90	100	13.01	27.00	97.32	49.57	1052.16	3032.57	3131.03	9.24

181	2	50	100	12.58	26.83	98.43	49.25	1039.07	3012.58	3110.76	9.24
182	2	50	50	13.84	26.20	100.92	52.20	1070.56	3213.68	3316.05	9.24
183	2	90	50	14.29	26.77	101.21	52.53	1086.02	3236.61	3339.27	9.24
184	1	60	70	16.27	23.29	82.35	48.66	1213.52	2959.50	3043.84	10.87
185	1	30	70	14.24	21.04	85.93	48.45	1152.82	2957.13	3029.53	10.87
186	1	30	40	14.21	20.89	90.84	51.38	1153.72	3158.63	3219.20	10.87
187	1	60	40	15.55	23.77	92.18	52.18	1202.48	3214.02	3274.35	10.87
188	2	90	100	14.39	24.47	93.50	50.58	1101.36	3099.53	3199.64	10.87
189	2	50	100	13.87	23.76	93.79	50.18	1083.25	3074.08	3173.08	10.87
190	2	50	50	14.75	22.22	96.27	53.26	1103.46	3293.86	3391.72	10.87
191	2	90	50	15.28	23.42	97.04	53.70	1122.57	3322.05	3419.51	10.87
192	1	60	70	15.09	23.86	86.67	49.79	1197.43	3058.13	3107.26	12.42
193	1	30	70	13.37	20.82	88.74	49.49	1141.96	3032.01	3078.56	12.42
194	1	30	40	13.57	20.66	93.38	52.39	1148.84	3239.70	3277.19	12.42
195	1	60	40	14.95	23.38	94.25	53.02	1197.79	3288.99	3327.61	12.42
196	2	90	100	14.43	22.71	92.35	51.27	1118.19	3154.00	3233.88	12.42
197	2	50	100	13.69	21.25	91.85	50.84	1091.53	3125.62	3204.24	12.42
198	2	50	50	14.27	20.37	95.66	54.17	1103.63	3366.12	3436.36	12.42
199	2	90	50	14.97	21.58	96.29	54.53	1127.74	3398.29	3469.17	12.42
200	1	60	70	15.00	21.40	86.18	50.30	1195.94	3130.57	3168.36	14.01
201	1	30	70	12.94	18.75	87.97	49.96	1130.87	3084.45	3118.86	14.01
202	1	30	40	12.53	18.38	94.68	50.23	1120.98	3325.45	3348.33	14.01
203	1	60	40	14.36	21.27	95.17	50.20	1183.14	3380.68	3405.65	14.01
204	2	90	100	14.22	19.36	90.18	49.99	1116.13	3218.71	3283.16	14.01
205	2	50	100	13.36	18.12	89.58	49.78	1085.85	3192.53	3253.19	14.01
206	2	50	50	13.49	17.67	95.69	50.95	1087.42	3475.29	3528.56	14.01
207	2	90	50	14.37	19.19	96.56	51.09	1117.27	3503.08	3563.24	14.01
208	1	60	70	14.44	20.53	88.20	48.39	1184.35	3207.44	3235.62	15.52

209	1	30	70	12.29	17.47	88.12	47.83	1116.37	3126.38	3150.89	15.52
210	1	30	40	12.23	17.99	95.27	48.39	1116.68	3363.21	3383.54	15.52
211	1	60	40	14.07	21.10	96.45	48.23	1179.17	3426.05	3449.89	15.52
212	2	90	100	13.66	18.18	90.70	47.89	1104.07	3276.20	3330.51	15.52
213	2	50	100	12.67	16.94	90.20	47.49	1071.25	3246.68	3296.11	15.52
214	2	50	50	12.69	16.79	97.07	48.22	1071.80	3536.05	3590.97	15.52
215	2	90	50	13.58	18.40	98.25	48.30	1101.44	3567.87	3628.84	15.52
216	1	60	70	14.34	20.25	87.31	46.72	1181.90	3216.17	3241.80	17.00
217	1	30	70	12.15	17.44	89.22	46.56	1112.88	3171.73	3193.56	17.00
218	1	30	40	12.08	17.91	96.99	46.88	1113.51	3419.91	3438.91	17.00
219	1	60	40	13.92	21.06	98.52	46.76	1176.15	3491.52	3517.29	17.00
220	2	90	100	13.44	17.97	92.14	46.75	1099.77	3336.97	3389.62	17.00
221	2	50	100	12.49	16.90	91.84	46.42	1068.42	3306.56	3354.45	17.00
222	2	50	50	15.94	12.23	74.87	49.17	1102.75	3550.04	3650.29	17.00
223	2	90	50	17.98	12.55	66.03	49.61	1128.13	3531.88	3656.95	17.00
224	1	60	70	10.39	15.24	58.46	31.11	1050.20	2274.56	2316.42	18.57
225	1	30	70	5.23	12.59	68.20	30.43	912.15	2258.14	2278.24	18.57
226	1	30	40	5.04	13.73	77.53	29.74	910.13	2435.03	2453.44	18.57
227	1	60	40	9.04	17.27	76.27	30.22	1030.02	2519.52	2547.30	18.57
228	2	90	100	7.01	12.06	70.81	31.04	927.47	2396.46	2443.21	18.57
229	2	50	100	5.07	10.65	72.39	30.59	872.55	2360.27	2399.32	18.57
230	2	50	50	4.89	11.45	78.97	30.23	869.51	2581.40	2615.63	18.57
231	2	90	50	6.94	13.97	79.68	30.43	929.50	2639.76	2682.25	18.57
