New York State Energy Research and Development Authority

Visual Refrigerant Fault Detector for Optimum Performance of Residential HVAC Systems

Final Report

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Visual Refrigerant Fault Detector for Optimum Performance of Residential HVAC Systems

Final Report

Prepared for the

New York State Energy Research and Development Authority

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NOTICE

ABSTRACT

Proper refrigerant charge affects the performance and lifespan of air conditioner and heat pump equipment. According to EPA's Energy Star website, "recent field studies suggest that approximately 75% of installed cooling equipment may have incorrect amount of refrigerant. Incorrect refrigerant level can lower efficiency by 5 to 20% and can ultimately cause premature component failure, resulting in costly repairs that could have been prevented." According to Carrier Corporation, "air conditioners off by more than eight ounces from the required factory charge can potentially fail in less than five years. Currently, there are no products on the market to monitor refrigerant charge in residential air conditioning equipment during operation.

Therefore, Steven Winter Associates, Inc. (SWA) identified an opportunity to develop a low cost, stand-alone, visual device that detects refrigerant overcharge and undercharge faults, which critically impact the energy use of air-conditioning systems. This device can be mounted on the outdoor unit or the indoor unit depending upon the type of expansion device used and monitors the charge level continuously. If the device is mounted outdoor, it can be equipped with a wireless transmitter and a display unit located indoors instead of being hardwired.

NYSERDA funded this project (NYSERDA contract no. 10929) to develop a refrigerant charge fault detection technology. Key tasks undertaken during this project were – 1) evaluate different techniques to determine refrigerant subcooling to characterize refrigerant charge fault; 2) perform field tests to establish Normal/Abnormal Charge Envelope; and 3) build and test the pre-prototype charge fault detector in the field. The project successfully developed and demonstrated a digital prototype for detecting refrigerant charge fault.

KEY WORDS

Refrigerant, charge, fault, HVAC, energy, subcooling, condenser, temperature, detection

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SUMMARY

Proper refrigerant charge affects the performance and lifespan of air conditioner and heat pump equipment. According to EPA's Energy Star website, "recent field studies suggest that approximately 75% of installed cooling equipment may have incorrect amount of refrigerant. Incorrect refrigerant level can lower efficiency by 5 to 20% and can ultimately cause premature component failure, resulting in costly repairs that could have been prevented." And according to Carrier Corporation, "air conditioners off by more than eight ounces from the required factory charge can potentially fail in less than five years. Currently, there are no products on the market to monitor refrigerant charge in residential air conditioning equipment during operation.

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The project successfully developed and demonstrated a digital prototype for detecting refrigerant charge fault. The study first evaluated three different techniques to detect refrigerant charge fault based on sensing condenser subcooling. A digital, differential temperature measurement and control device with two temperature sensors to sense subcooling directly was considered an ideal candidate based on its cost-effectiveness, simplicity and performance. A digital prototype for refrigerant charge fault detection was built from a temperature measurement and control kit, which uses a programmable interface controller (PIC) for controlled temperature sensing, two temperature sensors, two light-emitting diodes (LEDs), and a buzzer that can be used as indicator devices when specified conditions are met, and an LCD display. The PIC controller was programmed to display a measured temperature and the differential temperature (subcooling) along with controlling the two LEDs to indicate normal (no LED), undercharge (LED A) and overcharge (LED B) conditions. SWA tested for the accuracy of the temperature sensors and for the fault detection algorithm in its laboratory.

SWA utilized its earlier field data from tests, analyzed the laboratory data from the National Standards and Technology (NIST), and conducted one field study in Middletown, NY in September 2011 to develop normal/abnormal charge envelope for subcooling. The digital prototype built by SWA for refrigerant charge fault detection was field tested for its operational performance. The prototype successfully detected refrigerant faults introduced on a 3-ton air conditioning system in field tests. The prototype detected and visually displayed both undercharge and overcharge faults. The simple algorithm based on subcooling envelope for refrigerant charge, enables this.

1. Introduction

According to Associate Professor James Braun of Purdue University, "Condition monitoring involves the measurement of one or more indices of performance over time for the purpose of providing information concerning the 'health' of a piece of equipment or system." Steven Winter Associates, Inc. (SWA) has identified an opportunity to develop a low cost, stand-alone, visual device that indicates the health of a residential air conditioning system. More specifically, the device detects refrigerant overcharge and undercharge faults that critically impact the energy use of air-conditioning systems. This report describes SWA's research associated with the development of a residential HVAC refrigerant condition monitor.

1.1 *The Problem*

Faulty operation of HVAC systems, including air-conditioners and heat pumps in residential buildings is prevalent and results in increased energy use. Common faults are incorrect refrigerant charge, incorrect airflow, evaporator fouling (dirty indoor air-filter), and condenser fouling (dirty outdoor coil). Correct refrigerant charge is very important for proper operation of an air-conditioner or heat pump.

An overcharged unit can cause the refrigerant to flood back to the compressor crankcase. This dilutes the compressor oil and can result in oil bearing damage/failure. An undercharged unit will provide less than rated capacity while consuming more energy. In addition, the compressor can overheat due to insufficient refrigerant returning to the compressor. This overheating will result in a breakdown of the compressor oil leading to potential sludge formation in various refrigerant components. Both conditions reduce efficiency, but undercharge will result in a higher loss. [1]

Many factors are responsible for incorrect refrigerant charge. Over charge is typically due to HVAC technician's error and under charge is due to refrigerant leaks or can be attributed to technician's error, lack of charging protocols, and quality control. Typically air-conditioning systems come with a fixed refrigerant charge from the factory. Nevertheless, when an air-conditioner is installed, refrigerant charge is corrected (added or removed) by a technician depending upon the lengths of refrigerant lines from the outdoor unit to the indoor air-handler. Possible causes for errors are incorrect charge calculation and weighing of refrigerant. Technicians try to verify the charge through the system operation and in-situ measurements by measuring refrigerant subcooling and evaporator superheat to determine if the charge is normal. Use of pressure gauges and temperatures sensors to determine these parameters, also contributes to error. Even if the initial charge is accurate, a slow gradual leak can lead to an underperforming system.

Subcooling is the condition where the liquid refrigerant is colder than the minimum temperature (saturation temperature) required to keep it from boiling and, hence, change from the liquid to a gas phase.

Subcooling [^{o}F] = Condenser Temp at Saturation – Condenser Outlet Temp

Superheat refers to the number of degrees a vapor is above its saturation temperature (boiling point) at a particular pressure.

Superheat [^{o}F] = Evaporator Outlet Temp – Evaporator Temp at Vapor Point

A recent California study that tested over 4,000 residential air-conditioning systems showed about 34% were undercharged and 28% were overcharged. A similar testing study in New Jersey showed 60% of units were improperly charged."[2] According to EPA's Energy Star website, "recent field studies suggest that approximately 75% of installed cooling equipment may have the incorrect amount of refrigerant. Incorrect refrigerant level can lower efficiency by 5 to 20% and can ultimately cause premature component failure, resulting in costly repairs that could have been prevented."[3] According to the Carrier Corporation, "air conditioners off by more than eight ounces from the required factory charge can potentially fail in less than five years."[4]

"Based on laboratory testing and fault prevalence data, low refrigerant charge appears to have the greatest impact on residential AC efficiency of any fault, i.e., substantially greater than similar degrees of overcharge and insufficient evaporator airflow."[5] In 2001, there are more than seven million households in New York State [6] that use more than 42 billion kWh/year of electricity. More than half of these are single-family. There are about 4.7 million units with air-conditioners that consume 3.3 billion kWh/year. Assuming 50% of these homes have systems with improper charge and 10% of energy is wasted, it is estimated that 165 million kWh of energy is wasted annually. Cost of this energy waste is about $26 million ($0.16/kWh). Therefore, there is significant opportunity for a refrigerant fault detection device.

1.2 *Industry Shortcomings*

According to Buck Taylor of Roltay, Inc., "HVAC crews aren't empowered to properly install high efficiency systems. The technicians don't understand [energy efficiency] fundamentals, or the impact of what they're measuring."

According to Brian Cumming of BCA Engineering, "Almost all technicians use head and suction pressures to check refrigerant charge. They expect head pressures between 230 and 360 lbs and suction pressures between 60-80 lbs. Technicians use a pressure range because most know that the proper pressures change with varying load conditions. Still, they continue to use this pressure method and use these ‘ranges’ as guides. This results in over and under charged systems, which causes low equipment life.”[7]

More knowledgeable technicians may use diagnostic techniques, such as superheat or subcooling tests, a gravimetric test, a sight glass, thermostatic expansion valve (TXV) frosting, or motor signature analysis, to verify adequate system charge. Only the superheat and subcooling tests are truly quantitative methods and therefore, will be the focus of SWA’s prototype development. The typical manufacturers’ performance tolerances for superheat and subcooling are ±5°F and ±3°F, respectively. Based on SWA prior field monitoring experience, TXVs are best assessed by subcooling and fixed-orifice units are more easily assessed by superheat, though was verified in Task 2.

Refrigerant charging tables for a two-stage heat pump are available for technicians, but how often is this being used in the field? Even when manufacturer’s data is used, there are times HVAC contractors aren’t properly applying manufacturer’s charging charts. Often these two-stage high efficiency systems are charged in low capacity (rather than the manufacturer required high capacity).

In another example, SWA recently worked with a New York State HVAC contractor on a project in which refrigerant lines would be longer than the charge set by the manufacturer. Therefore, SWA informed the contractor that additional charge would be required for the system to properly operate and that a subcooling test would be required to confirm proper installation. The HVAC contractor provided the following table (Figure 1-1) to demonstrate these long refrigerant lines would result in the cooling capacity being diminished for the project, so SWA’s Manual J sizing was incorrect.

Unit Nominal Size (Btuh)	Maximum Liquid Line Diameters (In. OD)	Vapor Line Diameters (In. OD)	Cooling Capacity Loss (%) Total Equivalent Line Length ft. (m)								
			Standard Application		Long Line Application Requires Accessories						
			26–50 (7.9–15.2)	51–80 (15.5–24.4)	81–100 (24.7–30.5)	101–125 (30.8–38.1)	126–150 (38.4–45.7)	151–175 (46.0–53.3)	176–200 (53.6–61.0)	201–225 (61.3–68.6)	226–250 (68.9–76.2)
18000 1 Stage Puron AC	3/8	1/2	1	2	3	4	6	7	8	9	10
		5/8	0	0	1	1	1	2	2	3	3
24000 1 Stage Puron AC	3/8	5/8	0	1	1	2	3	3	4	4	5
		3/4	0	0	0	0	1	1	1	1	1
		7/8	0	0	0	0	0	0	0	0	0
30000 1 Stage Puron AC	3/8	5/8	1	2	3	3	4	5	6	7	8
		3/4	0	0	1	1	1	2	2	2	3
		7/8	0	0	0	0	1	1	1	1	1
36000 1 Stage Puron AC	3/8	5/8	1	2	4	5	6	8	9	10	12
		3/4	0	1	1	2	2	3	3	4	4
		7/8	0	0	0	0	1	1	1	2	2
42000 1 Stage Puron AC	3/8	3/4	0	1	2	2	3	4	4	5	6
		7/8	0	0	1	1	1	2	2	2	3
		1 1/8	0	0	0	0	0	0	0	0	0
48000 1 Stage Puron AC	3/8	3/4	0	1	2	3	4	5	5	6	7
		7/8	0	0	1	1	2	2	2	3	3
		1 1/8	0	0	0	0	0	0	0	1	1
60000 1 Stage Puron AC	3/8	3/4	1	2	4	5	6	7	9	10	11
		7/8	0	1	2	2	3	4	4	5	5
		1 1/8	0	0	0	1	1	1	1	1	1

Applications in this area are long line. Accessories are required as shown recommended on Long Line Application Guidelines

Applications in this area may have height restrictions that limit allowable total equivalent length, when outdoor unit is below indoor unit See Long Line Application Guidelines

Line Length

Capacity Loss

Figure 1-1 Table that was incorrectly interpreted by an HVAC contractor for line set lengths and the associated capacity loss.

The contractor stated, “Attached is a page from the Carrier Submittal for the condensing units. The bottom half of the page breaks down the vapor line sizing and the cooling capacity loss. The important thing to look at right now is the total equivalent line length and the resulting cooling capacity loss. Applications in the dark shaded area are long line as stated at the bottom of the page. Even applications less than 80 ft. have a loss in capacity, just not as drastic as say a line 100 ft. long.”

They wanted to use the 81-100’ line length capacity loss correction when sizing the coils, which they believed would result in a lower cooling capacity by 24.7 – 30.5%. What they were actually reading was the feet to meters conversion and not the cooling capacity loss, which was closer to 2-4%. This is an extreme example of a contractor not being technically savvy with HVAC design, but when contractors don’t understand this or how to properly do a Manual J sizing calculation, you start to wonder what else they are “glossing” over.

1.3 *Current Solutions In The Market*

A simple device in the category of on-board fault detection systems for residential HVAC systems is Honeywell’s W8710A Equipment Monitoring System. The device, has two temperature sensors measuring supply and return air temperatures, and generates alarms if the temperatures and temperature difference deviate from reference values. The device does not provide information on refrigerant charge or air flow. Honeywell has another comprehensive diagnostic system (HVAC Service Assistant) for field service technicians, however there are few other devices being marketed or under development. There have been several concepts proposed [Refs. 8-11] for refrigerant charge diagnosis, briefly noted below:

- Bahel, et al. [8] developed an overcharge-undercharge diagnostic system for air conditioner control. In this method, the compressor discharge temperature is measured at a predetermined expansion valve setting and compared with the reference discharge temperature. If the measured temperature is higher than the reference, the system is undercharged and if the measured temperature is lower than the reference, the system is overcharged.

- Bessler [9] proposed a system to detect low refrigerant charge by monitoring the compressor discharge pressure and temperature. The controller reads the sensor output signals and produces a low charge signal whenever a combination of a high discharge temperature and a low discharge pressure is detected.

- Tulpule [10] disclosed a refrigerant monitoring system with neural networks. First, the neural network is trained to learn the characteristics of the system. Then, the trained network timely computes refrigerant charge during a runtime mode of operation. The variance data is made available.

- Bathla [11] proposed a method to detect charge by measuring pressure and temperature at the condenser outlet. The detection here determines actual sub cooling and compares with the reference sub cooling to arrive at the charge condition.

Furthermore, there have been several efforts related to somewhat generalized fault detection and diagnosis applied to vapor compression systems [Refs. 12-17]. Sigel, et. al. [18] evaluated three different types of refrigerant charge diagnostic equipment for residential cooling systems. The equipment used a superheat method for fixed orifice systems. Two of the three systems tested were found to be suitable.

