01.138

Prepared by:
Proctor Engineering Group, Ltd.
San Rafael, CA 94901
(415) 451-2480

System Optimization of Residential Ventilation, Space Conditioning and Thermal Distribution

Prepared for:
Air-Conditioning and Refrigeration Technology Institute

Final Report
October 2005

Contributors:
John Proctor, P.E.
Joe Pira

Creators of CheckMe!®

ARTI-21CR/611-30060-01

SYSTEM OPTIMIZATION OF RESIDENTIAL VENTILATION, SPACE CONDITIONING AND THERMAL DISTRIBUTION

Final Report

October 2005

John Proctor, P.E.; Joe Pira

PROCTOR ENGINEERING GROUP, LTD.
418 Mission Avenue, San Rafael, California 94901

Prepared for the
AIR-CONDITIONING AND REFRIGERATION TECHNOLOGY INSTITUTE
4100 N. Fairfax Drive, Suite 200, Arlington, Virginia 22203

DISCLAIMER

Funding for the 21CR program provided by (listed in order of support magnitude):
- U.S. Department of Energy (DOE Cooperative Agreement No. DE-FC05-99OR22674)
- Air-Conditioning & Refrigeration Institute (ARI)
- Copper Development Association (CDA)
- New York State Energy Research and Development Authority (NYSERDA)
- California Energy Commission (CEC)
- Refrigeration Service Engineers Society (RSES)
- Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI)

Available to the public from

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Available to U.S. Department of Energy and its contractors in paper from

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(423) 576-8401

ARTI-21CR/611-30060-01

SYSTEM OPTIMIZATION OF RESIDENTIAL VENTILATION, SPACE CONDITIONING AND THERMAL DISTRIBUTION

Final Report

October 2005

John Proctor, P.E.; Joe Pira

Prepared for the
AIR-CONDITIONING AND REFRIGERATION TECHNOLOGY INSTITUTE
Under ARTI 21CR Program Contract Number 611-30060

Acknowledgements

Proctor Engineering Group gratefully thanks Elizabeth Jones and Bill Freeborne at ARTI for their feedback and assistance with this project. We acknowledge the feedback and assistance of the ARTI project monitoring subgroup, consisting of John Andrews, Harvey Sachs, Esher Kweller, and Jeff Christian. In addition, we thank all participants in our presentations at ACEEE, EEBA, Affordable Comfort, and Comfortech. We are particularly thankful for Esher Kweller's persistence in following this project through to the end.

Prologue

Within the time frame of this research some of the concepts have undergone further development and implementation. Any reader interested in a particular concept should contact the firm involved with its development to obtain the latest information.

In addition DOE Report "Energy Consumption Characteristics of Commercial Building HVAC Systems - Volume III: Energy Savings Potential" estimates the energy savings potentials of more than 50 commercial HVAC technologies.
http://www.eere.energy.gov/buildings/info/documents/pdfs/ hvacvolume3finalreport.pdf

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This project focused on the discovery, documentation, analysis, and ranking of optimization concepts for residential space conditioning, ventilation, and distribution systems. The structure of the project was an iterative loop of discovery from all available sources. Each concept was analyzed for energy savings, peak reduction, and cost. The detailed discussion of each of the concepts is contained in Section IV.

These concepts and analyses were submitted to domain experts for discussion, feedback, and ranking.

A nine-point scale was produced for these criteria:

- Perceived cost
- First cost
- Operational/maintenance costs
- Expected reliability
- Thermal comfort
- Peak load reduction
- Health and safety impacts
- Acceptability
- Major changes required for market actors

The market actor comments were helpful in producing the overall concept ranking. These comments are contained in Appendix C of this report.

Market Actor Evaluations

The project evaluated many HVAC concepts that show considerable promise.

The top four rated concepts were associated with load reduction and loss mitigation. These concepts are relatively easy to implement from the market actor perspective. There are large gains possible from simply applying current technology correctly.

Load reduction strategies with high scores included:

- low solar heat gain windows,
- roofing with reduced heat gain characteristics,
- reduced infiltration with controlled ventilation,
- sealed insulated crawlspaces,
- advanced framing,
- exterior shading, and
- ducts in conditioned space

While reduced loads are not integral to the efficacy of most of the HVAC concepts, they make the integrated heating, cooling, dehumidification, and ventilation systems more viable by producing a more stable load. They also make improved aerodynamics and duct design easier since the airflows are lower.

Design and installation practices were considered important to the market actors. The top ten scores in the evaluation included:

- closer HVAC equipment sizing to loads,
- sealed ductwork,
- shorter duct runs with improved register placement lead the list of improved design/installation practices,
- expert system diagnostics,
- ensuring proper refrigerant charge and airflow,
- and integrated design to provide cooling, heating and airflow.

Mechanical systems with high scores included:

- ductless mini-split systems,
- integrated heating, cooling, dehumidification, and ventilation systems, ERV/HRVs coupled with reduced infiltration,
- frostless heat pumps,
- matched components to combined peak efficiency,
- evaporatively cooled condensers,
- improved aerodynamics (low watt draw per cfm) on both air handler/furnace and the outdoor AC unit,
- higher SEER, and

- combined space and water heating.

Conclusions

This project has convinced the investigators that the variety of interior and exterior weather conditions even at a single site calls for adaptability to obtain superior performance under the common conditions. Given the variety of building performance even when built by a single builder, the systems have to adapt to the situation presented by that building.

Adaptability calls for improved control systems, increased technician skill and "production" quality assurance. To the degree that the equipment is adjustable to the local situation, there needs to be verification that the adjustment has been properly applied before the technician leaves the site.

Favored Concepts

Given the increased emphasis on ventilation, we favor concepts that combine mechanical ventilation, dehumidification, and sensible cooling. Two such designs are described as Designs 7 and 8 in Section V. These designs use and air-to-air heat exchanger to precool the ventilation air (or combined ventilation and return air), bringing it closer to its dew point. The precooled ventilation air and return air enter an evaporator coil that (through manipulation of the return and ventilation air volumes) can provide variable latent capacity according to the need. The supply air leaving the evaporator coil is passed through the air-to-air heat exchanger then delivered to the house. These systems can supply either balanced or unbalanced airflow as appropriate.

Section VII is contains a list of market barriers and motivations based on interviews with market actors and their experience. These data on market forces indicate items that might improve or impede the adoption of these concepts.

I. INTRODUCTION

This project focused on the discovery, documentation, analysis, and ranking of optimization concepts for residential space conditioning, ventilation, and distribution systems.

As shown in Figure 1.1.1, the structure of the project was an iterative loop of discovery from sources including: literature and comments from experts in related disciplines as well as conference participant, and advisory committee offerings.

Following the concept discovery, each concept was analyzed and described so that it could be submitted to the next round of participants. At each presentation discussion and feedback were elicited and ranking surveys were administered to participants.

These concepts were discussed in increasing detail at the following conferences:

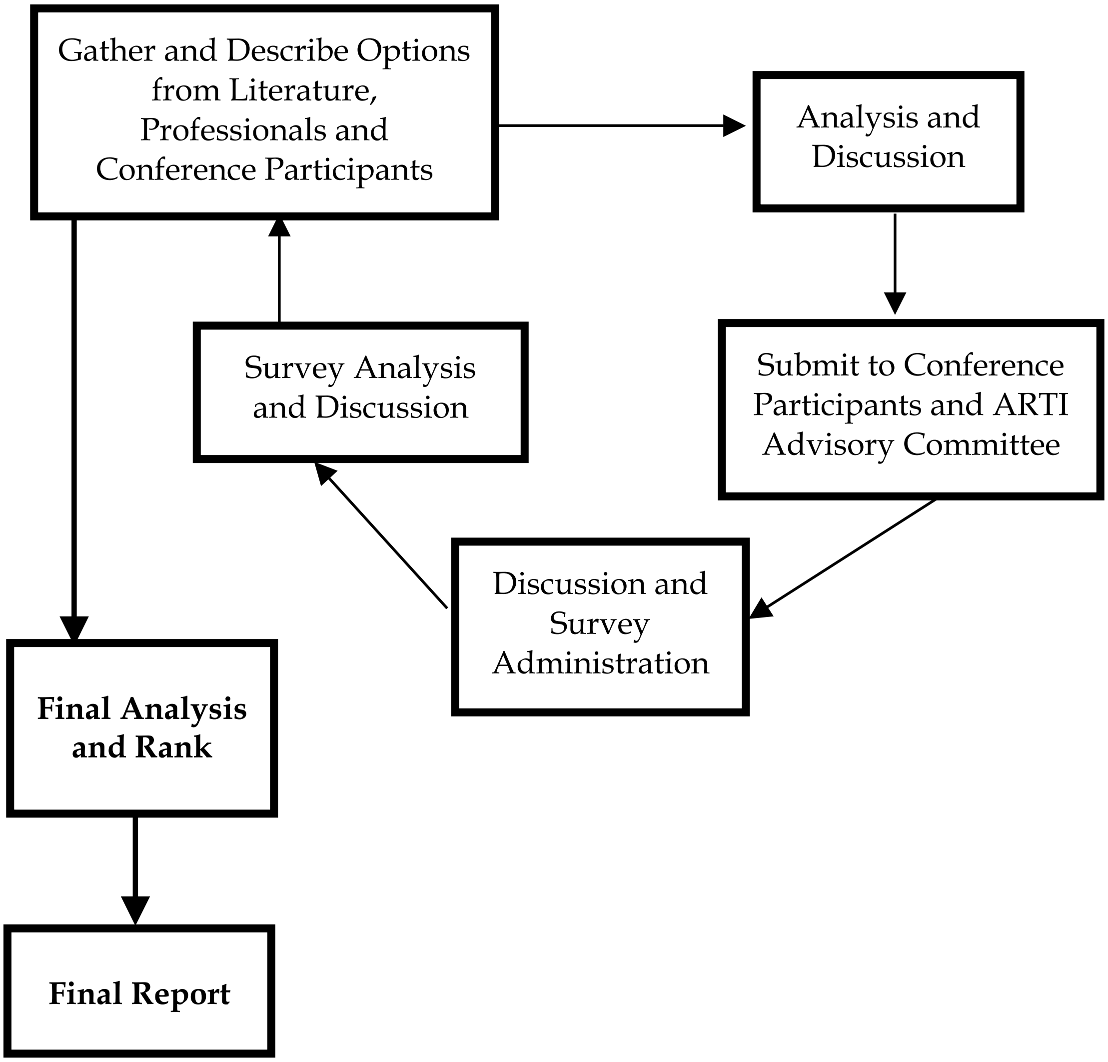
- Energy and Environmental Building
- American Society of Heating, Refrigeration, and Air-Conditioning Engineers
- Comfort Tech
- Air-Conditioning and Refrigeration Technology Institute (web conference)
- American Council for an Energy Efficient Economy
- Affordable Comfort

These conferences elicited comments and evaluations from: Builders, Architects, HVAC Contractors – Distributors and Manufacturers, Building Scientists and Researchers, as well as Homeowners.

The final results of the project include the analysis of each concept contained in Chapter 4, an analysis of alternative designs applicable to combined cooling and ventilation, particularly in moist hot climates in Chapter 5, the overall rankings from the participants and the authors contained in Chapter 6, as well as an analysis of market barriers applicable to implementation of optimized HVAC designs in Chapter 7.

This report will be posted at www.proctoring.com for additional comments, discussions, and updates.

Figure 1.1.1. Project Structure



II. METHODOLOGY

2.1 Concept Ranking

Based on interviews and interactions with the program committee the evaluation criteria in Table 2.1.1 were chosen to rank the concepts discussed in this report.

Table 2.1.1. Evaluation Criteria for Concept Ranking

Criteria	**Description**
Perceived cost	Market-actor rankings on cost of implementation
First cost	Estimate of first cost
Operational/maintenance costs	Estimate of operating costs based on power and maintenance requirements
Expected reliability	Based on component reliability
Thermal comfort	Pull-down rate, temperature swings, humidity level, etc.
Peak load reduction	Effect on utility peak draw
Health and safety impacts	Effect on indoor air quality and building shell/mold growth
Acceptability	Ranking based on market actor's input
Major changes required for market actors	Analysis of departures from common practice

A one to nine scale was produced for each of these criteria with a score of one being the worst and nine being the best. The scale for each criterion is displayed in Table 2.1.2.

In combination with the market actor surveys described below, the team produced the concept rankings contained in Section VI.

Table 2.1.2. Concept Ranking System

Score	Perceived overall cost	First cost	Operational/ Maintenance cost	Expected reliability	Thermal comfort	Peak load reduction	Health and safety impacts	Perceived acceptability	Major changes required for market actors
1	Cost too high	More than 2X increase in first cost	More than 20% increase in operational/ maintenance cost	Unreliable	Less thermal comfort	Peak load increase by >20%	Potential negative health and safety impacts	Impossible	Major changes required for more than 3 market actors
2									
3									
4									
5		Same first cost	Same operational/ maintenance cost	Same reliability	Same thermal comfort	Same peak load	No change in health or safety impacts		No major changes required
6									
7									
8									
9	Low cost	Less than half the cost	More than 20% decrease in operational/ maintenance cost	Much improved reliability	Thermal comfort greatly improved	> 20% reduction from standard methods	May increase health and safety of home	Easy	Greatly simplifies market actors' duties

2.2 Presentations to Market Actors and Surveys

Throughout the development of the concepts in this report a series of discussions were held and presentations were made to market actors at conferences. These presentations were interactive discussions of the concepts to refine their definitions and evaluations. The market actors involved were architects, builders, HVAC contractors, HVAC distributors, HVAC manufacturers, building scientists/researchers, and homeowners.

The criteria in Table 2.1.1 were simplified into the survey in Appendix A. In the simplified form the survey consisted of six pages with rankings for cost and market acceptability. These rankings were on a five-point scale and are translated into the nine-point scale used in the concept ranking.

2.3 Barriers Assessment.

Proctor Engineering Group compiled a list of market barriers based on interviews with market actors and their experience within the HVAC industry. The purpose of the market barriers assessment was to gather data on market forces that might improve or impede the adoption of an integration concept.

III. TECHNOLOGY OVERVIEW

3.1 Concept list

There are abundant methods to improve HVAC systems. Many of them are enhanced by or enabled by other changes to the house (including thermal boundary, pressure boundary, direct heat gain reductions or gains, etc.) Some methods have been applied on a limited basis to a few homes. Other methods are used on commercial buildings where the size of the load is sufficient to justify higher cost solutions.

Table 3.1.1. Residential HVAC Optimization Concepts

1. Sizing and Matching Closer AC sizing to load Closer distribution system sizing to room and equipment demands Matching each component to work at peak efficiency with the other components **2. Controls** Anticipatory thermostats Controls that closely match run parameters to efficiency characteristics **3. Obtaining and Maintaining Designed Operation** Ensuring proper refrigerant charge Ensuring adequate evaporator airflow Expert system diagnostics **4. Load Reduction** Windows Advanced framing Roof and attic characteristics Exterior shading (e.g. Roof overhangs) Reduced infiltration with controlled ventilation Reduced infiltration with ERV/HRV **5. AC Component Improvements** Compressors Refrigerant metering devices Frostless heat pump ACs designed for climate region Evaporatively cooled condensers Improved aerodynamic outdoor AC/HP units	**6. Distribution System Improvements** Improved fan motors Evaporator fans, housings, and cabinets Sealed ductwork Ducts in conditioned space Sealed crawlspace Register placement/short duct design Small-duct, high-velocity systems **7. Integrated Appliances** Heat pump domestic water heaters Desuperheaters Combination space conditioning and water heating Integrated AC and furnace design Integrated heating, cooling, dehumidification, and ventilation **8. Alternative Approaches to Providing HVAC Functions** Ductless mini-split systems Residential chillers Dedicated dehumidification system Dedicated ventilation system

3.2. Concept Summaries

The following sub-sections have summaries of the concepts. More detailed descriptions are located in the sub-sections called out at the beginning of each summary (e.g. Details in Section X.x).

3.2.1. Sizing and matching

The purpose of sizing system components is to obtain the optimum intersection of efficiency and cost.

Details in Section 4.1.

Table 3.2.1. Sizing and matching concepts

Closer sizing to load	Providing equipment sized to meet provide adequate cooling and heating produces more efficient systems at a lower initial cost.
Closer distribution system sizing to room demand and equipment capabilities	Distribution of heating and cooling proportional to the demands of individual rooms improves occupant comfort. Designs take into account the interactions between the air handler capabilities and the duct system design.
Matching each component to work at peak combined efficiency with the other components	Components have efficiency “curves” when matched appropriately produce designs with superior efficiency.

<u>Sizing to loads</u>

The results of oversizing are increased energy consumption, increased electrical peak, and in some cases insufficient dehumidification. Contractors use oversizing of air conditioners as an “insurance policy” in order to reduce the callbacks. The tools provided by the Air Conditioning Contractors of America (ACCA Manuals J and S) specify air conditioners of adequate size to provide customer comfort in all weather conditions.

<u>Sizing to room loads and equipment capability</u>

Distribution systems are often designed poorly, having high resistance to airflow that the air handler fan/motor combination cannot overcome. The results are low airflow through the heater/cooler as well as hot and cold rooms. ACCA Manual D covers one set of procedures that can be followed for proper design of a duct system. Other changes in the distribution system such as shorter duct runs as well as better placement and selection of terminals, are advantageous. Efficiency of an air conditioner increase with increased airflow, however these improvements are severely limited by the large increases in power consumption by the fans at high flows.

Component matching

Manufacturers design their systems to least cost for a given level of reliability, durability, performance, and customer demand. This design process involves tradeoffs between many components to find an apparent optimum design. When the performance metric is narrowly defined or does not capture an important aspect, the results may not be optimized from that perspective (such as installed performance). The performance gaps are more likely when multiple pieces of equipment are selected and assembled by a contractor.

3.2.2. Controls

Controls can provide a means of optimizing the response "efficiency" of any unit that has multiple potential run modes.

Details in Section 4.2.

Table 3.2.2. Controls

Anticipatory Thermostats	These thermostats can be used to take advantage of a homes thermal mass to reduce overall energy usage.
Controls that closely match run parameters to efficiency characteristics	Advanced control systems can respond to varying loads and conditions more efficiently.

Anticipatory thermostats

Since buildings have mass that becomes charged with heat (of lack thereof) and insulation that slows down the flow of heat, there is a substantial time delay in most heat gain/heat loss mechanisms. Advanced thermostats can respond to both indoor and outdoor temperatures or other inputs from external sources or information gained locally over time.

Matching run parameters to efficiency characteristics

A single element of the HVAC system seldom has a constant efficiency. Controls have the potential to optimize the system to the current conditions. One example of this technology is the control of an Electrically Commutated Motor to various duct systems, and to varying levels of humidity. Implementing a variable controller with a performance map can increase the multi point performance of HVAC systems.

3.2.3. Obtaining and maintaining designed operation

Obtaining and maintaining designed operation/efficiency of an HVAC system can be accomplished by installing and maintaining the equipment within the manufacturers' specified criteria. Ensuring the performance of units in the field is difficult.

Details in Section 4.3.

Table 3.2.3. Control and operation optimization methods

Ensuring proper refrigerant charge	Installing proper refrigerant charge produces air conditioners that perform as designed.
Ensuring adequate evaporator airflow	Evaporator airflow can be controlled and maintained to provide proper performance.
Expert system diagnostics	Expert system diagnostics can accurately determine performance and insure proper HVAC function.

<u>Proper refrigerant charge</u>

A common error in the installation of split-system equipment is neglecting the additional refrigerant required by the installed line set. Refrigerant mischarge continues through the life of the air conditioner, being altered by technician adjustments and leaks. This issue on new and existing equipment can be addressed by: third party verification, verification by statistical analysis, mitigation through machine design, or devices to detect and report refrigerant charge errors.

<u>Indoor coil airflow</u>

Startup technicians do not regularly check for sufficient airflow and the causes of low airflow are often history by the time of startup. Reductions in airflow reduce sensible and total capacity, but they increase latent capacity and reduce the fan watt draw. In some cases struggling to achieve higher indoor coil airflow for cooling may be counterproductive. Indoor coil airflow can be addressed by: distribution system design, third party verification, verification by statistical analysis, machine design to higher static pressures, or devices to detect airflow problems and signal the need for correction.

<u>Expert System Diagnostics</u>

Expert system diagnostics use computer technology to accurately determine performance and/or identify faults in HVAC systems. Information may be fed into the expert system through sensors, through human inputs, or a combination of the two. To be effective, the expert system must not only provide a proper diagnosis, but also bring about proper system function.

3.2.4. Load Reduction

Load reductions can make the systems smaller, more compatible for multiple functions (such as cooling and ventilation) and easier to obtain optimized interactions (such as between ductwork sizing and air conditioner sizing).

Details in Section 4.4.

Table 3.2.4. Load reduction methods

Windows	Windows with low-e coatings are effective at reducing solar direct gain load.
Advanced framing	Advanced framing techniques provide better insulation while reducing the wood required.
Roof and attic characteristics	Radiant barriers, roofing materials, roof color, and sealed attics reduce solar load during peak cooling hours.
Exterior shading	Shading through overhangs, awnings, and trees reduce solar loads.
Reduced infiltration with controlled ventilation	Houses built with less air leakage can control the ventilation thus controlling heating cooling and dehumidification loads.
Reduced infiltration with ERV/HRV	ERVs/HRVs extract energy from ventilation exhaust reducing heating/cooling loads.

Windows

Heat losses and gains through windows account for one quarter of all the energy used for heating and cooling. New tighter window designs with combinations of low emittance coatings minimize conduction, infiltration and radiative energy transfer. The reduction in heat load at peak conditions can be as much as 1 ton of cooling in a house with 3.5 tons of load.

Advanced framing

Advanced framing reduces lumber use, scrap and labor while improving the thermal envelope. This increases the effective insulation levels of buildings. Some of the components of advanced framing are: two foot increments in design, aligning the trusses with the load bearing studs with the floor joists, a single top plate (the loads are now aligned), metal band bracing that allows for exterior insulation), planning for the HVAC system and its ductwork, as well as detailed framing plans on-site.

Roof and attic characteristics

The roof color and material, radiant barrier, as well as attic ventilation have significant affect on the attic heat flux and temperature. In particular, white roofing systems exhibit excellent thermal performance with over 60% reductions in attic heat flux. Colored pigments that have characteristics similar to white are now available. Radiant barriers decrease attic heat flux by adding a layer of aluminum foil in the airspace between the roof surface and the attic insulation. Unvented sealed attics with insulation at the roof level have also been used in some climates to reduce attic temperatures and recapture the cooling lost by leaky ducts.

Exterior shading

Awnings, extended roof overhangs, and solar shade screens all reduce the direct solar gain through windows. Cooling cost reductions of between 10% and 28% have been demonstrated from external shading alone.

Reduced infiltration with controlled ventilation

"Build it tight and ventilate it right."(Nisson and Dutt 1985) With such construction, the ventilation air can be controlled and always supplied in the proper quantity. The science and practice of building a reasonably tight building envelope is relatively well known. There are various methods of supplying ventilation: supply only, exhaust only, and balanced flows. The two "unbalanced" systems result in a pressurization or depressurization of the building, which can be detrimental in certain climates.

Reduced infiltration with ERV/HRV

HRVs and ERVs are air-to-air heat exchangers that transfer energy from the house exhaust stream to the incoming ventilation stream. HRVs and ERVs provide annual heating and cooling savings relative to any other system that supplies the same amount of ventilation. The savings potential is dependent on the amount of heating/cooling load that is attributable to ventilation.

3.2.5. AC/HP Improvements

Details in Section 4.5.

Table 3.2.5. AC/HP improvement methods

Compressors	Compressor efficiency can be increased through motor or compressor detail improvements. System efficiency can be increased with smaller or multiple speed compressors.
Refrigerant metering devices	Metering devices able to control to a very small superheat without risking compressor failure improve system efficiency.
Frostless heat pumps	This technology reduces frost formation and the energy used for defrosting the outside coil.
AC optimization for climate region	ACs designed to a specific climate region can achieve better performance.
Evaporatively cooled condensers	In hot dry climates, evaporative cooling at the condenser coil enables the air conditioner to maintain efficiency at higher outdoor temperatures.
Improved aerodynamic outdoor section	Outdoor fan design that address more aerodynamic inlet, outlet, and more complex blade shapes can improve airflow and reduce watt draw.

Compressors

Smaller compressors with "larger" heat exchangers have higher efficiency. This is accomplished in units with large coils and also in variable speed units that reduce the compressor capacity to improve efficiency at part load. The efficiency of the compression cycle can be improved through close attention to flow passages and other design revisions. Under some conditions for example, scroll compressors can be more efficient than their reciprocating counterparts. Under other conditions scroll compressors over compress the refrigerant. Finally there are a number of higher efficiency motors that could be used in residential size compressors.

Refrigerant metering devices

The highest efficiencies occur when the entire evaporator coil has refrigerant changing phase. This occurs when superheat is at or near zero. An electronic expansion valve (EEV) has the potential of controlling superheat more accurately than a thermostatic expansion valve (TXV). With an EEV the superheat could be reduced providing an increase in capacity and efficiency.

Frostless heat pump

Heat pumps periodically run through a defrosting cycle to keep the outdoor coil free of obstruction. The system reverses the refrigerant flow, heating the outdoor coil and cooling the indoor coil. In order to maintain comfort electric resistance heat is added to the indoor air stream. The frostless heat pump adds electric resistance heat to the accumulator to raise the condenser temperature slightly under conditions of high frost accumulation and to defrost when necessary.

ACs designed for climate regions

Sensible and latent loads vary from climate to climate. A potential method of AC optimization is to design region-specific air conditioners that are optimized for local conditions. Specific designs could produce the higher sensible heat ratios needed in the West and could produce high latent ratio machines needed for cost effective application in Eastern wet climates.

Evaporatively cooled condensers

Evaporative condensers use evaporation to lower the outdoor heat sink temperature. Evaporative condensers have the advantage of a near constant EER at a wide range of outdoor temperatures in dry climates. The application of this technology to residences is dependent on water quality or on a design that mitigates scaling or corrosion.

Improved aerodynamic outdoor AC/HP units

Improved condenser fan blade technology combined with better fan entrance and discharge conditions can reduce the fan motor watt draw. Units have been tested that reduce fan watt draw by 25% with a standard PSC motor.

3.2.6. Distribution Systems

Sixty-three percent of housing in the U.S. utilizes forced-air distribution systems. The design and layout of these systems has a great effect on the comfort level of the home, as well as the energy efficiency of the system. Non-energy effects include pressure changes in the structure. These pressure imbalances can cause side effects such as backdrafting or moisture migration within the structure.

The air handler with its cabinet, fan, motor and heat exchangers is another part of the air distribution system. There is potential to increase the aerodynamic efficiencies of common residential furnace air handlers.

Details in Section 4.6.

Table 3.2.6. Distribution system optimization options

Improved fan motors	Alternative higher efficiency motors are available and in development to reduce watt draw.
Evaporator fans, housings, and cabinets	Higher efficiency designs can reduce the watt draw associated with a given flow. Such a change would shift the point of optimization.
Sealed ductwork	Sealing leaky ductwork can typically save between 15 to 25% on heating/cooling costs.
Ducts in conditioned space	By installing ductwork in the conditioned space, duct leakage is captured within the envelope of the building.
Sealed crawlspaces	In homes with HVAC systems in the crawlspace, sealing and insulating the crawlspace reduces moisture problems while surrounding the ductwork by a conditioned space.
Register placement/short duct design	In energy efficient homes with tight envelopes, the ductwork can be redesigned to provide conditioned air delivery from high on interior walls. Duct length, and therefore duct losses, can be significantly reduced.
Small-duct, high-velocity systems	These systems can be installed in homes with minimal space to install ducts. SDHV systems benefit from decreased conductive losses at a cost of increased blower power.

Improved fan motors

Standard condenser and evaporator fan motors are PSC (permanent split capacitor) motors. Their efficiency varies between 50% and 70%. Efficiencies, above 80%, are possible with brushless permanent magnet motors (BPM). There are a number of newer motors on the market or in development intended to compete with the ECM motor, including PSC motors that offer true variable speed capability at lower cost.

Evaporator fans, housings and cabinets

The combined fan/motor efficiency of the indoor blower is a primary limiting factor in unit efficiency. In order to deliver proper airflow under all of the reasonable installation and operating conditions, various compromises to efficiency are necessary. Indoor blower design has recently been the subject of innovation. General Electric built and tested a backwards-curved centrifugal blower with a smaller ECM motor. Trane Corporation is producing an air handler with a molded plastic fan housing capable of higher delivery efficiency within small air handler cabinets.

Sealed ductwork

Duct losses are a major source of inefficiency in residential HVAC systems. The main contributors to duct losses are direct losses through leaks and conductive losses through duct surfaces. Multiple products address the duct leakage issue. These include: hand applied duct sealants, aerosol sealants sprayed into the ducts, as well as reduced leakage joint and fitting designs.

Ducts in conditioned space

An effective method of "recapturing" the energy lost from ducts is to install the ductwork in the space it is conditioning. The appearance of ductwork in living spaces is undesirable, so methods have been employed to conceal the ductwork. These include concealing the ductwork in dropped ceiling cavities or raised sections, with insulation on the outside of the cavities. When these methods are employed it is imperative that these sections remain isolated from unconditioned spaces by thermal and air boundaries.

Sealed crawlspaces

Studies have indicated that sealing and insulating the crawlspace can result in a large savings in energy without causing any moisture problems in the crawlspace. This concept is receiving improved acceptance by building departments. As with the sealed attic there are additional savings from a sealed crawlspace if the duct system runs through the crawlspace.

Register placement/short duct design

A promising method of integrated house and HVAC design is to improve the thermal envelope, including using high-efficiency windows, such that the register outlets can be moved from the typical perimeter locations to locations high on the inside wall. Thus the thermal distribution efficiency of the forced-air system is improved—and at a reduced cost.

Small-duct, high-velocity systems

Small duct, high velocity (SDHV) systems produce at least 1.2 IWC of external static pressure at 220-350 CFM per ton and use room outlets with velocities generally greater than 1000 fpm. These systems are ideal for retrofit applications in older buildings and like other high velocity outlets produce better mixing and less temperature stratification.

3.2.7. Integrated Appliances

Details in Section 4.7.

