Do Quality Installation Verification Programs for Residential Air Conditioners Make Sense in New England?

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Abstract:

Many New England utilities have instituted Quality Installation Verification Programs (QIV) to improve the efficiency of residential air conditioning (AC) systems by encouraging HVAC technicians to use third-party software to test the air flow and refrigerant charge conditions of AC systems they install or service. The QIV approach recognizes that many existing systems and new installations do not achieve the maximum efficiency because the refrigerant charge and air flow are not at the levels recommended by the equipment's manufacturer. The QIV programs provide incentives to technicians who use either the Honeywell Service Assistant (HSA) or the CheckMe tools to test system conditions.

This paper examines the results of programs in New England focused on encouraging HVAC firms to use the QIV testing approach when installing or servicing AC systems. This paper discusses whether the QIV tests save energy and avoid peak demand and whether there are other AC systems initiatives that deserve more attention in New England.

The paper finds that Quality Installation Verification Programs cannot be justified unless the AC systems have extra capacity at system peak. If systems have insufficient capacity, efficiency gains produced by air flow and refrigerant charge correction will not reduce peak demand. The undercapacity of air conditioners at peak appears to happen in many of the homes included in the 2002 base line assessment conducted by a group of New England utilities by RLW Analytics and in on-sites performed in 2006 on homes receiving a high efficiency air conditioner.

Introduction to QIV Programs in New England

Quality Installation Verification (QIV) is an emerging approach that seeks to empower HVAC technicians to improve AC system efficiency by providing tools that use inputted values for system temperatures and pressures to gauge the current system operating efficiency and provide feedback on how to correct for sub-optimal air flow and refrigerant charge conditions. The Massachusetts CoolSmart Program began with the participation of National Grid, NSTAR, Western Massachusetts Electric (WMECo), Unitil, and the Cape Light Compact in 2005. CoolSmart offered QIV incentives to contractors who performed the tests on new installations. National Grid of Rhode Island joined this effort in late 2005 and WEMCo, Unitil, and the Cape Light Compact left the program in 2006 because of budget issues. Program changes in 2006 permitted QIV type incentives for tests performed on existing units.

This QIV approach relies on the use of hardware/software tools that the technician uses to interpret system temperature pressure and temperature readings that the technician normally collects as part of any service or commissioning job. The two tools included in the New England programs are the Honeywell Service Assistant (HSA) handheld unit and the CheckMe software tool.

HSA required users to purchase a hand-held computer. The technician manually enters key measurements and the hand-held computer calculates all of the required information and the HSA immediately provides feedback on the AC unit and needed adjustments or repairs. The CheckMe approach requires the technician to call the necessary data in to a processing center; the processing center then provides to the technician recommendations for repairs and adjustments.

In the CoolSmart program, the unit must pass the tests to receive the incentives. If the first test performed by the contractor passes the charge and airflow tests, no further testing is required. If the refrigerant charge test does not pass, the contractor must fix the condition and submit a second test in order to receive the incentive. If the unit does not pass the airflow test, the contractor needs to either fix the system or obtain a signed-waiver from the customer. This waiver stipulates that the contractor explained the airflow problem, but the customer opts not to have it repaired. In 2006, the CoolSmart program paid incentives of $175 for tests in 165 new installations and 291 existing units.

How Does QIV Fit into a Demand Saving Program?

This paper is the result of an evaluation of the 2006 CoolSmart Program conducted by Wirtshafter Associates, Inc. and Performance Systems Development, Inc. The paper investigates whether the QIV approach being tried in New England makes sense. In that respect, the paper questions whether the program is now cost-effective and if not, will the eventual adoption of QIV techniques by contractors produce sufficient future benefits to justify current expenses. To determine this ultimate answer, it is necessary to break this question into a series of smaller questions. These questions include:

- What is the theoretical savings that fixing air flow and refrigerant charge could produce?
- How many of the units serviced by the program are realizing the savings, and how many of those are attributable to the use of the tools.
- What is the real value to the utility of the savings produced by the tools?

What Is the Theoretical Savings That Fixing Air Flow and Refrigerant Charge Could Produce?

There are very limited resources available for calculating the efficiency and demand impacts from incorrect charge and airflow. Much of the recent work in this area has come from California, typically a significantly hotter and dryer climate than New England. Other test results date back to the late 1980's with laboratory testing work done at Texas A&M. Information presented by Proctor Engineering to the California Energy Commission (CEC) as part of the CEC's adoption of code enhancements relating to AC efficiency is one of the few published estimates of the level of savings that can be achieved by fixing charge and air flow..[1]

It is important to understand how charge and airflow physically affect both efficiency and demand. Changes in airflow are easiest to understand. A duct system with too much resistance will use more fan energy and get less airflow than designed for, and reduced airflows will reduce the capacity of the equipment by reducing heat transfer across the coil. Increases in fan power to increase airflow rapidly cost more energy overall than is saved through increased capacity and shorter run times. Reducing resistance can sometimes be achieved by cleaning the filters and the coil, but more often may require an expensive retooling of the duct system. Figure 1 shows that as airflow decreases, the efficiency of the unit drops. This drop is more pronounced in systems that do not have Thermostatic Expansion Valves (TXV).