232	1	60	70	11.17	23.75	65.49	33.97	1060.43	1165.80	2198.96	9.24
233	1	30	70	8.47	20.73	70.56	33.28	979.47	1725.70	2150.49	9.24
234	1	30	40	9.15	19.39	72.23	35.59	997.09	2185.82	2271.32	9.24
235	1	60	40	11.55	23.17	72.69	37.04	1079.70	2263.13	2349.07	9.24
236	2	90	100	6.77	23.88	79.39	34.87	901.01	2153.93	2236.52	9.24

237	2	50	100	5.95	23.06	81.17	34.89	876.29	2155.78	2237.81	9.24
238	2	50	50	7.13	21.80	82.52	37.82	903.37	2312.83	2400.99	9.24
239	2	90	50	8.13	23.16	82.74	38.37	934.45	2342.84	2433.20	9.24
240	1	60	70	11.71	21.13	66.92	34.49	1088.80	2122.78	2199.67	10.87
241	1	30	70	8.27	16.51	67.39	33.76	980.66	2090.33	2158.81	10.87
242	1	30	40	7.93	15.87	71.00	36.49	974.21	2240.16	2297.61	10.87
243	1	60	40	10.67	20.74	72.15	37.80	1063.63	2312.66	2371.23	10.87
244	2	90	100	7.98	19.79	74.72	35.80	938.00	2202.91	2286.90	10.87
245	2	50	100	6.68	17.40	74.55	35.25	899.71	2175.11	2256.78	10.87
246	2	50	50	7.32	15.88	76.53	38.29	912.54	2341.95	2424.13	10.87
247	2	90	50	8.55	18.26	77.28	38.96	950.41	2379.20	2463.08	10.87
248	1	60	70	11.11	18.35	64.75	35.20	1080.47	2168.22	2229.30	12.42
249	1	30	70	7.09	13.91	66.61	34.42	956.79	2131.44	2179.53	12.42
250	1	30	40	6.69	14.24	71.63	37.11	949.20	2292.18	2328.98	12.42
251	1	60	40	10.20	19.29	72.18	37.90	1057.47	2360.10	2404.37	12.42
252	2	90	100	8.12	16.25	71.30	36.25	949.42	2236.20	2313.39	12.42
253	2	50	100	6.41	13.92	71.28	35.71	898.77	2208.78	2278.67	12.42
254	2	50	50	6.80	12.94	74.31	38.66	906.15	2392.68	2457.14	12.42
255	2	90	50	8.35	15.65	75.23	39.13	952.79	2430.95	2500.55	12.42
256	1	60	70	10.99	16.19	59.77	35.20	1071.47	2200.80	2252.22	14.01
257	1	30	70	6.14	12.95	67.03	34.48	933.33	2171.13	2202.76	14.01
258	1	30	40	5.80	13.66	73.63	34.40	927.68	2341.89	2365.82	14.01
259	1	60	40	9.70	17.93	72.93	35.51	1044.92	2412.75	2446.90	14.01
260	2	90	100	7.47	13.33	69.02	33.87	936.17	2248.85	2308.55	14.01
261	2	50	100	5.69	11.64	70.33	33.82	883.62	2253.05	2303.96	14.01
262	2	50	50	5.79	11.48	75.01	34.68	885.84	2451.42	2495.74	14.01
263	2	90	50	7.55	13.99	75.59	35.05	937.24	2492.86	2543.86	14.01
264	1	60	70	10.45	15.32	60.24	33.36	1060.38	2186.13	2229.73	15.52

265	1	30	70	5.77	12.57	66.40	32.82	924.84	2187.10	2213.59	15.52
266	1	30	40	5.57	13.65	74.01	32.32	922.72	2350.22	2372.19	15.52
267	1	60	40	9.53	17.22	73.01	33.16	1041.67	2432.18	2463.56	15.52
268	2	90	100	7.41	12.24	68.66	32.72	935.71	2313.80	2366.59	15.52
269	2	50	100	5.42	10.80	70.23	32.10	879.83	2282.93	2327.07	15.52
270	2	50	50	5.39	11.54	76.12	32.46	879.24	2487.09	2528.44	15.52
271	2	90	50	7.09	13.90	77.00	32.75	929.67	2534.74	2582.12	15.52
272	1	60	70	10.43	15.13	57.86	32.35	1055.55	2237.24	2277.69	17.00
273	1	30	70	5.46	12.62	66.68	31.43	917.24	2213.78	2235.72	17.00
274	1	30	40	5.36	13.65	75.41	31.20	917.87	2386.66	2405.27	17.00
275	1	60	40	9.41	16.91	73.86	31.80	1039.23	2473.89	2503.92	17.00
276	2	90	100	7.09	12.47	69.61	31.66	928.96	2349.58	2398.61	17.00
277	2	50	100	5.17	11.08	71.61	31.18	874.78	2318.27	2358.85	17.00
278	2	50	50	5.08	11.77	77.75	31.11	873.21	2529.31	2566.23	17.00
279	2	90	50	6.76	14.06	78.63	31.30	923.16	2577.06	2621.39	17.00
280	1	60	70	11.44	16.11	68.47	38.21	1076.15	2696.19	2730.95	18.57
281	1	30	70	6.82	13.50	80.24	37.78	953.05	2692.09	2710.12	18.57
282	1	30	40	6.71	14.73	90.34	37.60	954.35	2913.18	2924.52	18.57
283	1	60	40	10.53	18.88	89.46	37.93	1072.50	3006.51	3026.86	18.57
284	2	90	100	8.76	12.84	81.38	38.28	966.26	2843.99	2887.44	18.57
285	2	50	100	6.85	11.15	82.57	37.91	911.13	2804.67	2840.75	18.57