Under an SBIR project funded by the US Department of Energy (DOE), SWA developed a prototype thermostat (HSTAT, a device for HVAC health status and control) technology that incorporates temperature and humidity control, and on-board fault detection. A concept diagram for HSTAT is illustrated in Figure 1-2. This device is similar to a conventional thermostat with a humidistat, but has an additional on-board fault detection module. This fault detection module requires just 4 to 5 additional temperature measurements and is capable of detecting refrigerant undercharge, overcharge, and airflow faults.

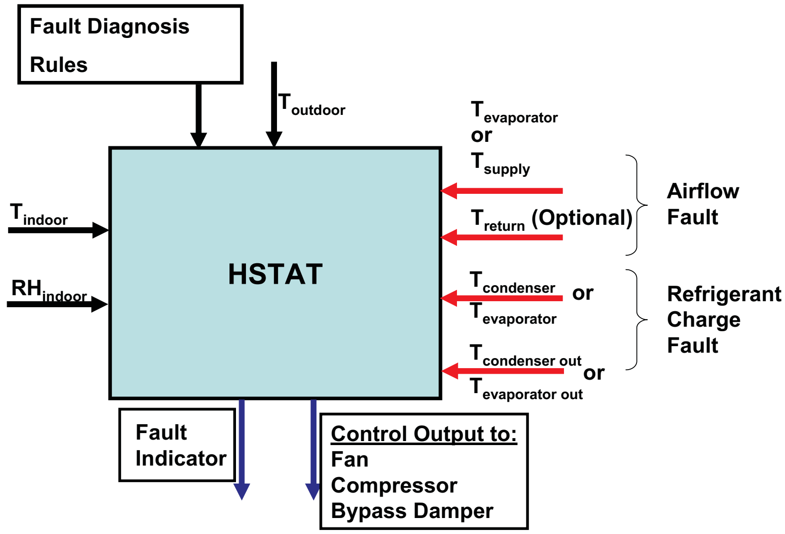


Figure 1-2 A Schematic Illustration of the HSTAT Concept Developed by SWA under a DOE SBIR Project.

As there are several refrigerant charge detection products in the market, the need for refrigerant fault detection has been recognized by others. Still, current solutions are fairly expensive and primarily tools for technicians only. "Diagnostic tools typically use or require high-quality instrumentation and often a handheld computer to analyze results. This increases the cost of acquiring the tools, as does the training required for technicians to come up to speed with the tools."[5] For this reason, SWA is looking to develop a low cost alternative that focuses solely on refrigerant charge fault detection that can be used for initial charging of the system and/or ensuring proper charge over the lifespan of the HVAC equipment.

Table 1-1 Why the Limited Market Penetration?

Current Market Solutions	cost	ease of use	continuous monitoring
Honeywell HVAC Service Assistant	$$$$$		
The IST Monitor	$$$		
Digital Refrigeration System Analyzer (DRSA)	$$$		
Verification Service Technology (VST) ChargeRite	$$$$$		
Testo 523	$$$		
Stargate SG3000	$$$$		
AC-Pal software	$$$		
CheckMe!	$$		
Proposed SWA Device	$	x	x

2. Techniques For Refrigerant Charge Fault Detection

SWA evaluated three different techniques – 1) using differential pressure sensing, 2) thermoelectric modules, and 3) differential temperature. The first technique is a novel technique. Based on SWA's literature review, this technique has never been used for this application. One refrigerant-filled bulb is attached to the condenser coil (near the two-phase region) and another bulb is attached to the outlet of the condenser. These refrigerant bulbs are commonly used in TXV devices. The refrigerant in two bulbs will boil at different rates, based on their sensed temperatures, and result in a differential pressure, which can be input to a differential pressure switch (that can display the charge level or close a contact to generate fault signal).

The second technique employs miniature thermoelectric modules, which produce electric signals when there is a temperature difference across their surfaces. The advantage of this technique is that these modules will generate power that may be adequate for powering an LED or a display to indicate fault. In this technique, one module is attached to the condenser coil in the two-phase region and the other is attached to the condenser outlet. The leads from the two modules can be connected such that the net voltage can indicate the subcooling (and hence charge) level.

The third technique involves a differential temperature measurement. In this technique, a pair of thermocouples/thermistors is used to sense temperature difference (subcooling). This is a simple technique, but requires an external power supply and electronics for signal processing (display).

The first technique would require a technician to install the system, while the later two techniques could potentially be installed by a "do-it-yourselfer". In all three cases, a simple LED light would be used to visually inform the user that refrigerant charge is improperly set. The advantages of the proposed product are:

- Low cost
- Simple to use
- Ability for continuous monitoring
- Basic visual indicator of fault

SWA has fabricated breadboard prototypes for the first and third techniques discussed above from off-the-shelf components and have tested them in our laboratory. Laboratory testing included studying the functionality in terms of the sensitivity of each device to temperature difference, accuracy, time-response, ease of field installation, and ability to couple to an indoor display/alarm unit. SWA has set a cost constraint of the add-on device (charge detector) at under $50, as this technology should be simple, reliable and cost-effective to allow greater market penetration and acceptance. Based on cost constraint and complexity in design, the third technique was not considered for further development and evaluation.

Further details of the evaluations of the three techniques for refrigerant charge fault detection are provided in the following sections.

2.1 Differential Pressure Technique

This technique involves sensing differential pressure corresponding to temperature differential (subcooling). The novelty of this technique is that it is non-intrusive and is totally passive requiring no external power. A schematic of the concept of differential pressure measurement for charge fault detection is shown in Figure 2-1. In this case, one fixed volume chamber (bulb 1) containing refrigerant is attached to the condenser (in the two-phase region) and another (bulb 2) is connected at the outlet of the condenser. These two chambers are then coupled to a differential pressure sensing element by small-diameter tubing. If there is a temperature between the two locations, then it is indicated by the pressure differential. Measured pressure differential can be correlated with subcooling to diagnose charge fault. This is a phenomenally simple method since it is passive and no electronics are needed.

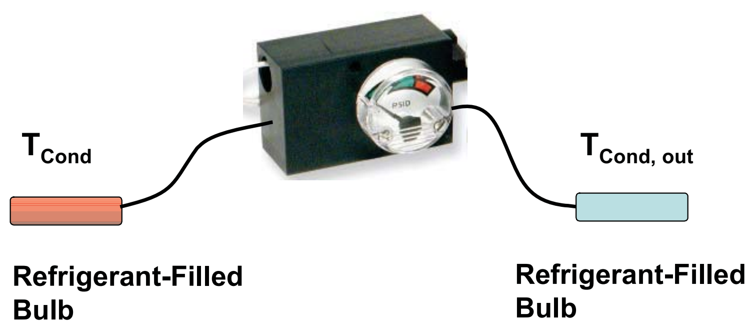


Figure 2-1 A Concept Using Differential Pressure for Detecting Subcooling.

For the design of the prototype, it is essential to know what typical condensing temperatures and corresponding condensing saturation pressures are expected in operation of an air-conditioner. Typical condensing temperatures and condenser pressures are shown in Figure 2-2 and Figure 2-3 for an R-22 refrigerant air conditioning system. If R-22 is used in the refrigerant-filled bulbs, pressures will be below 250 psi. Propane and R-134A will have pressures below 250 psi. Still, if R-410A is used, pressures of 400 psi can be anticipated. Since R-22 is being phased out under the terms of the Montreal Protocol (US enforcement by EPA under Title VI of the Clean Air Act) and R-410A is predominantly used in residential air-conditioning systems, R-410A will be SWA's primary focus for the initial prototype differential pressure indicator.

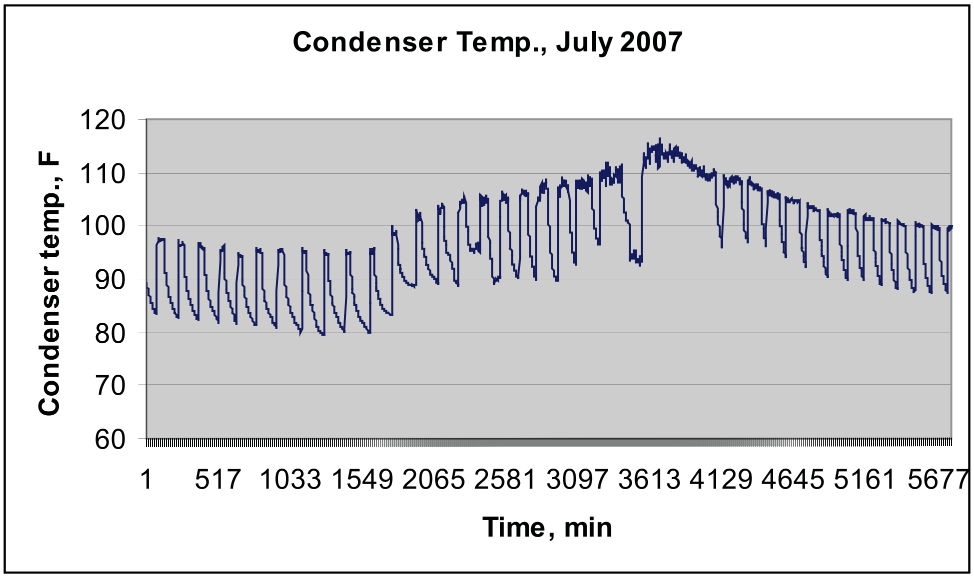


Figure 2-2 A Condenser Temperature Profile of an R-22 System.

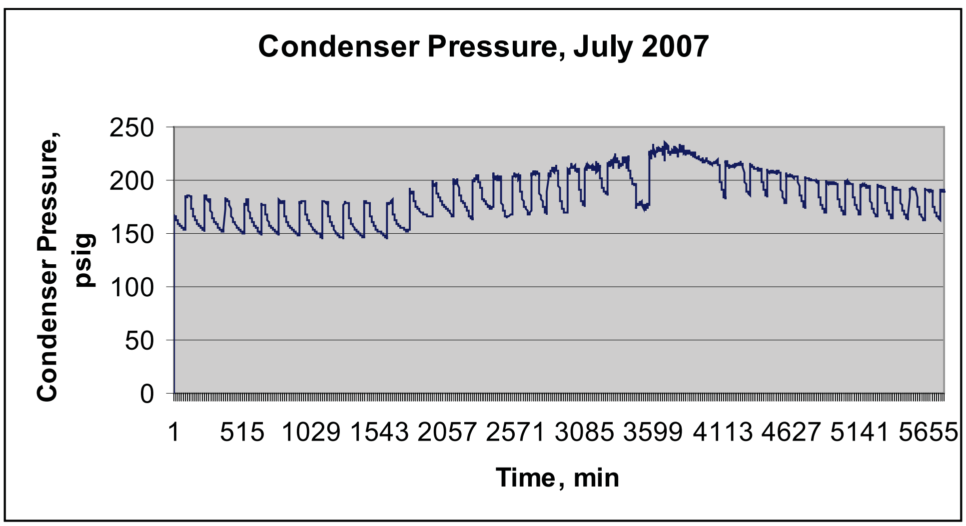


Figure 2-3 A Condenser Pressure Profile of an R-22 System.

SWA designed and built a first laboratory prototype as shown in Figure 2-4. It consists of two refrigerant bulbs (typically used in a TXV device), a differential pressure gauge (30 psi differential range; can withstand an absolute pressure of 5,000 psi), tubing, fittings and refrigerant charging ports.

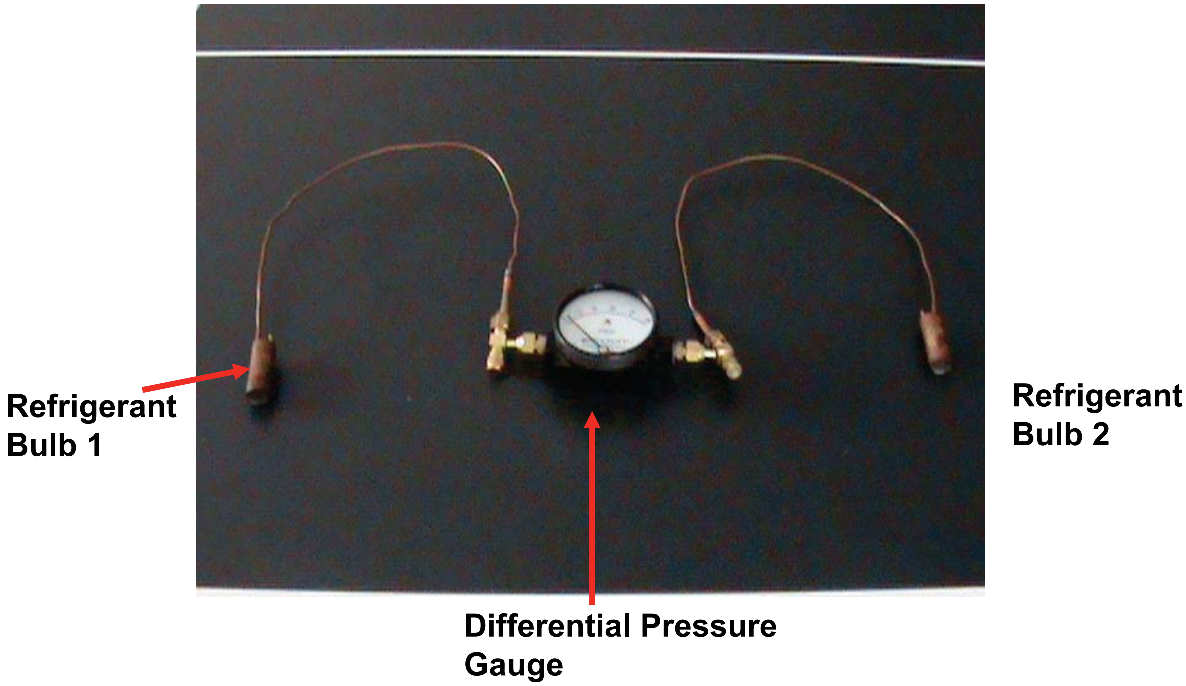


Figure 2-4 A Breadboard Prototype for Detecting Refrigerant Charge Fault Employing Differential Pressure Sensing.

Both refrigerant bulbs were charged to a pressure corresponding to a saturation pressure (~200 psi) at room temperature. Pressures in both bulbs were the same and yielded a differential of zero. This breadboard prototype was tested in the laboratory for its performance. The prototype's refrigerant bulb 1 (high-side) was placed in a hot water bath (also an incubator), while bulb 2 was at room temperature to yield a temperature differential. Measured pressure differential as a function of measured temperature differential is shown in Figure 2-5. At a temperature differential of 30^{o}F, measured pressure differential was only 7 psid. Saturation pressure differential (theoretical) corresponding to this temperature difference is more than 100 psid. There is a significant deviation between the measured and the anticipated pressure difference. This difference is attributed to multiple factors including a significant heat loss from bulb 1 to surroundings, fittings, the gauge, and refrigerant in tubing connected to bulb 2, and change in volume of high-side due to the gauge diaphragm movement. Because of these factors, theoretical pressure difference doesn't correspond to measured pressure difference. Still, it's possible to calibrate the measured pressure difference with the measured temperature difference, but the sensitivity of pressure differential change with respect to temperature differential is significantly low.