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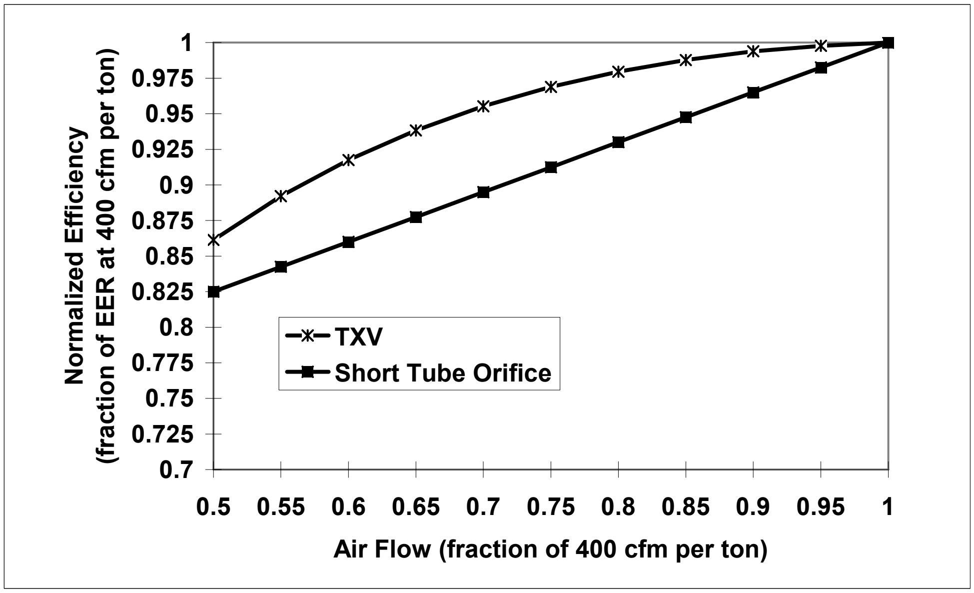
[1] See. Proctor, John, "AC Performance Associated with AB970", Powerpoint presentation to California Energy Commission, undated.

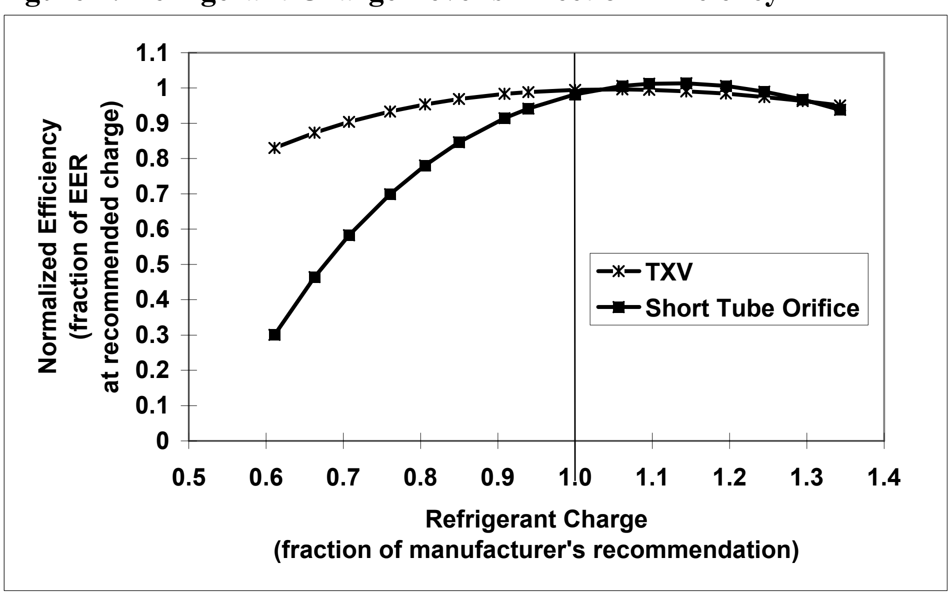
Figure 1: Airflow Effects on Unit Efficiency



From Proctor, John, “AC Performance Associated with AB970

Charge is more complicated. Achieving the correct charge optimizes the cooling output of the system relative to the energy going into the system. Figure 2 shows the relationship of charge level to a unit’s rated Energy Efficiency Ratio (EER). A system with too little charge, may actually use less energy, but will also produce less cooling and produce it less efficiently. Adding refrigerant to the system will increase instantaneous energy use by the compressor to pump the refrigerant, but the system will produce proportionally more cooling as it reaches its optimum design point, thereby increasing total system efficiency.