286	2	50	50	6.78	11.74	89.83	37.94	910.59	3067.95	3097.83	18.57
287	2	90	50	8.41	14.35	91.10	38.05	959.67	3124.79	3159.34	18.57
288	1	60	70	13.98	25.15	77.64	41.09	1147.17	2486.75	2581.20	9.24
289	1	30	70	11.29	21.66	78.98	40.16	1054.68	2431.73	2526.03	9.24
290	1	30	40	11.63	20.73	81.14	42.53	1064.60	2575.25	2666.46	9.24
291	1	60	40	13.76	24.37	82.03	43.86	1147.16	2656.80	2748.74	9.24
292	2	90	100	9.41	24.99	88.57	42.37	957.96	2568.57	2662.08	9.24

293	2	50	100	8.44	24.07	89.76	41.85	929.43	2535.90	2628.53	9.24
294	2	50	50	9.64	23.12	91.91	44.72	957.59	2715.56	2812.94	9.24
295	2	90	50	10.59	24.26	92.09	45.29	987.34	2751.90	2849.64	9.24
296	1	60	70	11.18	19.38	80.00	41.45	1062.95	2513.82	2581.75	10.87
297	1	30	70	9.16	17.60	79.40	41.11	1004.33	2499.02	2553.97	10.87
298	1	30	40	9.46	17.73	83.14	43.90	1015.36	2672.44	2720.32	10.87
299	1	60	40	12.37	22.68	83.95	45.00	1113.65	2739.49	2793.64	10.87
300	2	90	100	10.37	20.66	83.81	42.81	990.65	2599.76	2691.59	10.87
301	2	50	100	9.14	18.63	83.45	42.26	951.96	2566.69	2657.19	10.87
302	2	50	50	9.68	17.63	86.44	45.36	963.26	2763.53	2847.44	10.87
303	2	90	50	10.78	19.88	87.54	46.02	998.98	2805.66	2888.93	10.87
304	1	60	70	11.02	19.53	77.86	41.79	1068.81	2541.77	2595.86	12.42
305	1	30	70	8.20	14.77	78.17	41.40	983.77	2519.11	2564.03	12.42
306	1	30	40	7.99	15.22	83.02	43.98	979.64	2684.25	2720.68	12.42
307	1	60	40	11.30	20.31	83.41	45.12	1083.86	2756.75	2800.58	12.42
308	2	90	100	9.83	17.46	81.22	43.35	985.65	2639.01	2714.61	12.42
309	2	50	100	8.38	15.27	80.99	42.86	942.17	2609.74	2680.43	12.42
310	2	50	50	8.82	14.69	84.79	46.02	950.80	2823.61	2885.26	12.42
311	2	90	50	10.33	17.48	85.83	46.59	996.79	2869.42	2934.41	12.42
312	1	60	70	12.46	17.49	71.68	42.70	1114.58	2620.92	2668.62	14.01
313	1	30	70	7.85	14.40	78.61	41.88	977.94	2575.16	2605.16	14.01
314	1	30	40	7.70	14.68	84.79	42.55	976.64	2767.39	2789.56	14.01
315	1	60	40	11.23	19.50	84.55	42.73	1088.80	2845.10	2876.03	14.01
316	2	90	100	9.49	14.56	79.87	41.91	980.34	2699.56	2757.54	14.01
317	2	50	100	7.65	12.91	80.31	41.33	926.59	2667.29	2717.23	14.01
318	2	50	50	7.88	12.19	84.97	42.62	930.98	2901.54	2942.42	14.01
319	2	90	50	9.50	14.95	85.85	42.95	980.33	2948.91	2995.38	14.01
320	1	60	70	12.05	16.72	71.65	41.32	1105.85	2652.23	2691.06	15.52

321	1	30	70	7.46	13.42	77.16	40.36	969.10	2599.23	2624.34	15.52
322	1	30	40	7.25	14.57	85.83	40.18	966.77	2795.26	2812.09	15.52
323	1	60	40	11.04	18.90	85.08	40.62	1084.75	2881.55	2906.22	15.52
324	2	90	100	9.21	13.26	78.88	40.13	975.08	2741.98	2791.97	15.52
325	2	50	100	7.25	11.57	80.01	39.49	919.40	2702.67	2746.05	15.52
326	2	50	50	7.29	12.09	86.43	40.21	920.35	2950.78	2985.48	15.52
327	2	90	50	8.95	14.72	87.62	40.47	969.98	3001.50	3040.46	15.52
328	1	60	70	9.92	15.64	75.76	39.41	1038.54	2674.48	2699.60	17.00
329	1	30	70	6.56	12.51	79.20	38.90	943.84	2628.51	2647.12	17.00
330	1	30	40	6.25	13.69	87.75	39.34	938.25	2819.84	2834.71	17.00
331	1	60	40	9.51	18.01	87.73	39.40	1037.71	2900.26	2920.21	17.00
332	2	90	100	8.44	13.04	80.73	38.96	957.12	2774.90	2819.48	17.00
333	2	50	100	6.84	11.45	81.44	38.57	910.58	2742.67	2782.52	17.00
334	2	50	50	6.87	11.95	88.14	38.90	911.51	3000.35	3031.20	17.00
335	2	90	50	8.47	14.60	89.35	39.02	960.12	3053.47	3089.14	17.00

APPENDIX B. TRAINING KIT PYTHON PROGRAM

Automated Training Kit driver python code

```
#! /usr/bin/env python
# -*- coding: utf-8 -*-
"""Python script used to drive virtual sensor training kit hardware."""

