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Air Conditioner Service Light Project

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SUMMARY

Residential and small commercial air conditioning systems are not tested for performance and are not adjusted to ensure peak performance, even at the time of installation. The majority of these systems operate at 10-35% below their design efficiency. Significant energy savings can be realized by assuring that air conditioners are properly installed and maintained.

This project designed, built, and tested a device that continuously monitors the performance of an air conditioner to ensure efficient operation. The device is designed for permanent installation in any residential or small commercial air conditioning system. It performs real-time diagnostics to detect the two most common efficiency detractors: incorrect refrigerant charge and insufficient evaporator airflow. Proper operation is verified every time the air conditioner runs and achieves steady state operation.

The device was tested in the laboratory to verify sensor accuracy and data acquisition capability. One prototype was tested in the field under normal conditions, and under fault conditions. Following successful prototype testing, additional devices were constructed and installed on nine air conditioners in the field. Fault testing was conducted on four of those systems. The field test identified several areas for improvement. The majority of units performed well in the field, detecting faults that reduced efficiency by more than 5%.

The device provides a simple, non labor-intensive method of maintaining air conditioners at optimal efficiency.

INTRODUCTION

The majority of residential and small commercial air conditioning units are not installed properly or maintained for efficient operation. These units operate at 10-35% below their design efficiency due to incorrect refrigerant charge, insufficient airflow across the evaporator coil, and other problems. Data collected from over 80,000 air conditioners through Proctor Engineering Group's CheckMe!® program show more than 2/3 with incorrect refrigerant charge and more than half with insufficient evaporator airflow.

Significant energy savings can be realized by:

1. Detecting air conditioner problems as soon as they occur
2. Guiding service technicians through appropriate repairs
3. Assuring repair effectiveness

Background

This project extends Proctor Engineering Group's prior work in HVAC system energy efficiency improvement. The device developed in fulfillment of this project evolved from diagnostic algorithms used in the CheckMe!® program and hardware developed for the Green Box advanced onboard diagnostic device.

CheckMe!®

CheckMe!® is a computerized expert system and quality assurance program created by Proctor Engineering Group. The program guides HVAC service technicians to tune air conditioners for efficient operation. Specially trained HVAC service technicians report data from air conditioners they are servicing to the CheckMe!® call center. Operators at the call center analyze the data with the computerized expert system and guide the service technicians through appropriate adjustments and repairs. Once repairs are complete, the service technicians again report data to the call center for analysis and verification that the air conditioner is operating properly. Over 100,000 CheckMe!® runs have been recorded.

Green Box

In 2003, the U.S. Department of Energy funded research by Proctor Engineering Group to develop technology capable of implementing the CheckMe!® diagnostic algorithms on a continuous, real-time basis. The DOE project developed a device titled Green Box. The device continuously monitors the performance of air conditioning systems through eleven sensors, and alerts the building occupant if the air conditioner needs service. Data and diagnostic results are wirelessly transmitted to a handheld device carried by the service technician. Laboratory tests proved the device successful in detecting and diagnosing common air conditioner faults.

Service Light Unit (SLU)

In 2005, Proctor Engineering Group undertook a project funded by Sacramento Municipal Utility District (SMUD) and American Public Power Association (APPA) to design, build and test a less expensive version of the DOE Green Box. The device, named Service Light Unit (SLU) was designed to employ the minimum number of sensors to detect refrigerant charge and evaporator airflow problems.

Reducing the number of sensors presented design challenges. Determining what the air conditioner is doing is more difficult with fewer sensors. Algorithms were developed to detect when the air conditioner turns on and off, and when it has reached steady state operation. Only six sensors are required for the SLU device, compared to eleven sensors required for the DOE Green Box.

The Service Light Unit was designed to prevent efficiency loss greater than 5%. Refrigerant charge and evaporator airflow fault detection thresholds were developed based on the performance of air conditioners tested in the laboratory with faults of known magnitude.

Representatives from SMUD, Proctor Engineering Group, and Beutler Heating and Air Conditioning met at the SMUD facility in summer 2005 to discuss and document the process of installing air conditioners in new residential buildings. The Service Light Unit was designed for easy incorporation into Beutler's installation process.

SERVICE LIGHT UNIT DESIGN

Most residential and small commercial air conditioners operate at reduced efficiency due to improper installation and maintenance. Incorrect amount of refrigerant and insufficient evaporator airflow are the two most common problems. This project designed, built and tested a permanently installed air conditioner monitor. The Service Light Unit (SLU) continuously examines the air conditioner to ensure efficient operation.

Approach

The design approach was to apply the proven technology of Proctor Engineering Group's CheckMe!® system to an inexpensive, permanently installed device. The device continuously monitors any residential or small commercial air conditioning system and applies the CheckMe!® diagnostic algorithms to verify the system is operating properly.

Diagnostics

SLU employs the refrigerant charge and evaporator airflow diagnostic algorithms used in Proctor Engineering Group's CheckMe!® program. The algorithms are listed below. Note that the tolerances for detecting faults differ from the CheckMe!® program because the SLU is an inherently different implementation of the algorithms.

Refrigerant charge

In each case the SLU checks the refrigerant level indicators against the specifications from the manufacturer.

Fixed orifice metering device

For air conditioning systems with a fixed orifice refrigerant metering device, proper refrigerant charge is verified using the superheat method published by Carrier Corporation. The correct amount of superheat present in the suction line is calculated as a function of inside and outside temperature/humidity.

Thermostatic expansion valve (TXV)

For systems with a thermostatic expansion valve, refrigerant charge is adjusted to match the liquid line subooling specified by the manufacturer.

Lennox fixed orifice

Lennox specifies liquid line subcooling for fixed-orifice systems.

Lennox TXV

Lennox specifies liquid line approach for systems with a thermostatic expansion valve. Liquid line approach is the temperature difference between the liquid line and the outside air.

Evaporator airflow

Evaporator airflow is verified using the temperature split algorithm published by Carrier Corporation. Target temperature split is calculated as a function of indoor temperature/humidity.

Reliability

Reliable diagnostics are crucial for the SLU to be trusted and accepted by service technicians and building occupants. The unit must be sensitive enough to detect real faults, but not so sensitive that normal fluctuations in the system are interpreted as faults. For diagnostics to be reliable, the SLU must be able to detect when the air conditioner is operating at steady state, and the diagnostic algorithms must use appropriate tolerances to indicate when service is needed.

Steady State Detection

The air conditioner must be operating under steady state conditions for the above diagnostics to be reliable. If diagnostics were performed immediately after the air conditioner turned on, the SLU would likely indicate that the system was not operating properly. This would happen every time the air conditioner turned on. Proctor Engineering Group has developed a steady state detection algorithm capable of determining when the air conditioner has reached steady state.

Figure 2-1 illustrates the importance of steady state detection. Superheat increases rapidly as the air conditioner turns on, then stabilizes after some time period (in this case 5 minutes). Diagnostics performed prior to the system reaching steady state would indicate that the superheat is lower than expected.