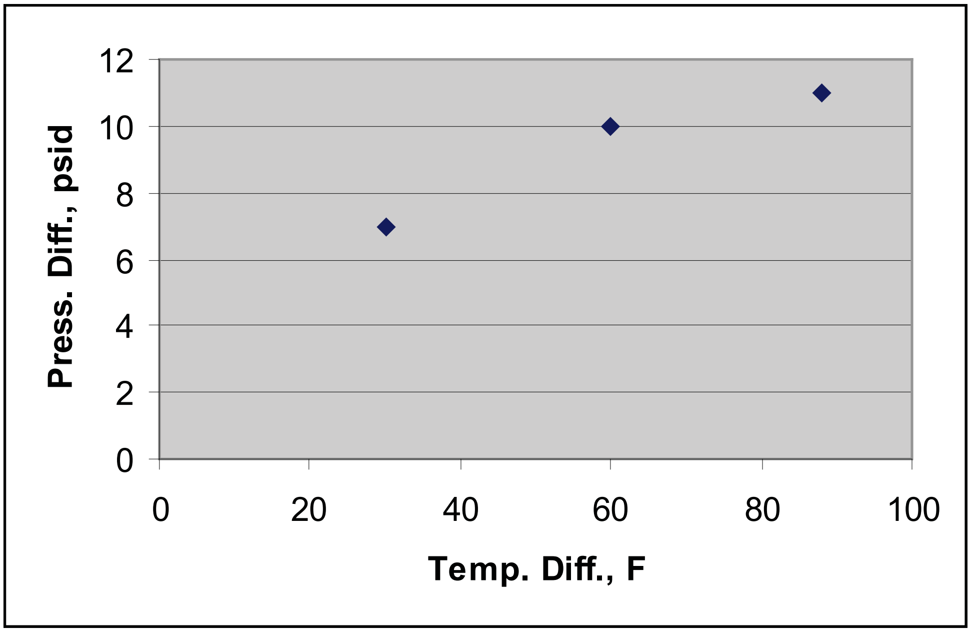
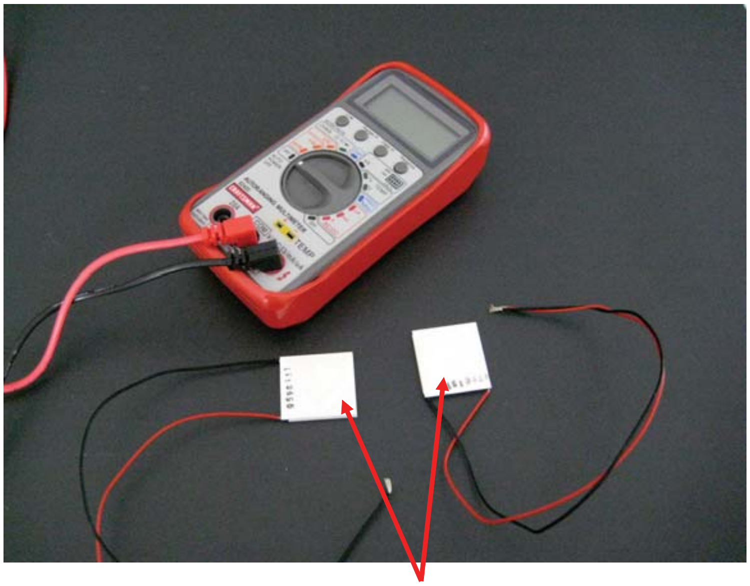


Figure 2-5 Measured Pressure Differential as a Function of the Measured Temperature Differential Using the Pressure Differential Prototype.

Cost factors for this prototype were considered. A differential pressure gauge is the main cost determining factor since the fittings and refrigerant charge can be obtained for under $10 in high volume. An accurate and reliable gauge costs about $100 retail. A reasonable estimate of the gauge cost in high volume is $50. Hence, the overall cost of the unit will be in the order of $60. If a mark-up is included, its cost could be significantly higher. Considering the cost factor and low sensitivity of the system, this concept was not considered for further development.

2.2 Thermoelectric Module Technique

The second technique employs miniature thermoelectric modules, which produce electric signals when there is a temperature difference across their surfaces. Figure 2-6, shows a photo of two thermoelectric modules. The advantage of this technique is that these modules will generate power that may be adequate for powering an LED or a display to indicate fault. In this technique, one module is attached to the condenser coil in the two-phase region and the other is attached to the condenser outlet. The leads from the two modules can be connected such that its net voltage can indicate the subcooling (and hence charge) level.



Thermoelectric Modules

Figure 2-6 Thermoelectric Modules for Measuring Subcooling.

Initial laboratory trials included measurement of voltage output from thermoelectric modules individually and in differential mode. Single-stage thermoelectric module (Tellurex G1-34-0315) produces only about 1.5 mW at 100°C temperature differential. In our application, the temperature differential on a single-stage module is less than 10°C. Therefore, net output from the module will be in micro-volts, which will not be adequate to power an electronics module. Also, cost of two modules needed for the differential temperature (subcooling) was $70. Additional electronics needed to measure the voltage from the modules and indicate charge fault would cost over $25. Therefore, this technique was not considered for further development.

2.3 Differential Temperature Measurement Technique

Refrigerant subcooling (the difference in condensing temperature and condenser outlet temperature) is a good indicator of the charge in an air-conditioner. As shown in Figure 2-7, a temperature differential can be measured directly or indirectly and charge fault can be detected based on a simple algorithm.

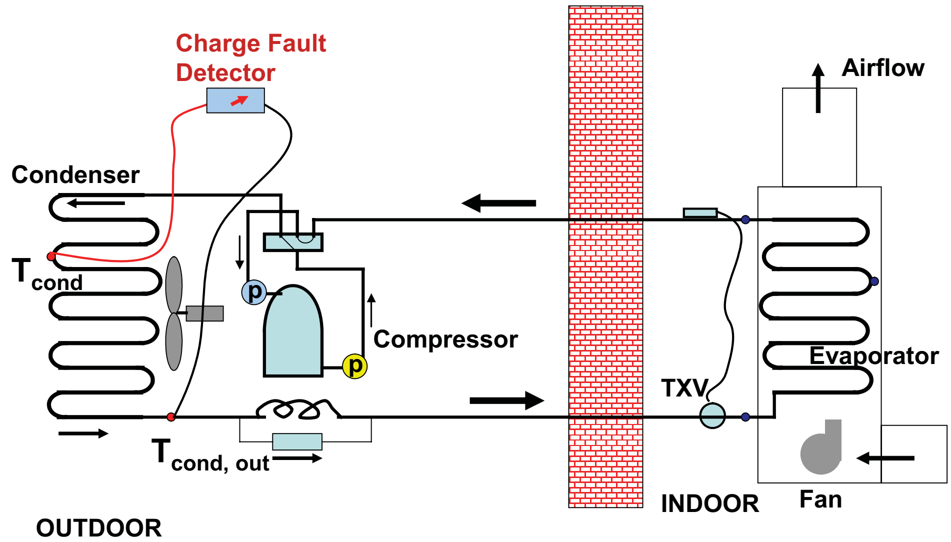


Figure 2-7 A Concept of Measuring Subcooling for Charge Fault Detection.

SWA was more inclined to this technique using temperature measurement for measuring subcooling since temperature measurement is accurate, simple, and proven. There exist meters to measure temperatures directly employing thermocouples or thermistors or RTDs. Also, there exist devices that measure temperature differential directly. These are typically hand-held meters. Nevertheless, our device is required not only to measure temperature differential (subcooling) but diagnose charge fault based on sensed temperature differential. SWA reviewed literature for existing products that could be used for the prototype. SWA identified two off-the-shelf products that could be modified for our application.

One kit is shown below in Figure 2-8. It is a differential temperature controller used for controlling a solar thermal collector water pump. It requires two input temperatures (thermistors) and turns the pump ON/OFF by comparing the sensed differential temperature with the pre-set temperature differential. SWA has evaluated this kit to modify for our application. The main circuit (PC) board is made up of a basic comparator circuit design using operational amplifiers as the main drivers. Beside the comparator aspect of the circuit, the output of the main board also drives two identical PC boards that convert the output signals from the thermistors to readable temperature values in Fahrenheit via two LCD output displays. Although the maximum temperature differential (delta-T) of the circuit design has been engineered to be approximately 10^{o}F, this can be easily modified to accommodate a different delta-T. Still, further modification to the circuit board would be necessary to provide the ability to measure more than one temperature differential to ultimately verify potential under charge, over charge, or properly charged refrigerant conditions. This device didn't have the capability of programming for detection algorithm, i.e., the ability to change/set the temperature differential ranges for determining fault conditions.

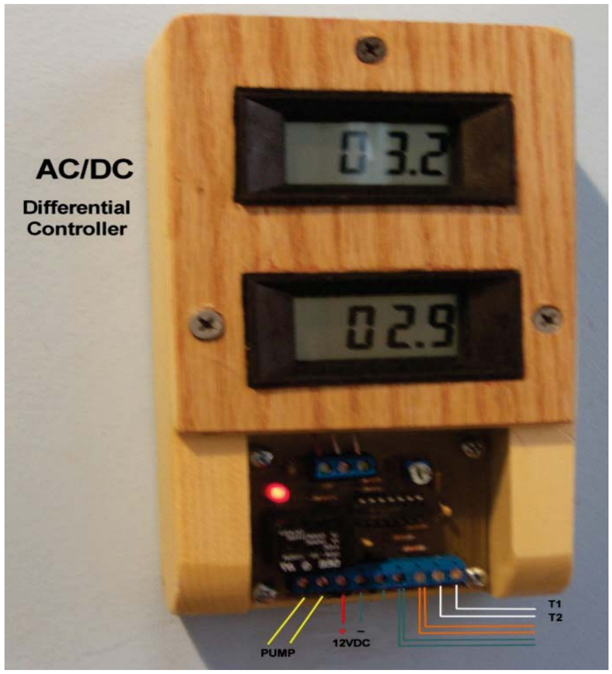


Figure 2-8 A Differential Controller Kit Evaluated by SWA for Sensing Subcooling.

SWA obtained an unassembled kit for dual temperature measurement and control, which uses a PIC (programmable interface controller) for controlled temperature sensing, two temperature sensors (integrated-circuit sensors), two LEDs and a buzzer that can be used as indicator devices when specified conditions (set by the user) are met, and an LCD display. The prototype kit assembled from scratch by SWA is shown in Figure 2-9 and Figure 2-10. The PIC controller was programmed to display a measured temperature and the differential temperature (subcooling) along with controlling the two LEDs to indicate normal, undercharge and overcharge conditions.

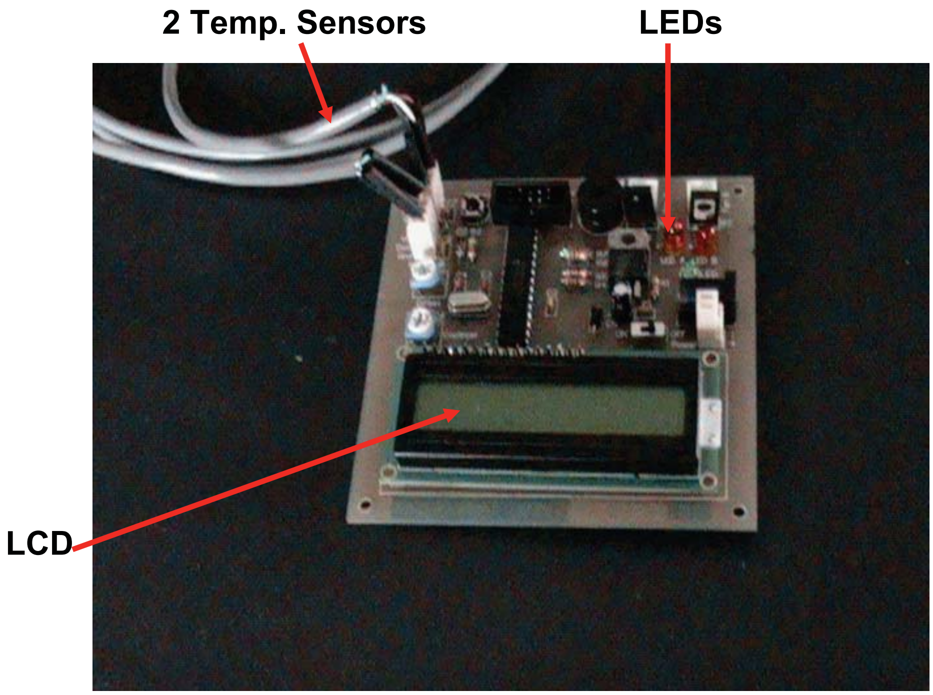


Figure 2-9 A Differential Temperature Prototype Built by SWA for Sensing Subcooling and Diagnosing Charge Fault.

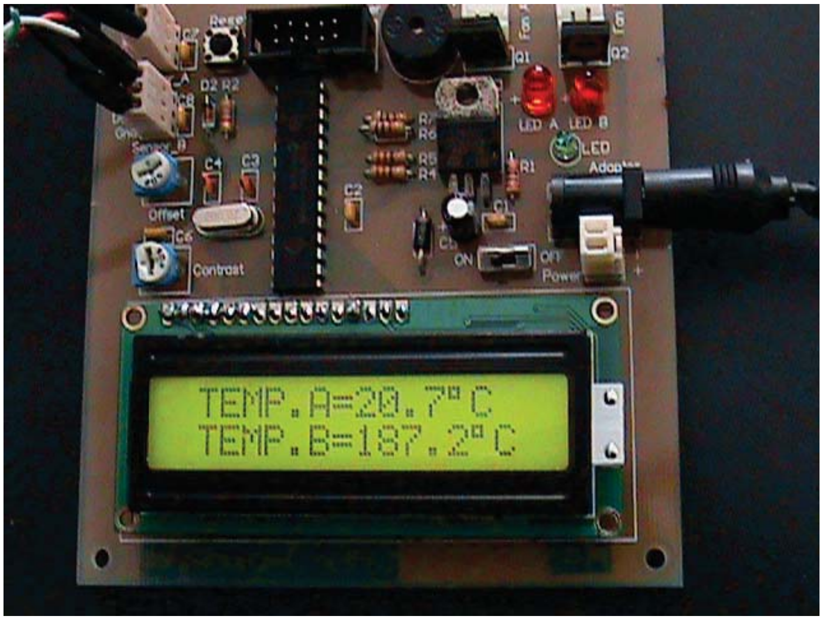


Figure 2-10 The Differential Temperature Prototype in Operation before Fault Detection Algorithm was Programmed.