from collections import deque
from datetime import datetime
import json
import re
from shutil import copyfile
import sqlite3
import time

from CoolProp.CoolProp import PropsSI as refprop
import numpy as np
import pandas as pd
import serial

from filters import steady_state_filter

DB_COLS = [('id', 'INTEGER PRIMARY KEY'),
        ('datetime', 'TIMESTAMP'),
        ('mode_cmd', 'INTEGER'),
        ('idf_cmd', 'INTEGER'),
        ('odf_cmd', 'INTEGER'),
        ('lo_vlv_cmd', 'INTEGER'),
        ('hi_vlv_cmd', 'INTEGER'),
        ('eri_t', 'REAL'),
```

```
        ('suc_t', 'REAL'),
        ('dis_t', 'REAL'),
        ('cro_t', 'REAL'),
        ('crs_t', 'REAL'),
        ('cao_t', 'REAL'),
        ('cai_t', 'REAL'),
        ('ret_t', 'REAL'),
        ('ret_phi', 'REAL'),
        ('sup_t', 'REAL'),
        ('sup_phi', 'REAL'),
        ('suc_p', 'REAL'),
        ('dis_p', 'REAL'),
        ('liq_p', 'REAL'),
        ('pwr_idf', 'REAL'),
        ('pwr_odf', 'REAL'),
        ('pwr_comp', 'REAL'),
        ('deltap_idf', 'REAL'),
        ('deltap_odf', 'REAL'),
        ('deltap_ra', 'REAL'),
        ('deltap_sa', 'REAL'),
        ('deltap_evap', 'REAL'),
        ('chrg_spt', 'REAL'),
        ('chrg_act', 'REAL'),
        ('steady', 'BOOLEAN'), ]
DB_CMD_COLS = ('mode_cmd', 'idf_cmd', 'odf_cmd', 'chrg_spt', )
DB_MEAS_COLS = ('eri_t',
            'suc_t',
            'dis_t',
            'cro_t',
            'crs_t',
            'cai_t',
```

```
             'cao_t',
             'ret_t',
             'ret_phi',
             'sup_t',
             'sup_phi',
             'suc_p',
             'dis_p',
             'liq_p',
             'pwr_idf',
             'pwr_odf',
             'pwr_comp',
             'deltap_idf',
             'deltap_odf',
             'deltap_ra',
             'deltap_sa',
             'deltap_evap',
             'chrg_act', )

SCALE_PATTERN = re.compile('\d+.\d+')

STEADY_STATE_LIMITS = [0.005,  # Approx 2.25 K / 10 min
                 0.005,
                 0.005,
                 0.005,
                 0.005,
                 0.100,  # Approx. 80 kPa / 10 min
                 0.100,
                 0.060,]


def between(val, lo, hi):
```

```
    """Test if value is between two numbers.

    Returns True if val >= lo and val <= hi otherwise False.

    """
    return True if val >= lo and val <= hi else False


def almost_equal(actual, desired, deadband):
    """Test if value is almost equal to desired value.

    Returns True if val >= des - db and val <= des + db otherwise False.

    """
    return between(actual, desired - deadband, desired + deadband)

def greater_than_equal(actual, desired, deadband):
    """Test if value is almost equal to desired value.

    Returns True if val >= des - db and val <= des + db otherwise False.

    """
    res = (actual > desired or
           between(actual, desired - deadband, desired + deadband))

    return res


class TrainingKitDriver(object):

    """Python class implementing virtual sensor training kit functionality."""
```

```
def __init__(self, config):
    with open(config) as f:
        self.setup(json.load(f))

def setup(self, config):
    """Setup driver communication and run-time parameters."""