Depending on conditions, it can take up to 15 minutes to reach steady state.

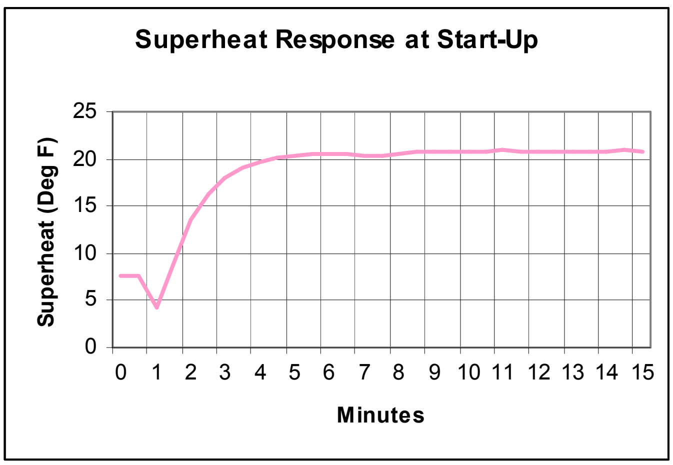


Figure 2-1: Superheat at AC Start-Up

Algorithm Tolerances

The SLU is designed to indicate a fault when air conditioner performance has degraded to the point where energy efficiency is compromised. Algorithm tolerances are designed to maintain air conditioners operating within an average of 5% of the EER at design refrigerant charge and evaporator airflow. The fault tolerance limits were developed through a study of laboratory data[1] from various air conditioners operating with refrigerant charge and evaporator airflow faults of known magnitude.

Tolerances were further studied to ensure that they are appropriate for continuous, real-time diagnostics, and that air conditioner service technicians are capable of tuning systems to achieve the limits.

The following factors were taken into consideration in developing the tolerances:

- Air conditioner efficiency
- Variability of system performance under normal operating conditions
- Sensor accuracy
- Margin of error in service technician's ability to optimize system performance
- Magnitude of the adjustment needed – when is it reasonable to require a service visit to be scheduled.

Hardware

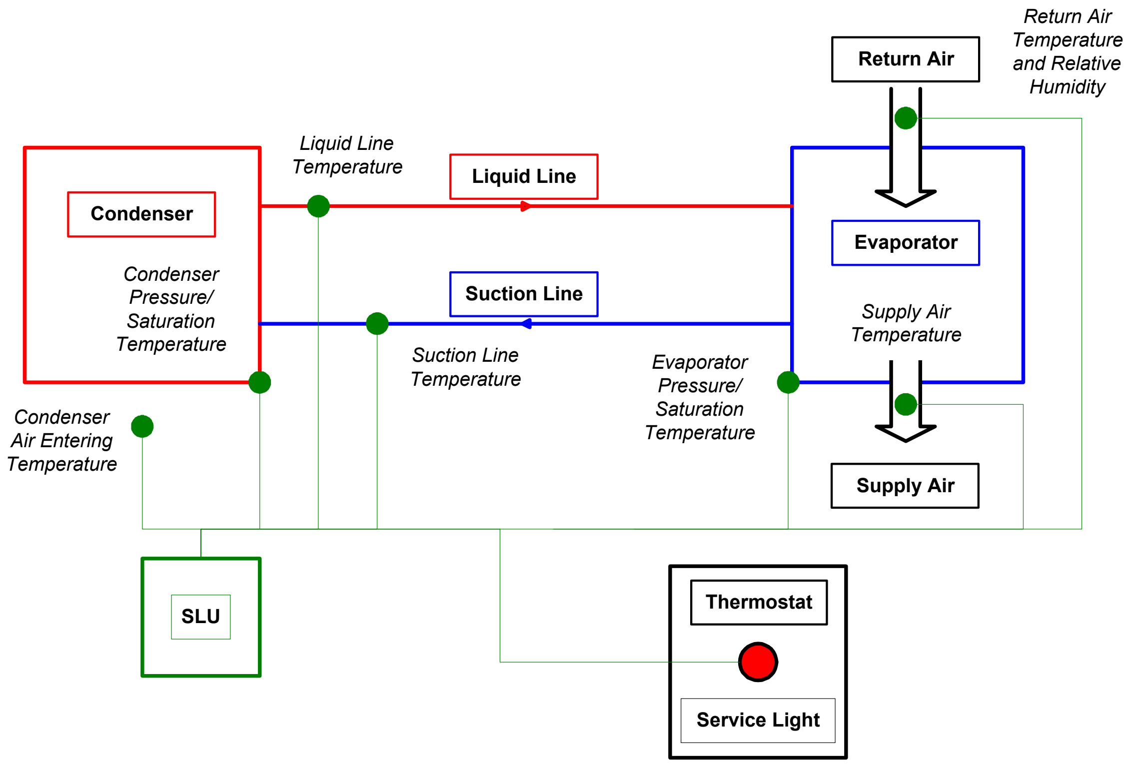
The SLU consists of a microcontroller that collects and analyzes data from an array of sensors. The following values are monitored:

- Return air temperature
- Return air relative humidity
- Supply air temperature
- Condenser air entering temperature
- Suction line temperature (for fixed orifice systems, not Lennox)
- Evaporator saturation temperature (for fixed orifice systems, not Lennox)
- Condenser saturation temperature (for TXV or Lennox fixed orifice systems)
- Liquid line temperature (for TXV or all Lennox systems)

To minimize cost, only those sensors required to perform diagnostics for the type of system being monitored (fixed metering device, TXV, Lennox) are used. Six sensors are used for each air conditioner.

1 Laboratory data was provided by Pacific Gas & Electric, Southern California Edison, Purdue University, and Texas A&M. Data from 16 different air conditioners were used. Tested units included fixed orifice and TXV, split and package, R22 and R410-A systems.

Figure 2-2: SLU Sensor Diagram



Microcontroller

The SLU is a Java programmable microcontroller designed to operate a network of digital sensors. The digital communication protocol provides data and power to all of the sensors through a single wire, with ground on an additional wire. All of the sensors are interfaced to the microcontroller through one twisted pair of wires, simplifying installation and reducing the cost of wiring.

Sensors

Inexpensive temperature and humidity sensors compatible with the digital communication protocol were selected for use in the SLU.

PROTOTYPE TESTING

Laboratory Testing

The SLU prototype was laboratory tested at the Pacific Gas and Electric test facility. More than 100 different tests were performed under a wide range of conditions. For each test, 30 minutes of data were collected. A comparison of SLU sensor performance to laboratory instrumentation is tabulated below.