SWA tested the pre-prototype for the accuracy of the temperature sensors and for the fault detection algorithm. SWA used an incubator (Figure 2-11) for testing temperature sensors at higher temperatures. A glass thermometer was used as a reference to check the accuracy of the temperature sensors. The difference between the temperature sensors and the glass thermometer was found to be within 1°F of each other.

Figure 2-11 Experimentally Checking Prototype Functionality at Various ΔT Conditions.

Figure 2-12 shows the agreement (slope of nearly one and y-intercept of nearly zero) between the sensor temperature and the reference glass thermometer.

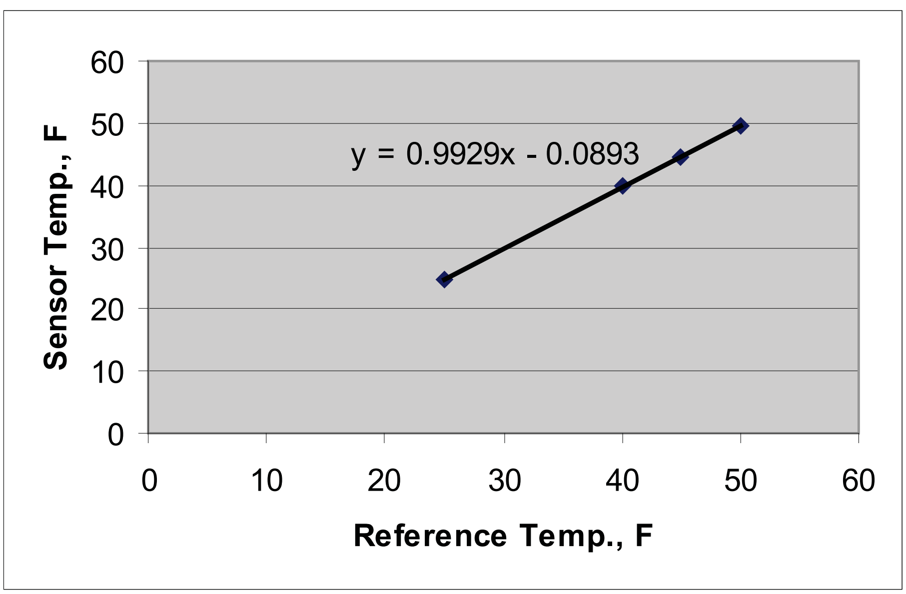


Figure 2-12 Agreement Between the Prototype's Temperature Sensor and the Reference Temperature.

For fault detection, the following criterion (tentative) was used for the subcooling in checking the prototype functionality:

1. If subcooling (temperature differential) > 25^{o}F, then the over charge fault is indicated by LED A turning on

2. If subcooling (temperature differential) < 9^{o}F, then the undercharge fault is indicated by LED B turning on

3. If 25 ^{o}F ≥ subcooling ≥9F, then the charge is normal indicated by both LEDs turning off.

For checking the algorithm, one temperature sensor was placed inside the incubator while the second temperature sensor was placed at room temperature. When the incubator temperature was varied, the prototype was able to successfully detect both faults and normal condition as well.

3. Field Tests To Establish Normal/Abnormal Charge

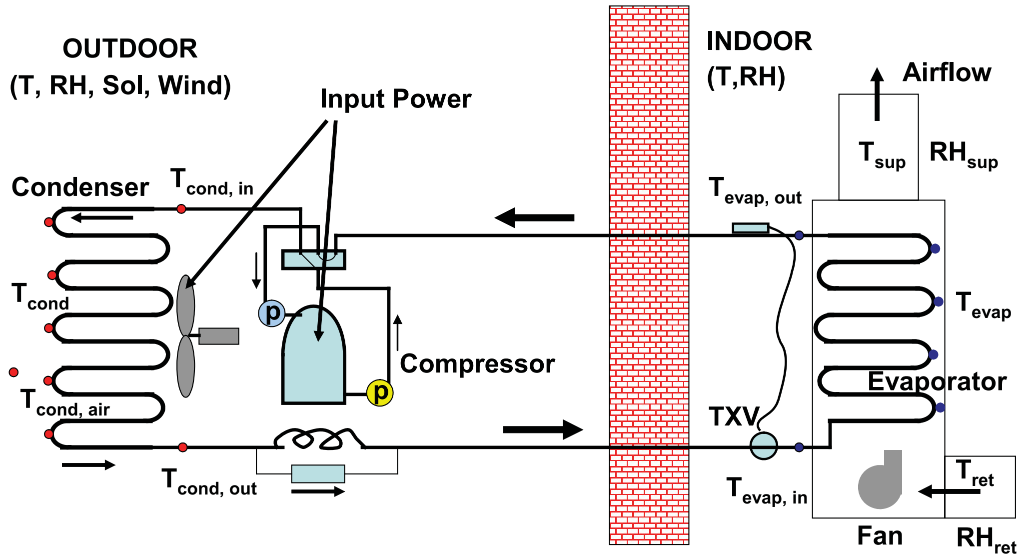
Under this task, SWA originally proposed to develop a database of Normal/Abnormal Charge Envelope for R-407C, R-22 and R410-A through field testing. After considering the fact that R-22 is already phased out and R-407C is not that common in residential air-conditioning equipment, SWA considered only R410-A for the development of refrigerant fault detection criteria by establishing "Normal/Abnormal Charge Envelope".

Instead of performing three field tests, SWA used its field data from tests, analyzed the laboratory data from the National Standards and Technology (NIST) and conducted only one field study in Middletown, NY in September 2011 due to difficulty in recruiting qualified, willing HVAC contractors. AStar Heating and A/C, Inc., a willing and qualified HVAC contractor in Middletown, NY was recruited for the field testing. AStar's interest and commitment to this technology can be seen in the attached letter of interest (Appendix A). Field test protocol and results are presented below.

3.1 Test Protocol

The goal of the field testing was to obtain "Normal/Abnormal Charge Envelope" by measuring condenser subcooling, an indicator of refrigerant charge fault, under normal-, under- and over- charge conditions in the field. The purpose of obtaining the subcooling data was to develop a simple fault detection envelope and algorithm for SWA's digital prototype. This subcooling data was compared with SWA's previous field test data and the NIST's laboratory data.

Below is a schematic of the vapor compression cycle (heat pump in cooling mode or air-conditioner, Figure 3-1) with various measurement variables identified to aid in the field testing. SWA's Energy Efficiency Ratio (EER) Box, shown in Figure 3-2, is a data acquisition system that is capable of measuring an air-conditioning system performance and can accommodate several sensors for temperatures, control signals, and weather parameters.



HEAT PUMP IN COOLING MODE

Figure 3-1 A Schematic of a Heat Pump/Air-Conditioner with Various Measurement Variables.

Key Measurements.

Fault Diagnosis (Main Measurements):

- *Condensing temperature (T_{cond}) for refrigerant charge diagnosis*
- *Condenser outlet temperature ($T_{cond,out}$) for refrigerant charge diagnosis*

Capacity/ EER:

- *Air-flow (Air flow in the supply duct needs to be monitored for characterizing the system performance, diagnosing reduced air flow)*
- *Supply and return air temperatures and relative humidity values*
- *Power consumption (condenser and air handler)*
- *Line pressures (suction and discharge lines)*
- *Ambient air temperature.*

Figure 3-2 SWA's EER Box in the Field (Middletown, NY).

Temperature sensor placement on the condenser is critical for determining the condensing temperature (T_{cond}). Temperature sensor should be placed in the two-phase regions on a U-bend of the condenser coil. Typically, the sensor needs to be above one/two coils above the mid coil to assure the two-phase region. In these field tests, ten sensors were placed on the condenser coil. These were adhesively bonded and insulated (using pipe insulation).

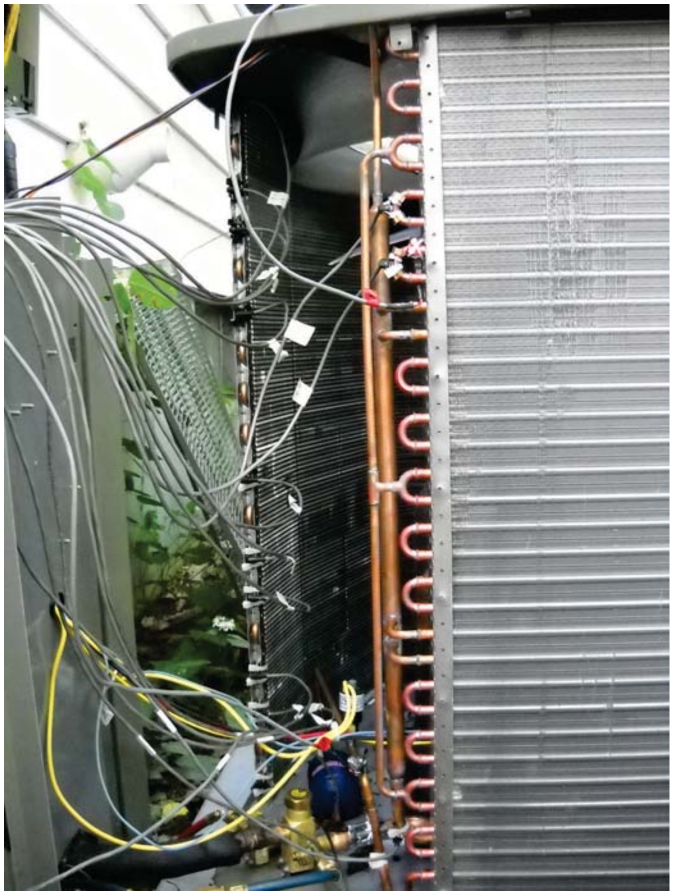


Figure 3-3 Condenser Coil (Outdoor Unit) with Temperature Sensors Placed.

The following test scenarios were considered for the field tests:

Test Scenario	Day	Airflow	Refrigerant Charge
Basecase	1st morning	Normal	Normal
Test 1	1st afternoon	Normal	-30%
Test 2	2nd morning	Normal	-20%
Test 3	2nd afternoon	Normal	-10%
Test 4	3rd morning	Normal	+20%
Test 5	3rd afternoon	Normal	Normal

Refrigerant charge can be determined in different ways. SWA considered gravimetric method (weight method) for determining the refrigerant charge (see Figure 3-4). Astar computed the normal charge based on factory recommendation and the length of refrigerant line to be 6 lb 11 oz. Based on this, refrigerant charge for various fault scenarios were determined.

Figure 3-4 Refrigerant Charging by Gravimetric (Weight) Method.

3.2 Results of Field Testing

Field tests were conducted on a 3-ton air-conditioning unit with refrigerant R-410A in Middletown, NY in September, 2011 employing the above test protocol. Brief test results are presented here. Since our focus is on the condenser subcooling envelope, condenser temperature profiles and subcooling profiles are presented.

Figure 3-5, presents temperature for the condenser coil from inlet to outlet at different U-bends. As shown in Figure 3-5, the refrigerant vapor entering the condenser is cooled quickly in the first region (single phase, sensible cooling) and the condensation begins in the second region (two-phase region). In the third region, condensed refrigerant liquid is subcooled (single-phase, sensible cooling) below its condensation temperature.

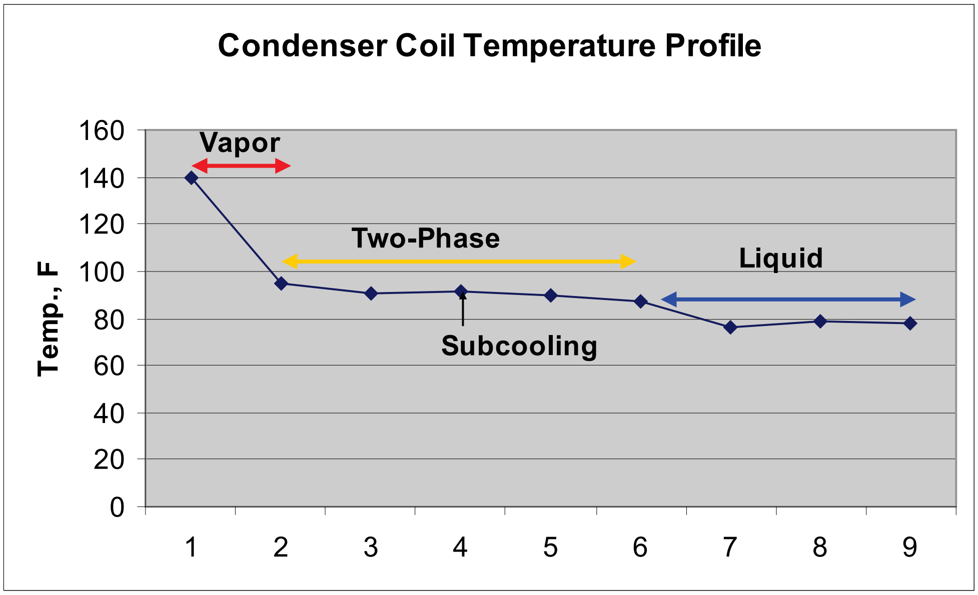


Figure 3-5 Temperature Profile Along the Condenser Coil Illustrating Phase-Change.

Subcooling profile for normal refrigerant charge is pictorially shown in Figure 3-6. As shown Figure 3-6, condenser subcooling begins to reach steady state in about five minutes, which indicates a minimum runtime needed for the system to estimate the subcooling. The average subcooling for the normal charge condition was 13^{o}F.

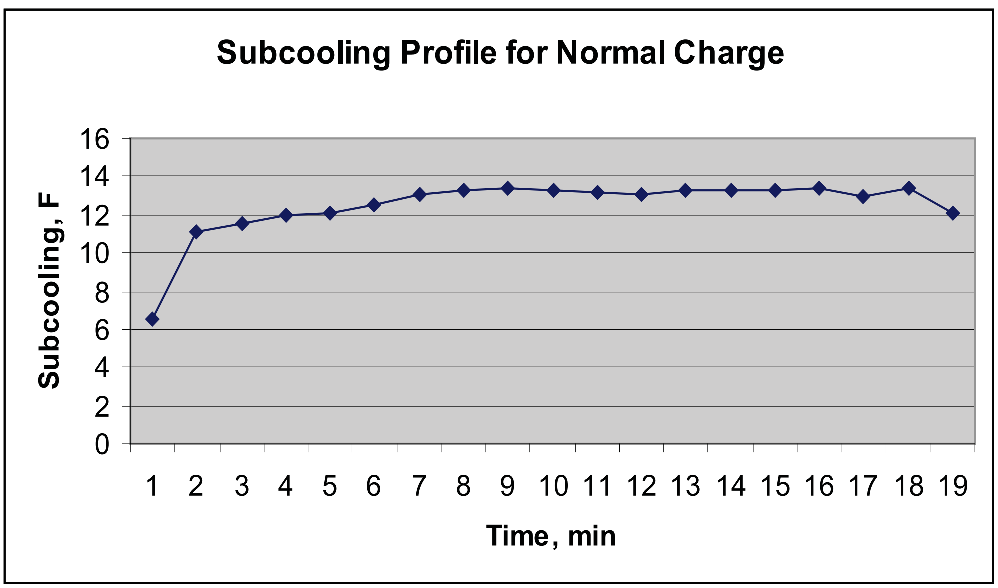


Figure 3-6 Refrigerant Subcooling as a Function of Time for Normal Charge.