    self._init_sqlite_connection(config['database_path'])
    self._init_serial_connection(**config['serial_conf'])
    self.test_sequence = config['test_sequence'][:]

    self.chrg_act = config['initial_chrg']
    self.chrg_spt = config['initial_chrg']
    self.init_chrg = config['initial_chrg']

    self.use_pressure = config['use_pressure']
    self.refname = config['refrigerant']

    self.transient_points = 200
    self.steady_points = 150

    self.steady = False
    self._old_weight = None

def _init_serial_connection(self, **kwargs):
    self.scale = serial.Serial('COM6', 19200, timeout=1)
    self.daq1 = serial.Serial('COM4', 115200, timeout=1)
    #self.daq2 = serial.Serial('COM10', 115200, timeout=1)

    time.sleep(1)  # Give connection time to initialize.
```

```
    assert self.daq1.isOpen()
    #assert self.daq2.isOpen()
    assert self.scale.isOpen()

def _init_sqlite_connection(self, *args, **kwargs):
    """Initialize SQLite database for store data."""
    self.db_conn = sqlite3.connect(*args, **kwargs)
    with self.db_conn as c:
        try:
            sql_string = "CREATE TABLE raw_data ({})"
            c.execute(sql_string.format(', '.join(map(' '.join, DB_COLS))))
        except sqlite3.OperationalError as e:
            # If table already exists, delete and retry.
            # TODO Change this so that existing data is handled better.
            _ = copyfile(args[0], args[0]+'.bak')
            c.execute("DROP TABLE raw_data")
            self.db_conn.commit()
            self._init_sqlite_connection(*args, **kwargs)
    self.db_conn.commit()

def run(self):
    """Run virtual sensor training kit algorithm."""
    progress_string = "{:%Y-%m-%d %H:%M:%S} {:1d} {:>3d} {:>3d} {:>4.2f}"

    init_weight = list()
    try:
        while len(init_weight) < 60:
            init_weight.append(self.read_scale())
        self.init_weight = np.median(init_weight)
        print("Initial scale value: " + str(self.init_weight))
        while len(self.test_sequence) > 0:
```

```
            next_test = self.test_sequence.pop(0)
            print("Beginning Test: " +
                  progress_string.format(datetime.now(), *next_test))
            self.next(next_test)
        else:
            self.shutdown()
            self.exit()
    except KeyboardInterrupt or InterruptedError:
        print("Keyboard Interrupt received")
        self.shutdown()
        self.exit()

def add_initial_charge(self):
    """Adds initial charge till 50% of the rated charge"""

    chrg_db = 0.05  # charge deadband
    self.steady = False

    cmp_stg = 0
    idf_spd = 0
    odf_spd = 0
    chrg_spt = 50*7.063/100

    self.chrg_spt = chrg_spt
    self.chrg_act = 0.

    command = [cmp_stg, idf_spd, odf_spd, 0, 0]
    print("Adjusting charge level...")
    while not greater_than_equal(self.chrg_act, self.chrg_spt, chrg_db):
        # Adjust refrigerant charge level to set-point value.
        data = self.adjust_charge(self.chrg_act, self.chrg_spt, command)
```

```
            print("chrg_spt :\t\t{:4.2f} lbs".format(self.chrg_act))
            print("chrg_act :\t\t{:4.2f} lbs".format(self.chrg_act))
        else:
            # Close solenoid valves.
            command[-2:] = [0, 0]
            print("Charge level set to 50%")
            print("chrg_spt :\t\t{:4.2f} lbs".format(self.chrg_act))
            print("chrg_act :\t\t{:4.2f} lbs".format(self.chrg_act))

    def next(self, test):
        """Proceed to next system control set-point sequence."""

        chrg_db = 0.050  # charge deadband
        self.steady = False

        cmp_stg, idf_spd, odf_spd, chrg_spt = test
        self.chrg_spt = chrg_spt

        start = datetime.now()

        command = [cmp_stg, idf_spd, odf_spd, 0, 0]
        print("Adjusting charge level...")
        while not greater_than_equal(self.chrg_act, self.chrg_spt, chrg_db):
            # Adjust refrigerant charge level to set-point value.
            data = self.adjust_charge(self.chrg_act, self.chrg_spt, command)
            # TODO It would be nice in some way to wrap methods using
            # that get update data with a decorator that 'automatically'
            # stores the data to the database.
            self.store(command, self.chrg_spt, data, self.steady)
            add_time = (datetime.now() - start).seconds
            self.print_out(add_time, command, data)
```

```
    else:
        # Close solenoid valves.
        command[-2:] = [0, 0]
        # Filter transient performance using steady-state detector.
        self.filter_transient(command)

def adjust_charge(self, observed, desired, command, deadband=0.05):
    """Add or remove refrigerant until it is equal to desired amount.

    Refrigerant charge addition and removal is accomplished using a
    solenoid valve at the compressor suction and a solenoid valve on
    the liquid-line respectively.  When charge needs to be added, the
    low-pressure-side solenoid valve connected to charging cylinder
    opens.  When charge needs to be removed, the high-pressure-side
    solenoid connected to a recovery cylinder opens.