Figure 2: Refrigerant Charge Level’s Effect on Efficiency



From Proctor, John, “AC Performance Associated with AB970

Removing charge from an overcharged system will decrease energy use and possibly reduce cooling output. But again, the system is operating more efficiently; more cooling energy is being produced per unit of energy going into the cooling system.

Thermostatic expansion valves (TXV) meter the charge going into the indoor coil by trying to maintain a set superheat temperature. This helps to maintain the efficiency of the equipment across a range of temperatures and charges. The TXV therefore reduces the impacts of poor charge and airflow. New systems installed under CoolSmart rebates are required to have TXVs.

Recently more work has been done in California to look at the impact of TXVs on charge and demand. Preliminary analysis of this work seems to indicate that TXVs are less capable of adapting to overcharging. The work also clearly indicates that the impact of TXVs on tolerance of charge variations is also dependent on proper installation of the TXV. A TXV that is uninsulated and/or not in good contact with the refrigeration pipe will not be able to correctly meter refrigerant.

How Many of the Units Serviced by the Program Are Realizing the Savings, and How Many of these Are Attributable to the Use of the Tools?

This previous section indicates that there are probably significant efficiency gains when severely undercharged systems without TXVs are recharged and the cause of the undercharge is remedied. Other units that are overcharged or that have TXVs will not see as large of a benefit. Similarly, units with airflow below 300 cfm/ton, will show some gain in efficiency if airflow is corrected. However, the extent of the savings is dependent on the actual conditions of the units being serviced, whether the charge and airflow deviate greatly from the recommended settings, and whether servicing of the systems actually leads to correction of these conditions. A final question is whether the tools fundamentally change what actions technicians would and do take to correct system conditions?

CoolSmart's program tracking data including uploaded results of the QIV tests suggest, although cannot confirm, that most tests involved one reading of the system, with little corrective action being recorded. The vast majority of HSA and CheckMe jobs are a single read at a home. Of these, 643 (66%) passed both the airflow and the charge test. In the other 34% of the uploaded sites, few contractors repaired the problem, re-tested the unit, and then submitted the rebate form. Of 981 unique units for which uploaded data are available, only 77 involved multiple tests on the same unit; and only 31 of these units were fixed and received rebates. We cannot confirm this low number of fixed systems because:

- some contractors may have taken a reading they did not upload, fixed the system and then taken the reading which we record as a single-read pass.
- some may have taken and uploaded a failed reading, fixed the system and then either not taken a second reading, failed to upload the second reading, or did not submit the application.

These high rates of failure for these critical tests indicate that while the program has gotten some technicians to use the tool, the technicians are not always leaving the systems operating at their intended maximum efficiency. Some technicians are using the tool but not yet using it to change their practices. On the other hand, there may be cases where the technician cannot easily fix the system, or cannot convince the homeowner to make the necessary investment. More study is needed to determine the reason why so many CoolSmart jobs are not achieving the expected outcomes. The low achievement level is particularly troubling for commissioning jobs where more flexibility exists to match system unit size to the ductwork capacity.

Reassessing the Value of Savings from Residential Air Conditioning Efficiency Programs in New England

Even supposing that many units were in need of charge and air flow correction, and that the use of the QIV tools leads contractors to repair those systems, there is a more fundamental reason to question whether New England utilities should be offering QIV incentives at this time. The correction of air flow and charge may not be supportable because those corrections are unlikely to produce sufficient utility benefits to be justified. The reason that benefits are lower than expected, and likely lower than in other parts of the country is that the weather conditions in New England lend themselves to systems having insufficient capacity to meet peak weather conditions. When this happens, efficiency corrections end up not reducing peak electric demand, and thus produce very little utility benefits. To explain this fully, we must explore more deeply the relationship between AC use and peak demand, particularly the effects that the sizing of the system will have on peak demand reductions.

The Importance of Peak Demand Reduction Benefits for New England Utilities

Many New England utilities do not even have cooling efficiency programs because the cooling loads are small. From a traditional energy only standpoint, this exclusion of cooling is correct, however, many utilities are recognizing that summer peak loads are increasing and becoming more expensive to supply. Surprisingly, despite the milder climate of New England, summer peak reduction programs may be more justified in New England than they would be in hotter climates. This is because of the pronounced spike to the AC load profile for this area.

As Table 1 confirms, the Massachusetts cases actually have almost the same number of hours as Texas in extreme weather, defined here as the number of hours in which the temperature exceeds the design conditions.[2] Table 1 also shows the same situation from the perspective of the relative difference between the design and peak temperature conditions. The differences are less than 5°F difference in Texas, and nearly twice that in Massachusetts. In Massachusetts, the total number of cooling hours is significantly lower, less than 1/5th of the Texas hours.