Table 3.2.7. Integrated appliances

Heat pump water heaters	Heat pump water heaters use the refrigeration cycle to remove heat from one medium and reject it to the domestic water. The cooling function can be usefully integrated with dehumidification and can capture heat from the house exhaust air in the winter.
Desuperheaters	Desuperheaters extract excess heat from an air conditioning cycle to heat water.
Combination space conditioning and water heating	Combining a conventional water heater with a hydronic heating coil eliminates the need for a separate furnace or boiler.
Integrated AC and furnace design	Designing a combined appliance with the air conditioner evaporator coil integral with a gas furnace provides additional design options that may improve efficiencies.
Integrated heating, cooling, dehumidification, and ventilation	The most common form of heating and cooling, all ventilation, and virtually all dehumidification utilize forced air movement. This makes integrating these tasks potentially positive

<u>Heat pump water heaters</u>

Electrically heated domestic water is used on 38% of US households. Heat pump water heaters have improved efficiency over conventional electric resistance units. These water heaters remove heat from a source such as: house air, outside air, ventilation air, or exhaust air and reject heat into the domestic hot water. These water heaters can be usefully integrated with balanced ventilation system cooling and dehumidifying incoming air in the summer and capturing some of the heat from exhaust air in the winter.

<u>Desuperheaters</u>

A desuperheater can remove waste heat from the hot refrigerant discharged from the compressor to the condenser coil. Domestic water is circulated through a heat exchanger on the hot gas line capturing waste heat in the summer. To protect from freezing the water in the winter, the hot refrigerant line must run from the outdoor unit to indoors.

<u>Combination space conditioning and water heating</u>

Dual integrated appliances are water heaters that provide domestic hot water. The domestic hot water is used directly within the home and also pumped to a water to air heat exchanger in the air handler. In areas with low heating demand, this design will have lower first costs than two stand-alone units, but they do not produce the efficiency available from a high efficiency furnace combined with a high efficiency water heater.

Integrated AC and furnace design

In a gas-pack (package air conditioner with gas heating and electric cooling) the furnace heat exchanger, evaporator coil, and inside section are designed together. For split air conditioners however the furnaces are designed to stand alone, yet provide sufficient airflow to a wide variety of evaporator coils (or none at all). Furnace heat exchangers have to be integrated with the furnace airflow to ensure that proper heat transfer occurs and there are no hot spots. Evaporator coils' effectiveness are very dependent on both the airflow and the airflow distribution across various sections of the coil. If the furnaces were designed with an integrated air conditioner evaporator coil, then the design would have the possibility of providing optimized airflow distribution through the coil as well as avoiding hot spots on the furnace heat exchanger. This concept integrates coil design with furnace design. This concept is limited by the practicality of covering the variety of heating and cooling capacity combinations.

Integrated heating, cooling, dehumidification, and ventilation

The most common form of heating and cooling, all ventilation, and virtually all dehumidification utilize forced air. This makes integration attractive. One of the more promising designs utilizes an air-to-air heat exchanger in conjunction with a standard air conditioner to provide higher levels of dehumidification than are available from the air conditioner alone. Section V investigates integrating ventilation with cooling and dehumidification in moist climates.

3.2.8. Alternative Systems

Traditionally heating homes grew from providing heat in one location (fireplace, woodstove, stand alone heater, floor furnace) to central heating with air ducts, steam or water pipes. Heating or cooling a single location had the advantage of saving energy by not conditioning the entire home.

Alternative approaches to heating and cooling include heating and cooling a local area or providing each HVAC function with stand-alone equipment.

Combining a variety of functions within an HVAC system increases its complexity. The inverse tactic would be to split the tasks into separate units. This concept is sometimes applied to commercial systems where savings in operating costs can quickly make up for initial investments. As costs of newer technology decrease, applications in residential environments may become more prevalent.

Details in Section 4.8.

Table 3.2.8. Alternative systems

Ductless mini-split systems	Ductless minisplits eliminate losses associated with ductwork and provide zoning control.
Residential chillers	Chillers, while common in the commercial marketplace, may be scaled to residential applications. Hydronic cooling distribution would reduce distribution losses.
Dedicated dehumidification	Dedicated dehumidification systems separate latent cooling from sensible cooling and may provide better indoor air quality than combined systems.
Dedicated ventilation system	A dedicated ventilation system can be easily controlled and could include a ventilation cooling coil for sensible or latent heat removal.

Ductless mini-splits

One way to eliminate duct losses is to eliminate ducts. Mini-split system air conditioners have evaporator/air handler units within each conditioned space. Multi-evaporator systems run the refrigerant from one outdoor unit to several indoor units. Benefits of these systems include inherent zoning capability (cooling or heating only the area that needs to be conditioned), greatly reduced airside losses, and quiet operation.

Residential chillers

A scaled-down chiller can be used to cool homes. A hydronic distribution system circulates chilled water to fan coils that provide cool air each conditioned space. These systems can be easily zoned. Duct losses are reduced or eliminated with these systems.

Dedicated dehumidification systems

A properly sized stand-alone dehumidifier can provide excellent latent capacity, but it adds to the sensible load and can be noisy. The more sophisticated units have an internal air-to-air heat exchanger, provide quieter operation, and are more efficient at moisture removal.

Dedicated ventilation systems

A dedicated ventilation system can be easily controlled to provide precisely the amount of ventilation needed, when it is needed. One commercial concept is "dual-path" ventilation, in which a separate refrigeration coil is used to condition ventilation air before it is mixed with conditioned air from inside the building. This moves the majority of latent load from the return coil to the ventilation coil, simplifying humidity control.

IV. DETAILED DESCRIPTIONS OF OPTIMIZATION CONCEPTS

This chapter details the evaluated optimization methods. Figures and illustrations are included for clarity; references are in the subsections of this chapter.

4.1 Sizing and Matching

<u>Purpose</u>

The purpose of sizing system components is to obtain the optimum intersection of efficiency and cost. The theory is well known, but the barriers are many. In theory, sizing the air conditioner to just meet the loads of a home at design conditions will provide the most cost effective means of providing a nearly constant level of comfort. Providing an air distribution system that distributes the conditioned air to each room according to its load will provide uniform comfort throughout the structure, and if it is properly designed will integrate perfectly with the air handler to reduce the energy consumption for circulating the air. Matching the various components of the system: coils, compressor, refrigerant lines, cabinet, fan, motor, furnace heat exchanger, etc. will provide the optimum in comfort and low operating costs.

The theory runs headlong into the realities of the marketplace. Each component is likely to be mated with another component somewhat unlike the optimum design, and thus must be designed to perform adequately in a wide array of sub-optimum configurations.

4.1.1 Closer AC sizing to load

Air conditioners are often chosen without due regard for their actual capacity compared to the design load of the building. As a result the units often have excess sensible capacity compared to the cooling loads. There are many negative impacts from this situation. First, the cost of the system is higher. Second, there are negative impacts on energy usage and peak draw[1]. On a large scale these impacts increase the cost of maintaining sufficient resources to handle peak summer loads. Third, interior humidity conditions are compromised because the unit operates in shorter cycles, reducing dehumidification[2].

Figure 4.1.1 displays the results of a study of new homes' AC sizes compared to the Manual J (V.7) load estimate. This study agrees with others conducted in different regions around the country, Air conditioners are, on average, oversized compared to Manual J.

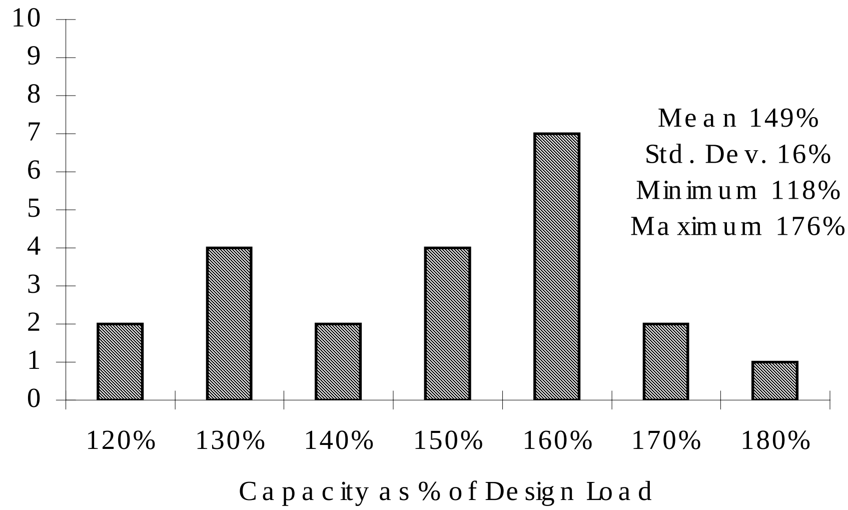


Figure 4.1.1. Installed AC Capacity as a Percent of Design Load

In addition, Manual J Version 7 has been shown to overestimate sensible cooling loads (Proctor 1997). The combination of AC selection larger than Manual J estimated loads and Manual J estimated sensible loads larger than actual sensible design loads can result in extreme oversizing.

The results of oversizing are increased electrical peak and, in some cases, insufficient dehumidification and increased energy consumption. Using a combined thermostat, air conditioner, and building simulation model, one study estimated that an AC system oversized by 50% would use 9% more energy than a properly sized system (Henderson 1992). A regression model based on data from 308 of the Florida field test of 368 homes estimated energy penalties of 3.7% and 9.3% respectively for units 20% and 50% oversized. In addition, homes with systems greater than 120% of Manual J averaged 13% greater peak cooling electrical load than homes without oversized systems (James et al. 1997). A study

1 Because of thermostat adjustments, there are a significant number of air conditioners that run continuously on peak regardless of their size. (Peterson and Proctor 1998)

2 At the beginning of an air conditioning cycle moisture evaporates off the coil and from the drip pan adding moisture to the air. The amount of dehumidification increases as the cycle progresses.

using DOE 2.1A estimated a cooling energy savings of 14% from downsizing from 56% oversized to 28% oversized (McLain et al. 1985 from Neal & O'Neal 1994). With the exception of the Florida field test, the estimates are based on models that were developed from a limited number of laboratory or field tests.

The energy consumption is dependent on the interactive behavior between the thermostat, the heat gain of the house, the delivered capacities and efficiencies[3] of the air conditioner, as well as the heat storage and transfer between the building interior and the air within the building.

<u>Delivered capacity vs. duty cycle</u>

There are significant variations in delivered capacity that are not correlated with the Run Time Fraction (aka Duty Cycle). Some of these variations are due to conditions entering the evaporator and condenser coils.

In order to better understand the relationships between the on-time of the air conditioner, its instantaneous sensible capacity and its cycle average sensible capacity, the authors recorded the average sensible capacity and the end of cycle instantaneous sensible capacity for each cycle of five air conditioners for one summer in Phoenix, Arizona. Each datum (instantaneous and average) comes from the same unit with identical condenser and evaporator entering conditions, resulting in less data "noise".

Figure 4.1.2 shows the relationship between the end-of-cycle sensible capacity (normalized to the average sensible capacity for that run) and Run Time Fraction. The relationship is generally as expected with the instantaneous capacity at the end of the cycle greater than the average capacity. Units 5 and 26 do not have a discernable dependence on the run time fraction. Unit 5 was in a home with two units and was used alternately with Unit 6. For Units 6, 23, 24, and 25, the results followed the expected patterns. That is, the end of cycle capacity for shorter cycles was substantially higher than the average capacity during that cycle. When the cycle is long, the average capacity and end of cycle capacity both approach steady state capacity.

3 Sensible and Latent

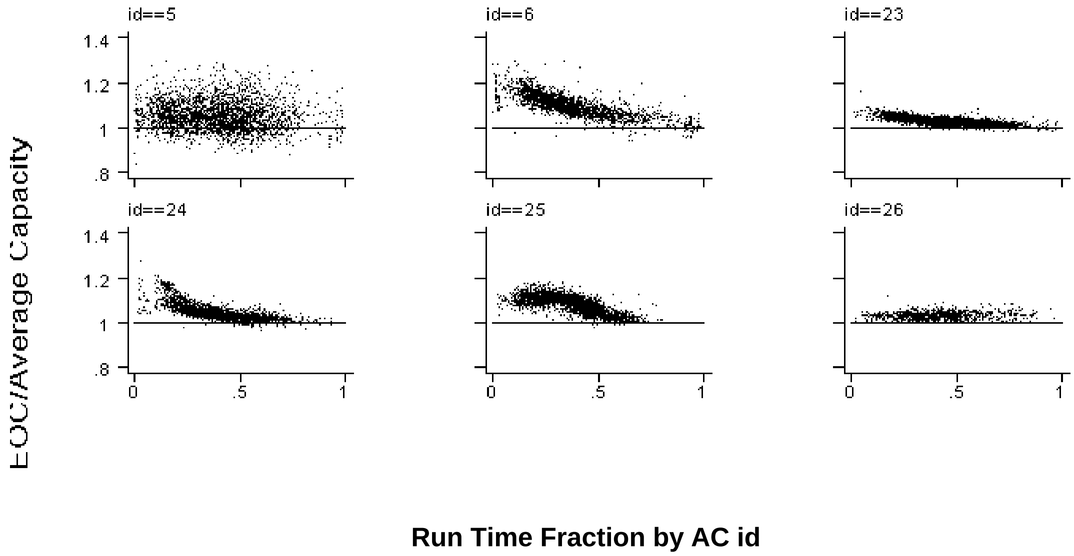


Figure 4.1.2. Normalized End of Cycle (EOC) Sensible Capacity vs. Run Time Fraction

<u>Minimum On-time</u>

For any given configuration there is a minimum thermostat on-time (t_{min}). The t_{min} is the time interval for the air conditioner to lower the temperature from the upper (on) set point to the lower (off) setpoint when there is no cooling load. The on-time for any cycle is t_{min} plus the amount of load that was incurred during the on-time. This is given by the equation:

$$time_{on} = t_{min} + time_{on} * RTF \qquad \textit{Eqn. 4.1}$$[4]

Where:

t_{min} is the minimum on-time of the configuration to meet the demand of the thermostat

$time_{on}$ is the on-time

RTF is the run time fraction

[4] Parken et al. 1985 developed this model based on assumptions of capacity independent of outdoor temperature and cycling rate. His model was restated in Henderson and Rengarajan (1996) to $time_{on} = t_{min}/(1\text{-}RTF)$. The current derivation is equivalent but avoids the assumptions within the Parken derivation.

This function defined by Equation 4.1 is shown in Figure 4.1.3 for the model assumption in the SEER rating procedure (ARI 1984). (implicit t_{min} = 4.8 minutes)

The minimum on-time for the field data from units monitored in Phoenix ranged between 2.5 and 5.5 minutes with four of the units at about 4 minutes minimum on-time.

Figure 4.1.3. On-time vs. Run Time Fraction -- Standard Assumption

Eqn. 4.1 as shown in Figure 4.1.3 above is repeated in Figure 4.1.4 below where it is labeled "Std. Model". As shown in Figure 4.1.4, the standard model provides a decent match to the general shape of the field monitored data labeled 23, 24, etc.

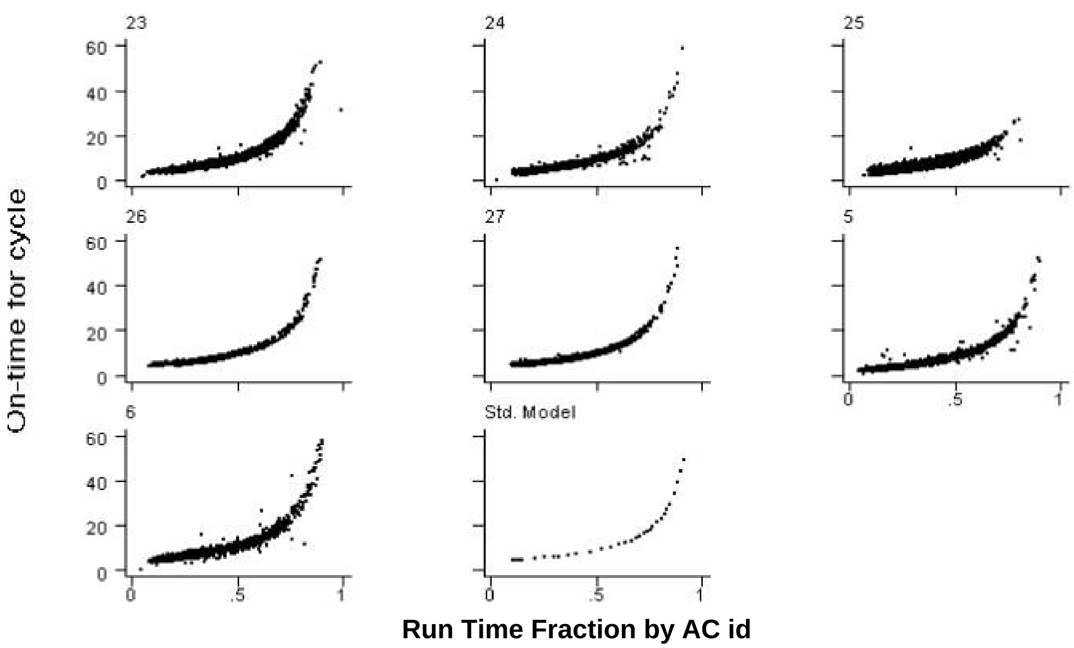


Figure 4.1.4 On-time vs. Standard Model On-time

A closer look at the field monitored data however shows that, in the range where sizing makes the most difference, from 0,0 to 0.5 Run Time Fraction, the Standard Model Assumption of Equation 4.1 does not do a very good job of tracking five out of the seven units. This discrepancy is present even when the t_{min} is adjusted to the actual minimum or is adjusted to provide the best fit.

Figure 4.1.5 shows two examples. In these units the actual on-times increase at a more rapid pace than suggested by Eqn. 4.1.

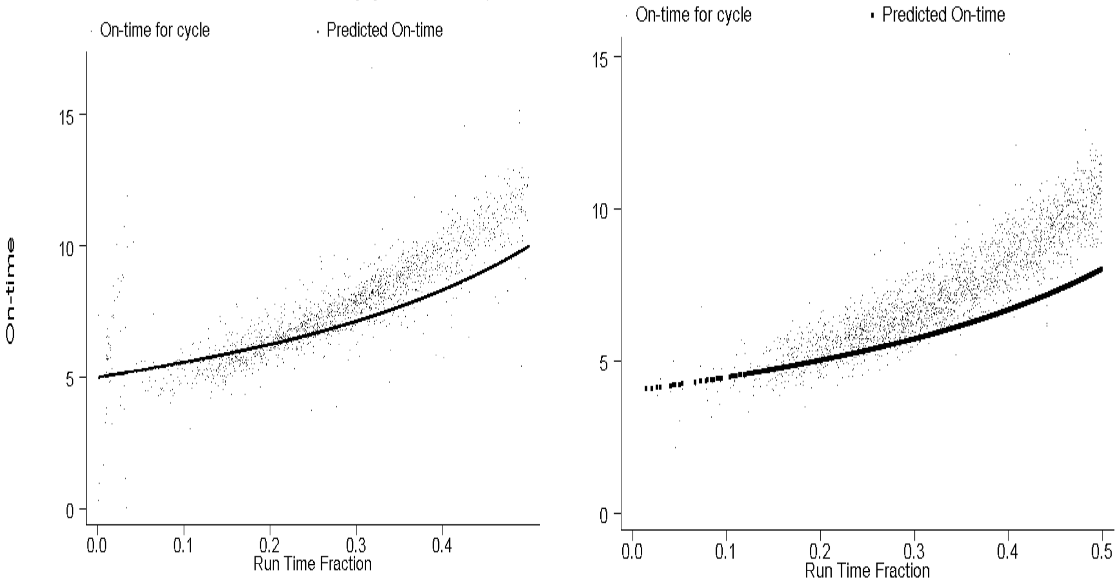


Figure 4.1.5 Difference between Standard On-time Model and Monitored Data

In order to make maximum use of the empirical data, a regression fit was applied. From that analysis, the on-times for the Arizona units fit the following empirical curve[5]:

$$time_{on} = -7.038829 + .7847497\ t_{min} + 7.235844/(1\text{-}RTF) \qquad \textit{Eqn. 4.2}$$

Where:

t_{min} is the minimum on-time of the configuration to meet the demand of the thermostat

$time_{on}$ is the on-time

RTF is the run time fraction

[5] Other combinations of tmin and RTF produce nearly as good regression fits, but none have any theoretical superiority over the others.

Empirical equation 4.2 produces a closer fit to the field data in 5 out of 7 cases[6]. Figure 4.1.6 displays the Standard Model Assumption and the regression model for two of the monitored units.

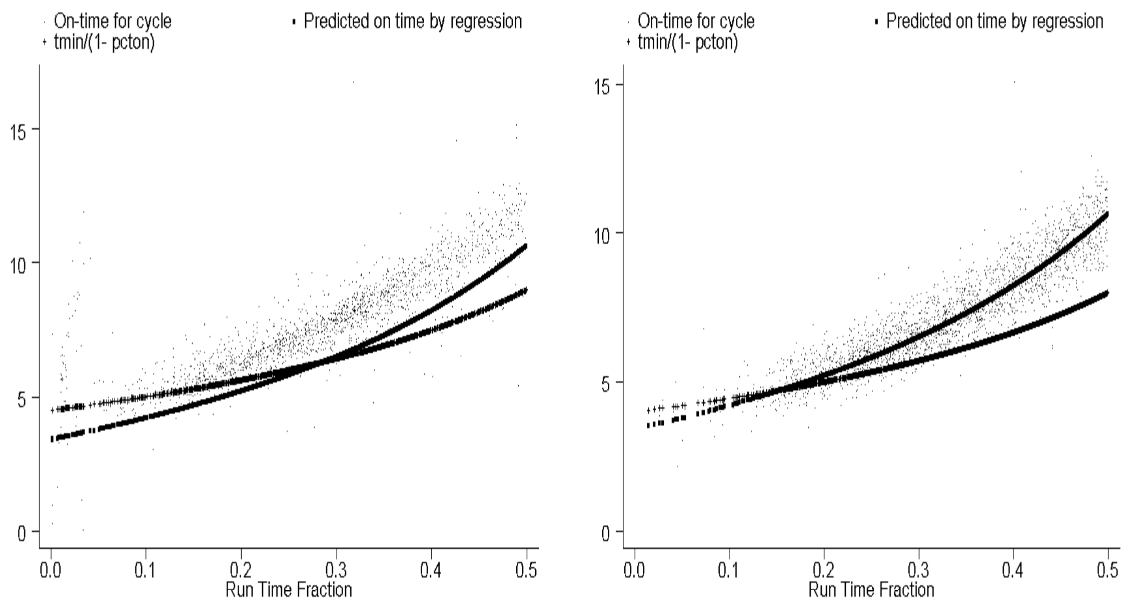


Figure 4.1.6. On-time vs. RTF, Regression Fit and Standard Model

<u>AC delivered sensible capacity</u>

The sensible capacity of an air conditioner is determined not only by it's nominal capacity at standard test conditions, but also length of the on cycle ($time_{on}$), the temperature of the air entering the condenser coil, the wet and dry bulb temperature of the air entering the evaporator coil, and other variables. The relationship between $time_{on}$ and the delivered sensible capacity is central to establishing a savings due to proper sizing.

The instantaneous sensible capacity of an air conditioner has been characterized by [7]

$$Qsens = Qsss\ (1-\exp(-timeon/\tau)) \qquad \textit{Eqn. 4.3}$$

6 The two remaining cases are essentially the same as the standard model

7 Henderson and Rengarajan 1996 and others

Where:

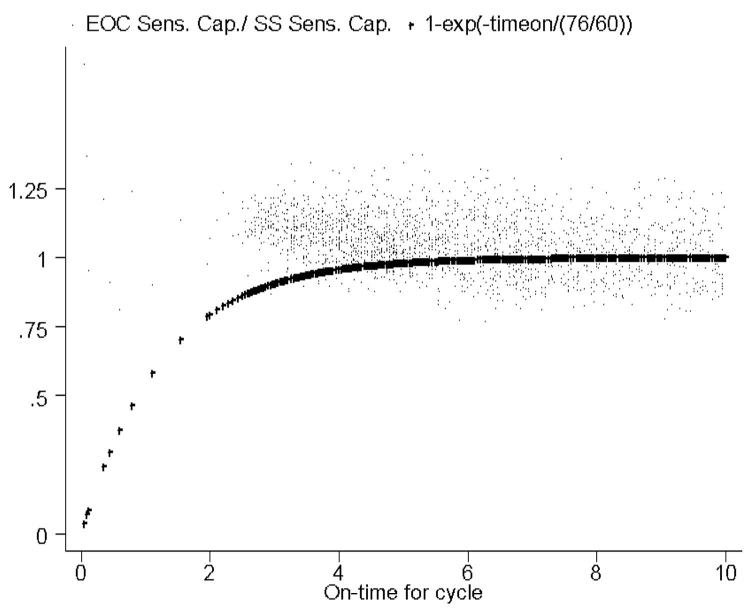
Qsens is sensible capacity of the air conditioner at $time_{on}$ minutes after the beginning of the cycle

Qsss is the sensible capacity at steady state for the same condenser air entering conditions

$time_{on}$ is the on-time

τ is the time constant usually taken in the range of 20 to 80 seconds

The field data had very few runs with less than 5 minutes where Eqn 4.3 can be tested. Figure 4.1.7 shows the relationship between the instantaneous sensible capacity and the steady state capacity as measured on one unit and as predicted by Eqn. 4.3 "1-exp(-timeon/(76/60))".



We hypothesize that the higher initial sensible capacities of some of the units are due to evaporation of water off the coil. This is a powerful influence over the initial sensible capacity of an air conditioner (Henderson and Rengarajan 1996).

Figure 4.1.7 Ratio of Instantaneous to Steady State Capacity vs. On-time

In order to investigate the performance at run times less than 6 minutes, the authors obtained laboratory data on the start up of a 3-ton residential air conditioner. Figure 4.1.8 plots power as well as instantaneous and average sensible capacity against on-time.

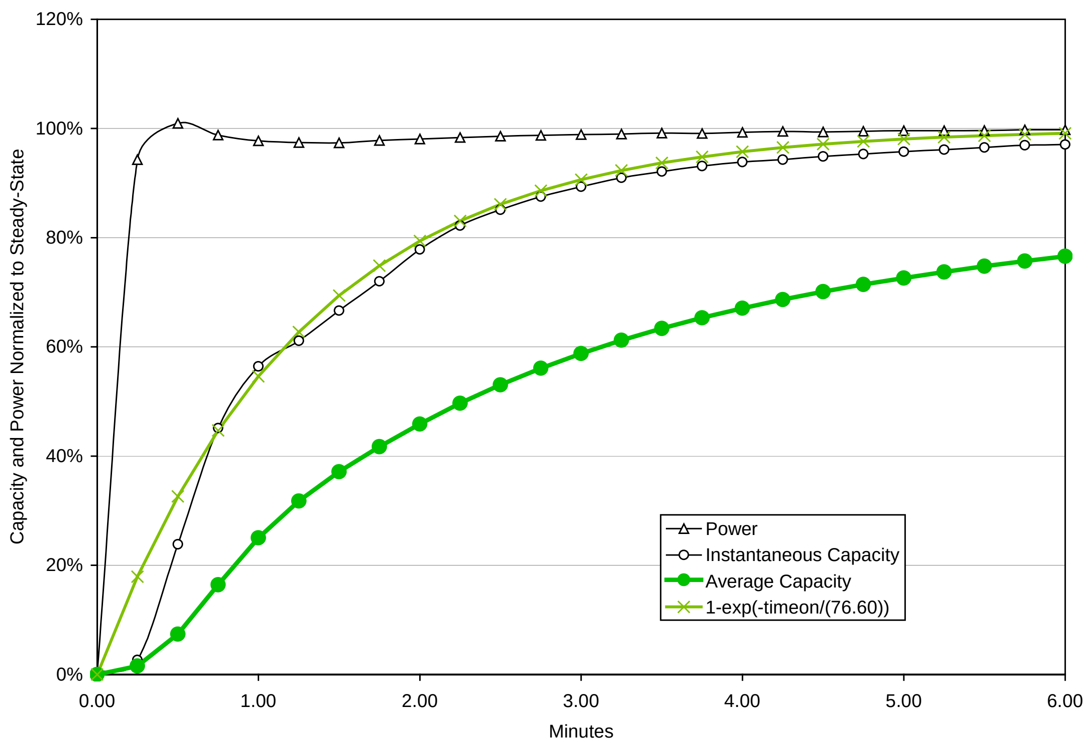


Figure 4.1.8 AC Transient Response -- Instantaneous and Average Sensible Capacity

The laboratory data closely resembles the function in Eqn. 4.3 for a time constant (τ) of 76 seconds[8]. Note that the capacity averaged over the entire cycle has risen to less than 80% of steady state by 6 minutes on-time. The field monitored units however do not follow the pattern from the laboratory test. The field average of 2190 cycles near 6 minutes show a cycle average capacity 94.3% of the steady state capacity[9].

We again hypothesize that the additional early sensible capacity is due to evaporation of water from the coil early in the cycle.

---

[8] Implicit Tau in SEER calculation

[9] Cycle average capacity and steady state capacity at the same conditions

No single equation provides an excellent fit to the field data on all units. Figure 4.1.9 shows the median Part Load Capacity Ratio (PLCR) for each unit by 1-minute time bins. Three units (5, 6, and 24) show a PLCR of around 0.45 in the 0 to 1 minute bin. This is substantially more than the <20% expected from the laboratory data. Notably Units 5 and 27 show no reduction in sensible capacity at shorter on-times.

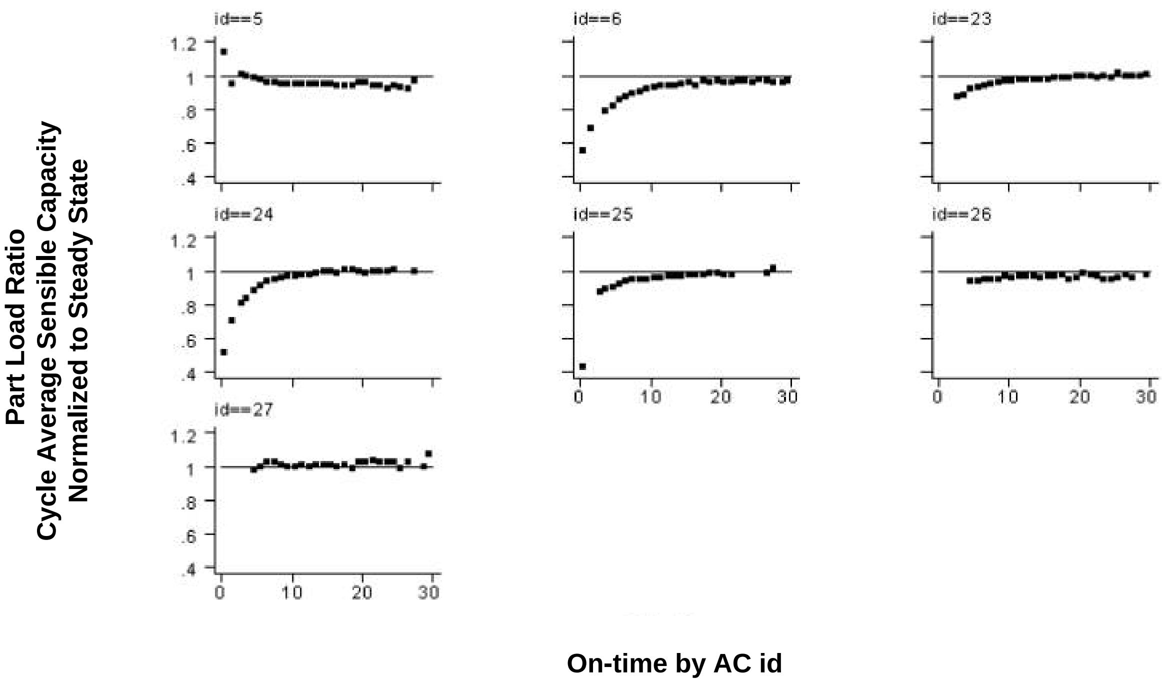


Figure 4.1.9 AC Transient Response –Part Load Ratio

Since the power consumption rises almost instantaneously to its steady state value, the Part Load Capacity Ratio is essentially the Part Load Ratio (PLR). From here forward we will refer to the PLCR as PLR.