    In order to determine the proper amount of refrigerant to add or
    remove, a weighing scale with a RS-232 digital output is used to
    measure the amount of refrigerant entering or leaving the system.

    Parameters
    ----------
    observed : float
        Actual refrigerant charge level measured after the previous
        command was sent in kilograms [kg].
    desired : float
        The refrigerant charge set-point level in kilograms [kg].
    command : list
        Current compressor stage, indoor fan speed, outdoor fan speed
        and solenoid valve command signals.
    deadband : float, optional [default 0.05]
```

```
            Refrigerant charge controller deadband in kilograms [kg].

        Returns
        -------
        update : list
            Updated sensor measurements from hardware data acquisition
            and control system.

         """

        # Adjust charge level until it is close to the set-point.
        # If observed is less than desired, need to add charge,
        # open low-side solenoid. If observed is greater than desired,
        # need to remove charge, open high-side solenoid.
        command[-2:] = [1, 0] if observed < desired - deadband else [0, 1]

        # Send new command to controller, and receive updated measurements.
        update = self.send(command)
        self.chrg_act = update[-1]

        return update

    def filter_transient(self, command):
        """Filter transient performance after mode change occurs.

        Parameters
        ----------
        command : list
            Current compressor stage, indoor fan speed, outdoor fan speed
            and solenoid valve command signals.
```

```
"""

start = datetime.now()
max_time = 25 * 60.

window_length = 200
window = deque([], window_length)

steady_state_point_limit = 200

while (len(window) < window_length and not
       (datetime.now() - start).seconds > max_time and not self.steady):
    # Append data to a FIFO buffer used to determine whether
    # system performance is transient or has reached steady-state.
    update = self.send(command)
    #self.chrg_act = update[-1]
    window.append([self.eri_t,
                   self.suc_t,
                   self.dis_t,
                   self.cro_t,
                   self.cai_t,
                   self.suc_p,
                   self.dis_p,
                   self.chrg_act, ])

    # Wait to apply steady-state detector until the minimum
    # number of samples has been added to the window buffer.
    if len(window) >= window_length:
        self.steady = all(steady_state_filter(window,
                                              STEADY_STATE_LIMITS))
```

```
            self.store(command, self.chrg_spt, update, self.steady)
            test_time = (datetime.now() - start).seconds
            self.print_out(test_time, command, update)
        else:
            # Begin collecting steady-state points.
            i = 1
            while (i <= steady_state_point_limit and
                   (datetime.now()-start).seconds < max_time):
                # Collect the required number of steady-state points.
                update = self.send(command)
                #self.chrg_act = update[-1]
                window.append([self.eri_t,
                               self.suc_t,
                               self.dis_t,
                               self.cro_t,
                               self.cai_t,
                               self.suc_p,
                               self.dis_p,
                               self.chrg_act, ])
                self.steady = all(steady_state_filter(window,
                                                      STEADY_STATE_LIMITS))

                self.store(command, self.chrg_spt, update, self.steady)
                test_time = (datetime.now() - start).seconds
                self.print_out(test_time, command, update)

                # Only increment if new point is steady.
                i += 1 if self.steady else 0

    def shutdown(self):
        """Shutdown virtual sensor training kit algorithm."""
```

```
        data = self.send([-1, 0, 0, 0, 0])

    def exit(self):
        """Terminate driver communication cleanly."""
        self.daq1.close()
        #self.daq2.close()
        self.scale.close()
        self.db_conn.close()
        time.sleep(1)  # Give connection time to initialize.

    def send(self, cmd):
        """Send control command to training kit control hardware.

        Parameters
        ----------
        cmd : list-like
            List of commands to each control variable. The elements of the
            list correspond to:
                0 - compressor stage [0=OFF, 1=LOW, 2=HIGH]
                1 - indoor fan speed [0-100]
                2 - outdoor fan speed [0-100]
                3 - low-side solenoid [0=CLOSED, 1=OPEN]
                4 - high-side solenoid [0=CLOSED, 1=OPEN]

        Returns
        -------
        data : list
            List of the measured sensor outputs recorded during averaged
            over the second following the command.

        """
```

```
# tick = datetime.now()

# Form DAQ command string before sending.
cmd_str = '[' + ','.join(map(lambda x: str(x), cmd)) + ',]'

# Trigger serial responses from DAQs by sending command.
self.daq1.write(cmd_str.encode('ascii'))
time.sleep(0.01)
# Read outputs from Arduino DAQ 1.
daq1_output = self.daq1.readline()
# Serial output is a string, convert each element to floats.
if not daq1_output or daq1_output == b'\xf0':
    daq1_output = self.daq1.readline()
    if not daq1_output or daq1_output == b'\xf0':
        daq1_output = ','.join(14 * ['-9999']).encode('utf-8')
outputs = list(map(float, daq1_output.decode().strip().split(',')))

self.eri_t = outputs[0]
self.suc_t = outputs[1]
self.dis_t = outputs[2]
self.cro_t = outputs[3]
self.crs_t = outputs[4]
self.cai_t = outputs[5]
self.cao_t= outputs[6]
self.ret_t = outputs[7]
self.ret_phi = outputs[8]
self.sup_t = outputs[9]
self.sup_phi = outputs[10]
self.suc_p = outputs[11]
self.dis_p = outputs[12]
self.liq_p = outputs[13]
```

```
    #self.daq2.write(cmd_str.encode('ascii'))
    #time.sleep(0.01)