Table 1: Total Cooling Hours and Extreme (Over Design) Hours in Texas and Massachusetts

TMY Source	Number of hours above 77°F	Design Temp	Peak based on TMY	Delta T Design	Delta T Peak	% difference for the Delta	Hours over Design Temperature	Percentage of Cooling Hours over Design Temperature
Houston	2805	93	97.5	17	21.5	21%	45	2%
FT Worth	2467	97	101.4	21	25.4	17%	25	1%
Boston Airport	530	87	95	11	19	42%	27	5%
Worcester	426	83	95	8	20	60%	80	19%

While the design conditions and annual cooling loads are much lower in New England than they are in Texas, the weather conditions on the peak day are almost the same. Since the utility must build

[2] ACCA Design Temperature is set at 97.5 percentile of the total summer cooling temperatures. In other words it is the temperature condition at which the home system is designed to meet all but 2.5% of the entire summer. The cooling period is set at 2,928 for the entire country and is not adjusted by actual number of hours where cooling is needed. For this reason, milder climates have a larger number of hours where cooling is needed above their design temperature than warmer climates do.

capacity to meet the peak day demand, utilities in both Texas and Massachusetts must build similar amounts of additional capacity to cover peak events. There are five major implications for this situation.

- The capacity requirements from residential AC are only a little smaller in Massachusetts than they are in Texas.
- Measures that save peak demand in New England are quite cost-effective. The cost of that capacity is estimated to be around $7,800/kW for NSTAR, $6,200/kW for NGRID in Massachusetts and $2,600/kW for NGRID in Rhode Island. However, measures that make units more efficient but do not save at peak conditions will probably not be justified.
- Utilities using billing by the kilowatt-hour have many times more kilowatt-hours of cooling in which to collect capacity related costs in Texas than they do in Massachusetts.
- The opportunity for cost-effective AC efficiency measures is much greater in Texas. In New England, it is pretty hard to justify large expenditures in efficiency, where for example a jump to SEER 14 from SEER 13 will only save the consumer around $15 a year.
- Incentives geared to measures that reduce peak demand need to be offered by utilities. The current price signal to contractors and homeowners will not encourage peak reduction because the average price tells the homeowner peak use is worth $0.15/kWh and not $7,800 per avoided kW.

The Effects of Sizing on Peak Demand Requirements

Determining the proper sizing of an AC system in a home involves the use of the Air Conditioning Contractors of America, Inc. (ACCA) Manual J. The process involves identifying the building cooling load, the summation of all heat gains and losses, at the *design temperature* set for the local weather conditions. The design temperature represents the temperature at which the cooling system is designed to fully meet the load requirements, 97.5% of the summer. In the NGRID and NSTAR territories the design temperature is between 86 ^{o}F and 88 ^{o}F depending upon the specific location.

It should be noted that the design temperatures are not the maximum summer temperatures ever experienced in these areas. Manual J understands that it is not necessary or efficient to install an AC unit that has the capacity to meet the maximum conditions because they occur so infrequently, and because the larger system will be oversized for normal use, resulting in comfort and efficiency penalties. Even so, Manual J calculations are such that they generally err on the side of overestimating cooling loads and thus oversize the system capacity required to actually maintain the indoor temperature during design conditions.

In practice, most HVAC technicians build even more wiggle room into their calculations and then round up to the next half ton size, so that virtually all systems installed in the US are oversized with respect to design conditions. This means that as temperatures rise above design conditions, the AC units still have the capacity to supply more cooling.