When the data for all units are collapsed to a single number for each bin, the resulting curve is as shown in Figure 4.1.10 and can be expressed by the following empirical equation.

$$PLR = Qavgsen / Qsss = (1 - \exp(-(7.26 + time_{on}) / \tau_2)) \qquad \textit{Eqn. 4.4}$$

Where:

Qavgsen is the average sensible capacity of the air conditioner over the time t=0 to $time_{on}$

Qsss is the sensible capacity at steady state for the same conditions

$time_{on}$ is the on-time in minutes

τ_2 is the time constant for the average sensible capacity = 4.511 minutes

Figure 4.1.10 shows the fit of Equation 4.4 to the field data. The numbers on the graph are the number of data points in the bin.

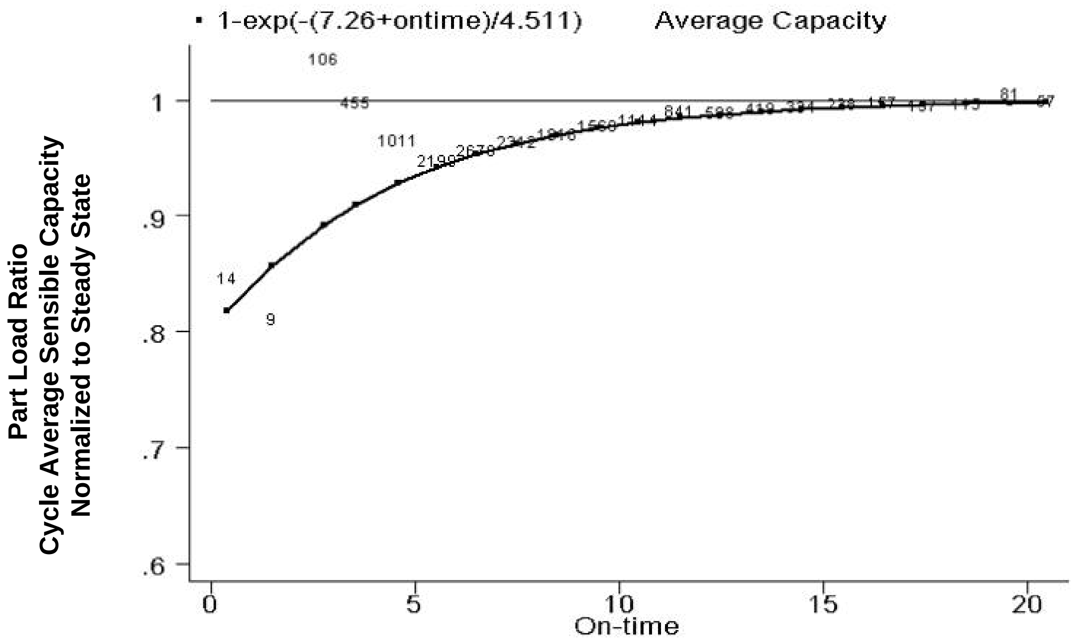


Figure 4.1.10 Part Load Ratio

<u>Energy Savings Estimates for Downsized Air Conditioners</u>

It is "common knowledge" that downsizing an air conditioner will produce an energy savings due to the longer run times.

In support of that position we have suggested that the minimum on-time is increased when a smaller unit is installed. In addition, the amount of run time in excess of the minimum is extended due to the reduced AC capacity.

One common energy savings estimate is based on the algorithms in Energy Plus™ and DOE2. These algorithms are:

Part Load Ratio = PLR = Sen. Cooling Load/Sen. Cooling Capacity *Eqn. 4.5*

Part Load Fraction = PLF = a + b(PLR) + c(PLR)^2 *Eqn. 4.6*

It is common to assume that coefficients "a" and "b" in Eqn. 4.6 are .75 and .25 respectively. PLF = .75 + .25(PLR)

Examination of data from the monitored air conditioners that the cycle average sensible capacity does follow the first order part load algorithm contained in Eqn. 4.6 with the following coefficients:

Table 4.1.1 Part Load Ratio to Part Load Fraction Coefficients

ID	6	23	24	25	26	Std. Assumption
a	.832	.898		.861	.883	.75
b	.168	.102	.252 (lo conf.)	.139	.117	.25
Variation explained by Eqn.4.6	42%	23%	25%	25%	49%	

Figure 4.1.11 shows the relationship on one of the air conditioners.

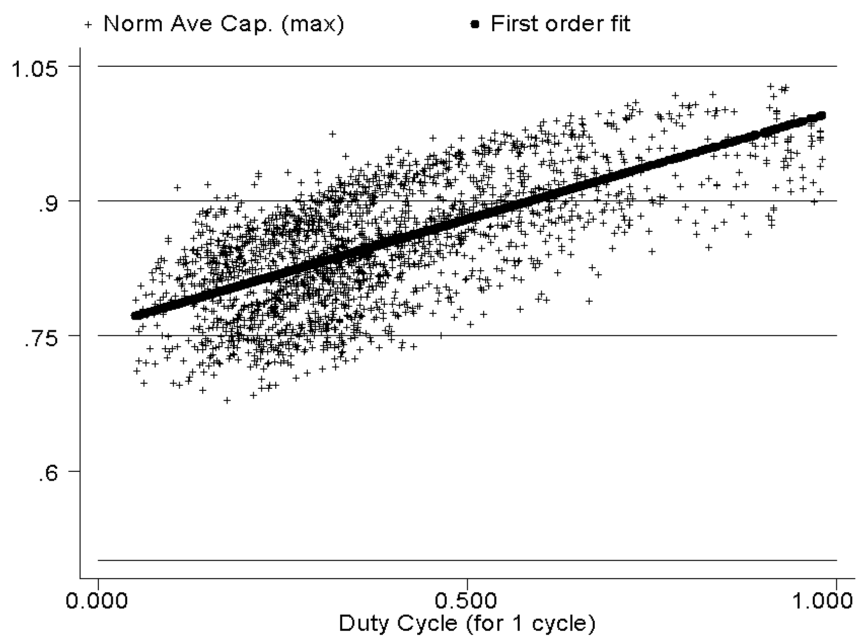


Figure 4.1.11. Monitored Part Load Ratio vs. Part Load Fraction

Conclusions

The efficiency of an air conditioner is dependent on a number of factors. When the size (capacity) of an air conditioner is considered relative to the load it is called upon to meet, the efficiency increases as on-times increase (all else being equal)[10].

There is substantial variation in the relationship between on-time and delivered sensible capacity even in the relatively small sample tested.

In addition the on-time is highly affected by the thermostat performance. A larger air conditioner in the same home (with a given thermal response) will reduce the minimum on-time. The reduced minimum on-time is very important as it dominates the on-time at low part load ratios and has an effect at all loads.

The savings associated with downsizing will vary with these relationships. When these data are worked into the format used in *Eqn. 4.6,* the coefficients are as shown in Table 4.1.2.

Table 4.1.2. Sizing Effect on Thermostat Constant and PLF Calculation Constants

Size Relative to Design Load	115%	130%	145%	160%	175%	190%
tstat constant	5.7 min.	5.0 min.	4.5 min.	4.1 min.	3.8 min,	3.5 min.
Eqn.4.6 intercept (a)	0.834	0.82	0.808	0.796	0.784	0.774
Eqn.4.6 slope (b)	0.166	0.18	0.192	0.204	0.216	0.226

Based on the analysis performed for this report the energy savings associated with reduced air conditioner sizing are approximately as shown in Table 4.1.3. These savings are based on temperature bins for New York City, sensible loads and sensible capacities. When latent loads are significant there is probably larger savings potential.

Utility system peak power reductions can be significant from reducing sizing. However, the amount of size reduction is limited by comfort considerations.

[10] This conclusion does not necessarily apply to situations were the sole or overwhelming load is only sensible.

Table 4.1.3. Effect of Sizing Reductions on Individual Unit Energy Consumption and Diversified Peak Loads

Sizing Reduction (% of original size)	**13%**	**23%**	**31%**	**37%**	**43%**	**47%**
Energy Savings (individual unit)	1.6%	3.1%	4.6%	6.0%	7.4%	8.7%
Diversified Peak Reduction[11]	8%	10%	12%	14%		

These figures are in close agreement with the previously mentioned Florida field test homes that estimated energy penalties of 3.7% and 9.3% respectively for units 20% and 50% oversized

Interactions

One of the major effects of an oversized air conditioner is the need for a larger duct system. The larger duct system is seldom installed (Please see Section 4.1.2).

References

ARI. 1984. ATI Standard 210/240-84, Unitary air-conditioning and air-source heat pump equipment. Air-Conditioning and Refrigeration Institute.

Henderson, H. 1992. "Dehumidification at Part Load." In *ASHRAE Transactions* Vol.98, Part 1, 370-380, 3579. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers.

Henderson, H. and K. Rengarajian 1996. "A Model to Predict the Latent Capacity of Air Conditioners and Heat Pumps at Part-Load Conditions with Constant Fan Operation" In *ASHRAE Transactions* Vol.98, Part 2, 266-274, 3958. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers.

James, P.W., J.E. Cummings, J.K. Vieira, and F. Klongerbo 1997. "The effect of Residential Equipment Capacity on Energy Use, Demand and Run Time" In *ASHRAE Transactions* Vol.103, Part 2, 297-303, 4082. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers.

[11] The peak reductions come from reducing the capacity of air conditioners running continuously at peak. This is practical on a lesser number of air conditioners for each increasing downsize category, since comfort issues will override. The calculation is based on downsizing units 15% of Manual J7 or less once they run continuously on peak.

Neal, L. and D. O'Neal 1994. "The Impact of Residential Air Conditioner Charging and Sizing on Peak Demand." *ACEEE 1994 Summer Study on Energy Efficiency in Buildings,* Vol. 2, pp. 189-200.

Neme, C., J. Proctor, and S. Nadel. 1999. *Energy Savings Potential from Addressing Residential Air Conditioning and Heat Pump Installation Problems*. American Council for an Energy Efficient Economy Report #A992, February.

Peterson, G. and J. Proctor. 1998. "Effects of Occupant Control, System Parameters, and Program Measures on Residential Air Conditioner Peak Loads." In *Proceedings from the ACEEE 1998 Summer Study on Energy Efficiency in Buildings,* 1:253-264. Washington, D.C.: American Council for and Energy-Efficient Economy.

Proctor, J. 1997. "Field Measurements of New Residential Air Conditioners in Phoenix, Arizona." In *ASHRAE Transactions*, 1997, V. 103, Pt. 2. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers

Proctor. J., T. Downey, M. Blasnik, and G. Peterson 1997. *Residential new Construction Pilot in Nevada Power Company Service Territory.* Electric Power Research Institute TR-108445. Final Report July 1997. Palo Alto, CA.

4.1.2. Closer distribution system sizing to room and equipment demands

Distribution systems are often designed poorly, having high resistance to airflow that the air handler fan/motor combination cannot overcome. The results are low airflow through the heater/cooler as well as hot and cold rooms. This problem is aggravated by the number of oversized air conditioners that have smaller duct systems than they need for proper performance.

In some cases contractors attempt the overcome low airflow with higher fan motor speed and power. The result is a slightly increased efficiency of the compressor circuit but substantial increase in evaporator fan motor energy consumption.

Many contractors are under the misimpression that Electronically Commutated Motors will supply adequate airflow through a heater/cooler regardless of the duct system design. This misconception feeds the existing contractor indifference to proper duct design.

There are a number of potential responses to this problem. One response is using a design methodology that ensures adequate airflow, such as ACCA Manual D or other legitimate[12] duct sizing methodology.

ACCA Manual D covers one set of procedures that can be followed for proper design of a duct system. It contains the information necessary to:

- determine the maximum allowable duct static pressure to ensure the design airflow can be delivered through the unit and to each room;
- take into account the resistance of evaporator coils, humidifiers, air filters, auxiliary heaters, dampers, etc.
- take into account the performance of the air handler fan under differing static pressures.

Other design methods, such as the Equal Pressure Drop method as applied by Davis Energy Group, are available. Some of these methods do not depend on dampers in every run and can provide a more efficient design.

Beyond proper conventional design, other changes in the distribution system such as shorter duct runs as well as better placement and selection of terminals, are advantageous.

<u>Savings</u>

Savings from a proper duct system design are quite variable and need to be evaluated in two parts: distribution proportional to the load (Room by Room) and airflow across the heat exchanger.

Room by Room

While it is generally accepted as “the right way to do things”, correct room-to-room distribution has not been tested to show energy savings. It has been proposed that if the distribution is uneven the savings from “balancing” the system could be either positive *or negative*. The simplest example of a negative savings from balancing would be when the room with the thermostat is the most frequently occupied and it receives more conditioning than the other rooms. In that case redirecting conditioned air to the other rooms would increase the load and result in higher energy use.

---

[12] We are calling a system that combines information about the airflow capability of the air handler under specific external pressure conditions, the design airflow, the flow resistance of devices external to the air handler, and the total resistance of the duct system a legitimate system.

We are calling a system that makes a blanket recommendation such as .1 IWC per 100 feet an illegitimate system.

Certainly when occupants decide to use a constant fan to overcome room-to-room distribution problems stemming from poor design, fan energy use increases and duct system losses increase.

Airflow Across the Heat Exchanger

Even determining what the proper airflow is for a particular situation provides challenges. The more common simplifying assumptions hide the complexity and uncertainty in the process.

Any manufacturer's data sheet will show that the capacity and efficiency of the unit increases as the evaporator airflow increases. In general, the data sheets are based on a static pressure of only 0.15 IWC (for a 3-ton unit) and the external static does not increase with increased flow. When viewing the manufacturers' tables it is reasonable to conclude that if latent capacity is of small or little importance in the local climate, then higher airflow will be preferable. For example a Carrier 38EZG036-30 with CK5B042 coil shows a Sensible EER (EER x Sensible Heat Ratio) of 7.5 at 1050 cfm and 8.1 at 1350 cfm, an efficiency improvement that would produce a 7% savings.

The situation however is more complex.

Table 4.1.4 contains figures generated by the Oak Ridge National Laboratory's simulation program HPDM[13] for a common SEER 12, 3-ton air conditioner. This table and the accompanying figures are based on external static pressures based on field data (0.50 Inches of Water not including the evaporator coil). The field data show fan watt draws higher than assumed in the manufacturers' tables. As airflow is increased, the evaporator fan watt draw negates the increased capacities. This table and these figures show the EER and Sensible EER associated with increasing evaporator airflow on a 3-ton air conditioner from 900 cfm to 1500 cfm by two methods.

Method #1 holds the duct resistance[14] constant and uses increasing horsepower blower motors to overcome the increasing pressure drop in the duct system and within the air handler cabinet.

Method #2 uses increasingly larger ducts to obtain the same airflow.

---

[13] The HPDM is: "A widely used tool developed by DOE through Oak Ridge National Laboratory is the Heat Pump Design Model (Mark VI release). This tool simulates the steady-state cooling and heating performance of air-to-air heat pumps and air conditioners, enabling users to specify such key parameters as type of vapor compressor, type of heat exchanger, air conditions, air flows, and type of refrigerants." (DOE 2004)

[14] Duct k Factor

Figure 4.1.12 shows that if the duct system is not sized properly for the airflow, the sensible efficiency of the air conditioner drops as the airflow is increased. This figure also shows that the sensible efficiency improvements from increased airflow are very limited (peaking at 400 cfm per ton in this example) even when the ducts are resized for the higher flow.

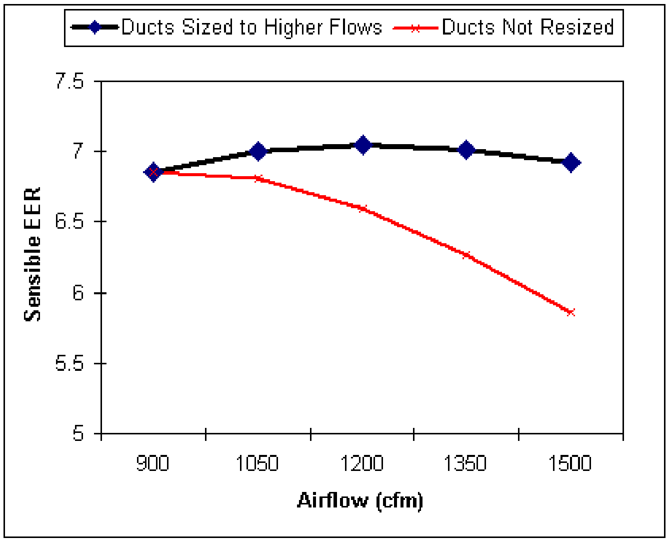


Figure 4.1.12. Effect of Duct Sizing and Evaporator Airflow on Sensible Efficiency

In areas where latent capacity is of higher importance the total efficiency is a more important indicator. Figure 4.2.13 shows the decrease in efficiency as the airflow is increased above 300 cfm per ton. Low airflow however can produce problems such as iced coils and compressor failures.

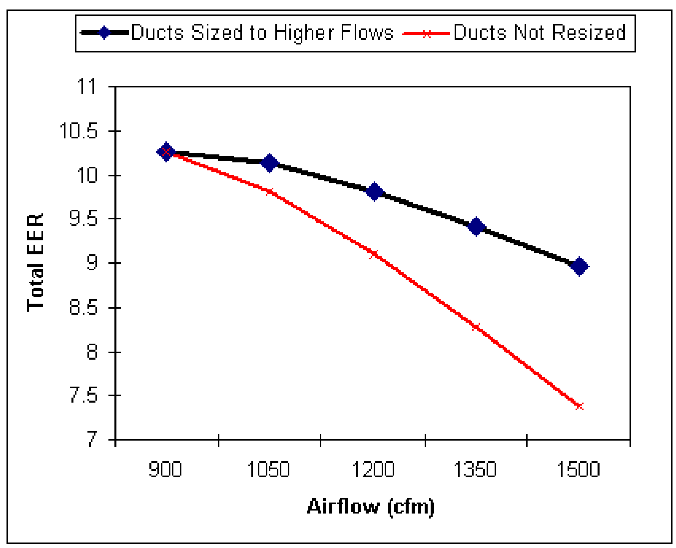


Figure 4.1.13. Effect of Duct Sizing and Evaporator Airflow on Total Efficiency

Table 4.1.4 explores the complexity of the design situation. Based on the manufacturer's tables, a Carrier 38EXG unit would be predicted to have a 7% savings when the cfm is increased from 1050 to 1350. However Table 4.1.4 shows virtually no change in Sensible EER (7.007 to 7.012) even if the duct sizing is increased to compensate for the higher flow.

This table also makes it clear that having adequate duct size improves the efficiency of the air conditioner.

Table 4.1.4. Effect of Increased Evaporator Airflow

CFM	**900**	**1050**	**1200**	**1350**	**1500**
Method 1[15]					
External Static Pressure	0.367	0.500	0.653	0.827	1.020
Average Duct Diameter	9"	9"	9"	9"	9"
EER	10.255	9.806	9.101	8.272	7.383
SHR	0.668	0.695	0.725	0.758	0.793
Sensible EER	6.850	6.815	6.598	6.270	5.855
Method 2[13]					
External Static Pressure	0.367	0.367	0.367	0.367	0.367
Average Duct Diameter (approx.)	9"	9.3"	10"	10.4"	10.8"
EER	10.255	10.127	9.812	9.413	8.955
SHR	0.668	0.692	0.718	0.745	0.773
Sensible EER	6.85	7.007	7.045	7.012	6.922
Method 2 Savings	0%	3%	7%	12%	18%

Table 4.1.4 does not present the effects of airflow and duct surface area on the efficiency of the duct system.

[15] Methods 1 and 2 assume: constant evaporator fan/motor combined efficiency, 95ºF condenser air entering temperature, 80ºF dry bulb return temperature, and 67ºF wet bulb return temperature.

References

ACCA 1995. *Duct Design for Residential Winter and Summer Air Conditioning and Equipment Selection (Manual D).* Air Conditioning Contractors of America, 1513 16th Street, N.W., Washington, DC 20036. www.ACCA.org

DOE 2004. Energy Efficiency and Renewable Energy, Building Technologies Program, http://www.eere.energy.gov/buildings/tech/hvac/

Personal communication, Dick Bourne, P.E., Davis Energy Group, Inc. 123 C Street Davis, CA 95616. www.DavisEnergy.com

4.1.3 Matching each component to work at peak efficiency with the other components

The discussion of duct systems in Section 4.1.2 leads to this optimization strategy. Proper design of a duct system takes into account the performance capabilities of the air handler and the airflow needs of each room.

We want the system to have sufficient delivered capacity (latent and sensible) AND ALSO high efficiency. Given this desire, components need to be selected with energy consumption in mind. Essentially ACCA Manuals J and Manual D calculate loads and select components based on capacities, not on efficiency. If one presumes that the duct system is going to be inefficient, ACCA Manual J recognizes an additional load and includes that load in the calculations. The energy penalty for an inefficient duct system is hidden.

When design criteria include both capacity and energy efficiency, the process is more complex and is likely to require comparisons between multiple options. Optimization is likely to require some iteration to find the most efficient combination.

The current selection methodology is a fairly linear process and is not applied by most contractors or design engineers. An iteration/optimization process would probably be a computer program to deal with time limitations. Such software would select all the components from a wide array of possibilities and work to minimize a variable (such as life cycle cost). Some of the selected combinations may be different from those in common use, which would cause resistance from contractors, builders, and designers.

Savings

This process would produce long-term savings hard wired into the HVAC system. The theoretical improvements could result in life cycle cost reductions of

50%. The reliability and durability for uncommon designs would be unknown and would impede their introduction.

References

ACCA *Manual J, Manual D, Manual S*. Air Conditioning Contractors of America, 1513 16th Street, N.W., Washington, DC 20036. www.ACCA.org

4.2 Controls

Purpose

Controls are available that can:

- make use of cooler outdoor air in the evenings to cool a home in preparation for the daytime loads,
- match the running mode of the HVAC system to current indoor and outdoor conditions, or any other signal, and
- control the operation based on anticipated conditions (weather, indoor conditions, energy prices)

These controls provide a means of optimizing the response "efficiency" of any unit that has multiple potential run modes. The "efficiency" can be defined in many ways: least cost, maximum comfort, reduced electrical peak, etc. Once the efficiency optimum is defined these devices can control the run modes to obtain optimization.

The above controls use optimization methods where the optimum is believed to be known.

Consider the case where the optimum is not known or the response of the entire system (HVAC equipment, air distribution, occupant preferences, economics, building shell performance, etc.) changes. One solution would be reprogramming as new situations arise (potentially a time consuming, expensive, and unlikely to be implemented method). Another solution is a class of controls known as "learning controls". These controls learn based on the response of the dependent (optimized) variable to deviations in the input variables. In the simplest implementation the learning control "notes" the deviations (excitations) of inputs that occur and the response of the optimized variable to those deviations. This would be a passive learning control.

Active learning controls have the ability to create excitations in the system and to monitor the responses to re-optimize the system over some finite time period.

An example of a passive learning device is a thermostat that has no fixed temperature setting. The occupant's potential inputs to the system are: Off, On, Cooler, Warmer. The passive learning thermostat would have an internal time clock that it would correlate with the inputs of the occupants.

Example: If every Friday the building was occupied earlier than during the rest of the week the occupants would press "warmer" or "on" on cold winter days. The thermostat would "learn" to come on earlier on Fridays and adjust to the most common temperature that satisfies the occupants. It is obvious that such a device would have some disadvantages. If the work schedules shifted to later hours, the thermostat would not “know” about the change because there was no one pushing the “off” button early on Fridays. This points out the superiority of active learning control. With an active learning thermostat of the same design (Off, On, Cooler, Warmer), the thermostat could periodically reduce the on-times or the setpoints to obtain a reaction from the “whole system”. If the reduced setpoints (excitation) produces a negative response (occupants pushing the “on” or “warmer” buttons) the thermostat brings the setpoints higher until an optimum is reached. If there is no response, the thermostat keeps lowering the thermostat to a programmed minimum.

4.2.1. Anticipatory thermostats

Since buildings have mass that becomes charged with heat (of lack thereof) and insulation that slows down the flow of heat, there is a substantial time delay in most heat gain/heat loss mechanisms. Traditional thermostats respond only to the inside temperature. Some controls on larger multifamily buildings respond only to the outside temperature (rather primitive given that keeping the occupied space in the comfort zone is the goal of the system). Most common thermostats provide off/on response.

More advanced thermostats can also respond to both indoor and outdoor temperatures or other immediate inputs. Providing a proportional response to the differential from the set point can increase the sophistication of the thermostat. The sophistication of the thermostat can be further increased by using the information gained over time (rate of change of temperature or other mathematical manipulation of temperature and time). This information can be used to anticipate the response of the system and reduce “overshooting”, which may waste energy.

A higher level of sophistication is to obtain data from other sources that allows improved anticipation of future climatological events and more optimized system response.

One such application has been demonstrated by Honeywell INUcontrol AB (Sweden). In one application two multifamily residences were monitored, one with the anticipatory control and the other with a conventional control[16]. The system used predicted hourly weather variables obtained electronically from the Swedish Meteorological and Hydrological Institute. These variables included

[16] the conventional control may have been based only on outdoor temperature, this information is not available at the time of the writing

outside air temperature, wind, and solar radiation. These variables were combined into an equivalent temperature (ET) that is influenced by learned responses of the indoor temperature to the input variables. The building with the anticipatory control used 10% less heating energy during the 2-year experiment

Another implementation of this concept is the NIC-aerc controller (Zumsteg 2002). This controller monitors indoor and outdoor temperatures, downloads local weather forecasts, responds to pricing signals, and can learn/adapt to the efficiency characteristics of the building equipment combination. This system can pre-cool during pre-peak periods to reduce peak period electrical consumption. It is particularly suited to heat pumps (avoiding strip heat) and air conditioners.

Adaptation is achieved through a series of correlation steps, performed periodically by the NIC-aerc:

1. Predicted and measured outdoor temperature are correlated to establish a bias due to the micro-climate at the site,
2. Measured indoor and outdoor temperatures are correlated to determine the thermal lag time,
3. HVAC controls are correlated with measured indoor temperature to monitor the response rate of the house (i.e. based on HVAC capacity, on-site weather, etc.)
4. Variable-rate energy pricing and the setpoint schedule are correlated to develop a cost-efficient HVAC schedule.

These adaptive controllers can have positive effects on comfort, energy consumption, and diversified peak electrical consumption.

<u>References</u>

CADDET Energy Efficiency 2001. “Local weather forecasts control building HVAC system” SE 00.503/3A.E01. Swentiboldstraat 21, 6137 AE Sittard, PO Box 17, 6130 AA Sittard, The Netherlands

Phil Zumsteg 2002. (Honeywell) “NIC-based Adaptive and Efficient Residential HVAC Control (NIC-aerc)” www.stratis-ltd.com/gpl/nic-aerc/index.html

4.2.2 Controls that closely match run parameters to efficiency/capacity characteristics

A single element of the HVAC system seldom has a constant efficiency. Controls have the potential to optimize the system to the current conditions.

One application has been demonstrated by the Cold Climate Heat Pump (Nyle Special Products, 2004), It controls the operating mode of an air source heat pump based on condenser air entering temperatures and two staged heating calls from the thermostat. The operating modes are made up of these elements:

- Primary Compressor Low Capacity Mode
- Primary Compressor High Capacity Mode
- Secondary "Booster" Compressor
- An "Economizer" that bleeds a small amount of refrigerant through a metering device. The resultant cooling is used to further subcool the liquid refrigerant before the primary metering device and inject intermediate pressure vapor (vapor injection) between the Primary and Secondary compressors when the pressure differential between the evaporator and condenser is sufficient to make vapor injection advantageous (larger indoor outdoor temperature differentials).

Table 4.2.1 Operating Modes of the Nyle Cold Climate Heat Pump

	Evaporator Air Entering Temperatures Range (ºF)				
Element	< 10 ºF	10 to 20 ºF	20 to 34 ºF	34 to 57 ºF	> 57 ºF
Primary Compressor – Low			Stage 1		Stage 1
Primary Compressor – High	Stage 1	Stage 1	Stage 2	Stage 1	
Booster Compressor	Stage 1	Stage 1	Stage 2		
Economizer Vapor Injection	Stage 1	Stage 2			
Electric Resistance	Stage 2			Stage 2	

Another and well known application of matching run parameters to efficiency/capacity characteristics is the controller for a General Electric ECM® motor. When applied to a furnace or air conditioner fan, this controller can adjust to maintain a nearly constant torque over a wide range of external static pressures. This results in the specified airflow even as other components become more resistant to airflow (dirty filters, dirty coil, closed registers, etc.)

Simple controls are often set to a single point and may maximize the efficiency at that point. Implementing a variable controller with a performance map can increase the multi point performance of HVAC systems.

<u>References</u>

Nyle Special Products LLC. 242 Miller St. Bangor, Maine 04401
www.nyletherm.com

4.3 Obtaining and Maintaining Designed Operation

<u>Purpose</u>

Obtaining and maintaining designed operation/efficiency of an HVAC system can be accomplished by installing and maintaining the equipment within the manufacturers' specified criteria. Ensuring the performance of units in the field is difficult. The final assembly of the HVAC system is performed, not in a factory with highly effective quality assurance systems, but rather by one or more individuals generally working without an effective quality assurance system. The parameters that are known to suffer under these conditions include refrigerant charge and airflow[17].

4.3.1 Ensuring proper refrigerant charge

The majority of heat pumps and air conditioners are not installed properly. A common error in the installation of split-system equipment is neglecting the additional refrigerant required by the installed line set. Figure 4.3.1. shows a histogram of this problem in new Phoenix Arizona homes. The units at 80% and 90% charge were short the amount of refrigerant necessary to bring make up for linesets that were longer than the factory standard length.