    # Read outputs from Arduino DAQ 2.
    #daq2_output = self.daq2.readline()
    #if not daq2_output or daq2_output == b'\xf0':
        #daq2_output = self.daq2.readline()
        #if not daq2_output or daq2_output == b'\xf0':
            #daq2_output = ','.join(8 * ['-9999']).encode('utf-8')
    # Convert serial output from string to list of floats and extend prev.
    daq2_output = ','.join(8 * ['-9999']).encode('utf-8')
    outputs.extend(list(map(float, daq2_output.decode().strip().split(','))))

    self.pwr_idf = outputs[14]
    self.pwr_odf = outputs[15]
    self.pwr_comp = outputs[16]
    self.deltap_idf = outputs[17]
    self.deltap_odf = outputs[18]
    self.deltap_ra = outputs[19]
    self.deltap_sa = outputs[20]
    self.deltap_evap = outputs[21]

    new_weight = np.median([self.read_scale() for i in range(5)])
    outputs.extend(
        [round(self.init_chrg + self.init_weight - new_weight, 3), ]
    )
    self.chrg_act = outputs[22]
    return outputs

def read_scale(self):
    try:
```

```
            self.scale.flushInput()
            o = self.scale.readline().decode(encoding='UTF-8').strip()
            return float(SCALE_PATTERN.findall(o)[0])
        except IndexError:
            return self.read_scale()

    def store(self, cmds, chrg_spt, data, steady):
        """Insert command outputs and sensor measurements into database.

        Parameters
        ----------
        cmds : list-like
            List containing the control commands to store in database. The
            elements stored in this list are:
                0 - compressor stage [0=OFF, 1=LOW, 2=HIGH]
                1 - indoor fan speed [0-100]
                2 - outdoor fan speed [0-100]
                3 - low-side solenoid [0=CLOSED, 1=OPEN]
                4 - high-side solenoid [0=CLOSED, 1=OPEN]
                5 - refrigerant charge setpoint [kg]
        data : list-like
            List containing the measured sensor outputs to store in
            database. The elements stored in this list are:
                0 - evaporator refrigerant inlet temperature [K]
                1 - compressor refrigerant suction temperature [K]
                2 - compressor refrigerant discharge temperature [K]
                3 - condenser refrigerant saturation temperature [K]
                4 - condenser refrigerant outlet temperature [K]
                5 - compressor refrigerant suction pressure [kPa]
                6 - compressor refrigerant discharge pressure [kPa]
                7 - actual refrigerant charge [kg]
```

```
    New Values:
    ERIT =
    SUCT =

"""

cols = ", ".join(("datetime",
                  "mode_cmd",
                  "idf_cmd",
                  "odf_cmd",
                  "lo_vlv_cmd",
                  "hi_vlv_cmd",
                  "eri_t",
                  "suc_t",
                  "dis_t",
                  "cro_t",
                  "crs_t",
                  "cao_t",
                  "cai_t",
                  "ret_t",
                  "ret_phi",
                  "sup_t",
                  "sup_phi",
                  "suc_p",
                  "dis_p",
                  "liq_p",
                  "pwr_idf",
                  "pwr_odf",
                  "pwr_comp",
                  "deltap_idf",
```

```
                "deltap_odf",
                "deltap_ra",
                "deltap_sa",
                "deltap_evap",
                "chrg_spt",
                "chrg_act",
                "steady", ))
sql = "INSERT INTO raw_data({}) VALUES ({})"
with self.db_conn as c:
    c.execute(sql.format(cols, ", ".join((len(DB_COLS)-1) * ['?'])),
              (datetime.now(),  # datetime
               cmds[0],  # mode_cmd
               cmds[1],  # idf_cmd
               cmds[2],  # odf_cmd
               cmds[3],  # lo_vlv_cmd
               cmds[4],  # hi_vlv_cmd
               self.eri_t,  # eri_t
               self.suc_t,  # suc_t
               self.dis_t,  # dis_t
               self.cro_t,  # cro_t
               self.crs_t,  # crs_t
               self.cai_t,  # cai_t
               self.cao_t,  # cao_t
               self.ret_t,  # ret_t
               self.ret_phi,  # ret_phi
               self.sup_t,  # sup_t
               self.sup_phi, # sup_phi
               self.suc_p,  # suc_p
               self.dis_p,  # dis_p
               self.liq_p,  # liq_p
               self.pwr_idf,  # pwr_idf
```

```
                self.pwr_odf,  # pwr_odf
                self.pwr_comp,  # pwr_comp
                self.deltap_idf,  # deltap_idf
                self.deltap_odf,  # deltap_odf
                self.deltap_ra,  # deltap_ra
                self.deltap_sa,  # deltap_sa
                self.deltap_evap,  # deltap_evap
                chrg_spt,  # chrg_spt
                self.chrg_act,  # chrg_act
                steady, ))  # steady
    self.db_conn.commit()

def aggregate(self):
    """Aggregate raw data into a summarized table of averaged values."""