Table 3-1: SLU Sensor Performance

Sensor	Rated Accuracy				SLU Deviation From Lab Measurement	
	SLU sensors		Laboratory sensors		Mean	Standard Deviation
Outside Air	0.9	Deg F	0.2	Deg F	-0.22	0.23
Return RH	2.0	% RH	1.5	% RH	3.51	0.61
Return Dry Bulb*	3.6	Deg F	0.2	Deg F	-1.53	0.22
Supply Dry Bulb*	3.6	Deg F	0.2	Deg F	-3.08	0.73
Suction Line	0.9	Deg F	2.0	Deg F	-0.69	0.23
Liquid Line	0.9	Deg F	2.0	Deg F	-0.76	0.38
Evaporator Saturation	Confidential		1.0	Deg F	0.66	0.15
Condenser Saturation	Confidential		1.0	Deg F	-0.78	0.41

* These sensors were upgraded to a more accurate sensor in the final design

Return and Supply Dry Bulb Temperatures

Laboratory testing demonstrated that the supply and return air temperature sensors were not accurate enough for reliable diagnostics. They were upgraded to a more accurate sensor, the same sensor used to measure outside air temperature.

Condenser and Evaporator Pressure/Saturation Temperature

The method of measuring condenser and evaporator pressure/saturation temperature is confidential. Laboratory testing proved the method accurate and reliable.

Prototype Performance in the Field

The SLU prototype was installed on an air conditioner in the field and tested under normal operating conditions, and with known faults. The air conditioner was a 3.5 ton split system with a fixed orifice refrigerant metering device, using R22. The evaporator and air handler were in the attic, and the condenser was in the back yard. Testing was conducted from June 2005 through September 2005.

The prototype SLU was configured to allow testing in either superheat mode (evaporator saturation and suction line temperatures measured) or subcooling mode (condenser saturation and liquid line temperatures measured). This allowed the behavior of the SLU prototype to be verified for both fixed-orifice and TXV air conditioning systems.

In addition to checking for faults, the SLU prototype was also programmed to behave as a data logger, storing data collected from the sensors and information pertaining to AC on/off detection, steady state detection, fault detection, and fault reporting. The prototype design was refined based on data collected.

Installation

The Service Light Unit's modular design and use of digital communication technology allow for easy installation on any air conditioning system. A single twisted pair of conductors connects all of the sensors to the microcontroller. Sensors can be connected at any location along the twisted pair. Sensor installation is as simple as mounting the sensor and connecting two wires.

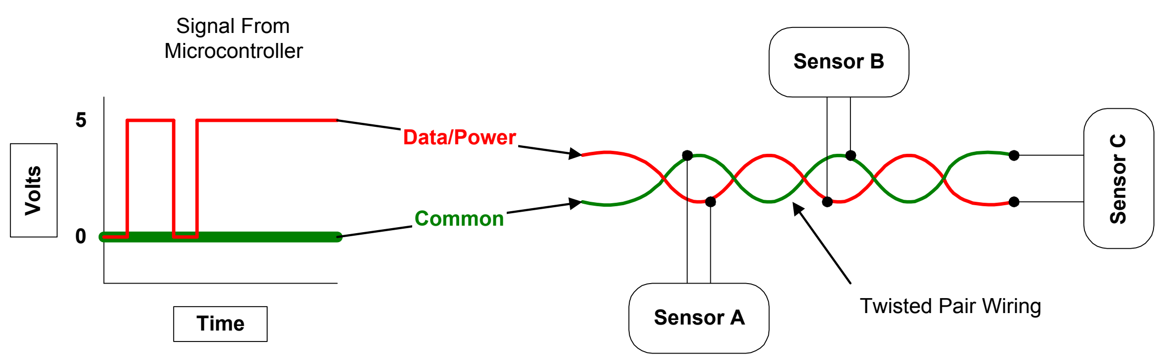


Figure 3-1: Digital Communication Protocol

Steady State Detection

Data collected from more than 200 air conditioner cycles proved the prototype reliable at detecting when the air conditioner was on, and when it had reached steady state. The prototype was tested in both superheat and subcooling configurations to verify performance when installed on both fixed orifice and TXV air conditioning systems.

Reliability

The SLU prototype collected data from June 2005 through September 2005 without experiencing any hardware or software failure or reliability issues. The only faults that were detected were those that were introduced intentionally, indicating that SLU fault detection is reliable.

Diagnostics

Airflow

A variable speed ECM motor and speed controller were installed in the field test unit air handler so that evaporator airflow could be adjusted. Airflow was measured with a TrueFlow® flow grid.

High evaporator airflow test results are shown in Figure 3-2. Points below the fault threshold activate the service light. High evaporator airflow was detected at 494 CFM/ton.

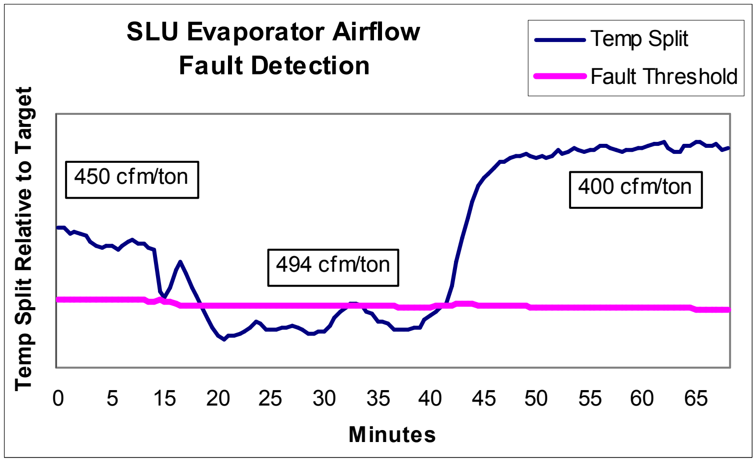


Figure 3-2: Evaporator Airflow Fault Detection (High Airflow)

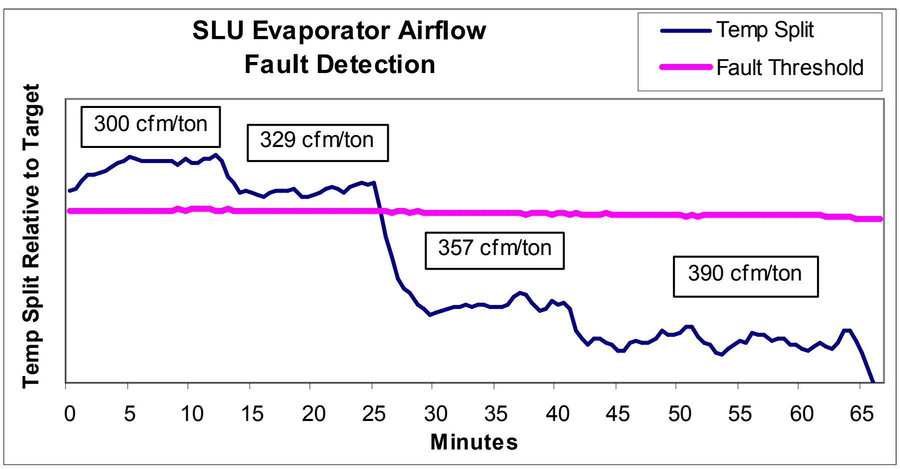


Figure 3-3: Evaporator Airflow Fault Detection (Low Airflow)

Low evaporator airflow test results are shown in Figure 3-3. Points above the fault threshold activate the service light. Low evaporator airflow was detected at 329 CFM/ton.