Subcooling profile for refrigerant undercharge (-10%) is shown in Figure 3-7. The average subcooling for this case was found to be 7°F, which is significantly lower than the subcooling for normal charge condition.

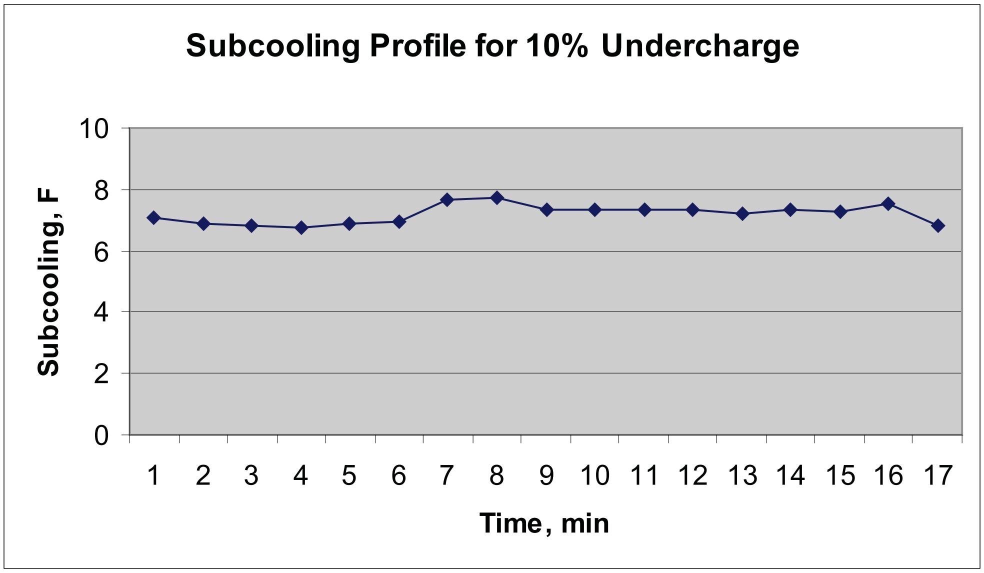


Figure 3-7 Refrigerant Subcooling as a Function of Time for 10% Undercharge.

Subcooling profiles for -20% and -30% refrigerant charges are shown in Figure 3-8 and Figure 3-9. These profiles show that the refrigerant subcooling falls below the 10% undercharge level. These also indicate that there is not much difference between -20% and -30% charge conditions since the accuracy of the temperatures is 1°F.

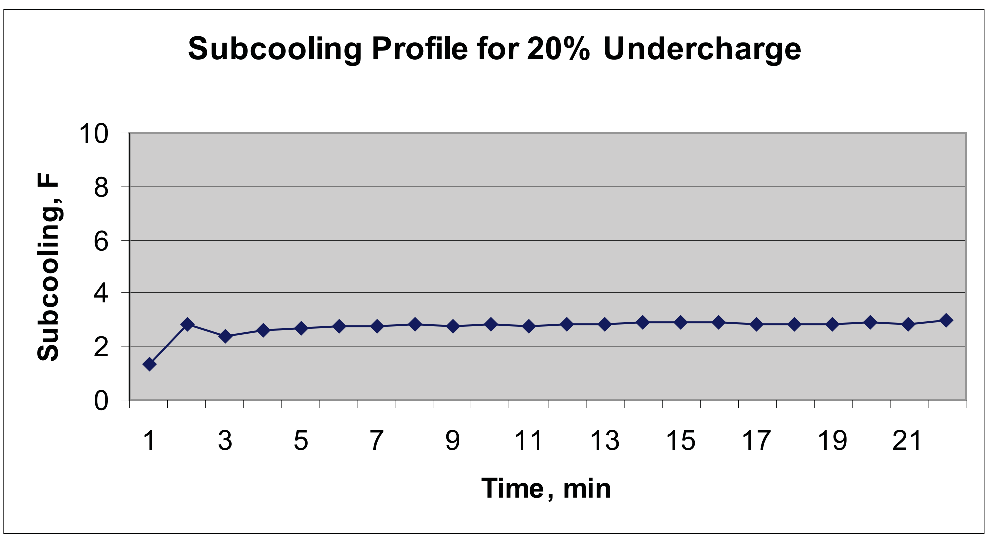


Figure 3-8 Refrigerant Subcooling as a Function of Time for 20% Undercharge.

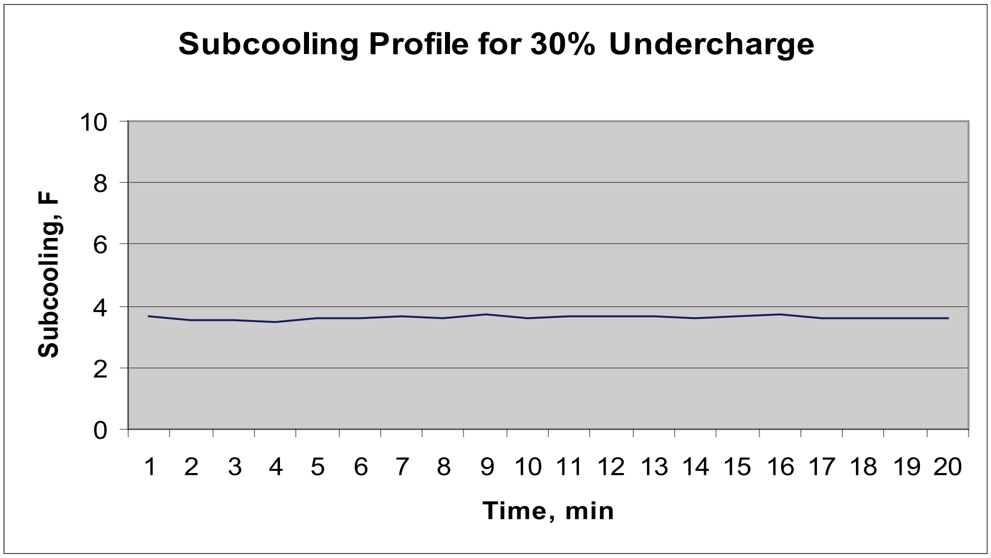


Figure 3-9 Refrigerant Subcooling as a Function of Time for 30% Undercharge.

Figure 3-10 presents the subcooling profile for the overcharge case. Comparing to Figure 3-6 for the normal charge, Figure 3-10 clearly shows that there is an increase in the subcooling due to overcharge. Overcharge fault doesn't impact the system efficiency significantly but can cause compressor damage due to liquid flooding.

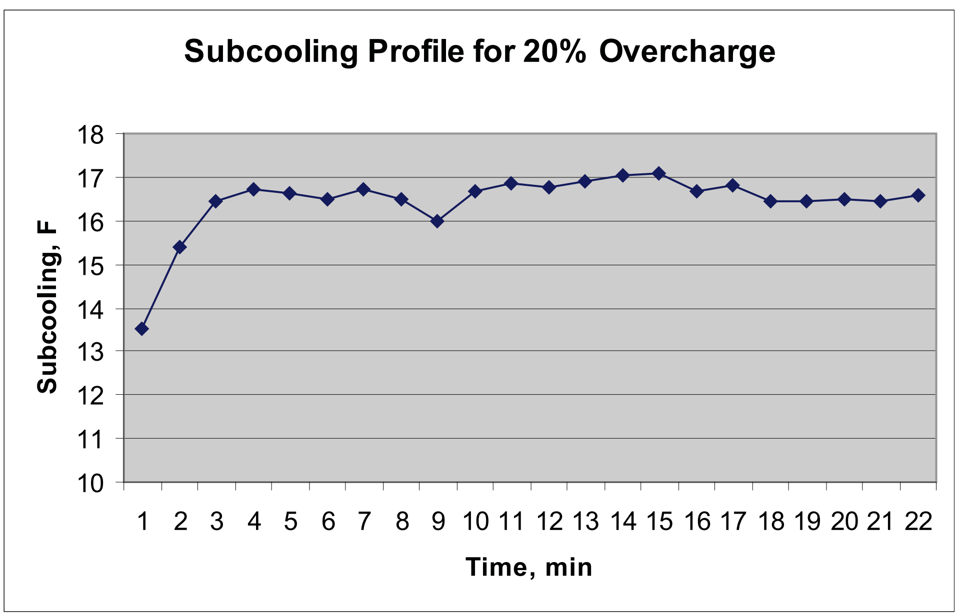


Figure 3-10 Refrigerant Subcooling as a Function of Time for 20% Overcharge.

The above results are compared with NIST's laboratory data as below. Figure 3-11 shows change in subcooling due to refrigerant undercharge. Figure 3-11 shows that the subcooling decreases by 6°F due to 10% undercharge. From Figure 3-6 and Figure 3-7, it can be noticed that NY's field tests show a similar magnitude.

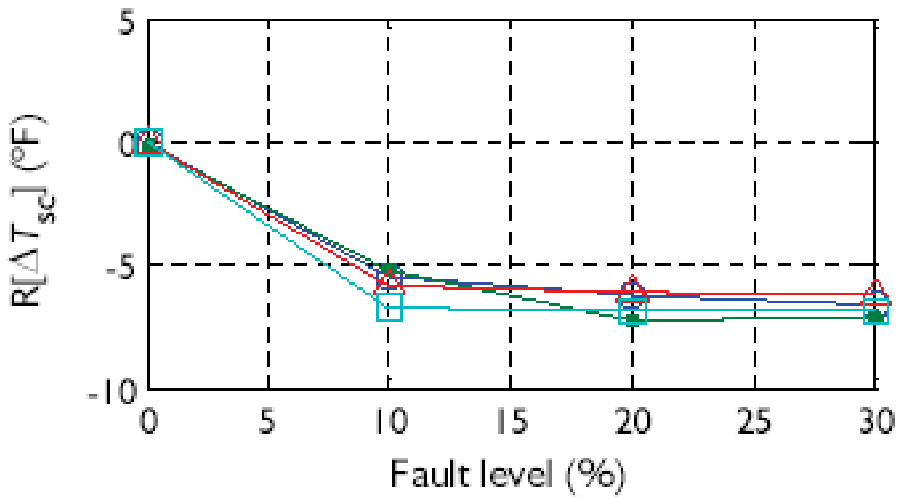


Figure 3-11 Refrigerant Subcooling Change as a Function of Undercharge (NIST data [15]).

Figure 3-12 presents NIST's data for refrigerant overcharge. The average subcooling for the overcharge case for NY's field test data was found to be 16.6°F, indicating an increase of about 4°F for 20% overcharge. NIST's data indicates about 6°F. SWA's field data (Asheville, NC and New Orleans, LA, Norwalk, CT) is summarized in Figure 3-13. This data is consistent with the current NY field data.

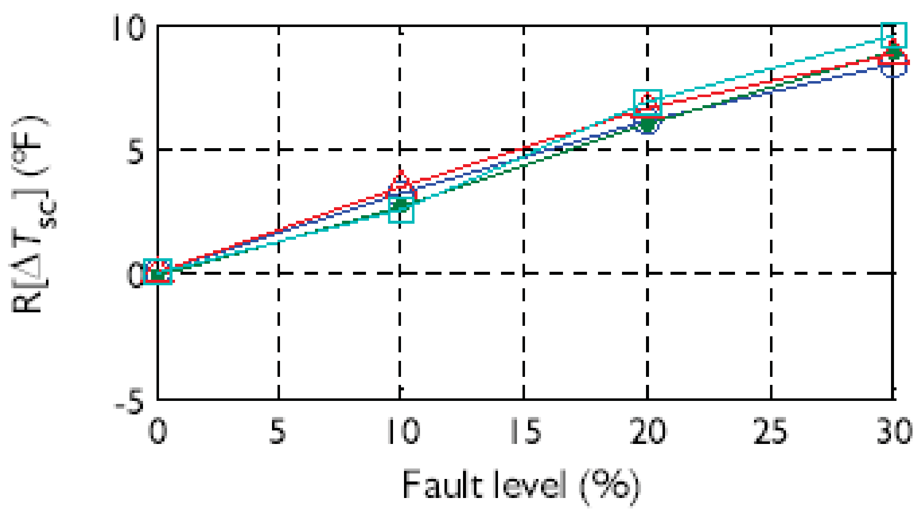


Figure 3-12 Refrigerant Subcooling Change as a Function Overcharge (NIST data [15]).

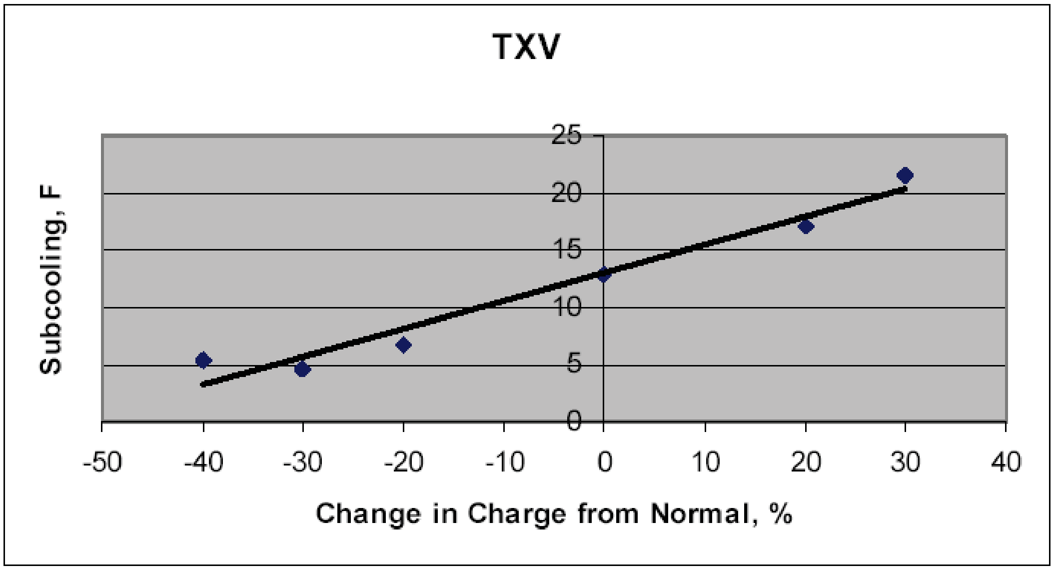


Figure 3-13 Condenser Subcooling as a Function of R-410A Refrigerant Charge (SWA data).