    sql_tmpl = "SELECT {0}, {1} FROM raw_data WHERE {2} GROUP BY {0}"
    sql_avg = "AVG({})".format
    c = self.db_conn.cursor()
    c.execute(sql_tmpl.format(', '.join(DB_CMD_COLS),
                              ', '.join(map(sql_avg, DB_MEAS_COLS)),
                              'steady == 0'))
    return c.fetchall()

def analyze(self):
    """Perform thermodynamic analysis to determine state points."""

    ref = self.refname

    df = pd.DataFrame(self.aggregate())
    if self.use_pressure:
        # Determine saturation temperatures using pressure measurements.
```

```
            df['eri_t'] = refprop('T', 'P', df.suc_p, 'Q', 1., ref)
            df['crs_t'] = refprop('T', 'P', df.dis_p, 'Q', 1., ref)
        else:
            # Determine saturation pressures using temperature measurements.
            df['suc_p'] = refprop('P', 'T', df.eri_t, 'Q', 1., ref)
            df['dis_p'] = refprop('P', 'T', df.crs_t, 'Q', 1., ref)

        # Determine suction superheat and discharge superheat.
        df['ssh'] = df.suc_t - df.eri_t
        df['dsh'] = df.dis_t - df.crs_t
        # Determine liquid-line subcooling.
        df['lsc'] = df.crs_t - df.cro_t
        # Superheat and subcooling cannot be less than zero.
        df.ix[df.ssh < 0]['ssh'] = 0.
        df.ix[df.dsh < 0]['dsh'] = 0.
        df.ix[df.lsc < 0]['lsc'] = 0.

        # Determine condenser outlet enthalpy (and equivalently evaporator
        # inlet enthalpy) in order to determine inlet quality.
        df['cro_h'] = np.nan
        df.cro_h.ix[df.lsc > 0.] = refprop('H',
                                           'T', df.cro_t.ix[df.lsc > 0.],
                                           'P', df.dis_p.ix[df.lsc > 0.], ref)
        df.cro_h.ix[df.lsc == 0.] = refprop('H', 'Q', 0.,
                                            'P', df.dis_p.ix[df.lsc == 0.], ref)
        df['eri_q'] = refprop('Q', 'P', df.suc_p, 'H', df.cro_h, ref)

    def train(self):
        """Determine empirical virtual sensor parameters."""
        pass
```

```
def export(self):
    """Export virtual sensor parameters from training algorithm."""
    pass

def print_out(self, test_time, cmds, data):

    print("Test Time:\t\t{0} min {1} sec".format(test_time//60.,
                                                  test_time%60.))

    print("Commands:")
    print("  Mode:\t\t{} -".format(cmds[0]))
    print("  IDF:\t\t{} %".format(cmds[1]))
    print("  ODF:\t\t{} %".format(cmds[2]))
    print("  Add Charge:\t{} -".format(cmds[3]))

    print("Charge:")
    print("  Setpoint\t{} lb".format(self.chrg_spt))
    print("  Actual\t{} lb".format(data[-1]))
    print("  Steady\t{} -".format(self.steady))

    print("Thermistors:")
    print("  ERI:\t\t{:4.3f} C".format(data[0] - 273.15))
    print("  SUC:\t\t{:4.3f} C".format(data[1] - 273.15))
    print("  DIS:\t\t{:4.3f} C".format(data[2] - 273.15))
    print("  CRO:\t\t{:4.3f} C".format(data[3] - 273.15))
    print("  Empty:\t{:4.3f} C".format(data[4] - 273.15))
    print("  CAI:\t\t{:4.3f} C".format(data[5] - 273.15))
    print("  CAO:\t\t{:4.3f} C".format(data[6] - 273.15))

    print("Pressures:")
    print("  SUC:\t\t{:4.1f} kPa".format(data[11]))
```

```
        print("  DIS:\t\t{:4.1f} kPa".format(data[12]))
        print("  LIQ:\t\t{:4.1f} kPa".format(data[13]))

        print("Temp./RHs:")
        print("  RAT:\t\t{:4.2f} C".format(data[7] - 273.15))
        print("  RAR:\t\t{:4.1f} %".format(data[8]))
        print("  SAT:\t\t{:4.2f} C".format(data[9] - 273.15))
        print("  SAR:\t\t{:4.1f} %".format(data[10]))

        print("Power:")
        print("  IDF:\t\t{:4.1f} W".format(data[14]))
        print("  ODF:\t\t{:4.1f} W".format(data[15]))
        print("  COMP:\t\t{:4.1f} W".format(data[16]))


def main(*args, **kwargs):
    """Main function entered via command line interface."""

    driver = TrainingKitDriver(*args, **kwargs)
    while True:
        print(datetime.now().strftime('%H:%M:%S'), driver.send([0, 0, 0, 0, 0]))
    else:
        print(datetime.now().strftime('%H:%M:%S'), driver.send([0, 0, 0, 0, 0]))
        driver.exit()


if __name__ == '__main__':
    main('COM7')
```

PUBLICATION

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