Refrigerant Charge

Refrigerant charge was adjusted to test SLU response. Charge adjustments were measured using a refrigerant scale. Correct refrigerant charge was defined as the amount of charge that provides correct superheat, as determined by CheckMe!®.

The service light was activated when 10% of the factory stamped refrigerant charge was removed, as shown in Figure 3-4. Points above the fault threshold activate the service light. When 10% of the factory stamped charge was returned to the system, the service light turned off.

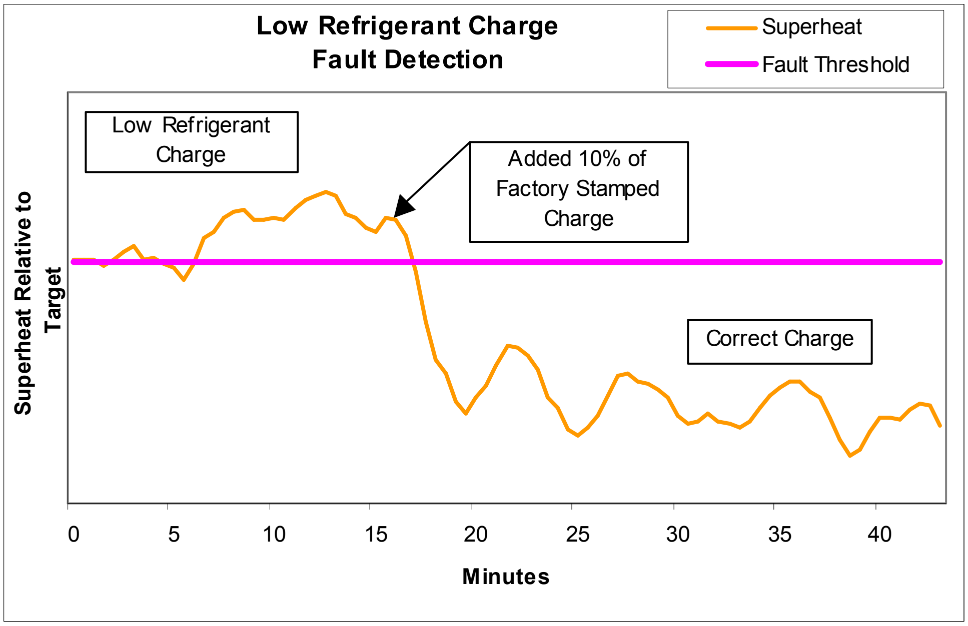


Figure 3-4: Refrigerant Undercharge Fault Detection

The service light was activated when the unit was overcharged by 20% of the factory stamped charge, as shown in Figure 3-5. Points below the fault threshold activate the service light. The service light turned off when 12% of the factory stamped charge was removed from the system. An additional 8% was removed to bring superheat to target.

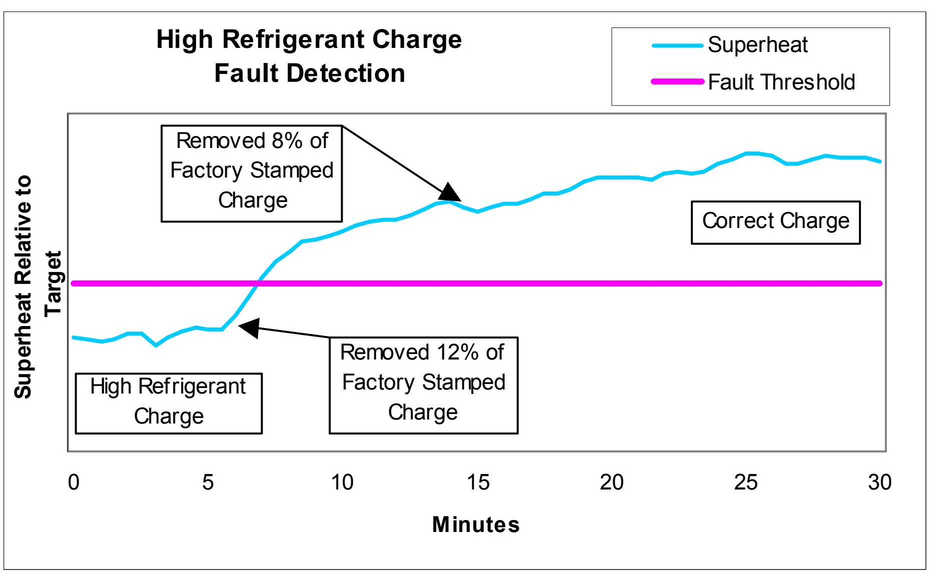


Figure 3-5: Refrigerant Overcharge Fault Detection

Fault Reporting

Data logged by the SLU prototype includes an indicator to record whether a fault is being reported and the type of fault. Figure 3-6 illustrates SLU fault reporting during two induced faults on the field test unit.

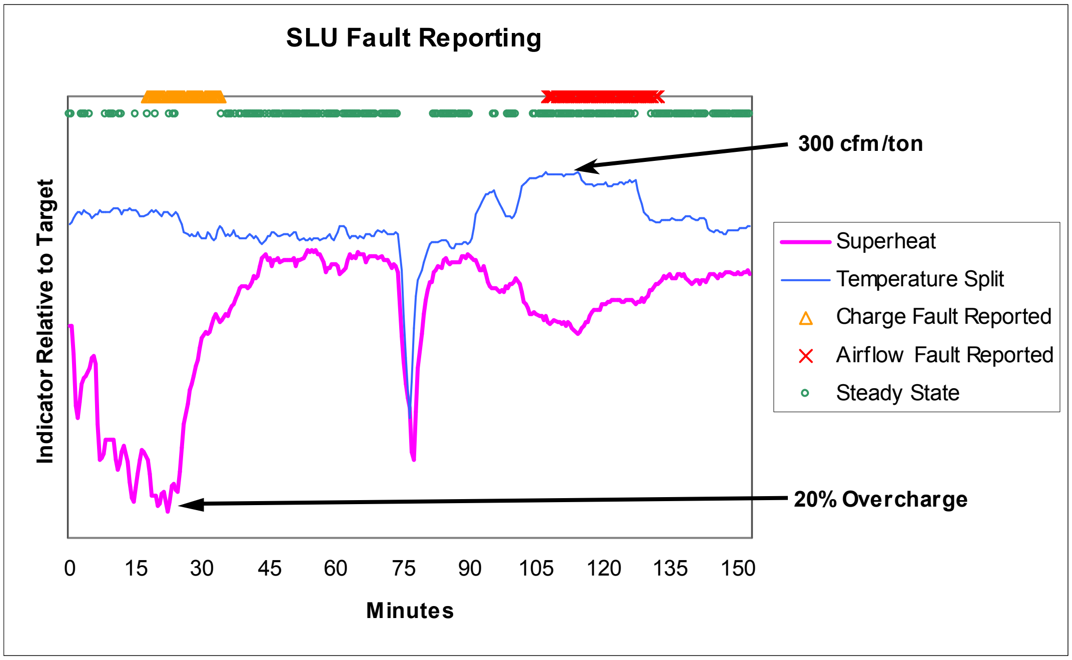


Figure 3-6: SLU Fault Reporting

First, the system was overcharged by 20% of the factory stamped charge. The SLU activated the service light to report a refrigerant charge fault. Then, refrigerant was removed to correct charge. Once the system returned to steady state, the service light turned off.