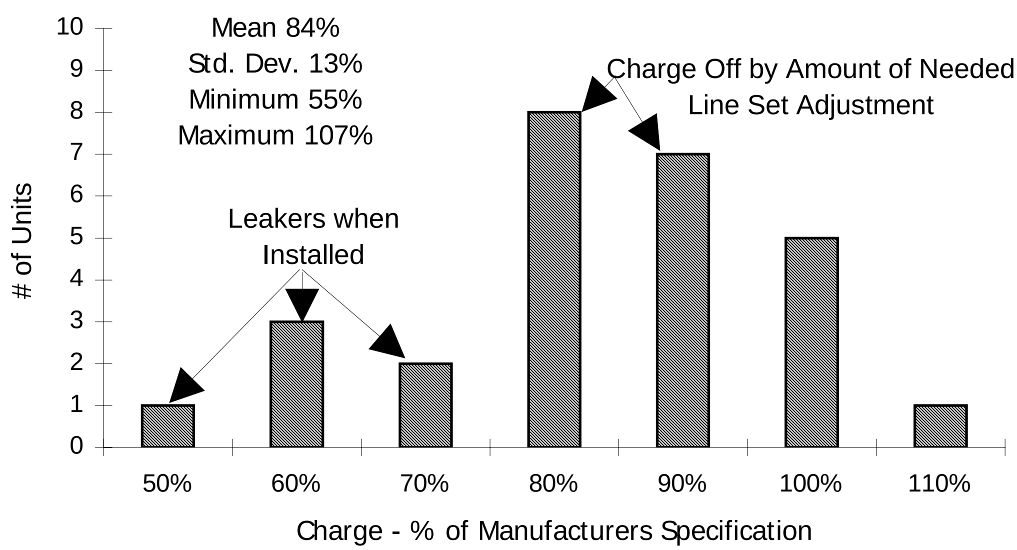


Figure 4.3.1 Refrigerant Charge in New Installations (Proctor 1997)

---

[17] as well as economizer function on commercial package rooftop units.

Refrigerant mischarge tends to continues through the life of the air conditioner, sometimes altered by technician adjustments and leaks that, on average, do not result in correct refrigerant charge.

The capacity and efficiency effects of incorrect charge have been measured in recent years on modern air conditioners. Laboratory tests have investigated a significant range of refrigerant charge on the same machine with different metering devices (both fixed and adaptive). The effects are found to be similar between R-22 and R-410A. Figure 4.3.2 shows the efficiency responses of a R-22 SEER 12 air conditioner and a R-410A SEER 14 air conditioner with both short tube metering devices (Orifice) and thermostatic expansion valves (TXV).

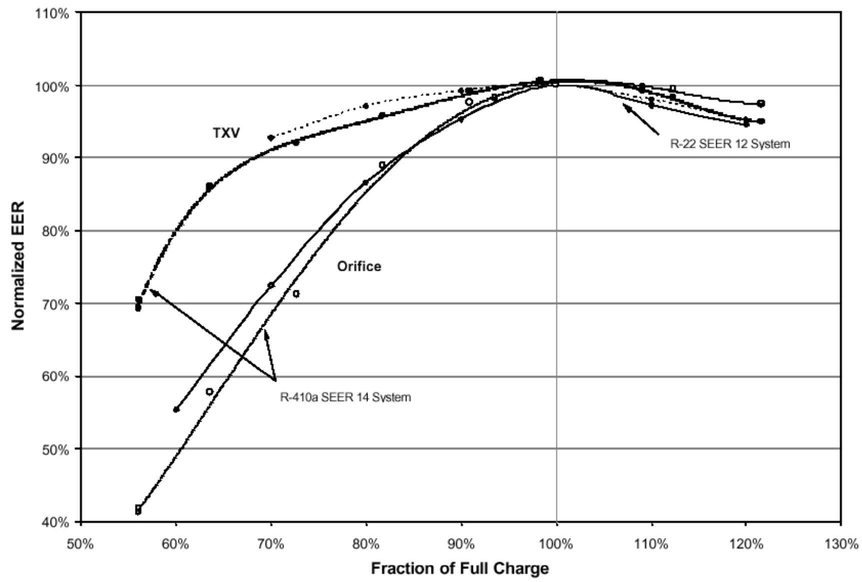


Figure 4.3.2 Effect of Refrigerant Charge and Metering Device on Efficiency (Davis 2001))

The Davis test was performed by fitting the air conditioners with both types of metering devices and using isolation valves to switch from one metering device to the other. The test arrangement is shown in Figure 4.3.3.

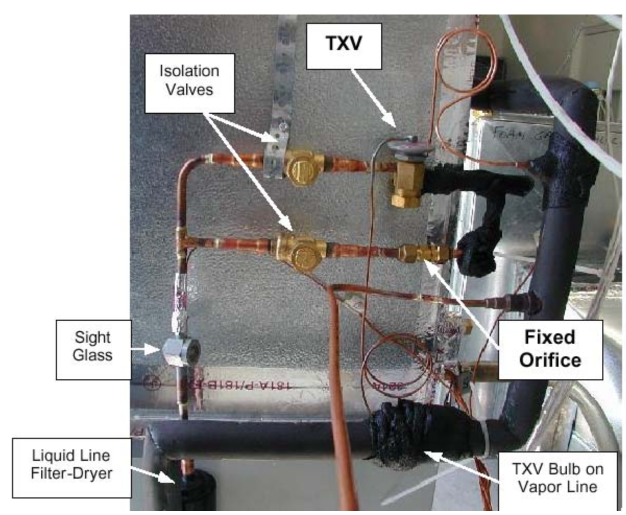


Figure 4.3.3 Method of Changing Metering Devices on AC Test (Davis 2001)

It has been suggested that the refrigerant charge issue on new AC and heat pump installations as well as on existing equipment can be addressed in a number of ways:

- Third party verification as in California 2001 Title 24 Standards,
- Charge verification through statistical analysis of data supplied by the startup technician
- Mitigation of incorrect charge effects in the machine design (through a TXV, electronic expansion valve, receiver, or accumulator), or
- Devices to detect incorrect charge and signal the need for correction

The average energy savings for air conditioner units initially diagnosed with incorrect charge and with the charge corrected is 10.5%. Correct charge also maintains the full capacity of the air conditioner, reduces compressor failures, and reduces warranty claims (both for charge related failures and misdiagnosis).

<u>References</u>

Davis, Robert 2001. *Influence of Expansion Device And Refrigerant Charge On the Performance of a Residential Split-System Air Conditioner using R410A Refrigerant* Report No.: 491-01.7. Pacific Gas and Electric Company, San Ramon, CA, April 2001

Proctor, John 1997. "Field Measurements of New Residential Air Conditioners in Phoenix, Arizona." In *ASHRAE Transactions*, 1997, V. 103, Pt. 2. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers

Proctor, John, Tom Downey, Abram Conant, and Dave Wright 2003. *Innovative Peak Load Reduction Program CheckMe!® Commercial and Residential AC Tune-Up Project.* Report 01.127 Proctor Engineering Group, San Rafael, and CA. November 2003

CEC 2001. *2001 Energy Efficiency Standards.* (Title 24) California Energy Commission. Sacramento, CA. August 2001

4.3.2. Ensuring adequate indoor coil airflow

The majority of heat pumps and air conditioners are installed with too little airflow through the inside coils. Startup technicians do not regularly check for sufficient airflow and the causes of low airflow are often history by the time of startup. Various studies show indoor coil airflow to be less than 350 cfm per ton on 44% to 90% of the units (average 70%) (Neme et al. 1999).

Low airflow is built in to the system due to a mismatch between the air handler capability and the restrictions to airflow throughout the system. The airflow degrades over time as the indoor coil picks up dirt, the blower wheel gets dirty, as register dampers are closed, and when higher arrestance filters are substituted for standard filters.

The capacity and efficiency effects of low airflow have been tested in laboratories including Texas A&M (Rodriguez et al. 1995), Pacific Gas and Electric Company (Davis 2001), and Florida Solar Energy Center (Parker et al. 1997). Figure 4.3.4 (Davis 2001) displays the results from one series of these tests.

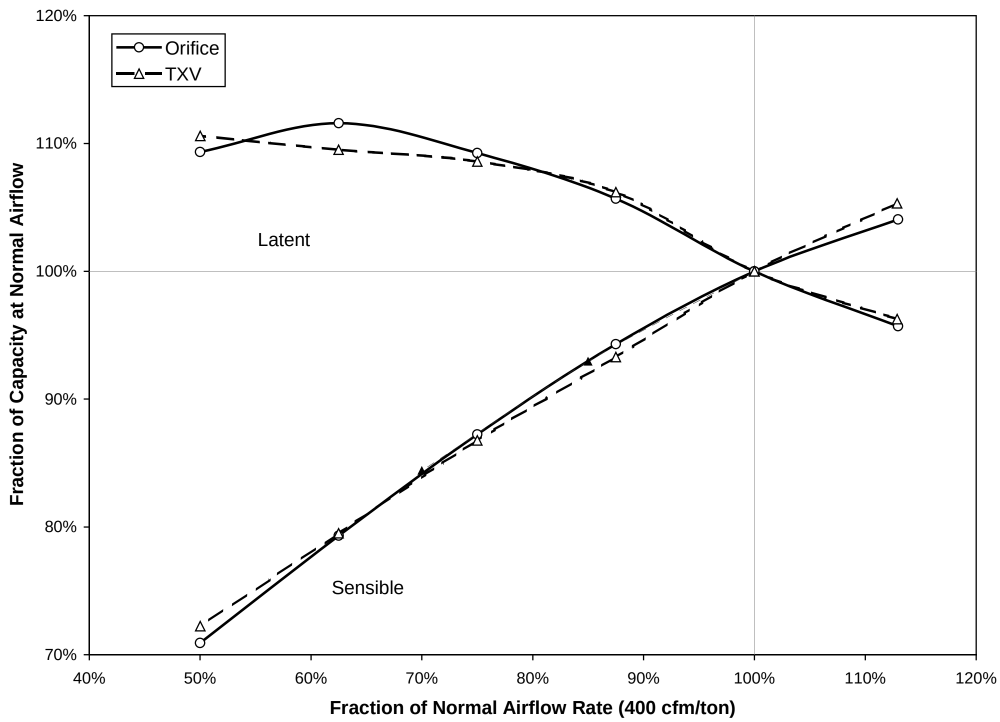


Figure 4.3.4 Effect of Evaporator Airflow on Latent and Sensible Capacity

The indoor coil airflow issue is more complex than the refrigerant charge issue. Reductions in airflow reduce sensible and total capacity, but they increase latent capacity and reduce the fan watt draw. In some cases struggling to achieve higher indoor coil airflow for cooling may be counterproductive. Given the current state of air handler efficiency and standard duct system design, the improvements in capacity and efficiency from increased airflow across the indoor coil are extremely limited. This is discussed in detail in Section 4.1.2.

It has been suggested that the indoor coil air flow issue could be addressed in any of the following ways:

- Mitigation of high static ducts in the machine design (higher efficiency fan/motor/cabinet design), or

- Third party verification of duct design as in California 2001 Title 24 Standards,
- The implementation of standards or incentives for low watts per cfm designs at given external static pressures,
- Third party verification of the watts per cfm as installed,
- Airflow verification through statistical analysis of data supplied by the startup technician
- Devices to detect airflow problems and signal the need for correction (See Expert System Diagnostics)

Conclusions

The industry, regulators, and contractors should be very cautious in blanket increases in airflow as a means to higher efficiency, even in climates with low latent load. The current designs of air distribution systems (ducts, fittings, fan/motor efficiencies) are not conducive to significant increases in evaporator airflow increases.

For optimization in hot dry climates there needs to be a concentration on the net delivered EER. Increases in fan flow need to be achieved in combination with improved duct systems, and overall delivery efficiency. It is possible to provide improvements in sensible EER through higher flows as long as any increases in watt draw are less than the effective watt reductions at the compressor for a given capacity.

A safe starting point is controlling the watts per cfm under defined flow and external static pressure situations.

References

Davis, Robert 2001. *Influence of Evaporator Coil Airflow in Relation to the Type of Expansion Device on the Performance of a Residential Split-System Air Conditioner* Report No.: 491-01.17. Pacific Gas and Electric Company, San Ramon, CA

CEC 2001. *2001 Energy Efficiency Standards.* (Title 24) California Energy Commission. Sacramento, CA. August 2001

Neme, C., J. Proctor, and S. Nadel. 1999. *National Energy Savings Potential from Addressing Residential HVAC Installation Problems.* Vermont Energy Investment Corporation for the US. Environmental Protection Agency.

Parker, D.S., J.R. Sherwin , R.A. Raustad and D.B. Shire. 1997. "Impact of Evaporator Coil Airflow in Residential Air Conditioning Systems." In *ASHRAE*

Transactions, *Summer Meetin*g. June 23-July 2, 1997, Atlanta, GA. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Parker, D.S. 1997. *Measured Air Handler Fan Power and Flow*. Memorandum to Armin Rudd. Cocoa, FL. Florida Solar Energy Center

Proctor, John and Danny Parker 2000. “Hidden Power Drains: Residential Heating & Cooling Fan Power Demand” *Proceedings of the 2000 ACEEE Summer Study.*

Proctor, John 2003. *Innovative Peak Load Reduction Program CheckMe!® Commercial and Residential AC Tune-Up Project* Report 01.127 Proctor Engineering Group, San Rafael, CA

Rodriguez, A.G., D. O’Neal, J. Bain, and M. Davis. 1995. *The Effect of Refrigerant Charge, Duct Leakage, and Evaporator Air Flow on the High Temperature Performance of Air Conditioners and Heat Pumps, Draft Final Report.* College Station, TX: Texas A&M University.

4.3.3. Expert System Diagnostics

Expert system diagnostics use computer technology to accurately determine performance and/or identify faults in HVAC systems. The purpose of a diagnosis is to select an effective treatment. The goal of a treatment is proper functioning of the HVAC system. To serve its purpose, the diagnostic system must bring about proper system function.The range of available diagnoses and identified treatments is dependent on the amount of artificial intelligence in the system, the amount of available information, and the accuracy of the available information. Microprocessors can perform high-level diagnostics and, to be consistently effective, need to be able to screen poor information from good information.

Information may be fed into the expert system through sensors, through human inputs, or a combination of the two.

<u>Savings</u>

The savings available from this technology are dependent on:

- the frequency of the faults it can identify,
- the faults’ effects on performance,
- the level of performance degradation it can identify,
- the accuracy of the treatment plan,
- the effective and timely communication of the treatment plan, and

- the effectiveness with which the treatment plan is carried out.

The savings can amount to 50% or better for the worst HVAC systems.

Another attribute of an effective system is improved occupant comfort. In some cases energy use will increase as occupant comfort preferences are addressed.

<u>Products</u>

One approach has been developed by Rossi and Braun (1997). Their product (ACRx) has been applied to air conditioners. It uses thermisters to determine the condenser air entering, suction line, and liquid line temperatures. This device uses pressure sensors to determine the high side and low side refrigerant pressures. A schematic of their basic array is shown in Figure 4.3.5.

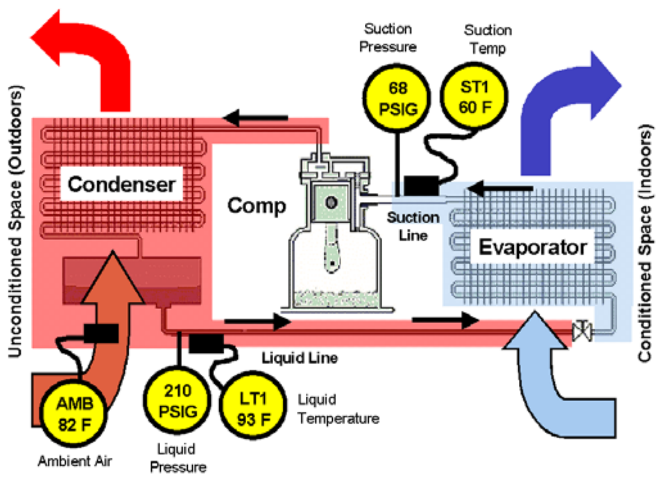


Figure 4.3.5. ACRx Diagnostic Tool Basic Sensor Array

Additional temperature sensors are also available for this product.

Rule sets are used to diagnose 5 possible faults: refrigerant leakage, liquid-line restriction, compressor valve leakage, condenser fouling, and evaporator fouling. The approach computes residuals based on a 1st order system performance evaluation and classifies the residuals that exceed a certain threshold as faults.

The basic rules used to calculate residuals are shown in Table 4.3.1.

Table 4.3.1 Fault diagnostics rules (Rossi and Braun 1997)

Fault	T_{evap}	T_{sh}	T_{cond}	T_{sc}	T_{hg}	ΔT_{ca}	ΔT_{ea}
Refrigerant leak	↓	↑	↓	↓	↑	↓	↓
Compressor valve leakage	↑	↓	↓	↓	↓	↓	↓
Liquid-Line restriction	↓	↑	↓	↑	↑	↓	↓
Condenser fouling	↑	↓	↑	↓	↑	↑	↓
Evaporator fouling	↓	↓	↓	↓	↓	↓	↑

Where: T_{evap} = Evaporator Saturation Temperature
T_{sh} = System Superheat
T_{cond} = Condenser Saturation Temperature
T_{sc} = Subcooling
T_{hg} = Hot Gas Temperature
ΔT_{ca} = Condenser Approach
ΔT_{ea} = Evaporator Approach

As temperatures change from base performance calculations, the residuals compound until the threshold is met and the fault is flagged. This system uses general fault rules that were developed by Rossi and Braun.

Another expert system diagnostic product is the Enalysis™ eScan. This product uses sensors to determine the inside and outside airflows, temperatures and humidities. It also senses high and low side pressures, suction line and liquid line temperatures. This product uses radio frequency communication with the expert system in a laptop computer and provides an immediate on-site printed report to the building owner.

Figure 4.3.6 Analysis eScan System

The Enalysis product provides diagnostic results for duct systems, furnace systems and air conditioning systems. This product senses more variables than the ACRx system and has the capability to provide more in-depth analyses.

Another expert system is the CheckMe!® system developed by the authors of this report. That system has been applied to air conditioners, heat pumps and duct systems. The basic products diagnose refrigerant charge, airflow, and duct system faults.

With the basic AC CheckMe!® thermocouples are used to determine the condenser air entering, suction line, liquid line, evaporator entering and evaporator leaving temperatures. A wet bulb thermocouple is used to determine the evaporator entering wet bulb temperature and standard refrigerant gauges are used to determine the high side and low side refrigerant pressures. The preferred airflow measurements use the TrueFlo™ Flow Grid shown in Figure 4.3.7. These data (along with make, model number, etc.) are phoned into a call center where the data are recorded and analyzed by the expert system. The immediate diagnosis and repair plan are communicated to the technician during that phone call. The analysis is based on manufacturers' specifications supplemented by error checking and statistical algorithms.

Figure 4.3.7. TrueFlo™ Flow Measurement

When the expert system or the call center operator detects problems or technician confusion the technician is immediately transferred to one of the on-call technical experts for support and assistance. Once the technician has performed the repairs the system is retested and its final performance verified. A third party report mailed to the building owner within a week of the technician visit.

Figure 4.3.8. CheckMe!® Performance Quality Assurance System

Copeland Corporation provides a system with onboard diagnostics to produce quick and accurate analysis of failures. Their system was tested on low experience level technicians and found to increase the level of correct diagnosis and repair from 17% to 92%.

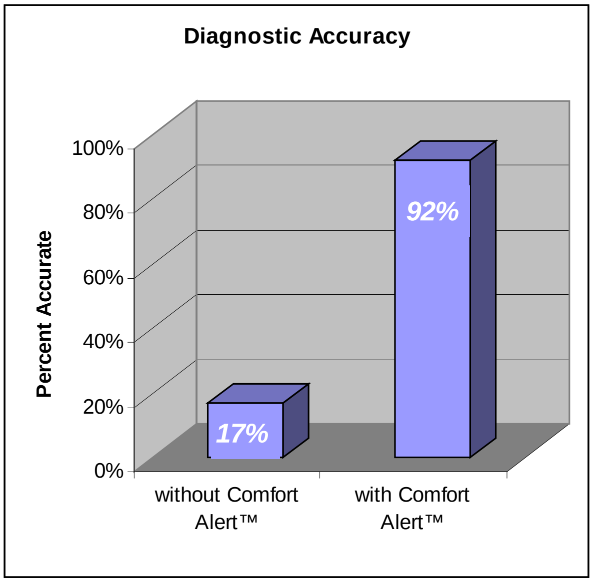


Figure 4.3.9. Success Rate for Copeland Comfort Alert™ System

Carrier-Aeroseal provides duct sealing that works by pressurizing the duct systems with sealant particles that lodge in the leaks and progressively seal them. The Aeroseal process is controlled by a computer that must be uploaded periodically to continue working. The uploaded data are analyzed for accuracy and technician performance. This system makes it possible for Carrier-Aeroseal to maintain quality performance by their franchisees.

Figure 4.3.9. Carrier/Aeroseal Duct Sealing

<u>References</u>

Breuker, M., T. Rossi and J. Braun. 2000. "Smart Maintenance for Rooftop Units." *ASHRAE Journal*, November, vol. 42, no. 11, 41-47.

http://www.copeland-corp.com/cp_ac/cp_ac_1_1_5_comfortAlert.htm

http://www.enalasys.com/products/escan.php

http://www.proctoreng.com/

Modera, Mark. Personal Communication Carrier/Aeroseal April 8, 2004

Neme, C., J. Proctor, and S. Nadel. 1999. *Energy Savings Potential from Addressing Residential Air Conditioning and Heat Pump Installation Problems*. American Council for an Energy Efficient Economy Report #A992, February 1999.

Rossi, T.M. and J.E. Braun. 1997. "A statistical, rule-based fault detection and diagnostic method for vapor compression air conditioners." *International Journal of Heating, Ventilation, and Air Conditioning and Refrigerating Research*, 3(1):19-37.

4.4 Load Reduction

<u>Purpose</u>

An integral aspect of many HVAC system optimization strategies is the reduction of the cooling or heating load. Load reductions can make the systems smaller, more compatible for multiple functions (such as cooling and ventilation) and easier to obtain optimized interactions (such as between ductwork sizing and air conditioner sizing).

4.4.1 Windows

Unwanted heat losses and gains through windows in residential and commercial buildings account for one quarter of all the energy used for heating and cooling. In order to combat these losses, new window designs are built to minimize conduction, infiltration and radiative energy transfer. The reduction in cooling requirements when upgrading a home with energy-efficient windows can be impressive. In a study conducted in Roseville, CA, two homes were monitored, each identical in layout and construction except for windows. One had standard double pane windows that met the California Title 24 standards. the other had high efficiency windows with a .41 SHG and .25 U Factor. The two homes are shown side by side in Figure 4.4.1

Figure 4.4.1. Identical Window Test Homes

In the Roseville experiment the house with the high efficiency glass produced equal comfort conditions with a 2.5-ton air conditioner, while the house with standard double pane windows required a 3.5-ton air conditioner. Figure 4.4.2 shows the AC compressor energy consumption of both houses on the same days.

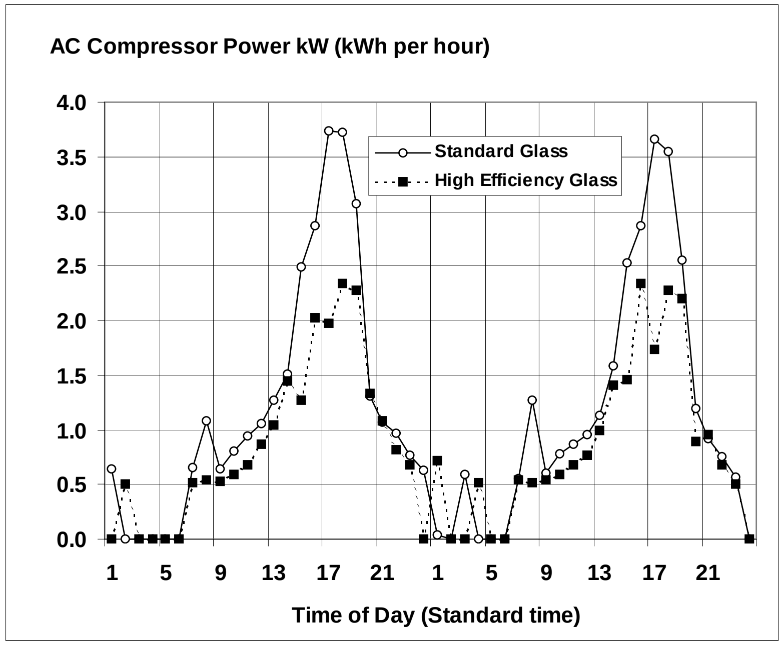


Figure 4.4.2. AC Compressor Power with Standard Double Pane Glass and High Efficiency Glass

The reduction in solar gain on the structure with the lowE² made the 2.5 ton air conditioner as effective in maintaining comfort as the 3.5 ton air conditioner, but at a lower initial AC unit cost and the opportunity to provide adequate airflow through the system without a high fan energy penalty.

References

Anello, M T, D S Parker, J R Sherwin, and K Richards. 2001. *Measured impact of advanced windows on cooling energy use.* FSEC-PF364-01. Florida Solar Energy Center, Cocoa, Florida.

Wilcox, B. and J. Larson 2004. "Measured Cooling Load, Energy, and Peak Demand Savings from High-Performance Glass in a California Production House" In *Proceedings of ASHRAE Performance of Exterior Envelope of Whole Buildings IX International Conference.* Atlanta, GA. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

4.4.2 Advanced framing

Advanced framing reduces the total amount of lumber used, reduces the scrap from building, increases the effective insulation levels of buildings, and reduces labor. Some of the components of advanced framing are:

- two foot increments in design wherever possible, particularly on sheathing and large framing members
- aligning the trusses with the load bearing studs with the floor joists
- using a single top plate since the loads are now aligned
- using metal band bracing rather than plywood (allows exterior insulation)
- in high wind and seismically active areas, using site or shop assembled shear panels that fit inside the framing rather than proprietary manufactured shear panels
- planning for the HVAC system and it's ductwork
- detailed framing plans on-site; with detailed framing plans the builder knows exactly the amount of material needed and can reduce overbuying

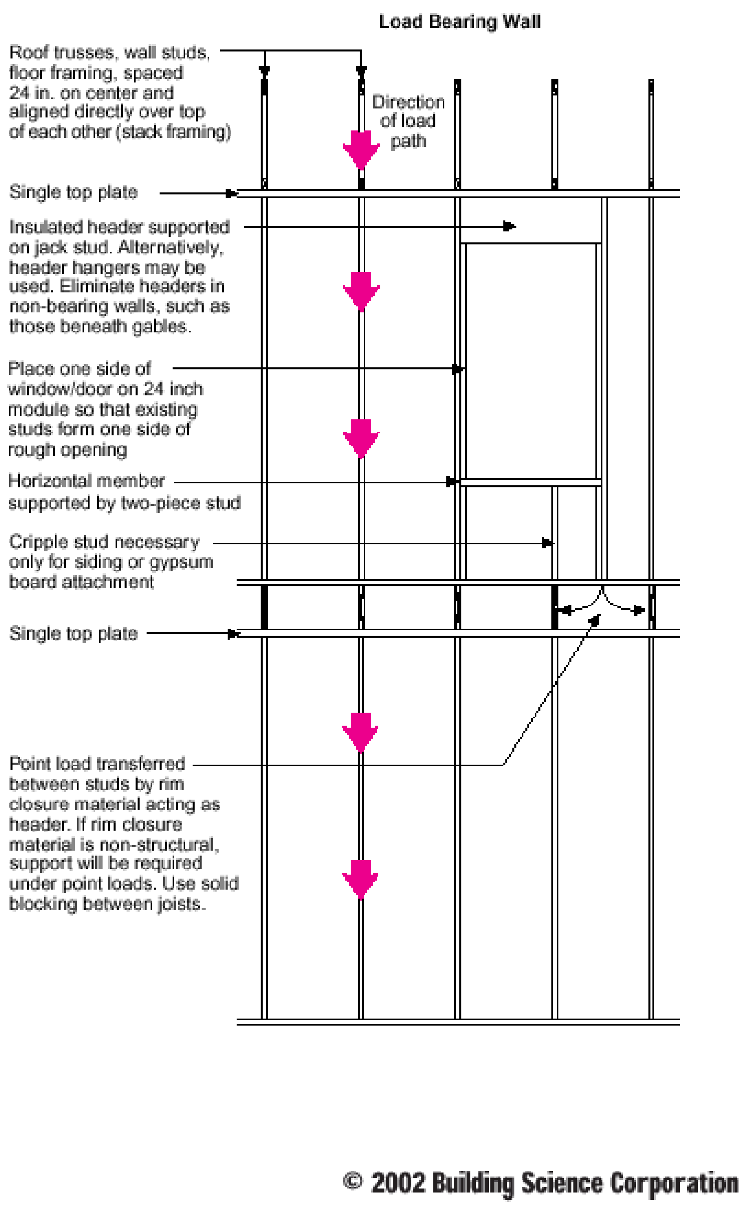


Figure 4.4.3. Advanced Framing

Savings

The savings available from this technology are dependent on the level to which the principles of advanced framing and its associated technologies are actually applied. In one example a 2,278 sq. ft. house was reengineered to remove $451 in framing materials and increasing the effective wall insulation value from R-9 to R-20.

References

"Advanced Wall Framing." 2003. Technology Fact Sheet, U.S. Dept. of Energy. http://www.eere.energy.gov/buildings/documents/pdfs/26449.pdf.

"Using Wood Effectively: From Optimizing Design to Minimizing the Dumpster" 2002 Building Science Corporation http://www.buildingscience.com/resources/misc/wood_efficiency.pdf

4.4.3. Roof and attic characteristics

Design of roofs and attics can enable large reductions in solar load during peak cooling hours. A number of studies have been performed analyzing various attributes of roofs and attics, including the following:

- Radiant barriers
- Roof material
- Roof color
- Sealed, unvented "Cathedralized" attics

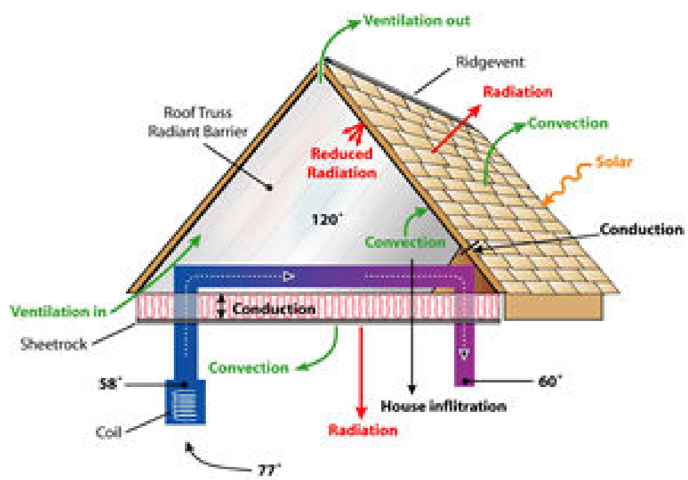


Figure 4.4.4. Roof and Attic Heat Gain
(Florida Solar Energy Center graphic)

Radiant barriers are a method of decreasing attic heat flux by adding a layer of aluminum foil in the airspace between the roof surface and the attic insulation.