4. An Improved Solution

Integrating thermostat function with humidity control and fault detection adds complexity to the system architecture requiring a high performance microprocessor and increasing the cost of the thermostat. Therefore, SWA has identified an opportunity to develop a low cost, stand-alone, visual device that detects refrigerant overcharge and undercharge faults, which critically impact the energy use of air-conditioning systems. This device can be mounted on the outdoor unit or the indoor unit depending upon the type of expansion device used and monitors the charge level continuously. It can have a visual display indicating fault; it can have an audible alarm as well. Alternately, if the device is mounted outdoors, it can be equipped with a wireless transmitter and a display unit located indoors instead of being hardwired.

Currently, there are no such products on the market. Oak Ridge National Laboratory (ORNL) [19] explored the concept of developing a refrigerant charge indicator and has not gone beyond the initial proof of concept. Figure 4-1 shows the pre-prototype charge indicator developed by ORNL. It was based on analog technology. The principle for detecting the system refrigerant charge is simply to measure the indoor coil refrigerant two-phase temperature. When the system is properly charged, the coil temperature (in the two-phase region) will be maintained at around 45 to 50°F for summer operation. When the indoor coil temperature drops below 40°F, for example, the system is likely undercharged or possibly leaking. When the coil temperature drops sufficiently, a warning signal automatically turns on to alert the equipment user that the system has a problem. This proof-of-concept has been demonstrated on an off-the-shelf air-conditioner in the laboratory. Still, this approach of measuring just the evaporator temperature is not reliable since it is a function of many variables not just the refrigerant charge. For instance, if an air-conditioner is in a humidification mode, the evaporator temperature is reduced due to decreased air flow over the evaporator coil.

Figure 4-1 A Pre-Prototype Charge Detector Built by Oak Ridge National Laboratory.

SWA proposed to use the differential temperature sensing rather than a single temperature measurement. This approach to the determination of refrigerant charge level is well known, but has not been implemented in any product. Typically, refrigerant sub-cooling in the condenser is employed for determining charge level. Refrigerant sub-cooling indicates the degree to which the refrigerant is cooled below its condensing temperature. It is the difference in refrigerant saturation (condensation) temperature and the refrigerant temperature at the condenser outlet, which is lower than the saturation temperature and thus is sub-cooled. Refrigerant saturation temperature is obtained from the saturation pressure-temperature relationship by measuring the refrigerant pressure at the condenser outlet or the liquid line in the refrigeration cycle. SWA's present approach does not use pressure sensors but rather a temperatures sensor to measure the saturation temperature directly, thus requiring only two less expensive temperature sensors (as shown in Figure 4-2). Nevertheless, identifying the two-phase region for the saturation on the condenser is tricky. SWA experimentally determined that one or two coils above the mid coil can assure two-phase region for measuring saturation temperature in the condenser. The difference in the saturation temperature and the condenser outlet temperature is the measured condenser sub-cooling. This temperature difference is a good indicator of charge level in systems with TXV expansion device, which are most commonly used now.

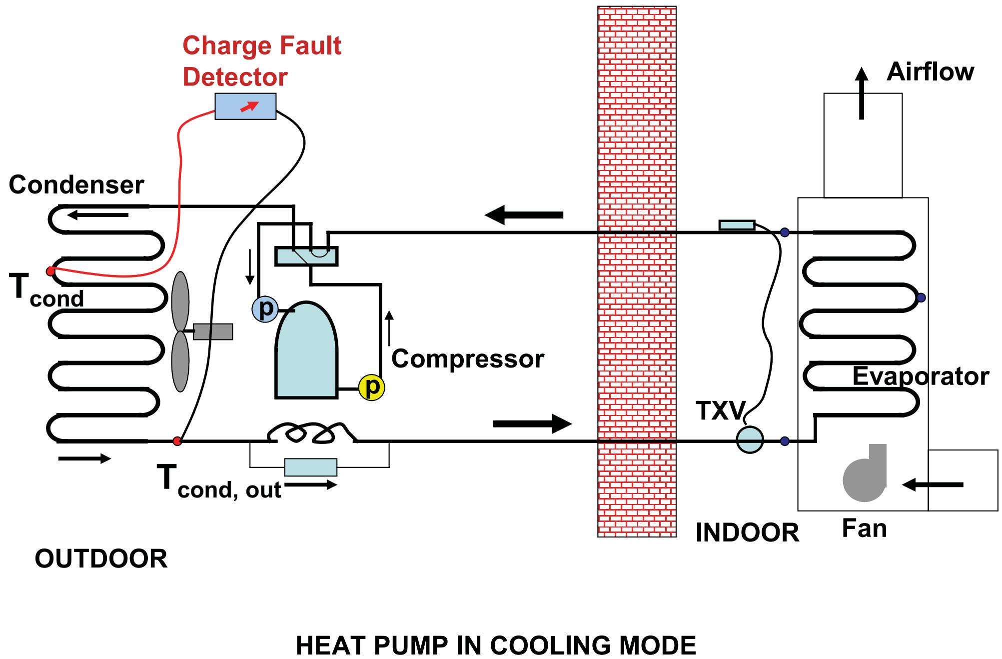


Figure 4-2 A Schematic of Stand-Alone Refrigerant Charge Detector Proposed by SWA.

The subcooling (or the temperature difference) can be obtained by measuring the two temperatures (by thermocouples or thermistors) or by measuring the temperature difference directly (thermopile). In addition, temperature difference can be obtained from two thermoelectric modules, which are also capable of providing the required power for powering display electronics. SWA has also conceptualized another innovative method to obtain temperature difference indirectly. This uses a temperature sensitive vapor pressure measurement technique. SWA proposes to evaluate these techniques and identify a simple, reliable and cost-effective technique to quantify subcooling, and hence detect refrigerant faults.

4.1 Field Testing Of The Prototype

The overall objective of this task was to test and evaluate the operational performance the visual charge fault detection prototype in the field.

4.1.1 Prototype Field Testing Preparation

As mentioned in Section 0, SWA built the digital prototype (Figure 4-3) for refrigerant charge fault detection from a temperature measurement and control kit, which uses a PIC (programmable interface controller) for controlled temperature sensing, two temperature sensors (integrated-circuit sensors), two LEDs and a buzzer that can be used as indicator devices when specified conditions (set by the user) are met, and an LCD display. The PIC controller was programmed to display a measured temperature and the differential temperature (subcooling) along with controlling the two LEDs to indicate normal, undercharge and overcharge conditions. SWA tested for the accuracy of the temperature sensors and for the fault detection algorithm. The difference between the temperature sensors and the glass thermometer [20] was found to be within 1^{o}F of each other. Also, LEDs functioned according to the algorithm used.

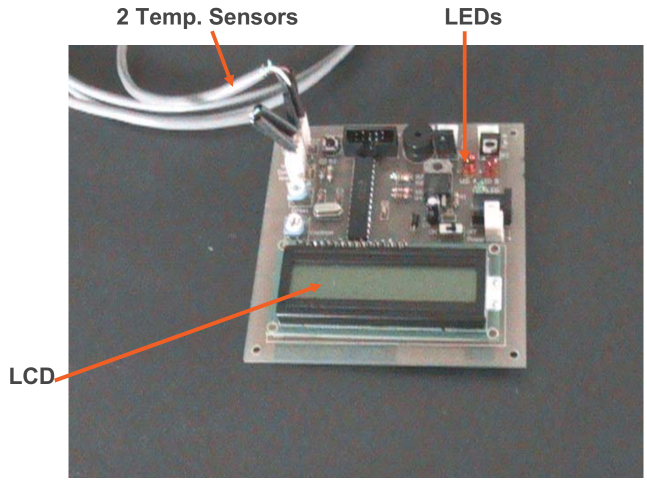


Figure 4-3 Digital Prototype Built by SWA for Refrigerant Charge Fault Detection.

SWA's first step in preparing the prototype for field testing and potential field conditions was to identify an enclosure that would not only house and protect the device, but allow visibility of the output devices (PIC output display module and LED indicators) during operation. SWA was able to modify an off-the-shelf enclosure to meet its needs (Figure 4-4). The next step was to modify (enhance) the prototype so it was robust for field operational conditions. The enhancements included placement of an on-board fuse for further overcurrent protection, utilizing a variable power-supply (AC to DC) for optimization of voltage input, upgrading the temperatures sensors to more durable and applicable device packages for field conditions and usage, and the addition of the capability for the prototype to be powered by a standard 9V battery as needed.

Since the LEDs only provide visual display of fault condition and cannot be automatically recorded for short-term monitoring in the field, SWA incorporated the ability to record ON/OFF by the EER Box data acquisition system.

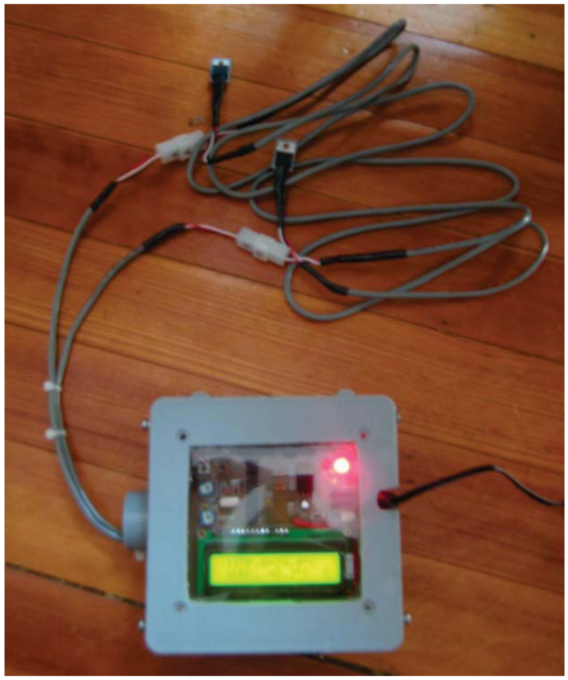


Figure 4-4 Field-Ready Refrigerant Charge Fault Detector Prototype Built by SWA.

4.1.2 Prototype Field Testing And Results

SWA employed the same field tests described above for validating SWA's digital prototype. Figure 4-5 and Figure 4-6 show the field operation of the prototype. One temperature sensor of the prototype was placed in the condensing region (above mid-coil) along with a Sense-A-Coil temperature sensor for comparison and the second sensor was placed at the outlet of the condenser. LED output signals were input to the data logger (EER Box) for recording fault conditions. The prototype was programmed to include a simple algorithm for fault detection as below:

LED A will light up if Subcooling is greater than 14F (overcharge)

LED B will light up if Subcooling is less than 5F (undercharge)

No LEDs will light up if 5F<Subcooling<14F

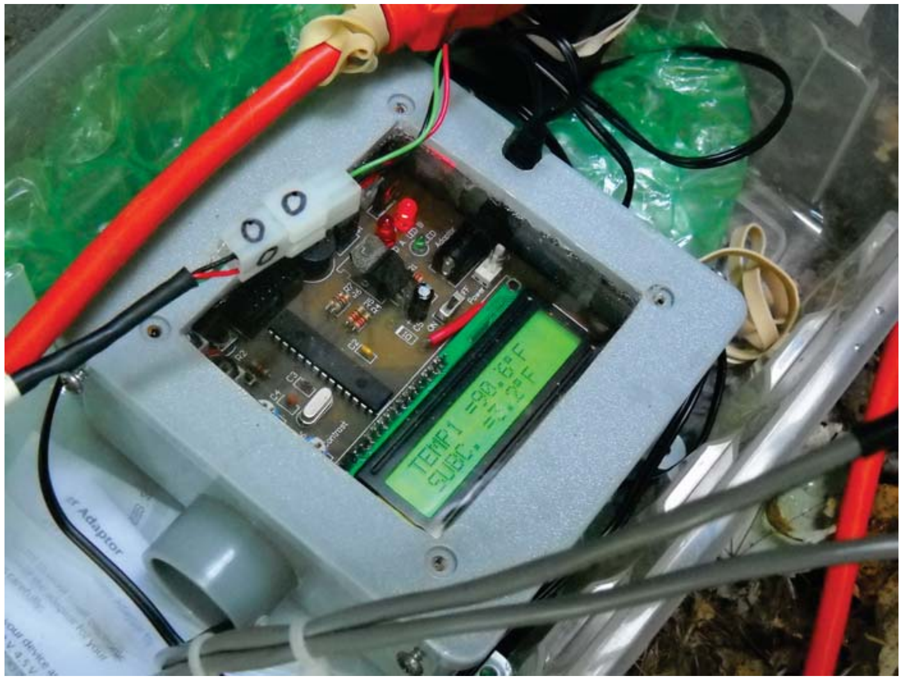


Figure 4-5 Ruggedized Prototype for Field Testing.

Figure 4-6 Prototype in Field Operation.

Results of prototype testing for normal charge, undercharge, and overcharge are discussed below. Figure 4-7 through Figure 4-11 display results of prototype field testing. As seen in Figure 4-7, no fault is detected (both LEDs are off), since it is for the normal charge condition and the subcooling is above 5°F and below 14°F. The agreement between the measured subcooling (additional sensors) and the prototype subcooling is good.

Figure 4-8 shows results for the 10% undercharge case. Even though the subcooling is low (about 7°F), it is still above the lower limit (5°F) for undercharge fault detection and hence no fault is detected. The lower limit of 5°F was selected so that no false positive is detected. This lower limit can be easily changed in the prototype program. Figure 4-9 shows results for the case with 20% undercharge. For this case, the undercharge fault is detected by the prototype with the LED B ON. The measured subcooling was below 3°F (which is below the set lower limit of 5°F). The case for the 30% undercharge is shown in Figure 4-10. The undercharge fault was detected with LED B ON here as well. The measured subcooling was below 5°F.