Evaporator airflow was then reduced to 300 CFM/ton. The SLU activated the service light to report an evaporator airflow fault. When airflow was restored to 400 CFM/ton, and the system had returned to steady state, the service light turned off.

FIELD TESTING

The Service Light Unit (SLU) was installed at five sites in California in 2005 and 2006. All of the air conditioners were split-system units with the condenser outside and the evaporator and air handler inside.

At four sites, two air conditioners per site were tested. The first air conditioner was a new standard efficiency R-22 unit. Midway through the summer, the standard efficiency unit was replaced with a higher efficiency R-410a unit. These sites were all single-family residential buildings. At the fifth site, one older air conditioning unit was tested. The unit served a training/conference room in a commercial building.

Table 4-1: Site Summary

House Specifications					
Site	Bakersfield	Concord	Madera	Yuba	Sacramento
House Size (square feet)	1200	1400	1650	1600	1200
Air Conditioner #1 Specifications					
Rated SEER	13	13	13	13	10
Nominal Size (Tons Cooling)	3	3	4	3	3
Metering Device	TXV	TXV	TXV	Fixed	Fixed
Nominal Evaporator Coil Capacity (Btuh)	48000	48000	48000	36000	-
Rated Sensible Capacity at 95/80/67 (Btuh)	24300	20800	31200	25000	-
Evaporator Airflow (CFM/CFM per ton)	1072/357	1084/361	1259/315	972/324	-
Air Conditioner #2 Specifications					
Rated SEER	14	14	14	14	
Nominal Size (Tons Cooling)	3	3.5	4	3	
Metering Device	TXV	TXV	TXV	TXV	
Nominal Evaporator Coil Capacity (Btuh)	37000	54000	60000	48000	
Rated Sensible Capacity at 95/80/67 (Btuh)	24100	26100	35500	25500	
Evaporator Airflow (CFM/CFM per ton)	1072/357	1080/308	1074/269	1117/372	

Evaporator airflow was measured by the pressure matching method as specified in California's Title 24. CheckMe!® diagnostics were applied to each air conditioner prior to beginning the field test. Refrigerant charge was verified to be correct. Evaporator airflow was lower than a desired 400 CFM/ton at some sites, and could not be increased.

The furnace was replaced when air conditioner #2 was installed at the Bakersfield, Madera and Yuba sites.

Monitoring System

In addition to the SLU devices, the Bakersfield, Concord, Madera, and Yuba sites were also monitored by a Campbell Scientific CR10X data logger with remote data download.

Data were gathered every 5 seconds. Instantaneous data were gathered from all sensors at the beginning and end of all cycles. The data were also averaged or summed as appropriate over each cycle. A dedicated computer in the Proctor Engineering Group office downloaded data from each Campbell data logger nightly.

Table 4-2: Monitored Parameters

Measurement	Sensor Type	Sensor Location
Supply Air Dry Bulb Temperature	4 Point RTD Grid	After Coil In Supply Plenum
Supply Air Dry Bulb Temperature	Thermocouple	After Coil In Supply Plenum
Supply Air Dry Bulb Temperature	Thermocouple	Supply Register
Supply Air Relative Humidity	Humidity Transmitter	With Supply Air Thermocouple
Return Air Dry Bulb Temperature	4 Point RTD Grid	Return Plenum Before Furnace
Return Air Dry Bulb Temperature	Thermocouple	Return Plenum Before Furnace
Return Air Dry Bulb Temperature	Thermocouple	Return Grill
Return Air Relative Humidity	Humidity Transmitter	With Return Thermocouple
Return Air Relative Humidity	Humidity Transmitter	Return Grill
Temperature Drop Across Coil	Thermopile	With Return and Supply RTD Grids
Outside Air Temperature	Thermistor (Shielded)	Outside Near Condensing Unit
Outside Air Relative Humidity	Humidity Transmitter	With Outside Air Thermistor
Indoor Air Temperature	Thermistor	Near Thermostat
Compressor Discharge Temperature	Thermocouple	Surface Mounted To Compressor Gas Discharge Line (Insulated)
Liquid Line Temperature	Thermocouple	Surface Mounted To Liquid Line at Evaporator Coil (Insulated)
Suction Line Temperature	Thermocouple	Surface Mounted To Suction Line at Evaporator Coil (Insulated)
Condenser Saturation Temperature	Thermocouple	Surface Mounted to Condenser Refrigerant Circuit
Evaporator Saturation Temperature	Thermocouples	Surface Mounted to Evaporator Refrigerant Circuit
Evaporator Condensate Flow	Tipping Bucket	Evaporator Condensate Line
Condensing Unit Power	Pulse Watt Transducer	Electrical Supply To Unit
Condensing Unit Power	Analog Watt Transducer	Electrical Supply To Unit
Furnace Blower Power	Pulse Watt Transducer	Electrical Supply To Furnace Unit
Furnace Blower Power	Analog Watt Transducer	Electrical Supply To Furnace Unit

SLU Performance

SLU was installed at the Sacramento site in October 2005. It was installed on the standard efficiency units at the four remaining sites during June and July 2006 and on the high efficiency units during July and August 2006. Data stored in the SLU memory was collected during the summer and fall of 2006 and analyzed to evaluate performance.

Table 4-3: SLU field test results

				% of steady state data points with fault detected	
Site	# Cycles	# Data Points	# Steady State Data Points	Refrigerant Charge	Evaporator Airflow
Madera Unit 1	1060	9000	300	0	0
Madera Unit 2	205	9000	285	0	8
Yuba Unit 1	313	15824	9333	2	0
Yuba Unit 2	118	9000	1669	0	0
Sacramento	345	10000	1416	2	3
Concord Unit 1	196	18859	1542	0	5
Concord Unit 2	11	9182	111	55	71
Bakersfield Unit 1	240	8913	4090	66	100
Bakersfield Unit 2	42	9000	112	22	100

Air Conditioner OFF Detection

Detecting when the air conditioner turned off was a challenge on several of the units equipped with TXV refrigerant metering devices. The detection error resulted in SLU logging data while the air conditioner was not running, reducing the number of data points available for analysis. Air conditioning unit #2 at the Bakersfield, Concord and Madera sites were particularly susceptible to this behavior. A software solution has been developed to address this challenge (see Appendix E).