A study by the Florida Solar Energy Center (FSEC) retrofitted radiant barriers in nine homes with attic duct systems. The retrofit showed an average maximum daily attic temperature drop of 8ºF, an energy savings of 9%, and a peak demand reduction of 16%. In addition, the measured interior room temperatures were, on average, more than 2ºF cooler. The retail installed cost for new construction varied between \$0.15 and \$0.35 per square foot (1994 Dollars).

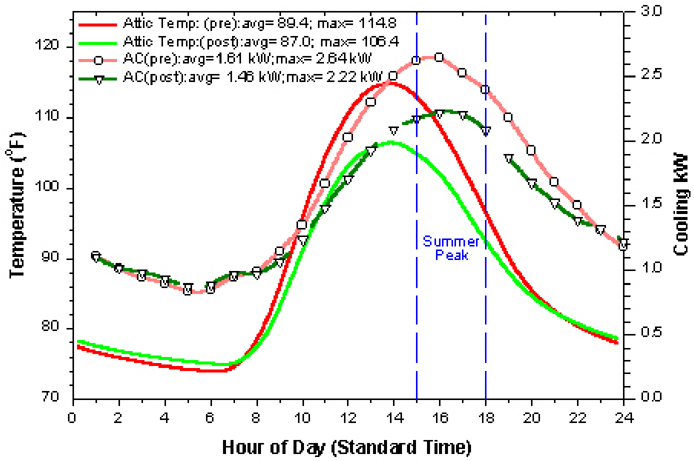


Figure 4.4.5 Attic Temperatures and AC Watt Draw with and without Radiant Barriers

FSEC has also performed testing of attic thermal performance using six different roof types (Parker and Sherwin 1998). The roofs varied in color, ventilation, roof mass, and the use of radiant barrier systems. All systems but one had 1 sq. ft. of attic ventilation per 300 sq. ft. of ceiling area.

The roof color and material, radiant barrier, as well as attic ventilation were shown to have significant affect on the attic heat flux and temperature. In particular, white roofing systems exhibited excellent thermal performance with over 60% reductions in attic heat flux. However, the use of white roofing on residential applications has not captured a major share of the market even in hot summer climates. It is hypothesized that homeowners are used to dark roofing materials.

A wider range of colors are becoming available. A study done by Miller (2000) demonstrates the use of complex inorganic color pigments to boost reflectivity in the non-visible infrared portion of sunlight. These pigments address color preferences when considering reflective roofing surfaces. The result is lower roofing temperatures, improved durability, and lower attic temperatures. The FERRO Corporation is currently producing these pigments under the names, Cool Colors® and Eclipse®. Their selection of pigments and their solar reflectivity are shown in Figure 4.4.6

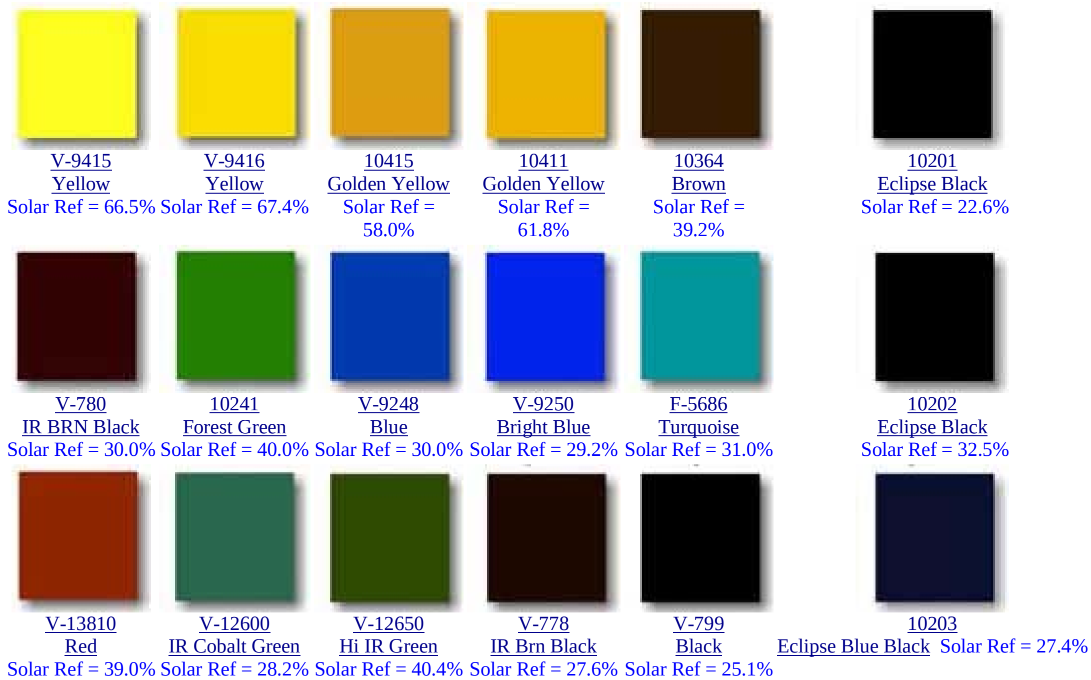


Figure 4.4.6. Reflective Color Pigments for Roofs

Potential for load reduction is significant, especially for homes with attic-mounted duct systems. Minimizing load through the roof and attic should be made part of an integrated strategy of HVAC design in cooling climates along with right-sizing ACs and ensuring proper installation.

In addition to roof color, roof material and reflective barriers "Cathedralized" attics (unvented sealed attics with insulation at the roof level) have been used. One advantage of this system is that leaky ducts are contained within the conditioned space. This design reduces the negative effect of duct leakage.

During the summer of 2000 seven unoccupied identical homes (except for attic/roofing configuration) were monitored in Ft. Meyers, Florida. The roofing systems tested and their average roof surface temperatures are shown in Figure 4.4.7.

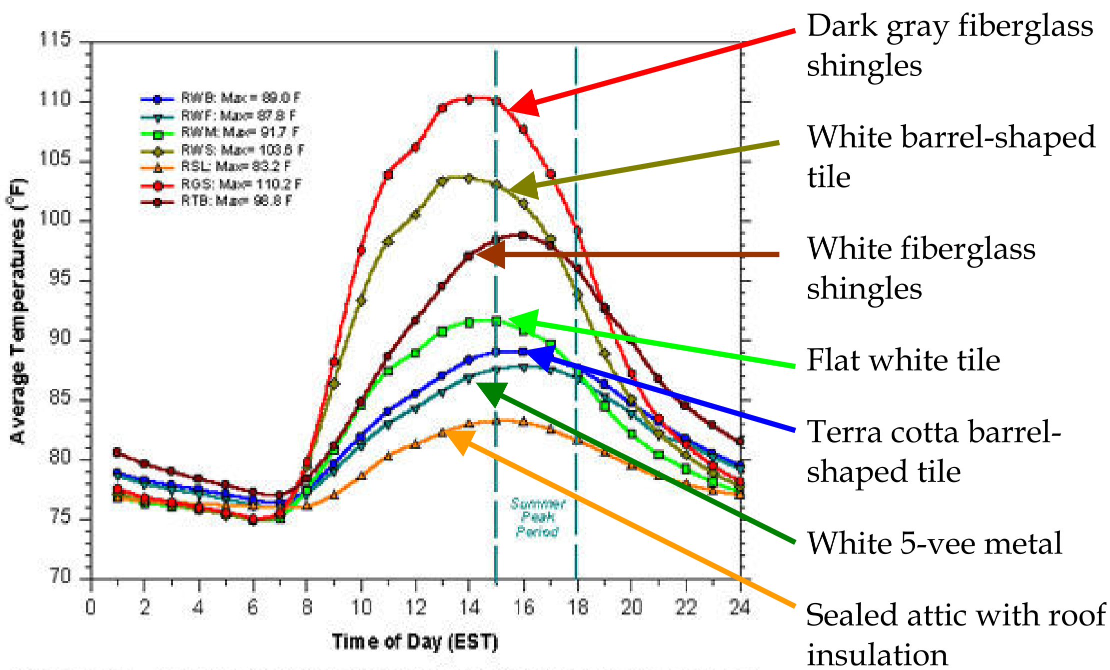


Figure 4.4.7 Attic Temperature Comparison for Roofing Color, Composition, and Sealed Attic

The home with the sealed attic had the lowest attic temperatures. At the same time the there is no insulation between the attic and the rooms below. The result was a higher amount of heat gain into the rooms below.

The attic/roof design influences the average cooling load and to an even greater extent the peak cooling load. Table 4.4.1 shows both the average cooling savings and 4 to 6 PM cooling peak reductions for each configuration[18].

Table 4.4.1 Average Energy Savings and Peak Reduction by Roof Design		
Configuration	Energy Savings	Peak Reduction
Dark Grey fiberglass shingles (Baseline)		
Terra cotta barrel-shaped tile	8%	4%
Sealed attic with roof insulation	8%	0+%
White fiberglass shingles	11%	12%
White barrel-shaped tile	19%	34%
Flat white tile	22%	38%
White 5-vee metal	24%	40%

The advantages of white (or high solar reflectance) tile and metal roofs are clear from the above table. A reduction of 30 to 40% in peak would produce the opportunity for substantially smaller air conditioners and duct systems.

<u>References</u>

Miller, W.A., K.T. Loye, A.O. Desjarlais, and R.P. Blonski. "Cool Color Roofs with Complex Inorganic Color Pigments." 2002 ACEEE Summer Study Volume 1 Pages 195-206

Parker, Danny 2005. *Literature Review of the Impact and Need for Attic Ventilation in Florida Homes*. FSEC-CR-1496-05 Florida Solar Energy Center Cocoa, FL.

Parker, D.S., J.R. Sherwin and M.T. Anello, January 2001. *FPC Residential Monitoring Project: New Technology Development – Radiant Barrier Pilot Project.* Contract Report FSEC-CR-1231-01, Florida Solar Energy Center, Cocoa, Florida.

Parker, D., and J. Sherwin. 1998. *Comparative Summer Attic Thermal Performance of Six Roof Constructions*. Florida Solar Energy Center FSEC-PF-337-98.

[18] adjusted for air conditioner efficiency and interior temperatures

Parker, D.S., J.K. Sonne and J.R. Sherwin. "Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida." 2002 ACEEE Sumer Study Volume 1, Pages 219-234

Ruud, A. F., J. W. Lstiburek, and N. A. Moyer 1997. "Measurement of Attic Temperatures and Cooling Energy Use In Vented and Sealed Attics In Las Vegas, Nevada" In *EEBA Excellence,* The Journal of The Energy Efficient Building Association. Minneapolis MN. Spring 1997

4.4.4. Exterior shading

Exterior shading plays an extremely important role in reducing solar loads through windows. Large overhangs and verandas have been traditional in many hot parts of the world. They have provided more comfortable conditions in homes without air conditioning and, if properly positioned, significantly reduce the required size of an air conditioner. Figure 4.4.8 shows a traditional veranda.

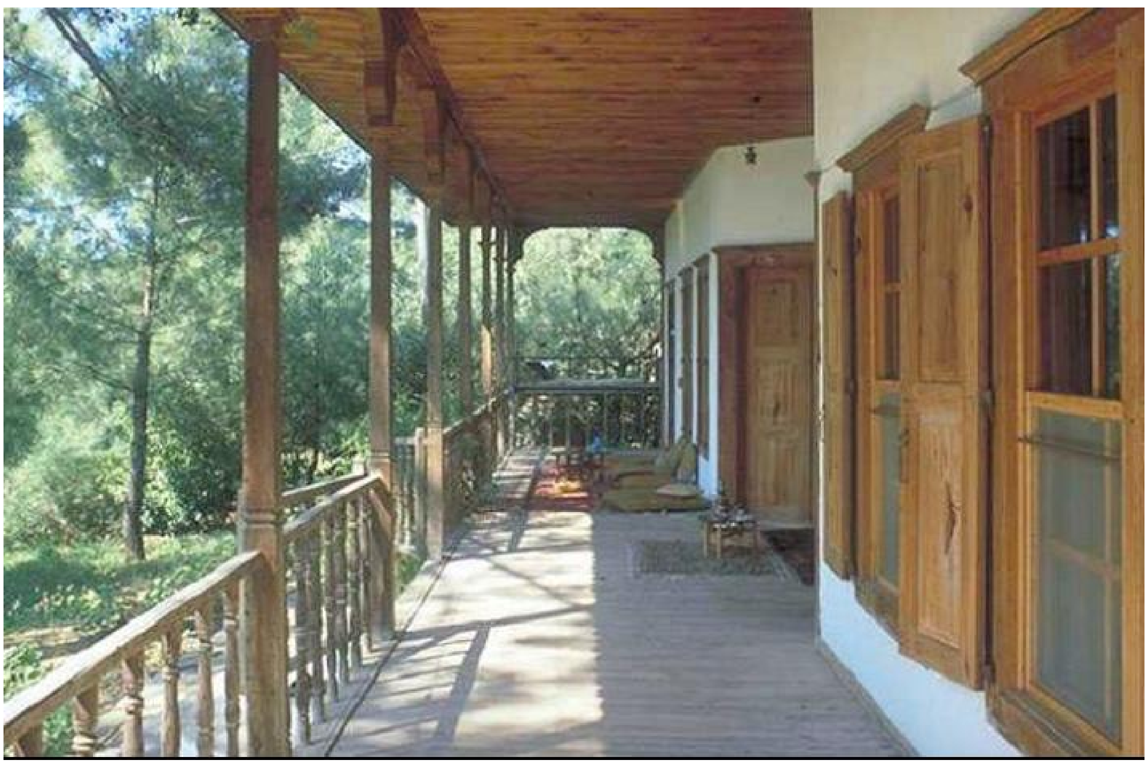


Figure 4.4.8 Traditional Veranda (Recipient of the Aga Khan Award for Architecture, 1983)

Awnings, extended roof overhangs, and solar shade screens all reduce the direct solar gain through windows. Awnings and extended roof overhangs can significantly reduce solar loads on the exterior walls of a home

Farrar-Nagy et al. (2000) investigated the effects of shading and glazing combinations on a home in Tucson, AZ. Through direct measurement and modeling they compared standard clear double glazing with spectrally selective windows (SC 0.37, center of glass U 0.296) with and without exterior shading. The results were cooling and heating cost reductions between 10% and 28% depending on orientation from the exterior shading alone. Figure 4.4.9 shows the results from that study.

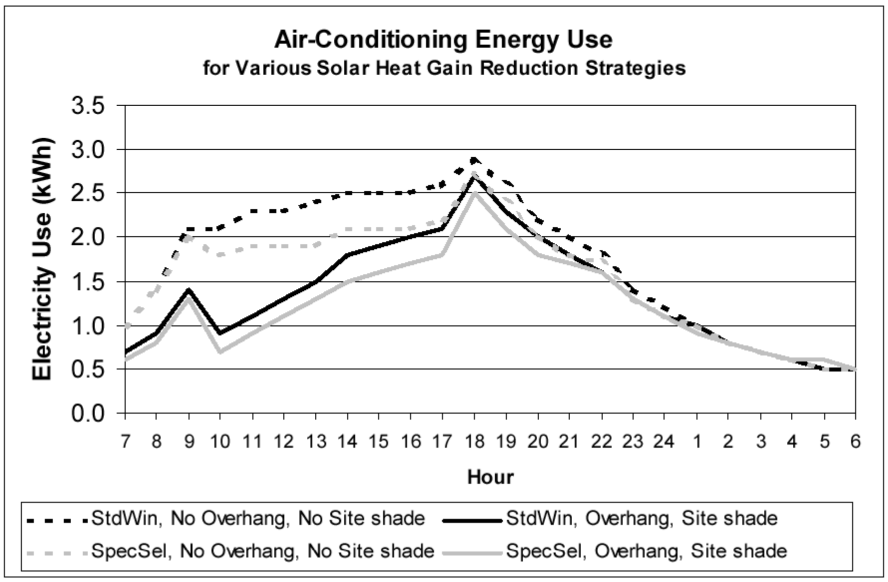


Figure 4.4.9 Air Conditioning Energy Use with and without Exterior Shading

<u>References</u>

Farrar-Nagy, S., R. Anderson, P. Reeves, and C. Hancock 2000. "Impacts of Shading and Glazing Combinations on Residential Energy Use in a Hot Dry Climate" in *2000 ACEEE Summer Study on Energy Efficiency in Buildings*.

Lib Reid-McGowan 2000. *Passive Cooling for Your North Carolina Home.* North Carolina Solar Center SC113, Raleigh, NC

Parker, D., Dunlop, J., Sherwin, J., Barkaszi, S., Anello, M., Durand, S., Metzger, D., and Jeffrey K. Sonne, J. 1998. *Field Evaluation of Efficient Building Technology with Photovoltaic Power Production in New Florida Residential Housing*. Florida Solar Energy Center FSEC-CR-1044-98, Cocoa, FL.

Veranda, **www.akyaka.org/cakirhan/odul_evi/ odul_evi_eng.htm**

4.4.5. Reduced infiltration with controlled ventilation

Ventilation has been the neglected stepchild of the residential HVAC system. In the past it has been considered unnecessary to provide any ventilation (other than "natural ventilation" from infiltration and operable windows).

Natural ventilation, otherwise known as infiltration, is predominantly driven by the stack effect (due to temperature differences between the air inside the home and the outdoor air), however the window opening behavior of occupants can change the ventilation rate quite significantly (Howard-Reed et al. 2002). Winds also drive natural ventilation. On a calm day with little temperature difference between inside and outside, natural ventilation approaches zero leaving a home under-ventilated. When the inside outside temperature differential is high (cold winter days and hot summer days) the average home is over-ventilated. At the times when the HVAC system is called upon to deliver the maximum cooling or heating, excessive ventilation adds significantly to the load.

This section does not discuss the need for ventilation, it is based on the position that it is needed and that the standards (ASHRAE 2004) that specify ventilation are appropriate for health reasons. (See Grimsrud and Hadlich 1999, Hadlich and Grimsrud 1999).

This section also does not address the problems of duct leakage and conduction losses, which affect the effectiveness of any ventilation system.

It has long been advocated that homes be built sufficiently airtight so that infiltration is small. "Build it tight and ventilate it right."(Nisson and Dutt 1985). With such construction, the ventilation air can be controlled and always supplied in the proper quantity.

<u>Methods</u>

The science and practice of building a reasonably tight building envelope is relatively well known and is practiced in new construction in the Building America Program. The primary differences in application are the methods of supplying the ventilation air to the building. The methods are:

- Supply only
- Exhaust only
- Balanced flows

Obviously all methods result in a balanced flow of air into and out of the building. The two "unbalanced" systems result in a pressurization or depressurization of the building.

Supply Only Ventilation Systems

Supply only ventilation systems force air into the building pressurizing the building above its “natural” pressure state. This type of system has the potential to drive moisture into the walls and cause home durability problems in some cold climates. At the same time it has the potential of assisting the removal of combustion products in vented combustion appliances.

One of the main advantages of supply only ventilation is that if the supply air is brought in through a single point (or limited number of points) the ventilation air can be treated (filtered, dehumidified, heated, cooled) prior to its introduction into the occupied space. Another advantage of the supply only system is that it can be implemented at low cost.

One form of supply only ventilation is a traditional outside air vent ducted to the return plenum of a forced air system. This system provides ventilation that increases with the run time of the furnace/air conditioner and provides no ventilation when the heating/cooling system is not operating. Since the operation of the heating/cooling system is synchronized with indoor-outdoor temperature differentials, the house can be over-ventilated when it is particularly hot, cold, or humid. When there is little call for heating, cooling, or dehumidification this system provides little or no ventilation.
The outside air ducted into the return system has been modernized by the addition of an electronic controller that which ensures the system operates at least a sufficient portion of the time to provide the required ventilation. A further expansion of this concept is closing a damper to the outside when the air handler run time exceeds that required for sufficient ventilation. Commercial versions of these methods are implemented in the FanCycler™

Other forms of supply only ventilation include the use of a high efficiency fan to continuously or intermittently supply outside air to the conditioned space.

Exhaust Only Ventilation Systems

Exhaust only ventilation systems pull air from the building depressurizing the building below its “natural” pressure state. This type of system has the potential to pull moisture into the walls and cause home durability problems in some hot moist climates. At the same time it has the potential of backdrafting combustion products into the conditioned space. Implementation of this method has been tried and rejected by some builders because CO alarms present in the homes were alerting the occupants to CO concentrations.

One of the main advantages of exhaust only ventilation is that it can be implemented at low cost.

The simplest form of exhaust only ventilation is a bathroom (or other) exhaust fan running continuously at a low (and preferably quiet) speed. Properly sized and operated this system can provide a known minimum amount of ventilation. In this form, there is no secure distribution system that fixes the amount of ventilation air to each room, it only guarantees that a certain amount of air is entering the home somewhere and leaving through the exhaust fan.

Other forms of exhaust only ventilation include the use of a high efficiency fan to continuously or intermittently exhaust air from a distributed collection system (in multiple rooms).

Balanced Ventilation Systems

The term balanced ventilation systems refers to systems that the outside air volume through the ventilation device is equal to the volume of exhaust air through the device. Such devices will not alter the inside/outside pressure differentials. Thus they have no effect on air entering or leaving through the building shell. Any combustion product drafting issues remain the same as in the "natural" pressure state. This type of system is most often applied with an energy recovery or heat recovery ventilator. However, exchange of heat or energy (sensible heat and moisture) between the airstreams is not necessary for a balanced system. (See "Reduced infiltration with ERV/HRV").

Savings

Reduce Air Leakage Adding any mechanical ventilation will increase the space conditioning costs above the cost of the same house without a mechanical ventilation system. In terms of reducing space conditioning costs, the first object would be to reduce the air leakage rate of the home. Take the example of a 2000 square feet three bedroom home with a "natural air change rate" of 0.70 air changes per hour (ACH) at maximum inside outside temperature differential. This house would be exchanging 233 cfm of air with outside. The ventilation need of this home based on ASHRAE 62.2 (2004) is only 100 cfm[19].

For a supply only system the supply fan would have to produce 233 cfm of airflow to force all the incoming air to flow through the supply system (for pre-conditioning outside air). If the house air leakage were reduced to provide only 0.15 "natural air change rate", 50 cfm supply would force all the incoming air to flow through the supply system.

---

[19] 62.2 is based on a default infiltration rate of 2 cfm per 100 square feet floor area. The standard for mechanical ventilation on top of that is 60 cfm for this example.

For exhaust only and balanced systems there is still an advantage to reducing the air leakage of the structure. The same reduction of maximum air exchange rates from 0.70 to 0.15 would lower the infiltration caused energy consumption for both exhaust and balanced systems by a factor of 4.7.

Conditioning Ventilation Air The ventilation air will be conditioned whether the air is conditioned on the way in, or conditioned once it is in the structure. The heating, cooling, and dehumidification loads caused by infiltration and ventilation depend on both the air exchange rate and the difference between the inside and outside conditions (temperature and moisture content).

Since any ventilation system will increase the amount of outside air introduced to the structure, they all will increase conditioning loads. Holton and Beggs (2000) performed a series of ventilation experiments on a test home in a "Mixed Climate". The annual heating cost for providing sufficient ventilation (0.35 ACH) to a home with a "natural air exchange rate" of 0.12 ACH is shown in Table 4.4.2.

Table 4.4.2 Average Annual Costs (Heating and Fan Energy) for Ventilation by Ventilation Strategy

Ventilation System	Heating Ventilation Cost ($ per year)	Fan Energy Cost ($ per year)	Total Ventilation Cost ($ per year)	Watts per 1000 cfm (through fan)
None	0	0	(inadequate ventilation)	
Supply Only Outside Air to Return Plenum	190	?[20]	190	see discussion
Supply Only Dedicated Fan	210	140	350	1250
Exhaust Only Dedicated Fan	210	150	360	1312
Balanced Flow Heat Recovery Vent.	90	84	174	1000
Balanced Flow	130	84	214	923

[20] Holton and Beggs state that there is no fan energy cost because all the other systems require constant air handler fan operation for distribution. We do not concur with that statement.

The supply only and exhaust only systems show the expected highest heating ventilation costs and the HRV system shows the expected lowest heating ventilation cost.

The fan energy costs are critical factors. The fan energy costs are determined by the efficiency that the ventilation system supplies air to the home (cfm/watt). Standard furnace fans and distribution systems are considered inefficient. They work at approximately 510 watts per 1000 cfm. The efficiency of these ventilation systems were even worse than the furnace air handler. The saving grace is that they did not move very much air.

Because of the pressure effects of supply and exhaust only systems, a balanced system should be able to supply the same amount of ventilation air as unbalanced systems with as little as half the airflow through the fans. (Palmiter and Bond 1991). In the Holton Beggs experiment the balanced systems produced the same .35 ACH with 75% of the airflow needed for the unbalanced systems.

References

ASHRAE 2004. *Standard 62.2-2004 – Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings.* Atlanta, GA. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc

Barley, Dennis 2001 *An Overview of Residential Ventilation Activities in the Building America Program (Phase I)*. May 2001 NREL/TP-550-30107. National Renewable Energy Laboratory

Grimsrud, D.T., and D.E. Hadlich. 1999. Residential Pollutants and Ventilation Strategies: Volatile Organic Compounds and Radon. *ASHRAE Transactions, Vol. 105, Pt. 2*.

Hadlich, D.E., and D.T. Grimsrud 1999. Residential Pollutants and Ventilation Strategies: Moisture and Combustion Products. ASHRAE Transactions, Vol. 105, Pt. 2.

Holton, J.K., M.J. Kokayko, and T.R. Beggs 1997. “Comparative Ventilation System Evaluations” in *ASHRAE Transactions*, Vol. 103, Pt. 1.

Holton, J.K. and T.R. Beggs 2000. “Comparative Ventilation Systems Tests in a Mixed Climate” in *ASHRAE Transactions*, Vol. 106, Pt. 2.

Howard-Reed, C., L. Wallace, and W. Ott. “The Effect of Opening Windows on Air Change Rates in Two Homes” in *Journal of the Air & Waste Management Association*. ISSN 1047-3289 Vol.52: 147-159

Nisson, J.D. and Gautam Dutt. 1985 *The Superinsulated Home Book* John Wiley and Sons.

Palmiter, L. and T. Bond 1991. “Interaction of Mechanical Systems and Natural Ventilation” In Proceedings from *AIVC Conference on Air Movement and Ventilation Control Within Buildings*, Ottawa, Canada, 1991. 11 pp.

Sherman, M. 1998. *The Use of Blower-Door Data.* LBL #35173 Laurence Berkeley Laboratory, Berkeley, CA March 1998

4.4.6. Reduced infiltration with ERV/HRV

With advances in materials and construction processes over the years, the envelope of residential buildings has become increasingly tight. This greatly reduces heating and cooling loads in the building, establishing a solid foundation for HVAC size reduction and energy savings. However, in the interest of load reduction, proper ventilation cannot be cast aside. Tight homes require mechanical ventilation, to meet ASHRAE 62.2 standards, to improve indoor air quality, and to reduce the possibility of mold growth. A balanced system requires an exhaust to maintain neutral pressure inside the home. With large temperature or humidity differentials between interior and outdoor conditions (i.e. during peak heating and cooling periods), much sensible and latent energy can be lost in the exhaust stream. Heat and energy recovery ventilators (HRVs and ERVs, respectively) are a means to prevent some of this energy loss.

HRVs and ERVs are air-to-air heat exchangers, commonly in a crossflow configuration, that transfer energy from the exhaust stream to the incoming ventilation stream.

<u>Savings</u>

HRVs and ERVs provide annual heating and cooling savings relative to any other system that supplies the same amount of ventilation. The potential for these recovery devices to save significant heating and cooling fuel is dependent on the amount of heating/cooling load that is attributable to ventilation. Tables 4.4.3 and 4.4.4 present savings analyses for Charlotte and Chicago.

Assumptions:

- hourly weather conditions – TMY2
- heating below 65ºF outside
- cooling above 80ºF and dehumidification above 71 grains of moisture in the summer
- winter indoor conditions 70ºF and 54 grains of moisture
- summer indoor conditions 75ºF and 66 grains of moisture
- average natural gas price $1.003 per therm
- average electrical price $0.0817 per kWh
- average dehumidifier efficiency 4 btu/kWh
- average furnace efficiency including duct losses in winter 60%
- average air conditioner efficiency including duct losses in summer 6 btu/kWh
- constant 60 cfm ventilation air (per ASHRAE 62.2)
- ventilation duct systems the same regardless of ventilation system used
- ventilation systems use equal efficiency fan/motor assemblies (.5 watts/cfm)
- HRV and ERV supply and exhaust 60 cfm
- supply only or exhaust only systems move 120 cfm into or out of the building to accomplish an additional 60 cfm of ventilation (contrary to ASHRAE 62.2 which makes no distinction between the flow rates between balanced and unbalanced systems)
- HRV and ERV are 70% efficient in energy exchange
- we are ignoring the fan heat, which is detrimental in the summer and beneficial in the winter
- the "open pipe" supply only system ducts outside air directly into the return plenum. uses a fan cycle controller and an ECM motor at half speed drawing .2 watts per cfm
- the "open pipe" system runs the air handler an additional 20% of the time to supply the ventilation
- winter latent load is calculated as if interior is maintained at 54 grains of moisture. <u>This load is ignored in the remaining calculations</u>.

Note:

- standard air conditioners are not able to provide the low sensible heat ratios required for the ventilation air alone. As sensible loads are decreased through improvements in the building shell, standard air conditioners will leave the houses overcooled (cold but not dehumidified).