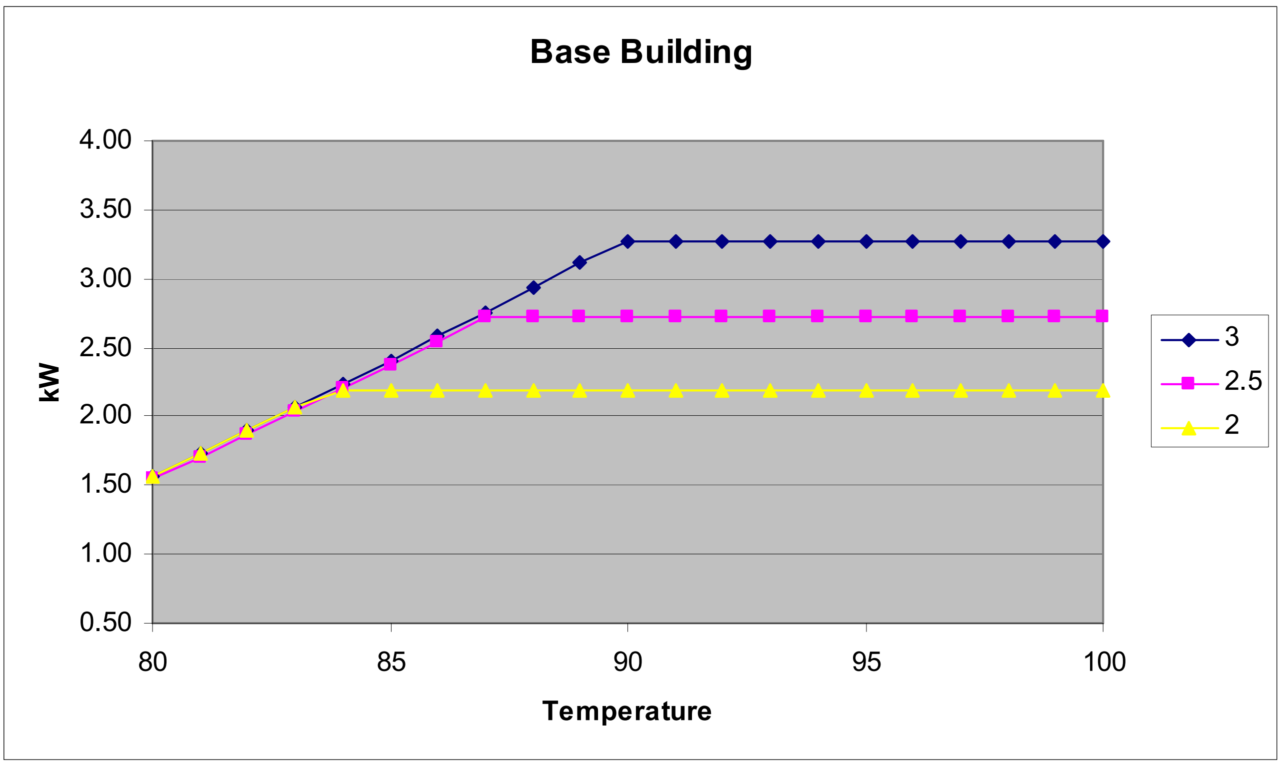
Defining the Term Oversizing: Throughout this paper, references are made to systems being oversized. The traditional meaning of oversized, and the one that is being referred to when statistics about technician practices are made, is *oversized relative to Manual J calculations at design temperature conditions*. Oversizing as defined by the industry does not mean that the system has sufficient capacity to meet all of the peak weather conditions.

When a system is oversized relative to any load, the unit cannot run continuously, but must cycle on and off, and/or modulate its output if it has variable speed capability. As the temperature rises and the building cooling load increases, the unit cycles less and less and the running time increases. At the point where the system capacity just meets the load, the system has a 100% running time with no cycling. If the load rises higher, the unit still runs at 100%, and the indoor temperature will begin to rise above the thermostat setpoint. At this temperature/load, the unit has insufficient capacity even if it is oversized according to Manual J.

The Relationship between Over and Under Capacity and AC Energy Efficiency Measures.

The oversizing and undersizing issue is further complicated by the fact that demand impacts are greatly affected by whether a system at peak, the AC has excess or insufficient capacity. Remember that a system that has excess capacity will cycle on and off during the period. We performed a series of simulations (see Wirtshafter 2007) using the base case home and system configuration found by RLW Analytics (2002). In our simulation, the building Manual J load suggests a unit sized at 2.11 tons. The mean AC unit size found in the RLW study is 3 tons or 43% oversized relative to the Manual J load. As Figure 3 illustrates as the temperature increases, the 3-ton unit run time, and energy consumption, increases as the unit cycles less and less during the time period. At some point, in our example at 90^{o}F, the unit reaches 100% run time and reaches maximum output and energy use. At temperatures above 90^{o}F, the system has insufficient capacity to meet the home's full load. As temperatures rise above the 90 ^{o}F point, the energy consumed by the AC system does not increase as the system is already operating at full capacity..