Madera

Unit 1

This unit was oversized and cycles were very short, averaging less than 4 minutes. The short cycles resulted in relatively few steady state data points. No faults were detected on this unit. Refrigerant charge and evaporator airflow were both correct.

Unit 2

This unit was oversized and cycles were very short, averaging only 3 minutes. The short cycles resulted in relatively few steady state data points. Low evaporator airflow was detected in 8% of steady state data points. Airflow was low, measured at 269 CFM/ton. Low airflow was detected 100% of the time in data from the Campbell Scientific data logger, taken at the end of cycles that were at least 4 minutes long. Appendix D discusses SLU sensor design changes for improved evaporator airflow fault detection.

Yuba

Unit 1

Refrigerant overcharge was detected in 2% of steady state data points. The faults were caused by improper location of the suction line temperature sensor. The sensor was located inside near the evaporator, but should have been located outside near the condenser. There is a temperature difference between the two locations.

Unit 2

No faults were detected on this unit. Refrigerant charge and evaporator airflow were both within acceptable limits.

Sacramento

Low refrigerant charge was detected in 2% of steady state data points, and low evaporator airflow was detected in 3% of the points. The faults were the result of premature steady state detection. All faults occurred within the first 15 minutes after the air conditioner turned on. This air conditioner tended to stabilize about 5 minutes after turning on, return to transient operation after about 10 minutes, then finally reach steady state after about 15 minutes. The faults occurred during the brief period of stability between 5 and 10 minutes. This issue is correctable in the SLU software.

The SLU was installed at the Sacramento site in October, 2005. Data was collected in November, 2006. The unit was still functioning properly after over a year in the field, with no intervention during that time.

Concord

Unit 1

Low sensible capacity was detected in 5% of steady state data points. Actual sensible capacity measured by the Campbell Scientific data logger was 72% of the manufacturer's rating (at 95°F outside temperature). The reason for the poor performance of the air conditioner is not known. Both air conditioners at this site performed poorly relative to the manufacturer's ratings.

Unit 2

Low evaporator airflow was detected in 71% of steady state data points. Evaporator airflow was low, measured at 308 CFM/ton.

Low refrigerant charge was detected in 55% of steady state data points. The faults were the result of sensor location issues (see Appendix C).

Bakersfield

All steady state data points were recorded as an evaporator airflow fault on both units. Many points were also recorded as refrigerant charge faults. These were erroneous determinations. These determinations were results of the installation locations of two sensors (see Appendix C and D).

Fault Testing in the Field

At four sites, faults were introduced into the air conditioner to test SLU fault detection capability. Faults were tested on the high efficiency air conditioning units at the Bakersfield, Concord, Madera and Yuba sites in October, 2006. All of these units have thermostatic expansion valves (TXVs) with the associated detection challenges previously discussed. Refrigerant charge and evaporator airflow faults were tested.

At three sites, the Campbell Scientific data logger was programmed to store data in 1 minute intervals. Diagnostic algorithms were applied to the Campbell data as well as the SLU data to verify SLU performance. Efficiency and capacity loss resulting from each fault was calculated from the Campbell data. Capacity was defined as the net capacity, meaning the capacity actually delivered to the house (gross capacity – fan motor heat). Efficiency was calculated as the net capacity divided by total power consumption. The basic target of the SLU is to provide a signal to the occupants when the efficiency falls by 5% or more.

Refrigerant charge faults were introduced by adding or removing refrigerant. Evaporator airflow faults were introduced by changing the blower speed and/or obstructing the return grille. Evaporator airflow was measured using a True Flow grid.

Table 4-4: Fault Test Results Summary

Site	Fault	Fault (%)	Fault Detected SLU	Fault Detected Campbell	EER change (%)	Sensible EER change (%)	Capacity change (%)	Sensible capacity change (%)
Madera	Refrigerant charge	Over	N	Y	-6	-7	+3	+3
		Under	N	N	-2	-3	-4	-3
	Evaporator airflow	Low	Y	Y	0	-1	0	-4
		Low	Y	Y	-5	-13	-7	-14
Yuba	Refrigerant charge	Over	N	-	-	-	-	-
		Under	N	-	-	-	-	-
	Evaporator airflow	Low	N	N	0	-4	-3	-8
		Low	Y	Y	+1	-6	-5	-11
Concord	Refrigerant charge	Over	N	N	-5	-5	0	0
		Under	Y	Y	-5	-9	-5	-8
	Evaporator airflow	Low	Y	Y	-	-	-	-
Bakersfield	Refrigerant charge	Over	N	-	-	-	-	-
		Under	Y	-	-	-	-	-
	Evaporator airflow	Low	N	-	-	-	-	-
		Low	N	-	-	-	-	-

Madera

The refrigerant overcharge was not detected even though the efficiencies dropped by over 5%. This was due to installation issues with one of the sensors (see Appendix C). The overcharge was detected when the diagnostic algorithms were applied to data from the Campbell Scientific data logger, and resulted in a 6% EER reduction. The refrigerant undercharge was not detected, but only decreased EER by 2%.

Evaporator airflow reductions were detected. This included detection of changes that resulted in as little as 1% change in EER. Larger airflow reduction was also detected, with a 13% reduction in sensible EER.

Yuba

The refrigerant overcharge was not detected. The refrigerant undercharge was not detected by the liquid line approach method, as specified by the manufacturer. The subcooling method did detect the undercharge. Proctor Engineering Group recommends including subcooling refrigerant charge diagnostics on Lennox TXV systems. No additional sensors are required to measure subcooling on these systems.

Evaporator airflow reduction was detected at a level where the Sensible EER was reduced by 6%.

Concord

Refrigerant undercharge was detected at a level that resulted in a 5% EER reduction. Refrigerant overcharge was not detected due to installation issues with one of the sensors (Appendix C).

Evaporator airflow 23% lower than 400 CFM/ton was detected. The efficiency of the unit was not measured under these conditions.

Bakersfield

Refrigerant overcharge was not detected due to installation issues with one of the sensors (see Appendix C). Undercharge was detected.

Evaporator airflow faults were not detected due to installation issues with one of the sensors (see Appendix D).

CONCLUSIONS

The majority of SLU units performed well in the field, in particular:

- The sensors all performed properly
- The data were properly recorded
- The cut off at 5% efficiency loss proved reasonable and achievable in the individual field tests of intentional faults
- The fault detection algorithms worked as designed when the sensors were in locations that read the intended parameter
- Undercharge, Overcharge, Low airflow and Low capacity were all detected
- The ON/OFF and steady state detection worked well on units with fixed metering devices.