Table 4.4.3 Heating, Cooling, and Fan Energy Costs for Ventilation in Charlotte, NC

Winter			
Ventilation System	ERV	Exhaust/Supply Only	Open Pipe
Sensible Load (btu)	7,143,857	7,143,857	7,143,857
Latent Load (btu)	4,212,393	4,212,393	4,212,393
Load Recovery (btu)	5,000,700	0	0
Heating Efficiency	0.60	0.60	0.60
Winter Gas Consumption (therms)	35.72	119.06	119.06
Gas Cost	$35.83	$119.42	$119.42
Fan Watts	60	60	120
Fan Hours	4380	4380	876
Winter kWh	263	263	105
Electric Cost	$22.89	$22.89	$9.16
Total Winter Cost	$58.72	$142.31	$128.58
Summer			
	ERV	Exhaust/Supply Only	Pipe Only
Sensible Load (btu)	603,949	603,949	603,949
Latent Load (btu)	4,184,893	4,184,893	4,184,893
Sensible Heat Ratio	0.13	0.13	0.13
Load Recovery (btu)	3,352,189	0	0
Cooling Efficiency (EER)	8	8	8
Dehumidification Efficiency (EER)	4	4	4
Cooling/Dehumid. kWh	337	1,122	1,122
Cooling/D Cost	$29.31	$97.70	$97.70
Fan Watts	60	60	120
Fan Hours	4380	4380	876
Fan kWh	263	263	105
Fan Cost	$22.89	$22.89	$9.16
Total Summer Cost	$52.20	$120.59	$106.86
Annual Cost	**$110.92**	**$262.90**	**$235.43**

Table 4.4.4 Heating, Cooling, and Fan Energy Costs for Ventilation in Chicago, IL

Winter	ERV	Exhaust/Supply Only	Pipe Only
Sensible Load	12,322,323	12,322,323	12,322,323
Latent Load	6,470,926	6,470,926	6,470,926
Load Recovery	8,625,626	0	0
Heating Efficiency	0.60	0.60	0.60
Winter Gas Consumption	61.61	205.37	205.37
Gas Cost	$61.80	$205.99	$205.99
Fan Watts	60	60	120
Fan Hours	4380	4380	876
Winter kWh	263	263	105
Electric Cost	$22.89	$22.89	$9.16
Total Winter Cost	$84.69	$228.88	$215.14

Summer	ERV	Exhaust/Supply Only	Pipe Only
Sensible Load	308,454	308,454	308,454
Latent Load	1,896,924	1,896,924	1,896,924
Sensible Heat Ratio	0.14	0.14	0.14
Load Recovery	1,543,765	0	0
Cooling Efficiency	8	8	8
Dehumidification Efficiency	4	4	4
Cooling/Dehumid kWh	154	513	513
Cooling/D Cost	$13.40	$44.66	$44.66
Fan Watts	60	60	120
Fan Hours	4380	4380	876
Fan kWh	263	263	105
Fan Cost	$22.89	$22.89	$9.16
Total Summer Cost	$36.29	$67.55	$53.82
Annual Cost	**$120.98**	**$296.43**	**$268.96**

References

www.aircycler.com

Holton, J.K., M.J. Kokayko, and T.R. Beggs. 1997. “Comparative Ventilation System Evaluations.” in *ASHRAE Transactions*, Vol. 103, Pt. 1.

Khattar, M.K., and M.J. Brandemuehl. 2002. “Separating the V in HVAC: A Dual-Path Approach.” ASHRAE Journal, May.

Lubliner, M., D.T. Stevens, and B. Davis. 1997. “Mechanical Ventilation in HUD-Code Manufactured Housing in the Pacific Northwest.” ASHRAE Transactions, Vol. 103, Pt. 1.

Matson, N. and H. Feustel 1998. *Residential Ventilation Systems* Final Report NYSERDA 98-7. Albany NY

Robertson, J.A., R.E. Brown , J.G. Koomey, and S.E. Greengerg. 1998. “Recommended Ventilation Strategies for Energy-Efficient Production Homes.” LBNL-40378.

Sherman, M.H. and N. Matson 1997. “Residential Ventilation and Energy Characteristics.” ASHRAE Transactions, Vol. 103, Pt. 1.

4.5 AC/HP Unit Improvements

The first level of system improvement is upgrading individual components. When the range of conditions the component experiences are well known this can be a very effective method of improving overall efficiency. Since this level of improvement is not necessarily compared against other possible improvements (for example: high efficiency motors vs. improved installation practices) the results may be less cost effective than an alternative.

Component improvements can be made on both the refrigerant side of the system (compressor, metering device, heat exchangers, etc.) and the airside of the system (fans, motors, cabinets, heat exchangers, etc.) The changes to the refrigerant side are discussed in this section.

4.5.1. Compressors

The efficiency changes from compressors can be broken into four parts.

First, the size (displacement) of the compressor relative to the size (UA) of the heat exchangers is critical. Improvements in system efficiency (such as improving the heat transfer at the coils) increase the air conditioner capacity. Capacity increases are countered by reduced compressor size resulting in a higher efficiency unit with the same capacity. Compressor costs are reduced when the compressor is downsized. The approximate cost reduction is 8% per 10% size reduction.

Second, variable capacity (multi-speed, variable speed, etc.) compressors are used primarily to improve efficiency at part load. Optimizing an HVAC system is not a simple process. The system must operate effectively under a wide range of psychrometric conditions within the home and in the ambient. At the same time the system is likely to be installed on a wide variety of homes, homes with different duct systems (leakage, resistance to flow, conduction losses), as well as homes with different HVAC loads due to building shell differences. Multi speed or variable speed compressors provide the opportunity to adapt the equipment to these vagaries.

Third, the efficiency of the compression cycle can be improved through close attention to flow passages and other design revisions. Scroll designs for example are significantly different from more conventional reciprocating designs. Under some conditions scroll compressors can be more efficient than their reciprocating counterparts. However scroll compressors are not universally a better choice than a reciprocating compressor.

Fourth, the efficiency of the compressor motor can be increased. The motor efficiencies for high performance compressors are in the high 80s (Pham 2005).

There are a number of motors available and being developed that could be used in residential size compressors. The primary issue is one of cost effectiveness. One potential motor design and control is produced by a group of companies (Friesen Power, Core Motion, Lynx Motion Technology, and Kinetic Art and Technology). They produce motors in the 1/5 to 200 hp range. Their motors are claimed to be more than 94% efficient at all speeds. Their magnet material is Neodymium. Friesen Power's neodymium magnets are as much 30 times more powerful (per cubic inch) than traditional, copper coil and Iron magnets, which allows them to build a much smaller and lighter motor. Their 1 hp motor weighs 8 lbs.

The manufacturer also states that their controls keep the power factor at unity and minimize any harmonic distortion on the incoming power.

<u>Savings</u>

A rise from an 89% efficient compressor motor to a 94% efficient motor on a unit where 82% of the power consumption is in the compressor would result in a savings of 4.4%.

<u>References</u>

Pham, Hung 2005. Personal communication January 2005, Copeland Corporation.

Proctor, J., T. Downey, C. Boecker, Z. Katsnelson, G. Peterson, and D. O'Neal. 1996. "Design and Construction of a Prototype High Efficiency Air Conditioner." Prepared for Pacific Gas & Electric Company Research Development Department.

Wheeler, J. 2004. "Wheeler On HVACR: New HVACR Technology — Compressors" in *Supply House Times* BNP Media.

4.5.2 Refrigerant metering devices

Refrigerant metering devices control the flow of refrigerant and provide the pressure drop from the high-pressure side of the system to the low-pressure side of the system. Feeding too little refrigerant into the low side will result in high evaporator superheat, which reduces efficiency and can cause compressor failure. Feeding too much refrigerant into the low side produces low or no superheat, potentially increasing the efficiency while running a risk of slugging the compressor and compressor failure.

The highest efficiencies occur when the superheat is at or near zero under any condition, so reaching for higher efficiencies has to balanced with protecting the compressor.

Thermostatic expansion valves (TXVs) are the metering devices of choice in most new high-efficiency air conditionings. Short tube orifices are the most common metering devices and they are used on baseline units of lower efficiencies.

A TXV is a self-adjusting device that meters the proper amount of refrigerant into the evaporator coil to maintain a constant superheat. To some degree the TXV can compensate for field errors in charging. A short tube orifice on the other hand has excessive superheat at low-pressure differentials and when the unit is undercharged.

An electronic expansion valve (EEV) has the potential of controlling superheat more accurately than a TXV. As a result the superheat could be reduced to provide some increase in capacity and efficiency.

Savings

Electronic expansion valves could provide a savings over TXVs between 1% and 4%.

References

Proctor, J., T. Downey, C. Boecker, Z. Katsnelson, G. Peterson, and D. O'Neal. 1996. "Design and Construction of a Prototype High Efficiency Air Conditioner." Prepared for Pacific Gas & Electric Company Research Development Department.

4.5.4 Frostless heat pump

Heat pumps periodically run through a defrosting cycle to keep the outdoor coil free of obstruction when the ambient temperature is below 40^{o}F. Defrosting occurs by reversing the cycle to heat the outdoor coil (and cool the indoor coil). The hot gas is discharged to the outdoor coil, condenses, travels to the metering device and is expanded in the indoor coil. The indoor coil picks up heat from the inside air (cooling it) which it delivers to the compressor. The heat removed from the inside air and the heat of compression ends up as heat discharged at the outdoor coil melting the frost. In order to compensate for the indoor cooling in the winter, electric resistance heaters are usually employed to reheat the indoor air.

A new technology developed at Oak Ridge National Laboratory (Mei et al. 2002) provides a reduction in frost accumulation as well as defrosting in a different manner – a resistance heater added to the accumulator. The accumulator electric resistance heat is added during the heating mode when frosting is a potential problem. Most of the additional heat is discharged into the inside air, increasing the delivery temperatures.

When defrosting is desired the cycle reverses as usual; however, rather than absorbing most of the defrost heat through the evaporator coil, electric resistance heat is added at the accumulator. The indoor fan is turned off during the defrost cycle reducing the need for electric resistance heat and saving the power of the fan.

Theoretically the system raises questions about the efficacy of increasing the outdoor coil temperature, compressor temperature and accumulator temperature. However, Mei et al. have tested this configuration in the laboratory and have projected significant savings from the reduction in the number and energy cost of defrost cycles. Our initial analysis indicates that this is likely to be a better defrost mechanism than defrosting with the inside fan running.

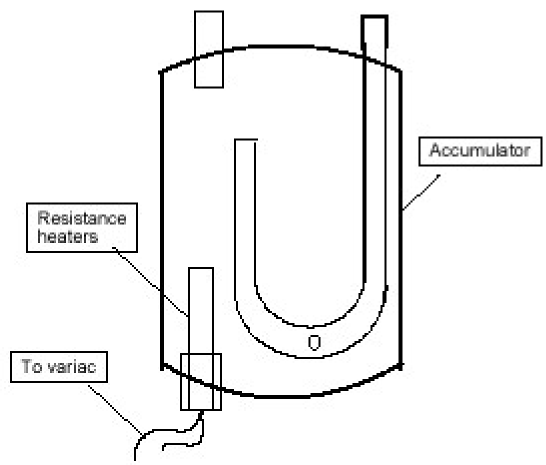


Figure 4.5.1 Electric Resistance Heater in Accumulator for Frostless Heat Pump

<u>Savings</u>

Assuming 1kW heat at the accumulator for defrost as opposed to 10kW at the inside airstream (and equal defrost time) Mei et al.'s analysis projects a defrost energy savings of 90% at all temperatures colder than 32°F.

Between 32°F and 41°F, the accumulator heater is on continuously, assumed to eliminate frost, all frost cycles, and resulting in a capacity higher than the baseline unit.

At outdoor temperatures warmer than 41°F the heat pump operated similar to the baseline.

Given these assumptions for Knoxville TN temperatures, the savings is 12.5%.

References

Mei, V.C., R.E. Domitrovic, F.C. Chen, and J.K. Kilpatrick. 2002. "The Development of a Frost-Less Heat Pump." In *ACEEE Summer Study Proceedings* August 2002.

4.5.6. ACs designed for climate regions

The needed sensible heat ratio (SHR) varies from hour to hour and region to region. A potential method of AC optimization is to design region-specific air conditioners optimized for a range of local conditions. For instance, homeowners from West Texas (out of the influence of the Gulf of Mexico moisture) to the California coast live in a dry climate[21]. They generally only have to worry about how much the air conditioner lowers the dry bulb temperature.

For the rest of the United States, and for homes in particular western microclimates, homeowners have to worry about the amount of moisture the outside air brings into the home. What is needed in the hot moist climates is moisture removal. As noted in the sections on reduced infiltration as well as Tables 4.4.4 and 4.4.5, the summer ventilation and infiltration sensible heat ratios in many locations are below .20. Standard air conditioners are generally not up to the task of removing that much moisture without overcooling the air.

Projects

Hot Dry Climates. A consortium of entities including: Proctor Engineering Group, Southern California Edison, Pacific Gas and Electric Company, California Energy Commission, and US DOE have undertaken a project to design, test, and assist into market an air conditioner with a primary design point of 115^{o}F outside, 80^{o}F return dry bulb and 63^{o}F wet bulb. This type of air conditioner is being designed to provide nearly 100% sensible capacity (as is most commonly needed in hot dry climates) with the ability to generate latent capacity when necessary. A point of concentration in this design is airflow through the indoor unit and duct system. Since high airflows produce increased sensible capacities, high airflow is desirable in this machine. The airflow is limited primarily by the large increases in fan motor watt draw as the flow is increased against the internal restrictions and external restrictions (duct system). These issues are discussed in more detail in Distribution System Improvements.

[21] The cities with drying climates are listed with 0 grains difference in ACCA Manual J7 Table 1. Cities in ACCA Manual J7 with wet climates are listed with substantially more than 0 grains difference in that table.

The design is expected to produce a 15% to 25% reduction in peak watt draw for same sized units.

Hot Wet Climates. Sensible cooling loads have dropped over the last 15 years. Insulation is more common, low solar heat gain roofs are available, and newer, high efficiency glass can block a major portion of the heat gain during the summer.

None of the above improvements has reduced the amount of moisture generated in the home or the amount of moisture entering the home with outside air. As the heat gain through walls, roofs, and windows is reduced, moisture removal becomes a larger and larger part of the cooling load.

Moisture buildup and moisture removal issues interact with the sizing issues.

In order to get any real moisture removal, the air conditioner must run long enough for the condensed water to run off the coil and down the condensate drain. For a coil that is starting dry, this can be as long as 10 to 20 minutes. The result is that a short run time—which is what larger air conditioners generally provide—fail to remove sufficient moisture in a wet climate. An air conditioner connected so the blower turns on and off with the compressor provides the most moisture removal. In addition, the moisture removal improves dramatically when the compressor runs longer (see Figure 4.5.2). Smaller air conditioners will run longer and do a better job of removing moisture. The effect of running the blower all the time (an increasing practice), is dramatic as well—in a very different way. Under continuous blower operation, moisture removal is zero until the compressor is running over 13 minutes every time it comes on (see Figure 4.5.2 based on Henderson 1998). Field data show that most compressor runs are less than 10 minutes, resulting in reduced moisture removal.

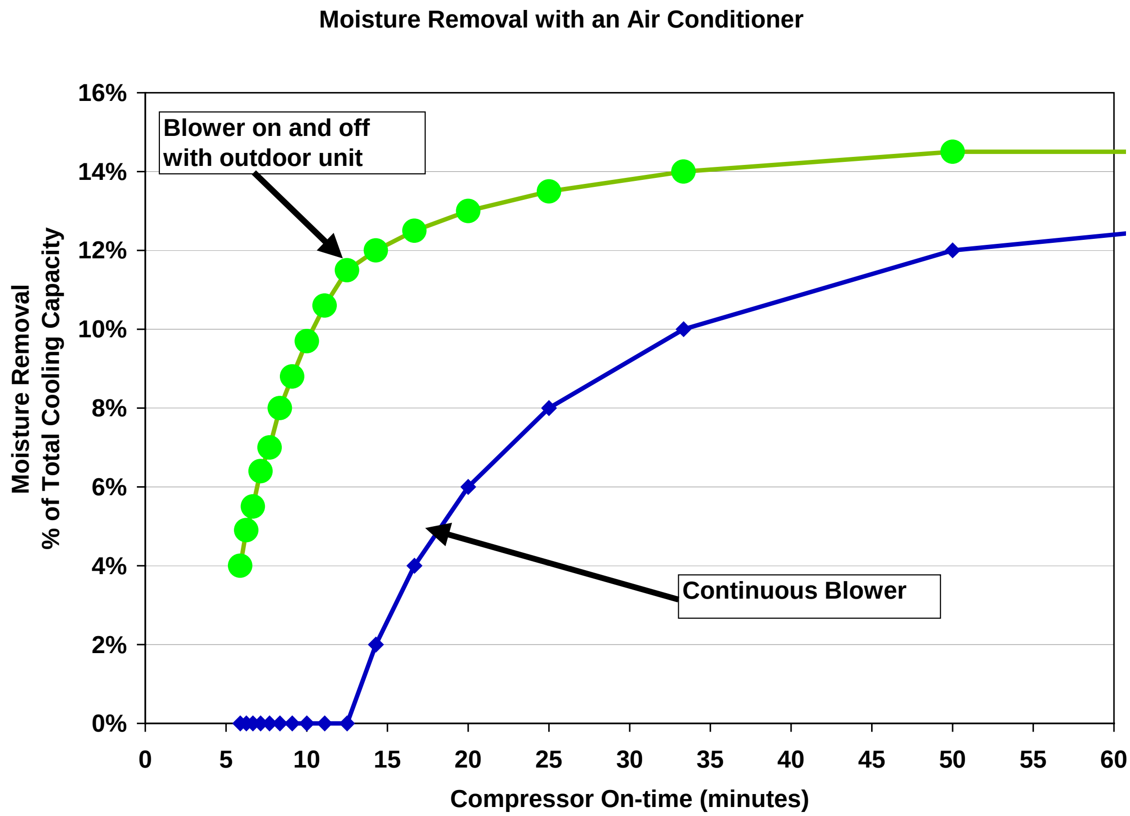


Figure 4.5.2 AC Moisture Removal as a Function of Compressor On-Time and Blower Controls

A consortium of entities including Florida Solar Energy Center has undertaken a project to design an air conditioner with substantially higher latent capacity as needed in hot humid climates.

<u>Savings</u>

Producing air conditioners that produce the ratio of sensible cooling to latent cooling required to keep the conditioned space in the comfort range without overcooling or over dehumidifying is estimated to reduce energy consumption between 10% and 20%.

Such changes also hold promise for reducing peak electrical demand.

<u>References</u>

ACCA *Manual J*. Air Conditioning Contractors of America, 1513 16th Street, N.W., Washington, DC 20036. www.ACCA.org

Henderson, H. 1998. “The impact of partload air-conditioner operation on dehumidification performance: Validating a latent capacity degradation model.” Presented at ASHRAE’s *IAQ & Energy* ‘98 conference.

Proctor, J., T. Downey, C. Boecker, Z. Katsnelson, G. Peterson, and D. O’Neal. 1996. “Design and Construction of a Prototype High Efficiency Air Conditioner.” Prepared for Pacific Gas & Electric Company Research Development Department.

Shirey, D., and H. Henderson 2004. “Dehumidification at Part Load” in *ASHRAE Journal* April 2004

4.5.7. Evaporatively cooled condensers

Standard residential air conditioners use airflow through the outdoor coil to reject heat. A little used technology for residential systems, which can improve heat transfer at the outdoor coil, is evaporative condenser technology. Evaporative condensers use evaporation to lower the outdoor heat sink temperature. Evaporative condensers have the advantage of a near constant EER at a wide range of outdoor temperatures in dry climates. In contrast, standard air-cooled systems loose efficiency at high outdoor temperatures. This decrease in efficiency increases utility peak power draws during hot summer days.

The energy efficiency improvement from this type of device is caused by a decrease in sink temperature at the outdoor coil. The cooling water can be chilled to within 5-10°F of the outdoor wet bulb temperature. Naturally these systems favor hot, dry climates in which there are large differences between the outdoor dry and wet bulb temperatures, differences that increase the evaporative cooling effect.

A system diagram of an evaporative condenser design is displayed in Figure 4.5.3.

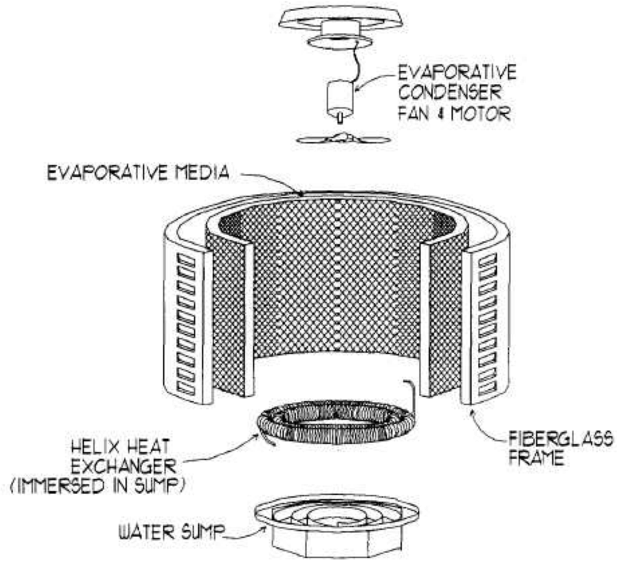


Figure 4.5.3 An Evaporative Condenser

<u>Savings</u>

The average evaporator and condenser saturation temperatures in the CheckMe!® database of over 100,000 tests are 42°F and 124°F, respectively, for properly charged air conditioners operating in an ambient air temperature of at least 95F. The ideal EER of an R22 system operating between these two temperatures is 22.4 (assuming an isentropic compressor, no superheat before compression or subcooling before expansion, and isenthalpic expansion). If the condenser saturation temperature is reduced to 100°F through the use of evaporative cooling elements, the ideal EER increases to 35.3, a 58% improvement.

Figure 4.5.4 shows actual system EER at varying outdoor temperatures for an evaporative condenser system as well as typical SEER 10 and 12 systems.

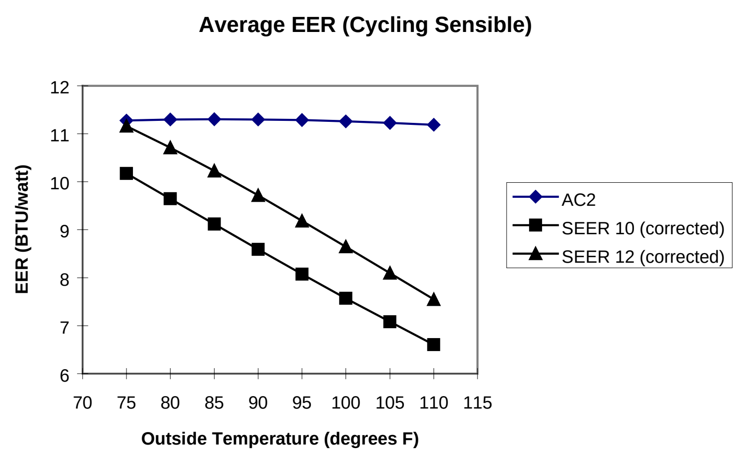


Figure 4.5.4 Field Test Efficiencies of an Evaporatively Cooled Condenser and Two Air Cooled Units

The trend in the data supports the percentage gain calculated in the theoretical analysis. Improvements are larger with increased wet-bulb depressions (drier climates).

References

Proctor, J., and T. Downey 1999. "Investigation of the AC2 Air Conditioner." Prepared for Pacific Gas and Electric Company Research and Development Department, November.

Hoeschele, M., M.J. Berman, L.E. Elberling, M.B. Hunt 1998. "Evaporative Condensers: The Next Generation in Residential Air Conditioning?" In *Proceedings of the 1998 ACEEE Summer Study on Energy Efficiency in Buildings*.

Hoeschele, M., J. Proctor and L. Elberling. 2000. "The Home Cooling Program: Lessons Learned in Transforming the Residential Cooling Market." In *Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings*.

4.5.8. Improved aerodynamic outdoor AC/HP units

Air handling efficiency is not only important at the air handler, but also at the outdoor coil. The typical outdoor heat exchanger matched with fan blade and single or dual-speed PSC motor leaves room for improvement.

Increasing condenser airflow without any changes in the coil, fan, or fan motor has an adverse effect. With increased airflow the compressor watt draw drops, the capacity increases, but, because of the increased fan power, the total kW draw increases. Increased airflow needs to be accompanied by increased fan/motor efficiency or lower resistance to airflow.

The top outlet of a typical condenser fan is essentially a free discharge covered by a fan guard. A diffuser at the condenser fan outlet improves the condenser airflow with little or no increase in watt draw.

The air entering a typical condenser fan has little or no flow preconditioning. There are potential gains in improving the inlet conditions to the fan.

Adding an inlet conditioner or an outlet diffuser would increase the materials and labor costs. In addition an outlet diffuser may significantly increase the height of the unit for shipping, unless it is shipped nested or flat separate from the outdoor unit.

The outdoor fan moves a large volume of air at low static pressure. Axial fans are well suited to the high volume and low static pressure applications of the condenser fan. The typical outdoor fan/motor combination is a propeller with a permanent split capacitor motor.

Higher efficiency combinations are potentially available including more efficient propeller fans and higher efficiency motors. The step beyond these fans is likely to be airfoil axial fans similar to those developed at Florida Solar Energy Center (Parker et al. 2005).

Figure 4.5.5 displays the FSEC Fan and Condenser airflow design (courtesy FSEC).

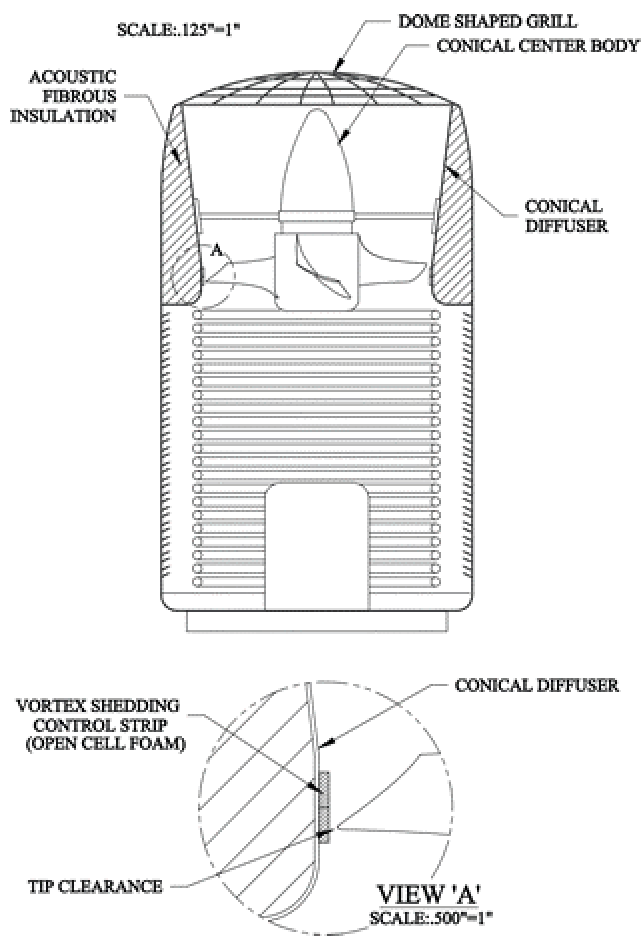


Figure 4.5.5 High Efficiency Condenser Fan Design

Savings

An improvement in condenser fan/motor efficiency of 25% (e.g. 7.5% to 10%) results in small peak reductions. However the larger impact is the potential to increase condenser airflow and improve the efficiency of the compressor due to lower condenser saturation temperatures and high side pressure.

The effect of condenser fan/motor improvements will have to be balanced against cost increases.

Current research by the Florida Solar Energy Center (FSEC) has shown that an aerodynamically designed configuration can improve the amount of airflow per watt by 28% (Parker et al. 2005).

References

Parker, D., Sherwin, J., Hibbs, B. 2005. " Development of High Efficiency Air Conditioner Condenser Fans", Draft paper to be published in *ASHRAE Transactions* in June 2005, Florida Solar Energy Center, Cocoa, FL, AeroVironment, Monrovia, CA. http://www.fsec.ucf.edu

4.6 Distribution System Improvements

Purpose

The efficiencies of conditioned air distribution systems are poor. There are losses due to conduction, leakage, and thermosyphoning. Typical duct systems lose 25 to 40 percent of the heating or cooling energy put out by the central furnace, heat pump, or air conditioner (Andrews 2001). Reducing these losses is one focus of distribution system improvements.

The air handler with its cabinet, fan, motor and heat exchangers is another part of the air distribution system. The aerodynamic efficiencies of common residential furnace air handlers are low. The average external static pressure (duct system, registers and grills, filter) is .50 IWC. With an average evaporator coil pressure drop of .25 IWC and an average watt draw of 510 watts per 1000 cfm (Proctor and Parker 2000), the aerodynamic efficiency is 17.5%[22]. Improvements in the cabinet, fan, motor, heat exchangers and duct systems can improve this efficiency. The U.S. Department of Energy (DOE) estimates that more than 14% of residential HVAC energy consumption can be attributed to air handling equipment.

Much more R&D effort is put into designing the air distribution systems of commercial applications—large engineered air handlers have efficiencies reaching 70%. This large discrepancy between residential and commercial systems reveals the extent of opportunities available for improving airflow in residential systems.

As efficiency improvements are made to the refrigerant side of the system, the outdoor fan and indoor blower become more important for power reduction.

For common new units working against a typical air distribution system, the fan and blower use between 15% and 20% of the total power. As the compression cycle is improved, cost-effective improvements are to be found in the fan and motor.