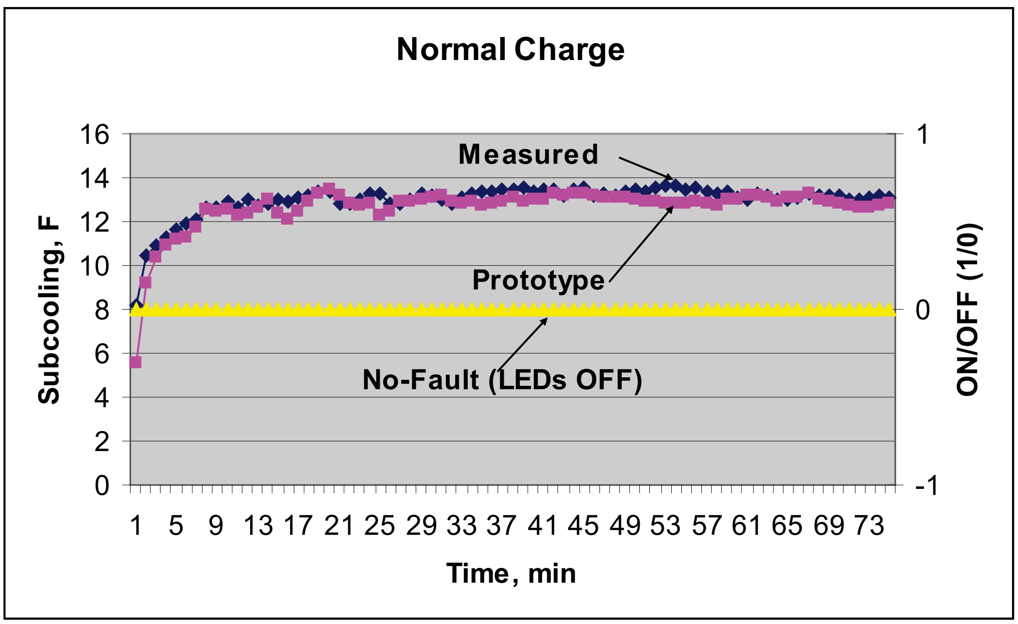


Figure 4-7 Subcooling Profile Along with ON/OFF Status for the Normal Charge Case.

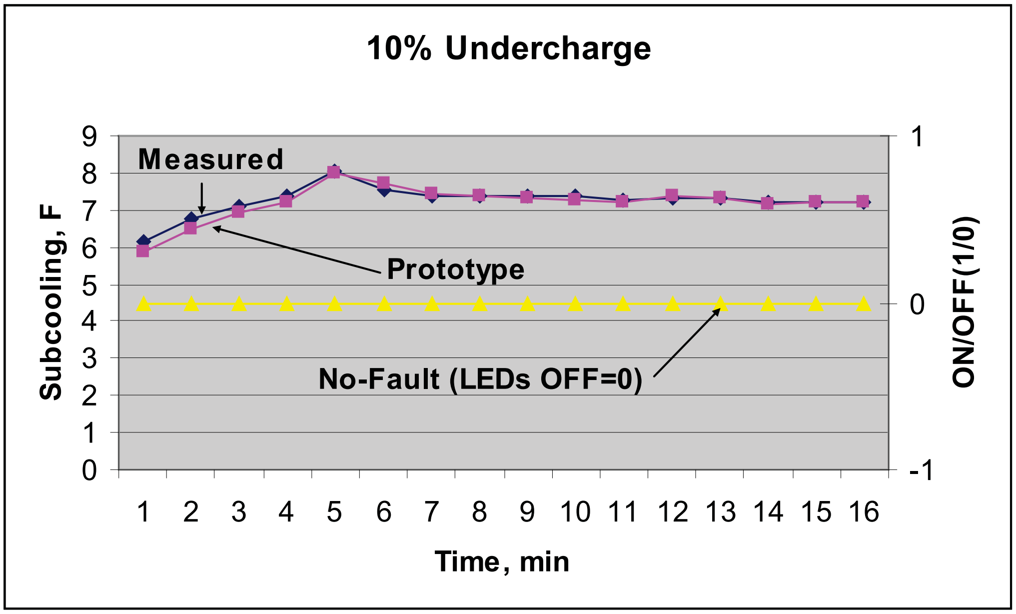


Figure 4-8 Subcooling Profile Along with ON/OFF Status for the 10% Undercharge Case.

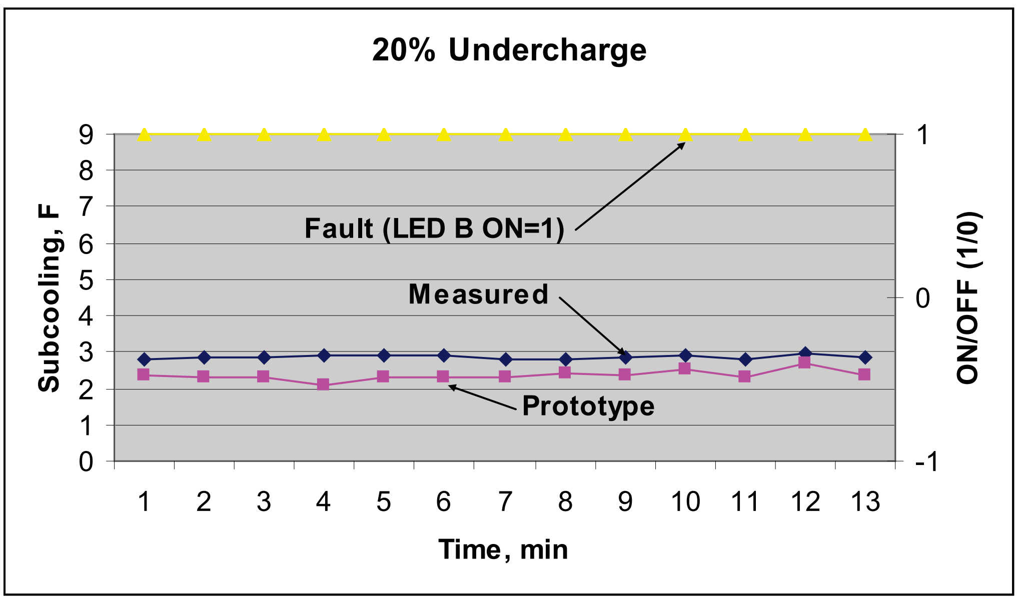


Figure 4-9 Subcooling Profile Along with ON/OFF Status for the 20% Undercharge Case.

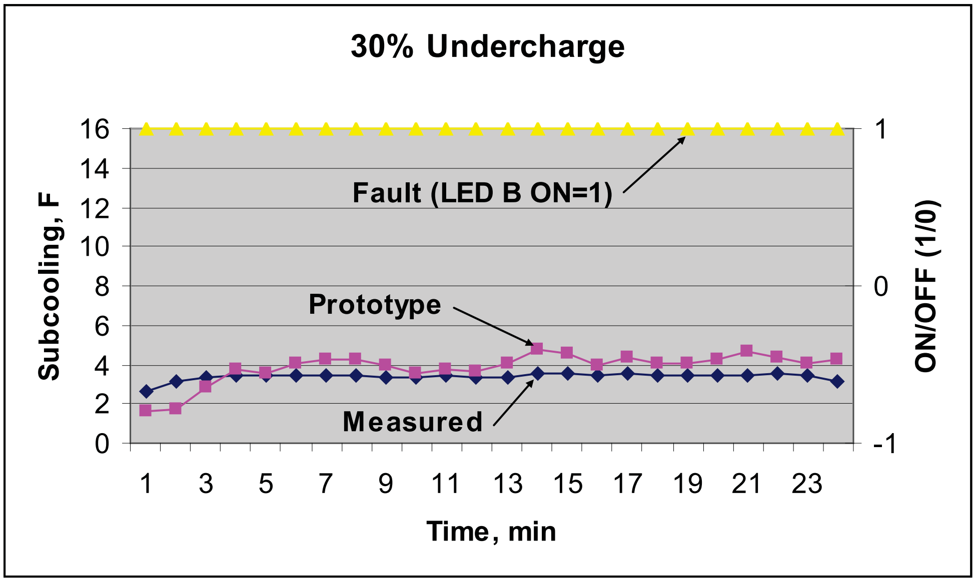


Figure 4-10 Subcooling Profile Along with ON/OFF Status for the 30% Undercharge Case.

Subcooling profile for the 20% overcharge case is shown in Figure 4-11. As can be seen in Figure 4-11, overcharge fault is detected with LED A ON. The measured subcooling was above the upper limit of 14°F indicating an overcharge fault.

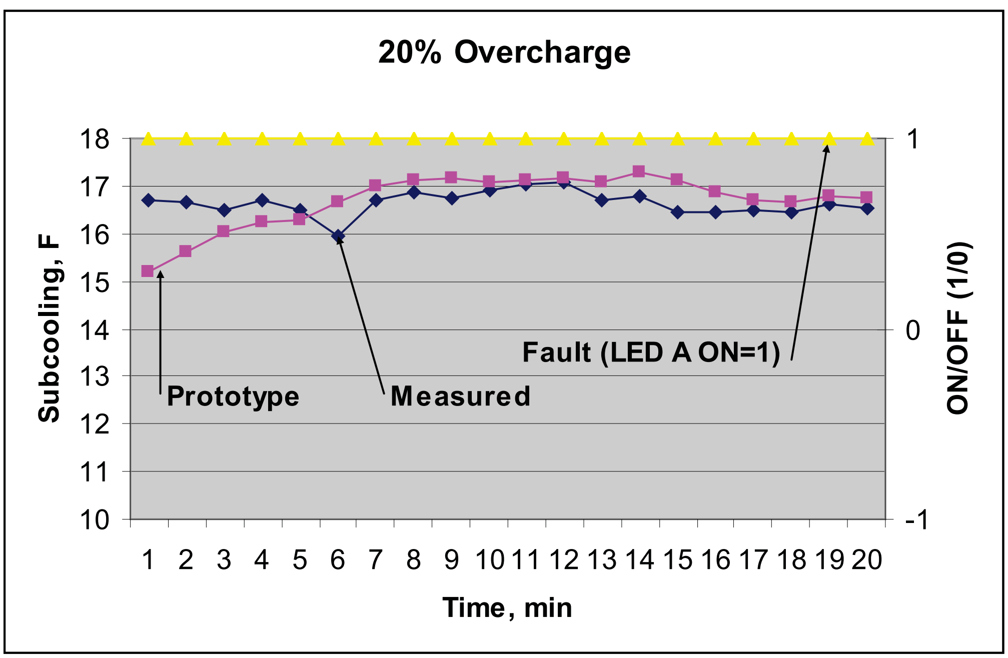


Figure 4-11 Subcooling Profile Along with ON/OFF Status for the 20% Overcharge Case.

These field tests clearly demonstrate that SWA's digital refrigerant fault detection device is capable of detecting refrigerant faults with a simplified criteria based on subcooling measurement with just two temperature sensors. Still, advanced development efforts are needed to refine the algorithm, simplify the device even further to reduce the cost and incorporate methods for integration/communication in HVAC maintenance.

5. NYS Commercialization Plan

The technology under development is an add-on to any residential space cooling system (new or existing homes). The costs associated with implementing the technology should be relatively small, as we are not looking to integrate into other controllers at this time. If either the thermoelectric module or differential temperature measurement technique are used for the final device, this product could potentially be marketed through home improvement stores, as the device could be strapped onto the cooling system.

Figure 5-1 is the two-pronged approach that SWA will be taking with this project. Final method of commercialization depends heavily on the measurement technique of the prototype product.

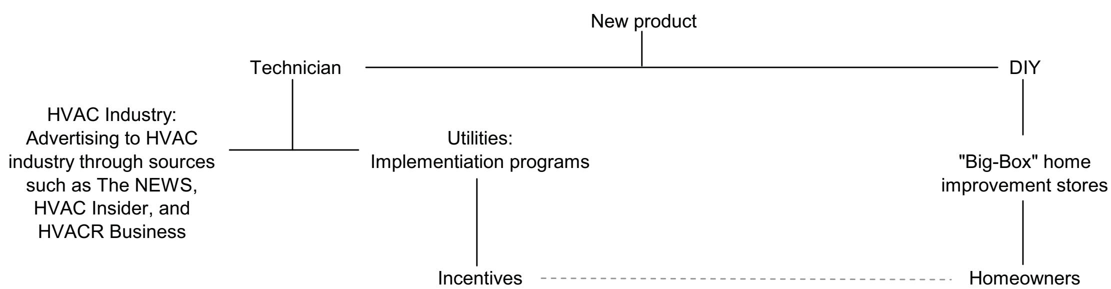


Figure 5-1 SWA's Commercialization Strategy

One of SWA's primary focuses in commercializing this technology in NYS will be to promote the device to/through utilities. Utilities seem to have taken on the role of the primary source for delivering energy saving options to customers through efficiency programs and rebates/incentives, and they have unique access to existing homes.

NYSERDA has been promoting Home Performance with Energy Star since April 2001. From then, through October 2005, "more than 8,700 homes across the state have been improved to use less energy. With each family saving approximately $600 per year, that is a cumulative savings of over $5 million per year. On average, more than 200 New York State homeowners sign on to have the efficiency of their homes improved every month."[21] Through year-end 2007, the program has increased its participation up to more than 11,000 new homes and 18,000 existing homes.[22]

SWA sees this as an ideal device for utilities to provide rebates/incentives. As a technician's tool (only the 2^{nd} and 3^{rd} method of determining faulty charge could work for a portable fault detector), this device would allow utility home energy service programs to be more effective. Currently duct leakage and airflow are tested during site visits. The last major component to optimize a cooling system is verifying proper refrigerant charge.

Significant investments are being made nationally and state-wide on incentives for home energy efficiency upgrades.

<u>Major New York Utilities & Energy Saving Programs</u>

- Consolidated Edison Company of New York, Inc. (Con Edison)
    - Demand response and programmable thermostat programs
- National Grid (including Niagara Mohawk)
    - Equipment and lighting rebates
    - NY Energy Star Labeled Homes incentives
    - Multi-family services (MassSAVE and Energy Wise)
- New York State Electric & Gas Corp (NYSEG)
- Central Hudson Gas & Electric Corp
- Long Island Power Authority
    - LIPA Cool Homes rebates
    - NY Energy Star Labeled Homes incentives
    - Equipment, Appliance, and Lighting incentives
- Rochester Gas & Electric Corp
- Orange & Rockland Utilities, Inc.
- NYSERDA
    - New York Energy Star Homes
- Federal
    - New Construction - 50% Heating and Cooling Savings tax credit
    - Existing Construction - Equipment tax credit.

What if similar or greater savings than system efficiency upgrades could be obtained with only a technician visit to properly charge the current HVAC system? This would have far more penetration with homeowners, as there isn't a large expense associated with this energy conservation measure. Even when efficiency upgrade investments are made, shouldn't utilities make sure that what they are providing incentives for is installed properly? A refrigerant fault detector device could provide homeowners with improved comfort and utility bill savings while utilities still benefit from peak demand reductions.

LIPA, UI and CL&P have Home Energy Solution (HES) crews that go out and air seal, duct seal, and change light bulbs. Once developed, this simple refrigerant fault detector device could be provided to similar type NYS crews to check refrigerant charge when on site to determine if a homeowner's current HVAC system needs to be optimized.