The following areas for improvement were identified:

- An installation issue with a sensor resulted in less effective refrigerant charge diagnostics for TXV systems. On these systems, SLU was unable to detect refrigerant overcharge. On two systems, SLU detected refrigerant undercharge when charge was correct. The installation issue is sensor placement. An improved installation procedure has been developed.
- Incorrect evaporator airflow diagnostics at one site were also related to sensor placement. The issue was caused by the furnace and ductwork configuration at that site. A solution has been developed that will not only correct diagnostics at that site, but also improve evaporator airflow diagnostics across the board.
- The SLU sometimes failed to detect when the air conditioner turned off on some TXV systems. The software has been updated to address this issue. ON/OFF detection performed correctly on fixed orifice systems.

Fault detection limits were chosen to alert the customer when the efficiency of their unit had degraded by 5% or more. The limits were tested by the intentional introduction of faults. In some cases, the actual capacity and efficiency changes were measured with data from more sophisticated loggers. Actual capacities and efficiencies were compared to SLU fault detection.

- Refrigerant undercharge was detected on 2 of 4 units. Efficiency loss was measured on one unit. The detected undercharge reduced EER by 5%. On one unit where undercharge was not detected, the efficiency loss was only 2%.
- Low evaporator airflow was detected on 3 of 4 units. Efficiency was measured on two of those units. The average loss in sensible EER was 3.5%.
- One unit was installed in the field in October 2005 and remained until November 2006. After over a year in the field with no intervention, the unit was still functioning properly. The data logged by that unit indicated no hardware or software malfunctions.

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- Beutler Heating and Air Conditioning
  - Shannon Jameson
  - Bob Radcliff
- The homeowners who volunteered their homes for the field test

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APPENDIX A: THE CHECKME!® PROGRAM

The CheckMe!® Air Conditioner/Heat Pump Re-Commissioning & Quality Assurance Program

Introduction

CheckMe!® is a turnkey system that produces energy savings, peak reduction, and requires minimal administrative work on the part of a client. In addition to making sure things work right in the field, CheckMe! provides the client a monthly report that includes reports on production, quality assurance, and project goals achieved. Proctor Engineering Group does the work. The client gets the reports.

The Opportunity

Air conditioners and heat pumps are a major source of energy waste. During the cooling season they place a huge demand on peak energy requirements. The principle sources of inefficiency in these units are improper refrigerant charge and low airflow across the coil. There is massive potential for energy savings from making sure air conditioners and heat pumps are serviced in a way that gets charge and air flow right.

The CheckMe!® system, developed by Proctor Engineering Group, assures heat pump and air conditioner re-commissioning that consistently, effectively, and verifiably addresses these crucial factors. CheckMe! is highly effective both for re-commissioning existing air conditioners, and for assuring that new units are operating at manufacturers' specifications. This is important given the growing body of evidence that suggests that most new equipment –both standard and high efficiency—is improperly installed. Recent studies suggest that the manner in which equipment is installed may have a much greater impact on actual operating efficiency than whether or not it has a high efficiency rating.

How CheckMe!® Addresses the Problem

The CheckMe! procedure uses the manufacturers' specifications (superheat or subcooling) for the refrigerant charge and temperature split for air flow verification.

CheckMe! AC makes sure the technician has the right tools, sufficient training in the proper procedure, and timely feedback on what repairs to make. Added to these is a system of built in error checking and accountability to ensure that the technician is consistently doing what he was trained to do. Here are some quotes from technicians after they began to use CheckMe!, "I was surprised to find charge wrong on units I have serviced over the years." "I have found 8 ounces overcharge on brand new units." "If you do it every time you have covered the bases." It has opened a whole new thing for me." "You learn to be more precise."

Steps in CheckMe!®

- A CheckMe! trained technician follows the protocol and calls the results into the CheckMe!® hotline.
- With the technician on the phone, an operator enters the numbers. The computerized expert program checks for errors, diagnoses the problems, and gives specific recommendations, in less then 3 minutes.
- With customer approval the technician makes repairs, retests the unit and calls back the CheckMe!® hotline.
- Following verification that the unit meets the manufacturers' specifications, a certificate is mailed to the customer, which explains results and provides for customer feedback.

What Kind of Training Is Provided?

Trainers are nationally recognized as experts in HVAC diagnostics, service, and training. Training is hands-on with only 2 to 4 technicians per trainer.

A Technical Staff Combining 55+ Years of Experience and Success

The senior staff of Proctor Engineering Group has more experience in training and evaluation of air conditioner systems than any three other people working together in the industry.

John Proctor, P.E., President, is an M.I.T. trained mechanical engineer who has gained a reputation as one of the foremost experts in the nation on space conditioning systems, and their interactions. Through practical application of research results Mr. Proctor has developed a systematic approach to implementation that produces cost-effective energy savings. He is the author of the "Ask Doctor Proctor" column in *Home Energy Magazine*.

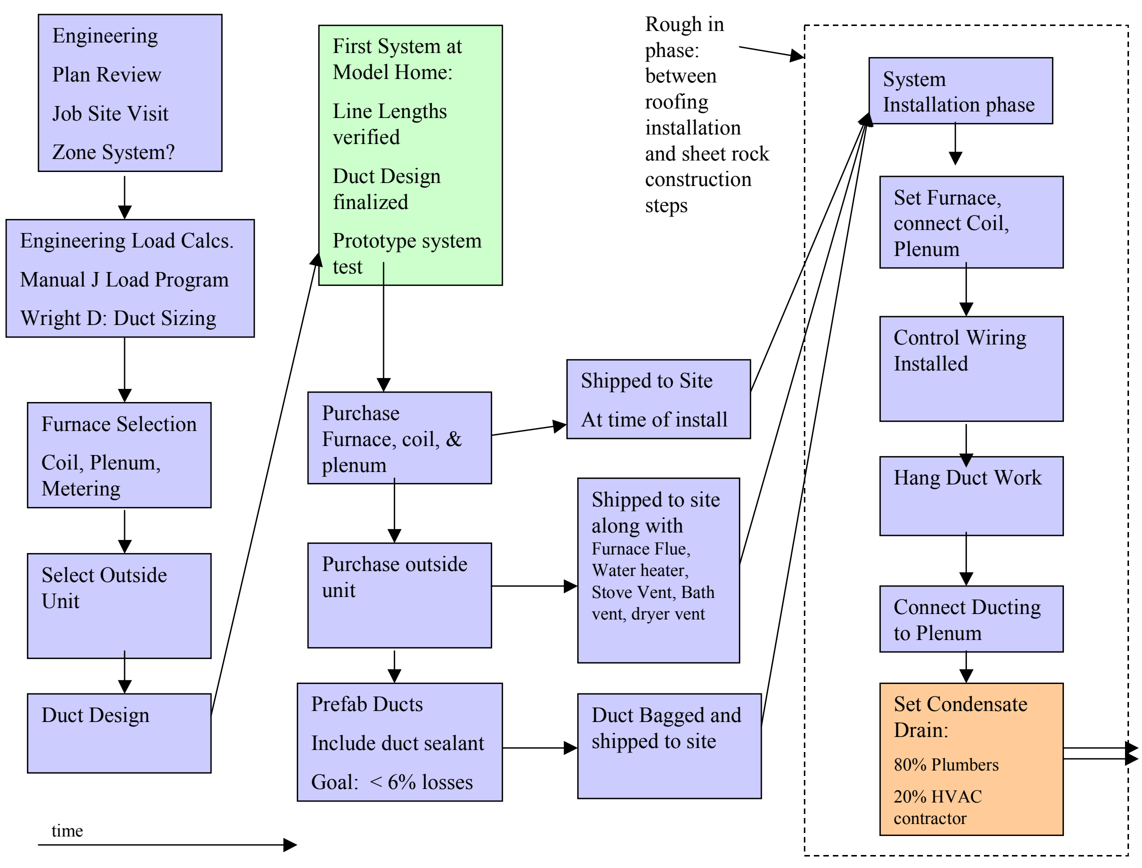
Tom Downey, Senior Program Manager, has over 17 years of experience training technicians and managing energy efficiency projects where the work of the field personnel is critical to the success of the project. Mr. Downey has established a reputation as one of the top trainers in the nation on all parts of the HVAC system and their integration into the whole building.