4.6.1 Improved fan motors

Condenser fan and evaporator fan motors in standard use are PSC (permanent split capacitor) motors. The efficiency of these motors varies between 60% and

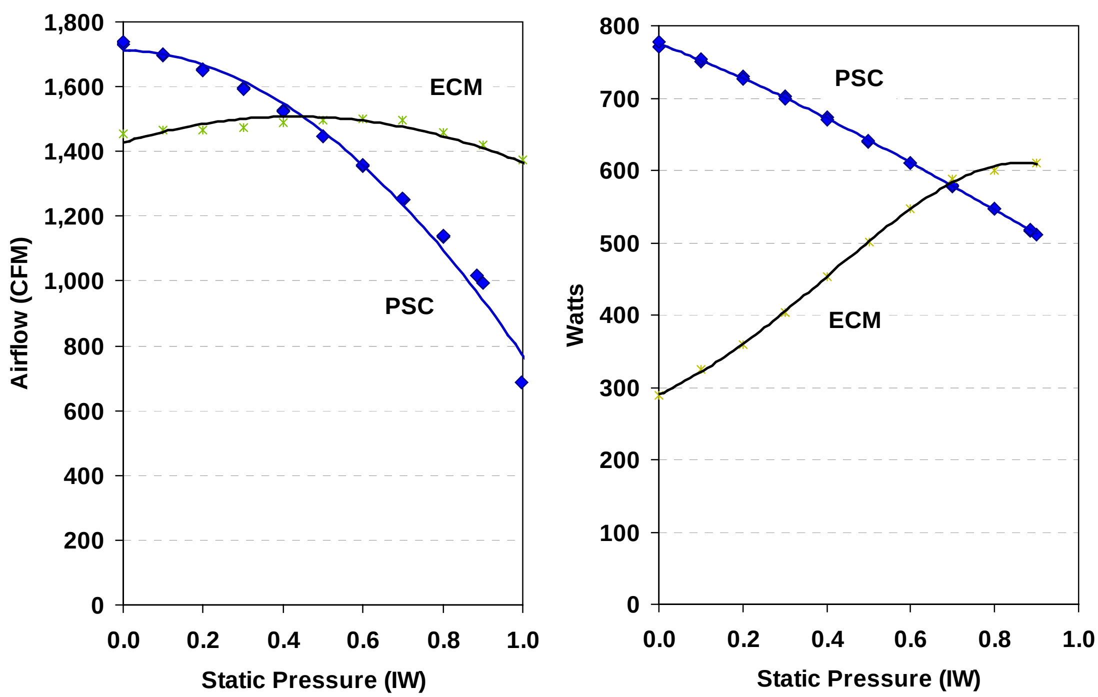
[22] in terms of work done outside the furnace cabinet

70% for evaporator fan motors and between 50% and 70% for condenser fan motors.

Higher efficiencies, above 80%, are possible with brushless permanent magnet motors (BPM). The BPM is a DC motor with a permanent magnet for the rotor. The brushes and commutator are replaced by an integrated circuit that electronically switches the stator winding polarities. The reversal rate is directly controlled at the motor, making the BPM motor inherently variable-speed. The best known of the BPM's is the General Electric ECM™.

Traditionally, multi-speed PSC motors have used such technologies as alternate taps on the windings to produce multiple speeds. The lower speeds are less efficient than full speed. With BPMs, the efficiency is significantly better than PSCs at the lower speeds. Manufacturers use BPM motors on their highest efficiency product lines.

Tests of a complete furnace with two different motors are good illustrations of the differences between standard PSC and BPM motors. Figures 4.6.1 through 4.6.3 show the flow, watt draw and efficiency of the fan/motor combination for a Carrier 58CTA090 furnace with a standard evaporator fan (Robert Davis and Emanuel D'Albora 2005).



Figures 4.6.1 and 4.6.2 ECM PSC Motor Comparisons in Same Furnace

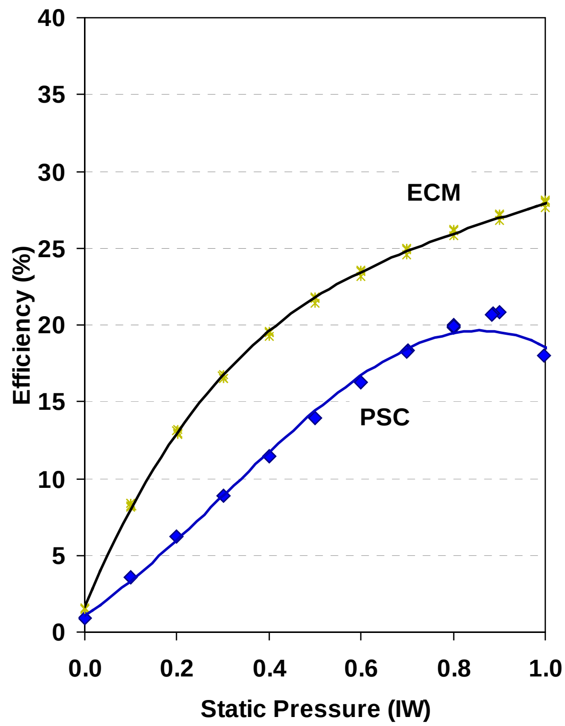


Figure 4.6.3 ECM vs. PSC Combined Fan/Motor Efficiency (External to the Cabinet) in the Same Furnace

There are a number of newer motors on the market or in development intended to compete with the ECM motor. These include permanent magnet motors from, a consortium of companies (Friesen Power, etc.) and McMillan Electric Company.

The Friesen Power motor is discussed in Section 4.5.1 (Compressors). The manufacturer claims that these motors will be price competitive with ECMs.

The McMillan Electric Motor is expected to be slightly less efficient than the ECM, but also less expensive.

DynaMotors is producing a brushless variable speed motor claimed to cost 35% less than an ECM. It does not use a permanent magnet. In the single example for which we have data, the maximum motor efficiency is approximately 65%, which is similar to a good PSC motor but less than an ECM. As shown in Figure 4.6.4, this motor draws substantially less power than a PSC when it is lightly loaded (at lower blower speed). This may be a desirable alternative to PSC motors where variable speed is desired.

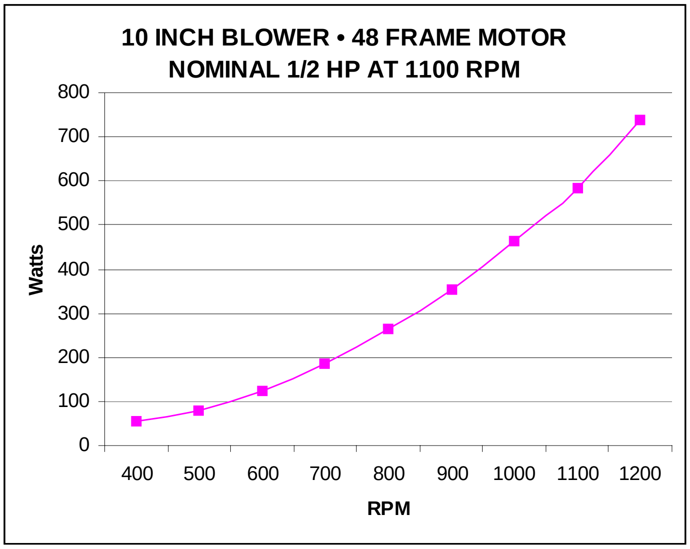


Figure 4.6.4 DynaMotor™ Watts vs. RPM

The efficiency of the indoor blower is more critical than the efficiency of the outdoor fan. When the efficiency of the blower is low not only must more energy be expended in delivering the proper airflow, but also all the energy goes into the air stream heating the air the air conditioner is trying to cool.

<u>Savings</u>

The savings from improved fan motors is not limited to the reduced watt draw of the fan motor at the same fan airflow. The improved fan motors also make it possible to increase evaporator and condenser airflow when increased airflow will improve the efficiency of the unit under the operating conditions.

In the Davis and D'Albora (2005) side-by-side test, at 1500 cfm with an external static pressure of 0.45 IWC, the ECM motor drew 477 watts and the PSC motor drew 655 watts. The pure watt draw savings keeping the flows equal is 179 watts. For a location with 1500 equivalent run hours and $0.0817 per kWh average electrical price, the savings would be $21.81 per year.

Probably of greater importance is the variable speed capability of the ECM (or other variable speed motors). Given the variable speed the air conditioner can be "tuned" to provide the best performance for a given distribution system and given interior and exterior climate conditions. In some locations, increasing the latent capacity of the system by moving fewer cfm will be the most efficient method of producing comfort in the home. At other times, or in other locations, the latent capacity may be of little importance and increasing the airflow will produce the most efficient system. In essence there are times when the fan watt draw changes will be traded off with increased or reduced compressor watt draw or unit run time.

References

Davis, Robert and Emanuel D'Albora 2005. *Draft Data from Wilcox, CEC, LBNL Furnace Testing.* Performance Testing and Analysis Unit, Technical and Ecological Services, San Ramon, CA.

Phillips, Bert. G. 1998. "Impact of Blower Performance on Residential Forced-Air Heating System Performance." *ASHRAE Transactions*, Vol. 104, Pt. 1, SF-98-30-2.

Proctor, J., and D. Parker, 2000. "Hidden Power Drains: Residential Heating and Cooling Fan Power Demand." In *ACEEE Summer Study Proceedings*.

Sachs, H.M., T. Kubo, S. Smith, and K. Scott. 2002. "Residential HVAC Fans and Motors Are Bigger than Refrigerators." In *ACEEE Summer Study Proceedings.*

4.6.2 Evaporator fans, housings and cabinet

Fan efficiency is the percentage of shaft horsepower that the fan converts into air horsepower. Virtually all the residential air handler blowers are forward-curved centrifugal fans. The potential efficiency listed in the literature for forward curved centrifugal fans is 70% (Culham and Okrasa 2001). The efficiency of these fans generally increases with increased static pressure (lower airflow) at a fixed rpm (when operating outside the surge zone). It may be that these units are properly optimized for their standard application, however an analysis of two different diameters and 4 widths of Morrison centrifugal fans showed static efficiencies always in the 35% range[23] (Morrison 1993).

The combined fan/motor efficiency of the indoor blower appears to be a primary limiting factor in unit efficiency when high sensible heat ratios are needed. In order to achieve high sensible heat ratios efficiently the flow across the evaporator coil will need to increase. The flow increases are limited by power law increases in fan watt draw.

One important design consideration for the blower is that the air duct system resistance to airflow is unknowable until the final installation. In addition, the flow resistance changes as the filter gets dirty, dampers and registers are closed,

---

[23] 2000 cfm and 1 IWC

etc. In order to deliver proper airflow under all of the reasonable installation and operating conditions, various compromises to efficiency are necessary. For example, the fan/motor assembly cannot be designed to achieve maximum efficiency at design conditions (particularly if those design conditions are as low as 0.10 IWC external static pressure). If it were, then at the common higher static pressures found in field installation would cause a rapid loss of airflow for a fan with a permanent split capacitor motor (PSC) as well as potential surging.

The potential efficiency[24] of the forward curved centrifugal blower is 70 to 75 percent. Until recently the blower wheels and housings were highly standardized.

Indoor blower design has recently been the subject of innovation. General Electric, under a DOE grant, built and tested a backwards-curved centrifugal blower with a smaller ECM motor. Trane Corporation is producing an air handler with a molded plastic fan housing capable of higher delivery efficiency within small air handler cabinets.

<u>Products</u>

Proctor Engineering Group has tested the Trane Corporation fan assembly in its designed (optimized) location and in a prototype air handler. The fan housing provides improved efficiency in both applications.

The General Electric product (Wang and Wiegman 2001) achieved a 70% peak static efficiency. The design was created for inclusion in a 3-ton residential heat pump. When compared to a baseline system, the new design resulted in a 30-50% reduction in mechanical power requirements.

[24] The fan efficiency is measured at the fan itself. The output is calculated based on the total pressure and airflow at the fan. The air handler efficiency, on the other hand (as shown in Figure 4.6.3) uses the pressure gain across the air handler and the airflow. Since the pressure gain measured across the air handler is less than the total at the fan, the output and efficiencies are lower.

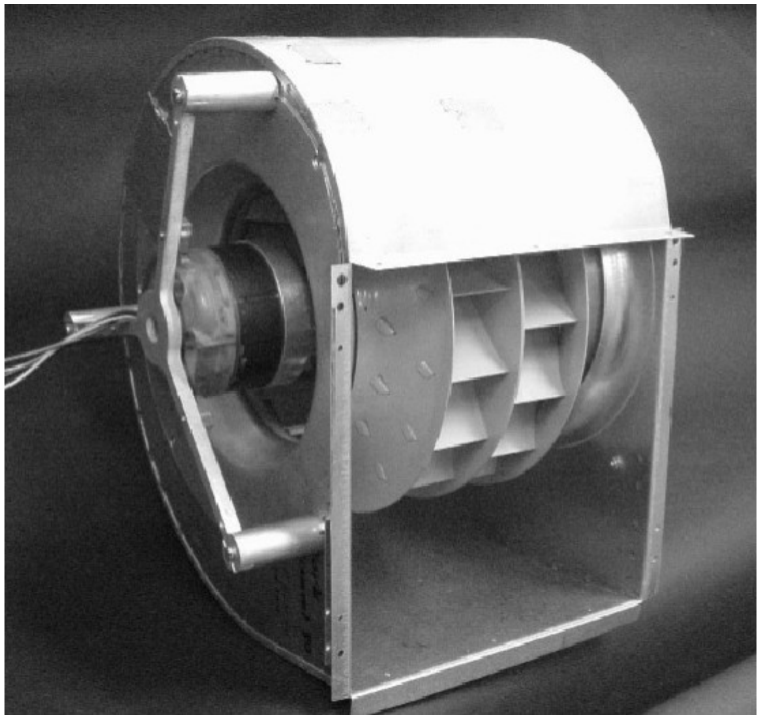


Figure 4.6.5 GE Fan with Rearward Inclined Blades Revised Housing, and Small ECM Motor

The study also demonstrated the importance of matching an integrated housing with the blower design. Table 4.6.1 shows the effects of different housing designs on static efficiency.

Table 4.6.1 Efficiency Levels for Changes in Blower, Housing, and Cabinet

Proposed change to the system	Static Efficiency
Increase housing dimension to ideal size (larger unit enclosure)	75%
Increase housing dimension to the maximum allowed by present enclosure	65~70%
Use present housing size but with shape redesign	60~64%
Use conventional housing and add an adapter inlet ring for GE-1 type wheel	55~60%
Use only one RI blower wheel to fit a wide range of present day systems	mid 50's%

Barriers to implementation include the costs of research and retooling for new designs. From an industry perspective, the incentive to create these new designs did not exist until the advent of stricter minimum SEER ratings.

Savings

An increase in fan efficiency from 35% to 45% with a PSC motor[25] would result in a savings of $17.85 per year. As with the fan motor improvements, the most important aspect of fan efficiency improvement is the potential to use higher airflows to achieve higher overall efficiency as well as higher sensible heat ratio when appropriate.

References

[CMHC] Canadian Mortgage and Housing Corporation. 1993. *Efficient and Effective Residential Air Handling Devices*, Final Report. Prepared by Allen Associates with Browser Technical, Geddes Enterprises, Brian Woods, and Ontario Hydro for Canada Mortgage and Housing Corporation, Ottawa, Ontario, Canada.

Culham R. and P. Okrasa, P. 2001. *Fans Reference Guide* 4th edition. Technology Services Department, Ontario Hydro

Davis, Robert and Emanuel D'Albora 2005. *Draft Data from Wilcox, CEC, LBNL Furnace Testing.* Performance Testing and Analysis Unit, Technical and Ecological Services, San Ramon, CA.

Morrison 1993. *Morrison Products Fan Catalogue.* Morrison Products Inc. Cleveland OH.

Phillips, Bert. G. 1998. "Impact of Blower Performance on Residential Forced-Air Heating System Performance." *ASHRAE Transactions*, Vol. 104, Pt. 1, SF-98-30-2.

Proctor, J., and D. Parker, 2000. "Hidden Power Drains: Residential Heating and Cooling Fan Power Demand." In *ACEEE Summer Study Proceedings*.

Sachs, H.M., T. Kubo, S. Smith, and K. Scott. 2002. "Residential HVAC Fans and Motors Are Bigger than Refrigerators." In *ACEEE Summer Study Proceedings*.

Wang, Shixiao and Herman Wiegman. 2001. *Topical Progress Report for the Variable Speed Integrated Intelligent HVAC Blower*. GE Corporate Research and Development report submitted to U.S. Department of Energy, Award #DE-FC26-00NT40993.

[25] based on Davis and D'Albora (2005) 1500 cfm with an external static pressure of 0.45 IWC, PSC motor draw 655 watts, a location with 1500 equivalent run hours and $0.0817 per kWh average electrical price

Wiegman, Herman. 2003. *Final Report for the Variable Speed Integrated Intelligent HVAC Blower*. GE Global Research. Draft report to be submitted to U.S. Department of Energy.

4.6.3. Sealed ductwork

Duct leakage is a major problem in both residential and commercial buildings. The amount of duct leakage, while variable from house to house is nearly always above 15% of air handler flow. Figure 4.6.6 shows the total measured leakage at .10 IWC compared to air handler flow

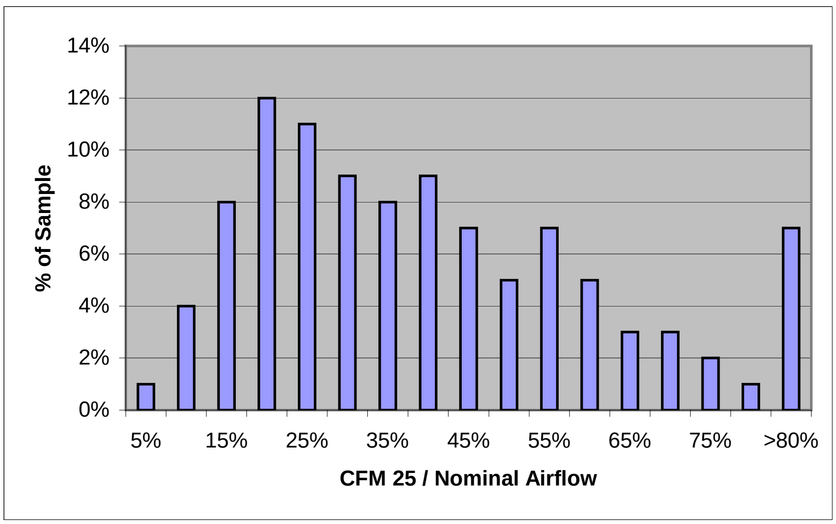


Figure 4.6.6. Duct Leakage in Existing Homes (CheckMe! 2001)

The effects of duct leakage depend on the inside and outside conditions, the location of the ducts, the flow through the air handler, and other factors. In a significant portion of the US housing stock duct leakage is sufficient to attract our attention.

Duct losses are a major source of inefficiency in residential HVAC systems. The main contributors to duct losses are leaks and conduction through duct surfaces. These losses occur when ductwork passes through an unconditioned space such as an attic or crawlspace. Typically, a duct system will lose 25 to 40 percent of the heating or cooling energy delivered by the central furnace, heat pump, or air conditioner (Andrews 2001).

With heat pumps, the duct losses reduce delivered capacity and bring in electric resistance heat. Electric resistance heat has a COP of 1 if it were delivered directly to the conditioned space. The COP is less than 1 when delivered through a duct system.

When working toward an optimized system, improvements in duct integrity allow the use of smaller air conditioners, smaller furnaces, smaller ducts, and smaller fan/motor assemblies.

Products

Multiple products address the duct leakage issue. These include hand applied duct sealants, aerosol sealants, as well as reduced leakage joint and fitting designs.

The hand application of duct sealants in the residential arena was almost exclusively cloth backed duct tape until field observations and laboratory tests showed that the seals were failing in short order. Through training programs and regulation a substantial number of installations now use mastic to produce a more durable seal.

Carrier-Aeroseal seals ducts by injecting sealant particles into a pressurized duct system. These particles lodge in the leaks and progressively close off the opening. (See Figure 4.3.9).

Proctor Engineering Group has developed a duct joining system that snaps the elements together forming a simultaneous seal and mechanical connection as shown in Figure 4.6.7.

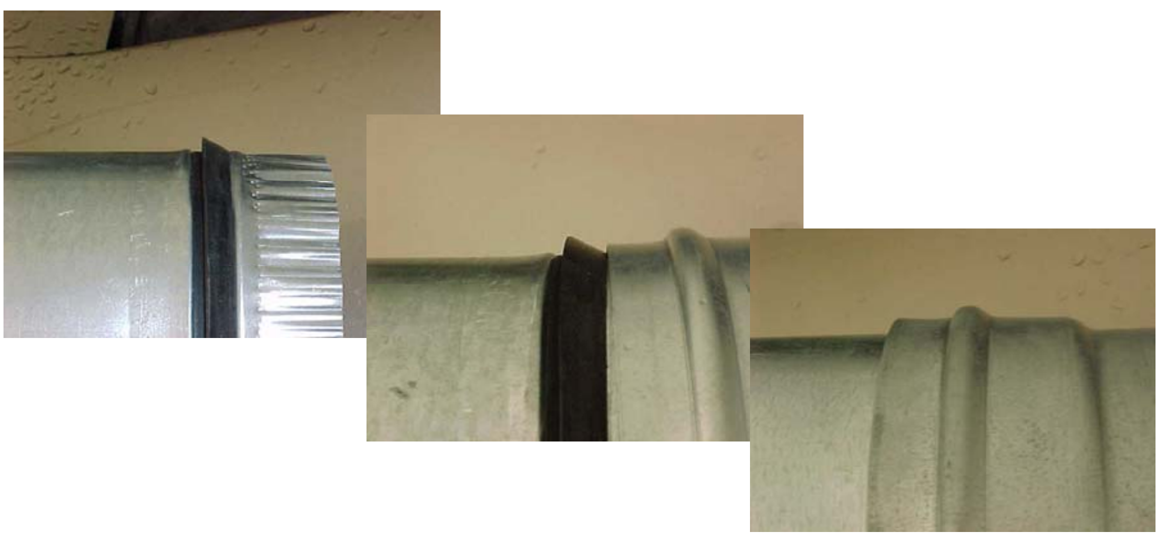


Figure 4.6.7 Steps in SnapDuct™ Connection.

The authors have also tested ducts and fittings from Seal Tite Corporation and found them to leak less than half as much as standard ducts and fittings.

Savings

Savings from duct leakage reductions can be estimated using ASHRAE Standard 152. Sealing ducts from "normal practice" to reasonably achievable minimum leakage had variable savings depending on duct location and climate. The average savings for hot climates with attic ducts is between 13% and 24%.

References

ASHRAE *Standard 152*. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers.

Andrews, J. 2001. *Better Duct Systems for Home Heating and Cooling* Prepared for Office of Building Technologies State and Community Programs U.S. Department of Energy Washington, DC 20585, BNL-68167, Jan. 2001.

Walker, I., J. Siegel, K. Brown, and M. Sherman. 1998. *Saving Tons at the Register*. LBNL-41957. Also published in Proceedings from the 1998 ACEEE Summer Study on Energy Efficiency in Buildings, 1.367-1.385.

4.6.4 Ducts in conditioned space

An effective method of "recapturing" the energy lost from ducts is to install the ductwork in the space it is conditioning. Leaks and conductive heat transfer may be captured by the space that the air is meant to condition, and losses are considered small.

While a simple concept, successful implementation can be difficult. The appearance of ductwork in living spaces is undesired, so methods have been employed to hide the ductwork. These include placing the ductwork in dropped ceiling cavities or raised sections. With these designs an air barrier and insulation are applied between the ducts and the unconditioned space. Since these designs are not standard practice, it is possible that those who install the drywall and insulation do not understand the purpose of such cavities and fail to properly seal or insulate the duct chaseways (McIlvaine et al. 2001).

Allowing leaks into conditioned spaces does not ensure proper distribution of cooling and heating throughout the home.

Recently, work has been done on extending the conditioned space to surround the ductwork. When the ducts are located in the attic this is referred to as "cathedralizing" the attic, and when they are located in the crawlspace it is sometimes called "basementizing" the crawlspace. Cathedralized attics are discussed in Sections 4.4.2 and 4.4.3. Basementized crawlspaces are discussed in more detail in Section 4.6.5 Sealed Crawlspaces.

The common situation of ducts running through an attic has multiple detrimental effects on an HVAC system. The capacity of the system is greatly diminished during peak heating/cooling hours, requiring a large system to be installed. During non-peak times the over-capacity leads to poor humidity removal. By installing ducts in the conditioned space, these problems are mitigated, improving both comfort and energy efficiency.

Savings

Savings from duct leakage reductions can be estimated using ASHRAE Standard 152.

References

Andrews, J.W. May 1999. “How to Heat and Cool a Home with 400CFM Supply Air and Keep the Ducts in the Conditioned Space.” BNL-66610.

Andrews, J.W. 2001. “Better Duct Systems for Home Heating and Cooling.” LBNL-68167.

ASHRAE *Standard 152*. Atlanta, Georgia: American Society of Heating Refrigeration and Air-Conditioning Engineers.

Griffiths, D., R. Aldrich, W. Zoeller, and M. Zuluaga. 2002. “An Innovative Approach to Reducing Duct Heat Gains for a Production Builder in a Hot and Humid Climate—How We Got There.” *ACEEE Summer Study Proceedings*.

McIlvaine, J.,D. Beal, and P. Fairey 2001. *Design and Construction of Interior Duct Systems*. FSEC-PF-365-01 Florida Solar Energy Center April 2001

Walker, I., J. Siegel, K. Brown, and M. Sherman. 1998. *Saving Tons at the Register*. LBNL-41957. Also published in *Proceedings from the 1998 ACEEE Summer Study on Energy Efficiency in Buildings*, 1.367-1.385.

4.6.5 Sealed crawlspaces

A common feature of houses in North America is a vented crawlspace under the ground floor of the house. Crawlspaces are functional in that they provide a level foundation for the building and provide a space in which plumbing and HVAC systems can be installed. Unfortunately, crawlspaces are also a location for moisture problems, which manifest themselves as mold growth, poor indoor air quality, and energy inefficiency.

Studies have indicated that sealing and insulating the crawlspace can result in a large savings in energy without any moisture problems in the crawlspace. A study performed by Hill (1998) in which a crawlspace was alternately vented and unvented yearly, provided proof of energy savings possible from sealed and insulated crawlspaces (see Figure 4.6.8)

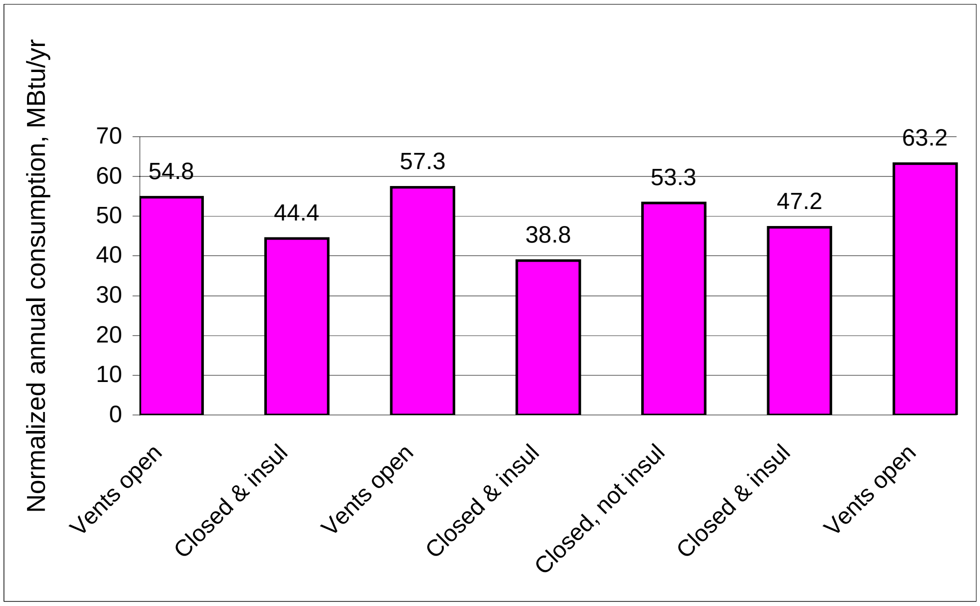


Figure 4.6.8 Energy Consumption for a Single House Alternating between Sealed and Vented Crawlspace.

Recent work by Advanced Energy Corporation (Dastur and Davis 2004, Davis and Dastur 2003), concluded:

- Foundation vents add excess moisture to crawl spaces during humid and wet weather, particularly in the summer. This excess moisture promotes mold-growing conditions.
- Ground vapor retarders (polyethylene) by themselves do not keep crawl spaces dry enough to prevent mold growth.
- Closed crawl spaces without foundation vents stay dry all the time, particularly during the summer and humid weather.
- Cooling energy savings in the experimental groups were 19% with an insulated floor and 36% with insulated crawlspace walls.
- Heating results in the experimental groups were 11% savings for insulated floors and a 2% consumption for insulated walls

<u>Savings</u>

The tests of sealed crawlspaces show heating and cooling savings in the 11% to 36% range depending on the location of the insulation.

References

Hill, W. 1998. "Measured Energy Penalties from Crawl Space Ventilation." *ACEEE Summer Study Proceedings 1998.*

Davis, B. and C. Dastur 2003. *Crawl Space Research Update Moisture Results.* Advanced Energy, Raleigh, NC. www.advancedenergy.org.

Dastur, C. and B. Davis 2004. *Crawl Space Research Update Princeville Project Energy Results.* Advanced Energy, Raleigh, NC. www.advancedenergy.org.

4.6.6 Register placement/short duct design

A promising method of integrated house and HVAC design is to improve the thermal envelope, including using high-efficiency windows, such that the register outlets can be moved from the typical perimeter locations to locations high on the inside wall. Thus the thermal distribution efficiency of the forced-air system is improved—and at reduced cost.

In the majority of homes currently built, duct systems are designed using rules of thumb and obsolete assumptions about house thermal characteristics (Hawthorne and Reilly 2000). A common rule of thumb is that the registers need to be placed towards the perimeter of the house, either below or above windows. These ideas were based on studies from the 1940s and 1950s that concluded that three factors favored these locations for registers: 1) floor warming due to conduction, 2) counteracting window convection currents, and 3) mixing capabilities. Buildings designed today differ greatly in thermal characteristics and can thus be designed with registers high on the inside wall.

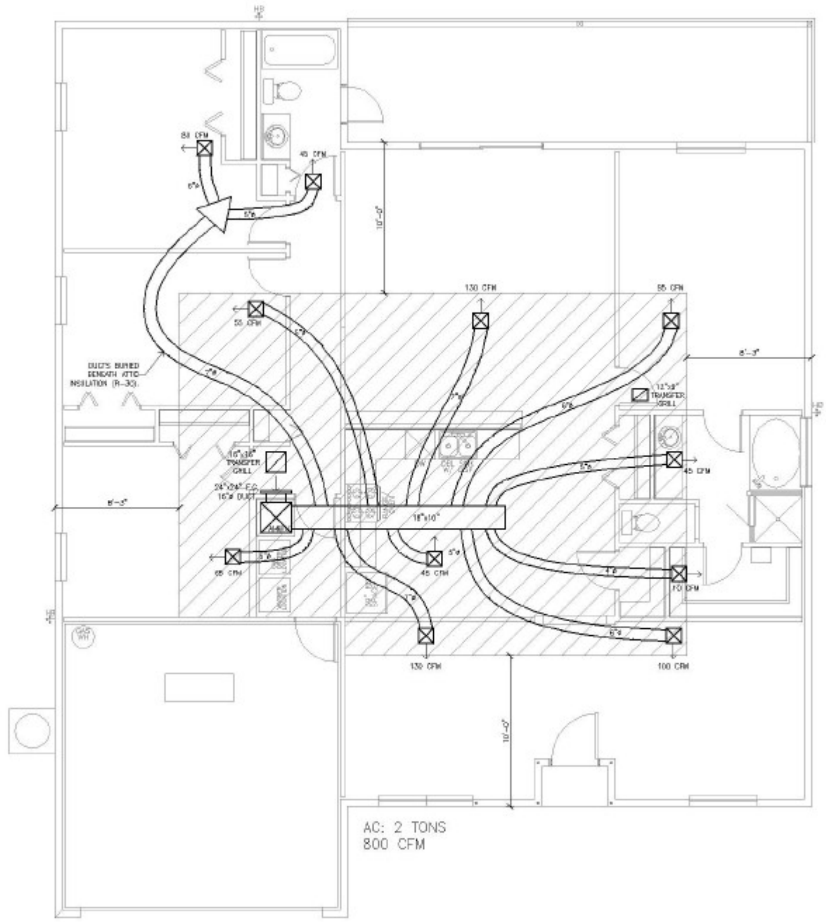


Figure 4.6.9 Short Duct Design with Center Ceiling or High Inside Wall Delivery (Steven Winter & Associates)

This system optimization strategy has been proven to work in homes built under the Building America program. Thermal distribution efficiency is greatly improved while retaining comfort conditions in the conditioned rooms.