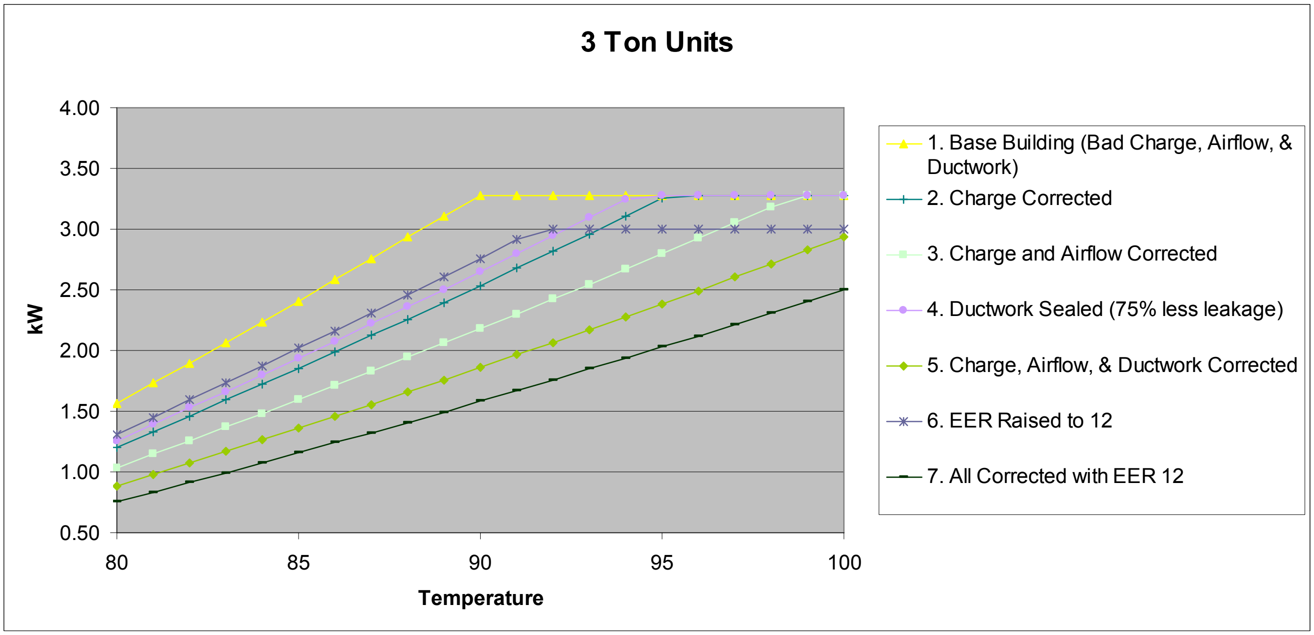
Figure 3: KW Demand for Base Case Conditions at Various Temperatures



In Figure 4 we add the profiles of the systems when improvements in charge/airflow and duct sealing are implemented. Figure 4 shows that fixing the charge/airflow and duct sealing measures makes the systems more efficient. However, fixing the charge alone still results in a system that has insufficient capacity to meet the full peak load. In other words, the system with corrected charge still uses the same amount of electricity on peak as the system without the corrected charge. (The indoor temperature of the home with the corrected charge level will be somewhat cooler than its counterpart with the uncorrected charge level).

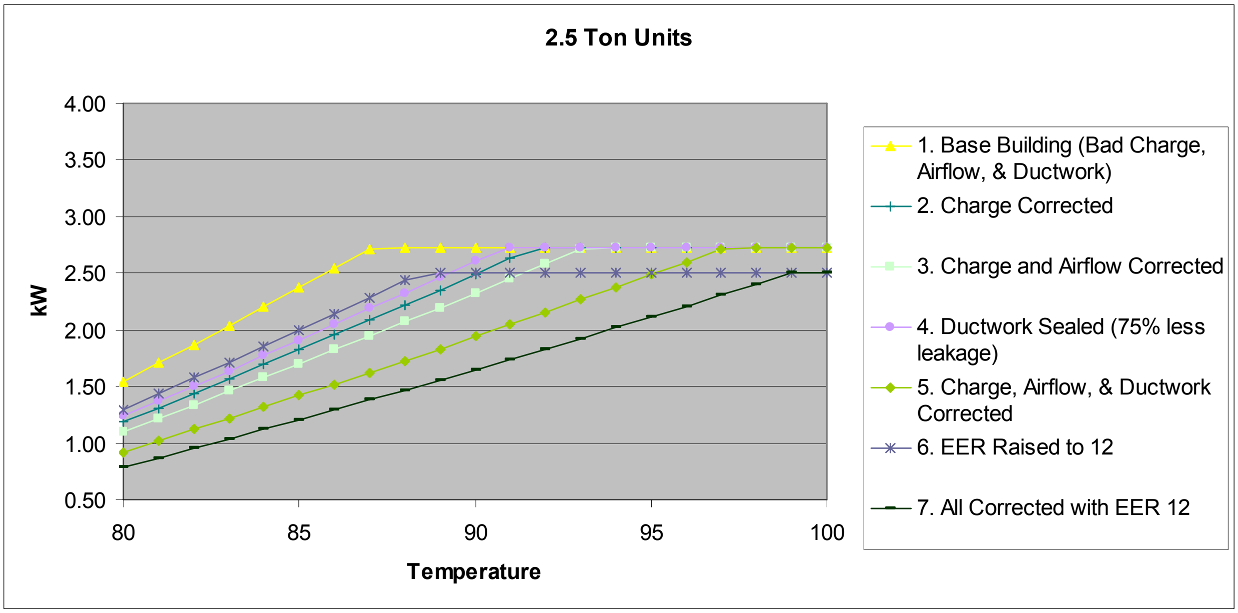
Figure shows that fixing the charge and airflow together does result in a small reduction in electricity used at the 95 ^{o}F peak conditions; about the same amount of savings as is achieved by increasing the system EER from 11 to 12 EER.