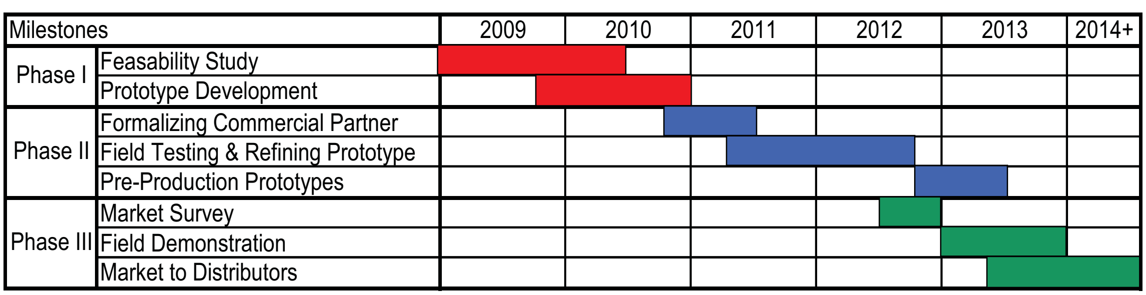
According to Con Ed, "Despite fluctuations in the economy and increasing conservation efforts, we project our customers' peak energy demand will increase by 10 percent over the next decade."[23] With many of the major New York utilities looking for methods to reduce peak demand and improve overall energy efficiency for their service territories, this seems like a better service than rebates or incentives for efficiency upgrades. Also with the push by the Obama Administration for home retro-commissioning programs, this seems like an ideal time for innovative, low-cost solutions.

5.1 Commercialization Timeline

SWA has been doing research on cooling systems and refrigerant charge for 10+ years. There is no intellectual benefit from our end of simply getting funding for additional field research. SWA's goal with this grant is to develop a working prototype that can lead to the development of a commercial product. SWA has continually transformed our business with the times. Starting as consulting engineers in seismic design, SWA has transformed itself into one of the premier companies in building science over the past 35 years. Over the past five years, SWA has become one of the lead providers of green (LEED for Homes) and energy efficiency (Energy Star Homes) certification in the Northeast. With the markets ever-changing, SWA continues to look to diversify our skill set. With our extensive history in building systems research through the DOE's Building America program, SWA has been able to identify technology gaps in the industry. Rather then just passing this intellectual knowledge on to manufacturing partners, SWA is now seeking to take a more hands-on approach to product development.

SWA realizes that product commercialization is a process, but we believe we have the ability (internally and through our industry contacts) to successfully deploy a low cost visual refrigerant fault detector. Our initial timeline for commercialization of this product is shown below. Delays in the field testing of our prototype device have shifted Phase II and Phase III activities back a year.

Path to Commercialization



5.2 Outreach

SWA is a respected member of the building science industry and as such, has extensive experience in presenting at national conferences/shows (ASHRAE, NESEA, RESNET, EEBA, SEBC, SBS, IBS, ACEEE, etc.) and writing papers for major industry publications. SWA will use these skill sets to promote the proposed product as a cost-effective solution to maintain cooling system performance in the residential market.

In addition, SWA has already contacted the New York branch of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) to determine a method of reaching out to their members for feedback on such a device. Om Taneja, ASHRAE NY board member, provided the following response. This is an excellent opportunity to obtain feedback from a knowledgeable focus group.

From: om.taneja@gsa.gov
To: "Srikanth Puttagunta" <sri@swinter.com>
Cc: "'kgallen@dewberry.com'" <kgallen@dewberry.com>, "'mprl@myway.com'" <mprl@myway.com>
Date: 01/20/2009 07:24 PM
Subject: Re: your help is requested

Srikanth;

Request if you can draft a brief note with a survey questionnaire that we can consider putting in ASHRAe NY bulletin. Please note that we can not write that this project is to compete with Honeywell or others, but just to. Emphasize the need for a cheaper user friendly device for techniciansM. For NYSERDA, we can also distribute survey at a dinner meeting where you can also make a brief introduction.

Thanks

Om

5.3 Mock DIY Sales Ad

Steven Winter Associates' new wireless visual refrigerant fault detector (VRFD) is a must have for residential cooling systems. This device is a quick method to ensure that your cooling system has the proper refrigerant charge and installation is fast and simple. What easier way to save energy than to make sure your current system runs optimally?

The VRFD reduces the operating cost of the cooling system by advising the homeowner or technician that refrigerant charge level is either high or low. The LED warning light informs the user that action is needed to optimize cooling performance. The unique two-component configuration (exterior sensing module and wireless interior visual device) allows for retrofit installations without a need to penetrate the exterior wall with additional wiring.

Get your cooling system running smoothly today. For more information, go to www.swinter.com/VRFD.

5.4 Industry Interest

To further substantiate that there is a market for a low cost visual refrigerant charge fault detector; SWA has contacted several industry representatives to support our development of the proposed device. The first letter is from Glenn Hourahan, Vice President of Research & Technology for the Air Conditioning Contractors of America (ACCA). ACCA is a group of over 4,000 air conditioning contractors who work together to improve their industry, promote good practices, and keep homes and buildings safe, clean and comfortable.

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15 January 2009

Srikanth Puttagunta
Steven Winter Associates, Inc.
50 Washington Street
Norwalk, CT 06854
{Sent via email: sri@swinter.com}

Re: Development of a low-cost refrigerant charge fault detector

Mr. Puttagunta:

Refrigerant leaks and improper system charge critically impacts the performance (e.g., effectiveness, comfort, energy consumption) of air-conditioning and heat pump equipment. Ensuring that new and existing systems are operating properly in an effective manner is an energy conservation measure that benefits homeowners (lower utility bills) and utilities (peak demand reductions) while allowing contractors to demonstrate that quality installation and quality maintenance was provided.

Proper refrigerant charge is an important requirement (see §4.2) mandated by the industry's *HVAC Quality Installation Specification* (ANSI/ACCA 5 QI – 2007; a PDF is downloadable at no charge from www.acca.org/quality). Proper refrigerant charge is also directed by equipment manufacturer's installation and operation instructions as well as in the industry standard *Maintenance of Residential HVAC Systems* (ANSI/ACCA 4 QM – 2007).

It is beneficial if HVAC technicians have ready access to a reliable, cost-effective tool that ensures the equipment refrigerant charge is correct. The capabilities built into the device becomes even more important once HVAC systems have been in the field for a few years and the "refrigerant charge fault detector" needs to discriminate from a number of competing possible faults (i.e., low airflow over the coil, dirty coils/filters, blocked ducts, etc.).

I look forward to seeing what SWA is able to develop and if I can be of further assistance, please don't hesitate to give me a call.

Regards,

Glenn C. Hourahan, P.E.
VP, Research & Technology

The next letter is from Brad Hesse of Enernet Corporation, a leading manufacturer in wireless heating and cooling controls with their T9000 wireless thermostat. SWA hasn't previously worked with Enernet, but has identified them as a potential phase II manufacturing partner. Enernet has shown interest in participating now and in the future, so this has been a good find in terms of a potential in-state manufacturer. Though SWA will continue to seek other potential manufacturing partners, Enernet's knowledge of wireless device is an asset that SWA currently lacks in developing the proposed device.

ENERNET
CORPORATION

January 15, 2009

Srikanth Puttagunta
Steven Winter Associates, Inc.
50 Washington Street
Norwalk, CT 06854

Subject: Development of a low-cost refrigerant charge fault detector

Thank you for seeking my input on the viability of Steven Winter Associates' (SWA) NYSERDA grant investigating a visual refrigerant fault detector for optimum performance of residential HVAC systems.

The key to a visual refrigerant fault detector is developing a technically sound methodology that can be implemented in a low cost platform. Market study is needed to determine price points. Broad implementation through general HVAC unit controls would be most advantageous.

Refrigerant leaks and improper charge impact energy use of air-conditioning and heat pump systems and the environment. While a refrigerant fault detector needs to differentiate other masking faults such as dirty filters, blocked coils or other heat transfer fluid flow issues, these problems are also of paramount concern effecting efficiency and energy. Ensuring that new and existing systems are properly operating is an effective energy conservation measure as well as peak demand mitigation tool.

As the developer of the T9000 wireless thermostat system, we see the potential for incorporating such a technology into our thermostats or as a stand-alone product. We have a number of our products manufactured in NYS and would be interested in exploring a potential partnership down the road should product development result in commercialization.

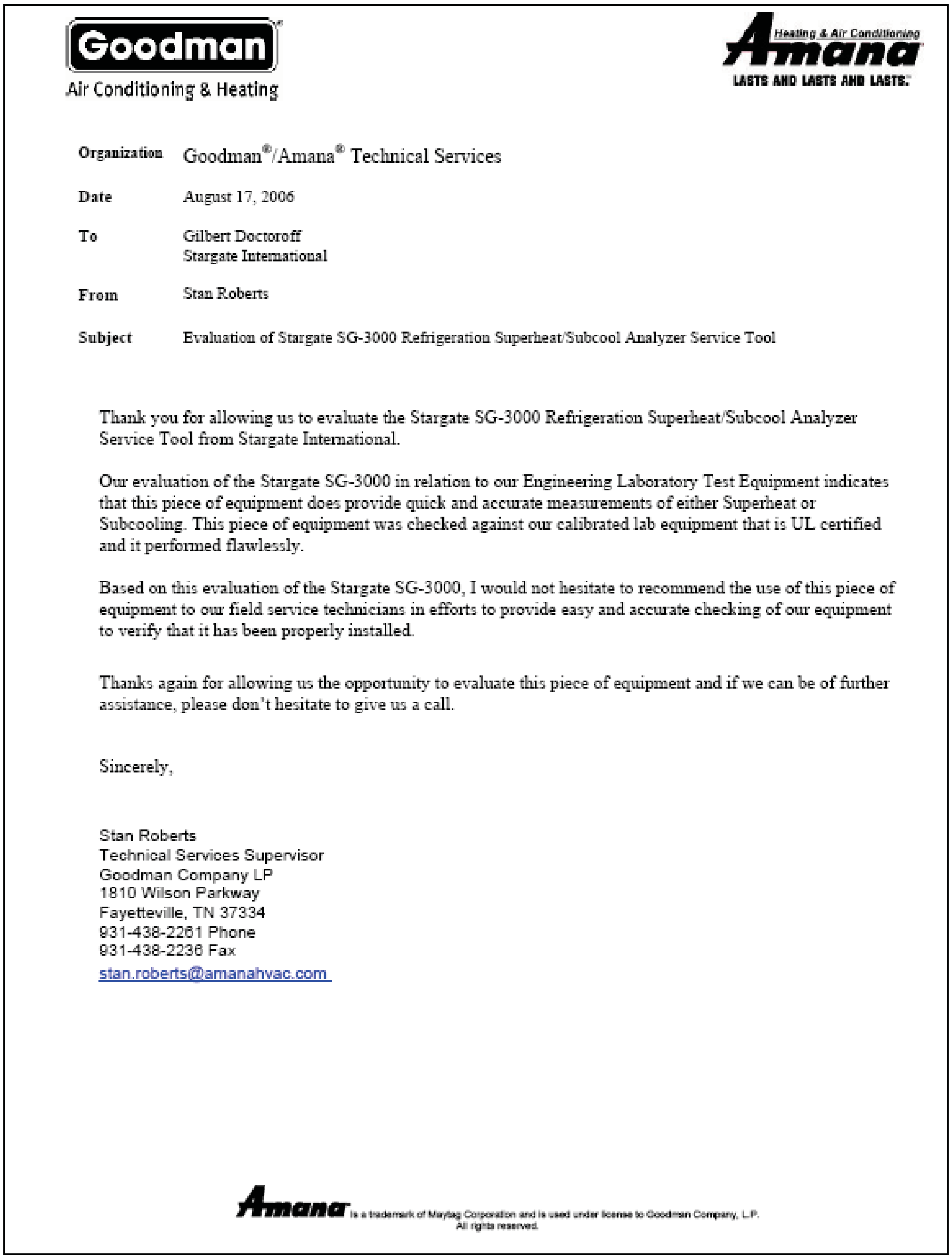
I look forward to seeing SWA's research and development outcome in this important effort. If I can be of further assistance, please don't hesitate to give me a call.

Sincerely,

Brad Hesse
President

307 Dewittshire Road, Syracuse, New York 13214 — Tel.: 315-449-0839 Fax: 315-449-3056

The last letter is not specific to SWA's proposed work, but is rather a letter from HVAC manufacturer, Goodman/Amana, about the viability of the Stargate SG3000 meter that is able to read the refrigeration systems super heat values in real time. [24] The SG3000 is a technician's tool, but our proposed fault detector could be used as a lower cost tool for technicians or as a permanent device for homeowner maintenance awareness.



Goodman
Air Conditioning & Heating

Amana Heating & Air Conditioning
LASTS AND LASTS AND LASTS.

Organization	Goodman®/Amana® Technical Services
Date	August 17, 2006
To	Gilbert Doctoroff Stargate International
From	Stan Roberts
Subject	Evaluation of Stargate SG-3000 Refrigeration Superheat/Subcool Analyzer Service Tool

Thank you for allowing us to evaluate the Stargate SG-3000 Refrigeration Superheat/Subcool Analyzer Service Tool from Stargate International.

Our evaluation of the Stargate SG-3000 in relation to our Engineering Laboratory Test Equipment indicates that this piece of equipment does provide quick and accurate measurements of either Superheat or Subcooling. This piece of equipment was checked against our calibrated lab equipment that is UL certified and it performed flawlessly.

Based on this evaluation of the Stargate SG-3000, I would not hesitate to recommend the use of this piece of equipment to our field service technicians in efforts to provide easy and accurate checking of our equipment to verify that it has been properly installed.

Thanks again for allowing us the opportunity to evaluate this piece of equipment and if we can be of further assistance, please don't hesitate to give us a call.

Sincerely,

Stan Roberts
Technical Services Supervisor
Goodman Company LP
1810 Wilson Parkway
Fayetteville, TN 37334
931-438-2261 Phone
931-438-2236 Fax
stan.roberts@amanahvac.com

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Appendix A

HEATING • AIR CONDITIONING • GAS FIREPLACES • WATER TREATMENT • WELL PUMPS

ASTAR

Get Comfortable with the Best

September 16, 2011

Steve Winter Associates
50 Washington St.
Norwalk, Ct. 06854

Dear Mr. Puttagunta,

It has been a pleasure supporting your NYSERDA research task on demonstrating the prototype refrigerant charge fault detection device in the field. This project was not a typical project for us, but we see the value of this research. We are very much encouraged by your field test results. We believe such a product will be valuable for HVAC contractors, homeowners and others. The prospect of manufacturing this product for under $100 is quite attractive to us. We hope you will continue to advance this technology. Our company will be glad to join you in the advanced product development, demonstration and commercialization of your technology. We are well positioned to promote this technology.

Sincerely,

Ed Engle,
President

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Visual Refrigerant Fault Detector for Optimum Performance of Residential HVAC Systems

Energy. Innovation. Solutions.

Final Report No. 11-28
November 2011

State of New York
Andrew M. Cuomo, Governor

New York State Energy Research and Development Authority
Francis J. Murray, Jr., President and CEO