Mike Sims, Trainer, is a licensed California HVAC contractor. He has extensive experience in the application of advanced air conditioning and duct diagnostic techniques. Mike has been an HVAC supervisor, HVAC trainer, auditor trainer, duct and blower door technician and trainer, as well as consultant on combustion safety testing and repair.

APPENDIX B: INSTALLATION PROCESS FLOWCHART

Representatives from Beutler Heating and Air Conditioning, Proctor Engineering Group, and SMUD met to document the steps involved in air conditioner installation for residential new construction. The flow chart (provided by Bill Warf) is shown below.

Figure B-1: Process Installation Flow Chart



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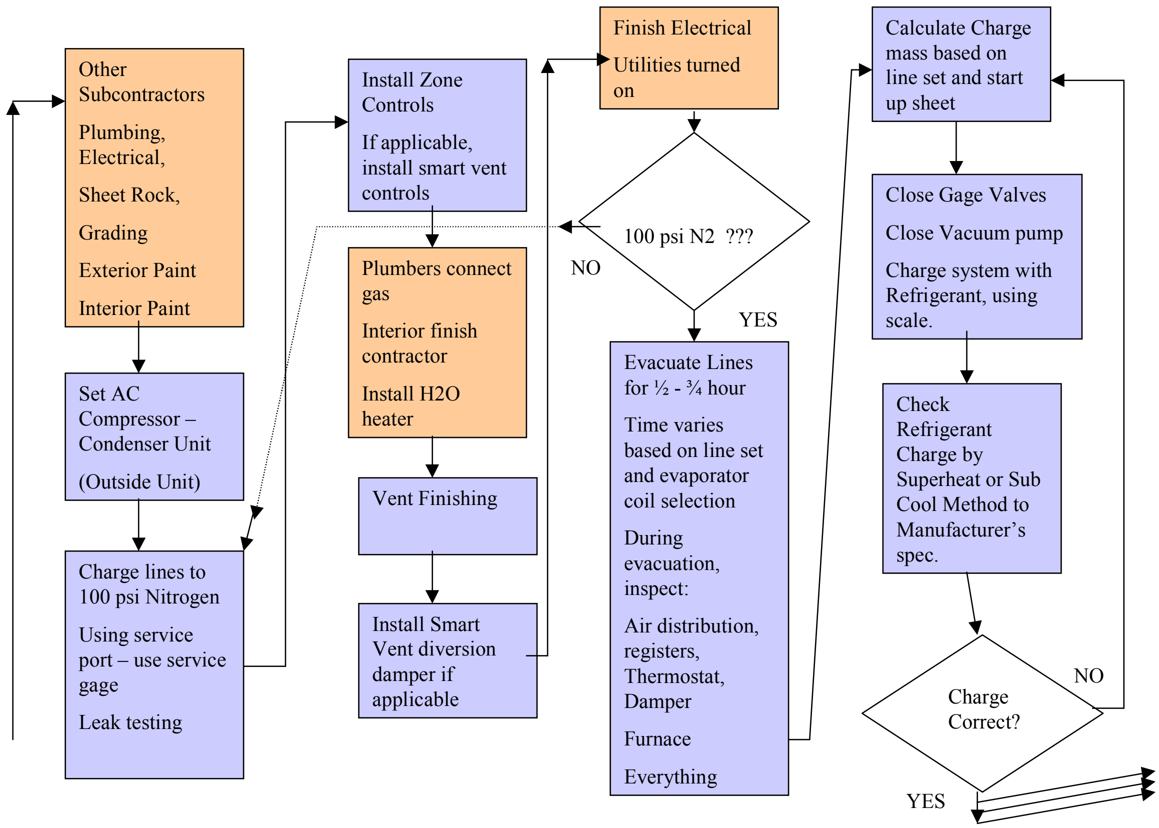

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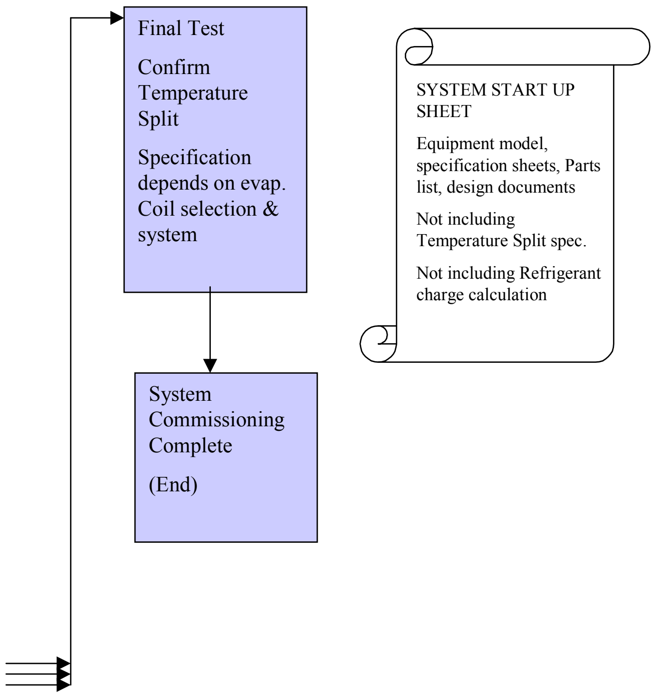

Notes:

1. Flow Chart produced by representatives of Beutler Heating and Air Conditioning, California Energy Commission, Proctor Engineering and SMUD on April 12, 2005 For the Air Conditioning Service Light Project
2. Beutler talked about its Comfort Club program, that provides a free follow-up thermostat training (and charge check for winter commissioned units). Ideal timing, move in + 45 days.