Figure 4: kW Effects of Efficiency Measures on a 3-Ton Unit



In Figure 5, we show the same measures plotted when the unit size is 2.5 tons. This represents a unit that is still sized 20% above the 2.1 ton Manual J level calculated size for the base home. As Figure 5 illustrates, for these smaller, but still oversized to Manual J, systems, the technician would need to fix the charge, airflow, and the duct leakage to produce any peak load savings. The major message of the example in Figures 4 and 5 is that the capacity of the system at peak conditions is the critical factor in whether the utilities should be paying incentives for measures taken to make the unit more efficient. If a system has insufficient capacity at peak conditions, then adjusting airflow and charge and fixing duct leaks will save energy but not reduce system demand. Even on systems that are more than 40% oversized above the Manual J level, fixing charge alone will not have any effect on system peak demand.

Figure 5: kW Effects of Efficiency Measures on a 2.5-Ton Unit



These simulations and additional on-site data collected as part of the CoolSmart evaluation suggest that while AC systems in Massachusetts are oversized to Manual J specifications, many if not most systems have insufficient capacity to meet peak demands given their current operating conditions. As the Table 1 reveals, the gap between design temperature and peak conditions is almost twice as large in Massachusetts as it is in Texas. Systems that are 30% or 40% oversized at Manual J are likely to have sufficient capacity to meet peak loads in Texas, but not as likely in Massachusetts. The simulation model shows that the 3-ton unit with the typical air flow and duct sealing found by RLW and placed in the RLW average sized home of 1,569 ft^2, has insufficient capacity to meet system peak load. If this unit has its charge and airflow corrected, then the unit has slightly more capacity than is needed at peak. The 2.5 ton system, one that is still almost 20% oversized will still have insufficient capacity at peak, even if charge, airflow and duct leakage are all corrected. Fixing these elements in the 2.5 ton system does not result in any peak savings for the utility.

What Measures Make the Most Sense in New England?

Table 3 presents data from the building simulations showing the relative savings realized by various measures which save energy and reduce peak demands of central AC systems. For each measure, the savings are for the difference between the baseline conditions of the 3-ton unit and the program supplied measures.

These results reveal that some measures included in CoolSmart save annual kWh but not much kW, while other are the opposite saving few kWh, but reducing peak kW significantly. For example, correcting refrigerant charge, when charge is more than 30% below recommended levels and no TXV is in place, will save 387 kWh for a 3-ton unit but will only reduce peak demand by 0.02 kW. Raising the EER in a 3-ton unit from 11 to 12 will only save 144 kWh, but will reduce peak demand by 0.27 kW. The biggest reductions in kW demand are realized by reducing the size of the AC system. A ½ ton reduction saves 0.55 kW and a 1 ton reduction saves 1.09 kW.

Table 3: Measure's Relative Impacts on kWh and kW Use for Baseline Home

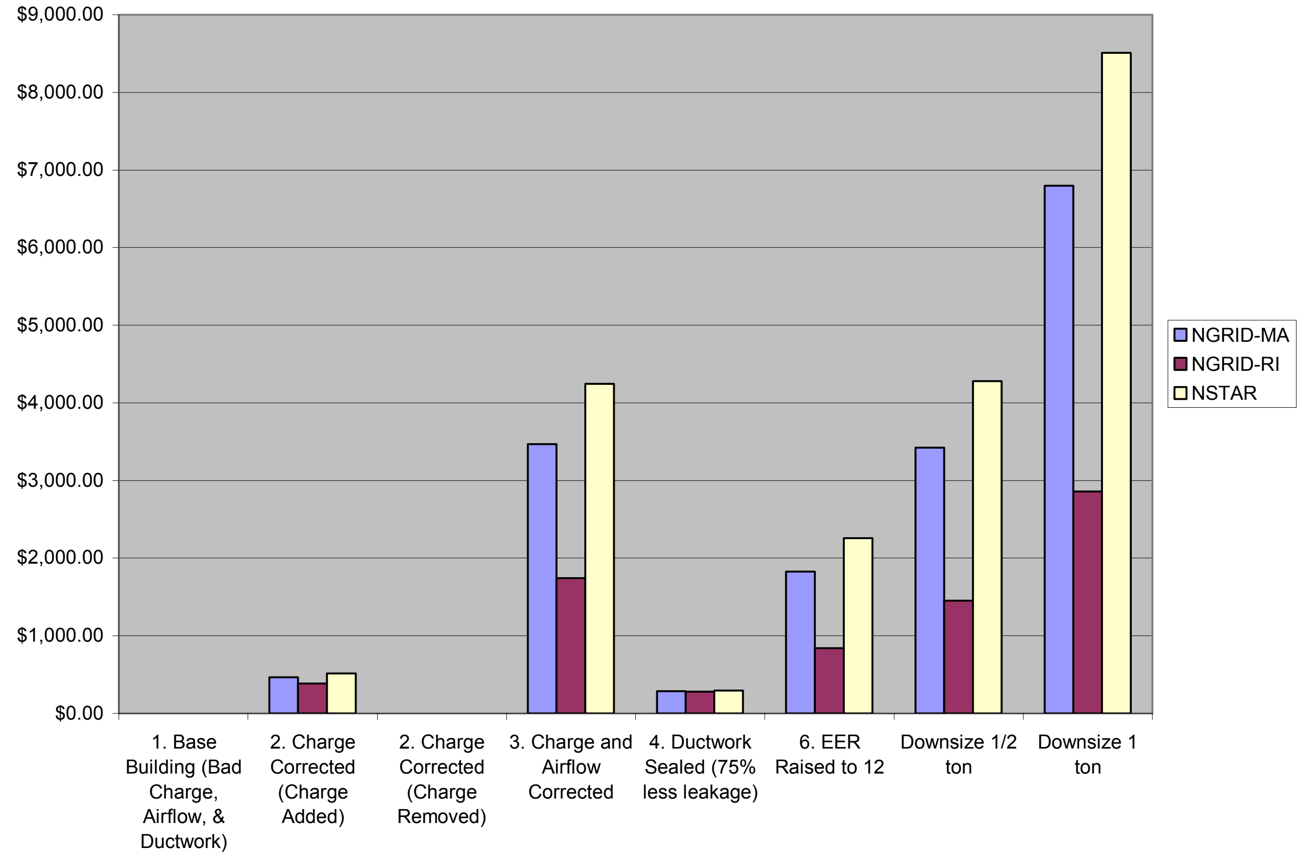
	3-ton AC Capacity		2.5-ton AC Capacity		2-ton AC Capacity	
	Annual kWh Saved	Peak kW Reduction	Annual kWh Saved	Peak kW Reduction	Annual kWh Saved	Peak kW Reduction
Base Building (11 EER & RLW-found Charge, Airflow & Ductwork Average Conditions)	0	0	25	0.55	-5	1.09
Charge Corrected (charge added}	387	0.02	411	0.55	389	1.09
Charge Added and Airflow Corrected	570	0.48	497	0.55	388	1.09
Ductwork Sealed (75% less leakage)	329	0.00	350	0.55	315	1.09
Charge added, Airflow and Ductwork Corrected	733	0.89	693	0.79	634	1.09
EER Raised to 12	144	0.27	160	0.77	132	1.27
All Corrected with 12 EER	804	1.25	767	1.16	711	1.27

Cooled square footage is 1,568 ft2,

As we noted, the sizing of the system makes a difference as to whether a particular measure produces peak savings or not. For example, the change charge and airflow measure saves 0.48 kW if the system is 3-tons but saves 0.0 kW if the system is smaller.

Figure 6 shows some of the individual measures converted into dollars of utility kWh and kW savings impacts. We use the Benefit Cost models of each utility to value the energy and peak demand. Again it should be noted that the various efficiency measure values are dependent on the unit sizing. While the change in charge and airflow measure will produce $4242 worth of benefits to NSTAR if the unit is 3-tons, the same measure on a 2.5 ton unit (not shown in graph) will only produce $448 of benefits.

Figure 6: Relative System Lifetime Value of Various AC Measures



Note: Values assume 18 year lifetimes, charge, airflow, and duct leakage measures which may last for fewer years would need to be periodically re-corrected to achieve these reductions.

Conclusions

Quality Installation Verification Programs cannot be justified unless the AC systems have excess capacity at system peak; a situation that only occurs in our simulations for systems that are more than 40% oversized according to Manual J. If systems have insufficient capacity at system peak, efficiency gains produced by air flow and refrigerant charge will not reduce peak demand.

Many of the homes included in the 2002 base line assessment and in on-sites performed in 2006 on homes receiving a high efficiency air conditioner had system sizes that had insufficient capacity to meet peak demands. One major reason why New England units may be more likely to have insufficient capacity at peak is that the gap between design and peak temperature is twice as large in New England as it is in Texas.

Because the number of run-hours for AC use is so small, basing programs on measures that save energy is difficult to justify in New England. On the other hand, utility programs in New England can justify giving substantial incentives if the measures produce peak demand reductions. Providing incentives that reduce the size of the unit is both easily justified and absolutely necessary if utilities want customer and their contractors to participate. The increasing trend of installation of air conditioning in milder climate will mean that other areas, similar to New England, will need to consider measures that reduce the summer peaks. If these areas have loads similar to New England, programs that encourage the installation of smaller and/or more efficient units will be the most cost-effective options available.

References

RLW Analytics, Inc. 2002; "Market Research for the Rhode Island, Massachusetts, and Connecticut Residential HVAC Market

Wirtshafter Associates, Inc, 2007; "2006 Massachusetts and Rhode Island CoolSmart Evaluation Report", Rydal, PA.