Shorter ducts provide less conduction area and less restriction to flow which provide opportunities for additional improvements elsewhere.

<u>References</u>

Holton, John K. 2002. "Observations on Changing Residential Design Conditions and Recommendations for Register Assessment for the High Performance Home." Paper 4585, ASHRAE Annual Meeting, Honolulu, HI.

Griffiths, D., R. Aldrich, W. Zoeller, and M. Zuluaga. 2002. "An Innovative Approach to Reducing Duct Heat Gains for a Production Builder in a Hot and Humid Climate—How We Got There." ACEEE Summer Study Proceedings.

Hawthorne, Wendy A. and Susan Reilly. 2000. "The Impact of Glazing Selection on Residential Duct Design and Comfort." ASHRAE Winter Meeting, Dallas, TX. DA-00-5-1.

4.6.7 Small-duct, high-velocity systems

Small duct, high velocity (SDHV) systems are defined to be a cooling and heating product that contains a blower and indoor coil combination that: (1) is designed for, and produces, at least 1.2 inches of external static pressure when operated at the certified air volume rate of 220-350 CFM per rated ton of cooling; and (2) When applied in the field, uses high velocity room outlets generally greater than 1000fpm which have less than 6.0 square inches of free area (DOE 2002).

SDHV systems are available in AC or heat pump configurations. The small diameter ducts used in such systems makes this product ideal for retrofit applications in older buildings. SDHVs have recently been established as a separate product class so that efficiency standards for these systems may be set differently than conventional residential air conditioners and heat pumps. The reason for this action is that the SDHV manufacturers and the industry trade association, the Air-Conditioning & Refrigeration Institute (ARI), noted that the special characteristics of SDHV systems make it unlikely that such systems will be able to meet the 13 SEER minimum-efficiency standards set for 2006.

The characteristics that distinguish SDHV systems from conventional HVAC units have multiple effects on performance of the unit. Some of the benefits to using these systems are

- Increased air outlet velocities result in better mixing and less temperature stratification throughout building
- Improved humidity removal at cooling coil due to lower airflow resulting in increased residence time and lower delivery temperatures
- Reduced duct losses due to smaller conductive surface area
- Retrofit capability in buildings due to small ducts that may fit into truss spaces

Manufacturers also claim that the small duct sizes simplify sealing tasks. However, sealing should be done very thoroughly due to the high static pressures involved, which would amplify losses due to leaks.

Some drawbacks of SDHV systems include:

- Sound level at registers
- Higher blower motor watt draw
- Higher cost than standard split system units

Conventional split system residential ACs operate at a nominal airflow of 400 cfm/ton. As stated above, SDHV systems operate from 220-350 cfm/ton. The lower air flow rates, compared to conventional systems, require higher efficiency outdoor units to be used in order to meet overall SEER requirements for the SDHV system. For instance, it is typical to use a 12 SEER outdoor unit in a 10 SEER SDHV system.

Although several manufacturers now offer models of SDHV systems, market share is small and these systems are niche products. SDHV systems are an alternative means of decreasing duct conductive and leakage losses, with the benefit of increased latent capacity, and the drawback of higher blower watt draw.

Savings

An ASHRAE Standard 152 analysis was performed to quantify the potential savings from reduced surface area in the ductwork. When replacing a typical 8" duct with a 2" SDHV duct, design cooling distribution efficiency increases from 62% to 72%, yielding an estimated energy savings of 14%. However, this can be offset in SDHV systems by increased blower motor power requirements.

References

Energy Design Update. 1995. "High-Velocity Forced-Air Heating and Cooling Systems", (15:4) pp. 9-12, April.

4.7 Integrated Appliances

4.7.1 Heat pump domestic hot water (HPDHW)

Heat pump water heaters are electrically powered water heaters that have improved efficiency over conventional electric water heaters. They obtain a portion of the heating energy from a refrigeration cycle. The evaporator of these water heaters removes heat from many possible heat sources: house air, outside air, air entering the house (in summer), air leaving the house (in winter) or the hot refrigerant in an operating central air conditioner. The condenser rejects heat into the domestic hot water tank.

Self-contained HPDHWs are the easiest to install. When these use air sources they cool the air and can dehumidify. These units have the same range of sensible heat ratios as standard air conditioners. Their dehumidification can be increased with an air-to-air heat exchanger as shown in Chapter 5 Design 8.

Heat pump water heaters cooling function can be useful when integrated with a balanced ventilation system where the incoming air can be dehumidified and cooled in the summer. Similarly, the heat in the exiting air can be captured in the winter.

Electrically heated domestic water (EDHW) is used on 38% of US households. Most of the EDHW are resistance heated while an insignificant percentage use Heat Pump DHW. Resistance DHW annual energy costs are approximately 60% higher than natural gas DHW, about equal to fuel oil costs and 15% less than LPG (EIA 1999).

Heat Pump DHW has a slower recovery than electric resistance DHW. Electric resistance backup is used when large water draws occur.

<u>Savings</u>

Heat pumps water heaters have a higher initial cost than resistance water heaters. Maintenance costs are higher than other domestic water heaters. The evaporator coil and filter must be cleaned regularly and in areas with scaling water the efficiency of the unit will drop unless descaling is used. Resistance water heaters obtain very little maintenance until the resistance units burn out and are replaced.

Assumptions:

- EIA domestic water heating costs (EIA 1999)
- Percent of water heating by HPWH = 85%,
- Percent of water heating by electric resistance back up = 15%,
- Resistance COP = 1,
- HP COP = 2.5,
- Incremental Maintenance Cost = $50,
- Incremental Initial Cost = $600

Table 4.7.1. Heat Pump Water Heater Savings

	Average Cost	Annual DHW Energy Cost	Energy Cost Savings	Net Savings	Payback (years)
HPWH (¢ per kWh)	6 to 8.99	107			
Electricity (¢ per kWh)	6 to 8.99	226	$ 119	$ 69	8.7
Natural Gas ($ per 1000 cf)	4.5 to 5.99	141	$ 34	$ -16	NA
Fuel Oil ($ per gal)	0.95 to 1.09	233	$ 126	$ 76	7.9
LPG ($ per gal)	0.75 to 0.99	265	$ 158	$ 108	5.6

The most appropriate freestanding application of a heat pump water heater is in an area where energy fuel costs are high. This technology has long been considered for integration with other appliances for the source of heat. These combinations include:

- Air Conditioning
- Heat Recovery Ventilation
- Heat Pumps
- Dehumidification

Niche products are available that combine the above heat sources with a heat pump water heater.

References

AERS. E-Tech WH60BX-1 Specifications. Applied Energy Recovery Systems, Inc.

Bodzin, Steve 1997. "Air-to-Water Heat Pumps for the Home." *Home Energy Magazine* July/August 1997.

ECR 2003. Watt Saver HPWH500AAOC Manual. Enviromaster International, LLC

EIA 1999. *A Look at Residential Energy Consumption in 1997*. DOE/EIA-0632 (97). Energy Information Agency. November 1999. Tables 3.1, HC5-2a, and CE4-6u.

Hiller, Carl C. 2002. "Heat Pump Water Heater Operating Experience in a Residence." *ASHRAE Transactions*. V 108 Part 2 p 793-799.

4.7.2 Desuperheaters

A desuperheater to heat domestic water is a refrigerant to water heat exchanger on the hot gas side of an air conditioner compressor. When cooling, the air conditioner discharges superheated hot gas to the condenser. The domestic water is circulated through the heat exchanger picking up heat from the hot gas and desuperheating it. This method picks up "free" heat that would be discharged to the outside air. In order to protect from freezing the water in the winter, the refrigerant line would have to be run from the outdoor unit into the house. Desuperheater-equipped air-source systems are rare in the marketplace because of the complexity of installing two sets of refrigerant lines and installation of a refrigerant-to-water heat exchanger. More common are residential ground source heat pump systems with desuperheaters because the compressor is already located in the building (usually) and a small water pump can be used to run an insulated water line from the water heater to the compressor unit/air handler.

4.7.3 Combination space conditioning and water heating

Dual integrated appliances (DIA) are water heaters used to provide both domestic hot water and space heating. The hot water is fed through a heating coil in the air handler, providing forced air heating.

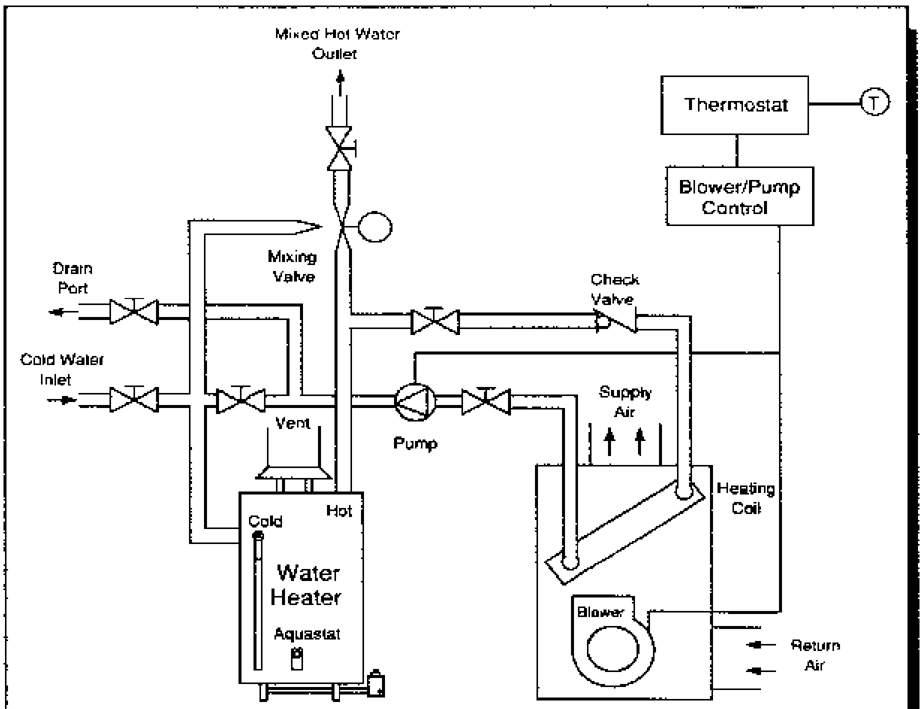


Figure 1. Schematic of typical Dual-Integrated Appliance system.

Figure 4.7.1 Dual Integrated Appliance Schematic

Dual-integrated appliances may save on first costs when compared to separate water and space heaters. These units however do not produce the efficiency available from an efficient furnace or boiler.

References

Bohac, D.L., M.W. Hancock and T.S. Dunsworth. 1994. “Energy Savings and Field Experiences with Dual Integrated Appliances.” *ACEEE Summer Study Proceedings.*

Bohac, D. 1992. “Once Heated, Twice Used.” Home Energy Magazine. July/August.

4.7.4 Integrated AC and furnace design

In a gas-pack (package air conditioner with gas heating and electric cooling) the furnace heat exchanger, evaporator coil, and inside section are designed together. For split air conditioners however the furnaces are designed to stand alone, yet provide sufficient airflow to a wide variety of evaporator coils (or none at all). Furnace heat exchangers have to be integrated with the furnace airflow to ensure that proper heat transfer occurs and there are no hot spots. Evaporator coils’ effectiveness are very dependent on both the airflow and the airflow distribution across various sections of the coil. If the furnaces were designed with an integrated air conditioner evaporator coil, then the design would have the possibility of providing optimized airflow distribution through the coil as well as avoiding hot spots on the furnace heat exchanger. This concept integrates coil design with furnace design. This concept is limited by the practicality of covering the variety of heating and cooling capacity combinations.

Furnace designs and air conditioner designs are not necessarily perfectly integrated. In a number of cases there are conflicting design needs. In hot climates with a large cooling loads there is a need for high airflows requiring larger fans, motors, and duct systems. These same areas often have small heating loads that would optimally use smaller fans, ducts, etc. Manufacturers have addressed these varied needs by producing identical furnaces cabinets with different heating input rates to accommodate different heating loads and different airflows to accommodate different cooling loads.

For example one manufacturer's 50" X 24" X 14" cabinet has heating input rates of 50,000 to 75,000 btuh and cooling airflows from 1200 to 1600 cfm. The heating input rates are determined by the number of burners (two or three) and heat exchangers, while the physical size of the blower wheel and the horsepower of the motor determine the cooling cfm. This method provides manufacturing economies because the same cabinet/burner/heat exchanger etc. can be used over a number of products. There are also drawbacks to this method. The units with only two burners potentially have large furnace heat exchanger bypasses as shown in Figure 3.7.2. This issue is addressed by installing baffles in the cabinet to force the airflow closer to the heat exchanger. Some units with high airflow demand have wide fan assemblies that are crowded by the sides of the cabinet.

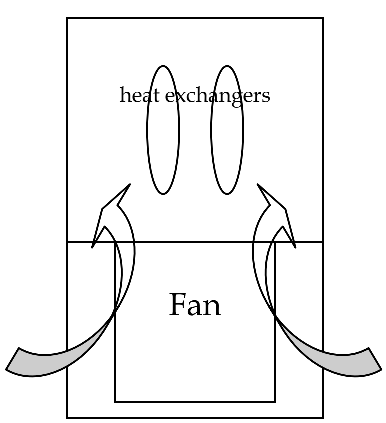


Figure 4.7.2. Furnace Fan Flow Past Heat Exchangers

In an installation that is also cooled, the furnace is topped by a DX coil of some configuration (A coil or other) as shown in Figure 3.7.3. Through rearrangement, it may be possible to use the DX coil as the device which causes the air flow to remain close to the furnace heat exchanger and either remove the baffles or move them to a location that helps equalize airflow through the DX coil.

This design concept utilizes the airflow resistance of the DX coil in a manner that assists in airflow distribution through the cabinet and past the furnace heat exchanger. In addition this change lowers the overall profile of the unit.

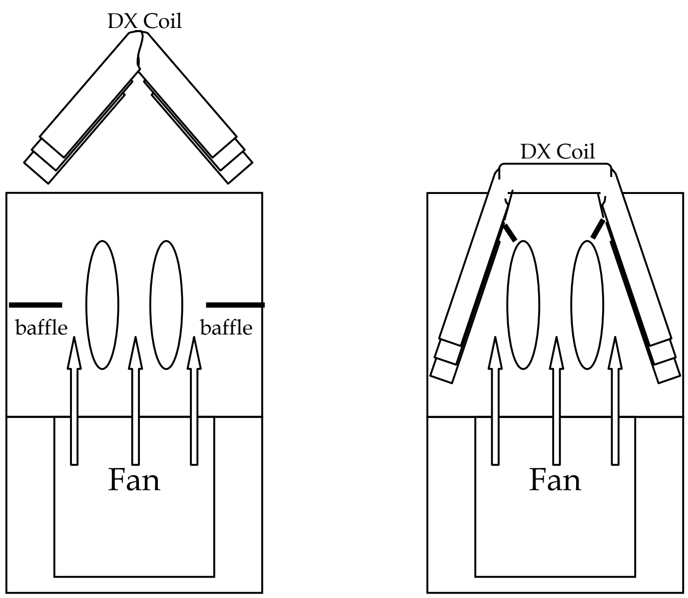


Figure 4.7.3. DX Coil as Furnace Heat Exchanger Diverter

4.7.5 Integrated heating, cooling, dehumidification, and ventilation

The most common form of heating and cooling, all ventilation, and virtually all dehumidification utilize forced air movement. This fact alone makes integrating these tasks potentially positive. The most common integration is a natural gas or propane furnace with an air conditioner. The air conditioner is a partially effective dehumidifier. Adding a duct from the outside to the return system will produce ventilation.

Filtration and heat/energy recovery have also been matched with forced air heating and cooling systems.

In general these systems are modular and various components added as desired by the HVAC contractor or builder. This often leads to mismatch of component systems, impaired performance, and complicated/misunderstood controls.

<u>Integrating dehumidification</u>

Most common dehumidifiers utilize a compressor and coils consistent with residential air conditioning. The primary difference (other than capacity) is that the dehumidifier discharges the heat into the inside air rather than outside the house. The addition of a reheat coil to a residential air conditioner would reduce the amount of sensible cooling while maintaining the same moisture removal. Because of the reduced sensible cooling, the air conditioner would run longer and dehumidification would increase. The inefficiency of removing heat then returning it to the air stream is an obvious drawback.

Teasing additional dehumidification from a residential air conditioner usually consists of reducing the evaporator coil temperature by reducing evaporator airflow. This method is limited by the fact that water freezes at a 32 degrees F.

A more sophisticated method of improving dehumidification is to precool the air entering the evaporator coil, bringing it closer to it's dew point. This can be accomplished using and air-to-air heat exchanger between the air leaving the evaporator coil and the air entering the coil. This method is shown in the next section (Figure 4.8.3). The same enhancement can be used with an air conditioner to shift the latent/sensible ratio without rejecting condenser heat to the indoor air.

Section V investigates integrating ventilation with cooling and dehumidification in moist climates.

4.8 Alternative Approaches to Providing HVAC Functions

Purpose

Traditionally heating homes grew from providing heat in one location (fireplace, woodstove, stand alone heater, floor furnace) to central heating with air ducts, steam or water pipes. Heating or cooling a single location had the advantage of saving energy by not conditioning the entire home at once.

Ventilation consisted of windows and doors while individual or area fans provided cooling. When central air conditioning began to get widespread use it was often added to the existing forced-air heating package. In some cases ventilation was added to the system through a return duct from outside the building. (This was sometimes intended to provide combustion air to the furnace.)

Alternative approaches to heating and cooling include:

- Reverting to heating and cooling a local area rather than the whole structure.
- Providing each HVAC function with separate stand-alone equipment.

4.8.1 Ductless mini-split systems

One method of eliminating duct loss is to eliminate ducts. Mini-split system air conditioners have evaporator/air handler units within each conditioned room. These multi-evaporator systems run the refrigerant from one outdoor unit to several indoor units. These systems are most commonly used in multifamily housing applications or retrofit applications in which there is insufficient space to install ductwork.

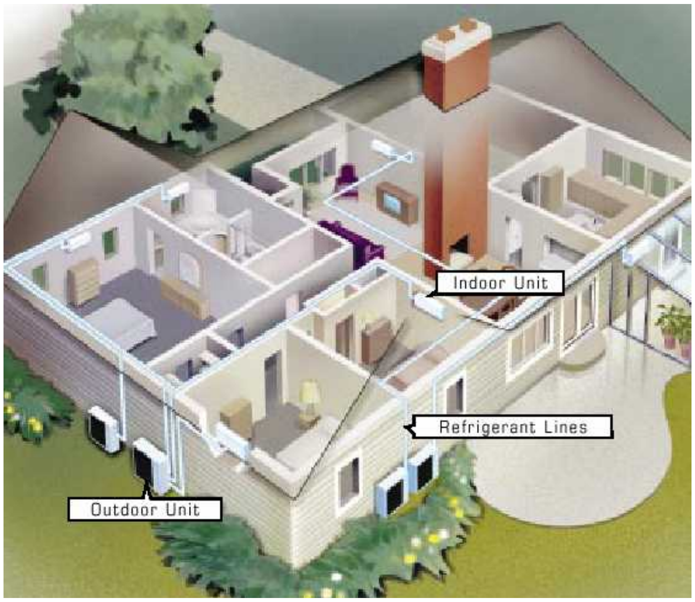


Figure 4.8.1 Mini-split System Layout (Mitsubishi Electric)

Benefits of these systems include inherent zoning capability (cooling or heating only the area that needs to be conditioned), greatly reduced airside losses, and quiet operation. Ductless systems are considered a niche market, with an estimated volume of 100,000 units per year in North America.

The main drawback of mini-split systems is their cost. The systems cost approximately 30% more than central systems. However, this does not include the cost of ductwork; therefore, in new construction, mini-splits will tend to be more cost-effective. Qualified installers and service technicians for mini-splits are more difficult to find than central AC installers. Many contractors earn a larger return on ductwork installation so they may be more reluctant to push sales of mini-splits except in cases where ducts are not feasible.

From a technical standpoint, Andrews (2001) provided a first-order analysis of the thermodynamic effects of increased refrigerant line lengths, with the results applicable to both mini-splits and central ACs with refrigerant lines exceeding 25 feet. The purpose of the study was to provide input for a proposed method of evaluating refrigerant distribution system efficiency. Total efficiency impacts from increased refrigerant tube length were:

- For cooling mode, total efficiency impacts from temperature drop and rise in the liquid and suction lines, respectively, and pressure drops in both lines ranges from a 0.5% reduction in efficiency per 10 feet of added length for a 0.5" OD tube to a 0.7% gain in efficiency for a 1.125" OD tube.

- For heating mode, total efficiency change for temperature and pressure drops in the liquid and discharge lines amounts to a 0.7-0.9% loss per 10 feet of added length.

The effects of added line length are small in comparison to savings associated from elimination of airside ducting. Duct losses can account for more than 30% of energy consumption for space conditioning, especially in cases where ductwork is located in an unconditioned space such as an attic.

<u>References</u>

Andrews, J.W. April 2001. "Impacts of Refrigerant Line Length on System Efficiency in Residential Heating and Cooling Systems using Refrigerant Distribution." BNL-68550.

"EREC Brief: Ductless, Mini Split-System Air-Conditioners and Heat Pumps." 2002. Available online: http://www.eere.energy.gov/consumerinfo/refbriefs/ad3.html.

Siegel, James J. 2001. “Don’t Overlook the Benefits of Ductless Mini-Splits.” *Air Conditioning, Heating, and Refrigeration News*, (213:7) pp. 9, June 18.

Siegel, James J. 2001. “Challenging Jobs Often Call for Ductless Systems.” *Air Conditioning, Heating, and Refrigeration News*, (213:7) pp. 10-11, June 18.

Siegel, James J. 2001. “A Ductless System with More Control.” *Air Conditioning, Heating, and Refrigeration News*, (213:7) pp. 14-15, June 18.

4.8.2 Residential chillers

A small chiller can be used in the residential marketplace. These systems are installed outside a building with the refrigerant circulated through a refrigerant to water heat exchanger in the building (freeze protection). A hydronic distribution system circulates chilled water throughout the household to provide cool air to the rooms that need it. Duct losses can be eliminated if hydronic cooling coils are used at the rooms rather than at a central location.

The potential drawbacks of this system include the need to insulate and protect chilled water pipes from sweating, as well as the need for condensate drains at every coil.

As it the case with minisplits, hydronic distribution cuts distribution losses by as much as 90%.

<u>References</u>

Mazurkiewicz, G. 2000. “Chillers go home; settle in for zoned cooling”. Air Conditioning, Heating, and Refrigeration News. May 5.

4.8.3 Dedicated dehumidification systems

Building Science Corporation (Rudd et al. 2003) field-tested the performance of stand-alone dehumidifiers against other systems (ERV, two speed AC with low fan speed for dehumidification, etc.). The test showed that the stand-alone dehumidifiers did a much better job of maintaining proper indoor humidity than the other systems tested. The results are displayed in Figure 4.8.2. The stand-alone dehumidifiers nearly eliminated indoor relative humidity excursions above 60% Rh.

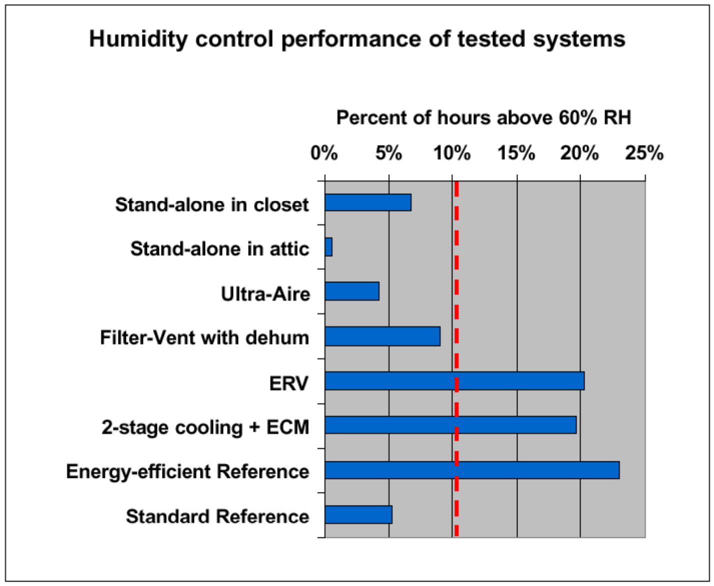


Figure 4.8.2. Humidity Control with Stand-Alone Dehumidifiers

A properly sized stand-alone dehumidifier can provide excellent latent capacity, but it also adds to the sensible load and can be noisy.

<u>Products</u>

Multiple stand-alone dehumidifiers are on the market. One product used in the Building Science Corporation field test was the Ultra-Aire dehumidifier manufactured by Therma-Stor LLC. That product uses an air-to-air heat exchanger between the return and supply airflows. The air–to-air heat exchanger removes sensible heat from the return airstream bringing the air entering the evaporator coil closer to its dew point. This reduces sensible cooling and increases moisture removal. The heat removed from the return air is rejected to the supply air leaving the evaporator coil. This arrangement is illustrated in Figure 4.8.3.

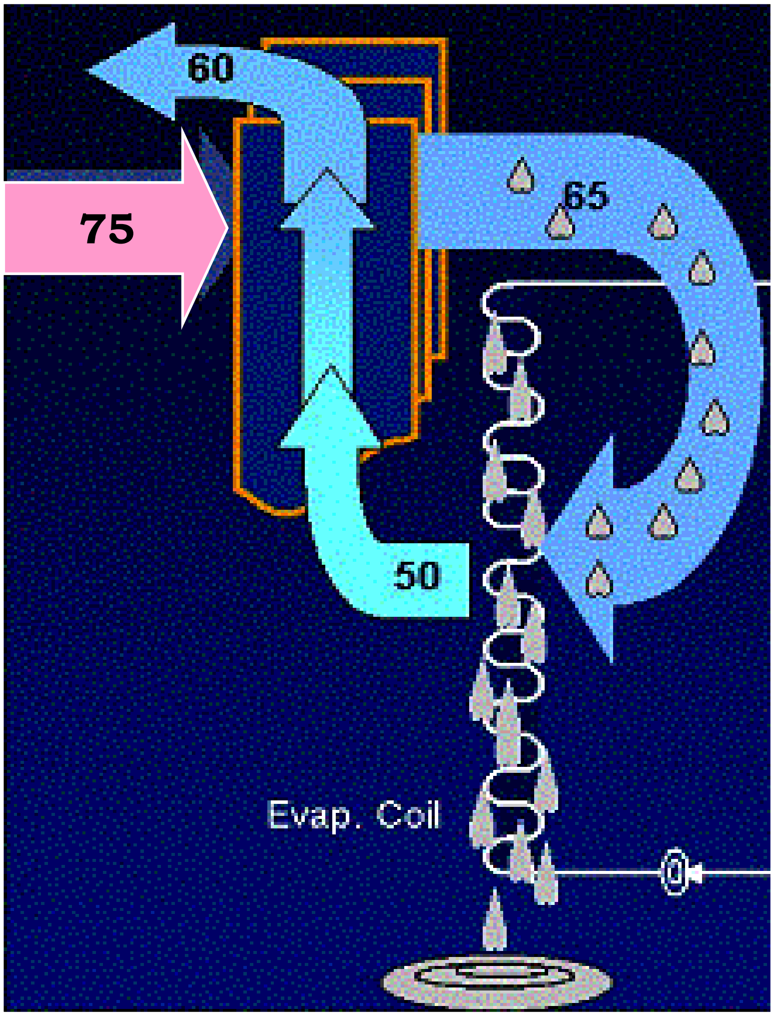


Figure 4.8.3. Dehumidification Enhancement with an Evaporator Air-to-Air Heat Exchanger

Section V (Design 8) further analyzes a dehumidifier with an evaporator side air-to-air heat exchanger.

<u>References</u>

Rudd, A., J. Lstiburek, and K. Ueno 2003. "Residential Dehumidification and Ventilation for Hot-Humid Climates" Presented at *24th AIVC Conference*. October 2003.

4.8.4 Dedicated ventilation system

Ventilation air can be considered a large leak in a building. One approach to maintaining proper ventilation while properly conditioning a building is to treat ventilation air separate from return air.

A concept that has been proven in the commercial arena is "dual-path" ventilation, in which a separate refrigeration coil is used to condition ventilation air before it is mixed with conditioned air from inside the building. This has the effect of removing the majority of latent load from the return coil and placing it at the ventilation coil. Humidity can be controlled better.

Khattar (2002) performed testing of a dual-path concept as applied to a large department store. Field-measured data showed excellent control of indoor relative humidity. The system maintained 40-45% Rh in Florida in the summer.

References

Khattar, M.K., and M.J. Brandemuehl. 2002. "Separating the V in HVAC: A Dual-Path Approach." ASHRAE Journal, May.

V. HVAC DESIGN COMPARISONS

This analysis includes hypothetical designs as well as designs now in production. Ten alternates were produced and analyzed for performance in Chicago IL and Charlotte NC. Each system is analyzed under two conditions: minimum airflow to meet ASHRAE 62.2 and twice the minimum ventilation rate for unbalanced designs.

These designs generally attempt to provide ventilation as specified in ASHRAE Standard 62.2. They also attempt to integrate some of the other cooling with the design. It is not necessarily assumed that these designs would be applied to homes with reduced infiltration, sealed ducts, high efficiency glass, or the other elements that have been identified for an optimized house. However, they would perform better in such a house.

This is a steady state analysis at average summer conditions. The assumptions and calculations are contained in Appendix A.

Table 5.1.1 contains diagrams of the designs using the symbols shown in Figure 5.1.1.

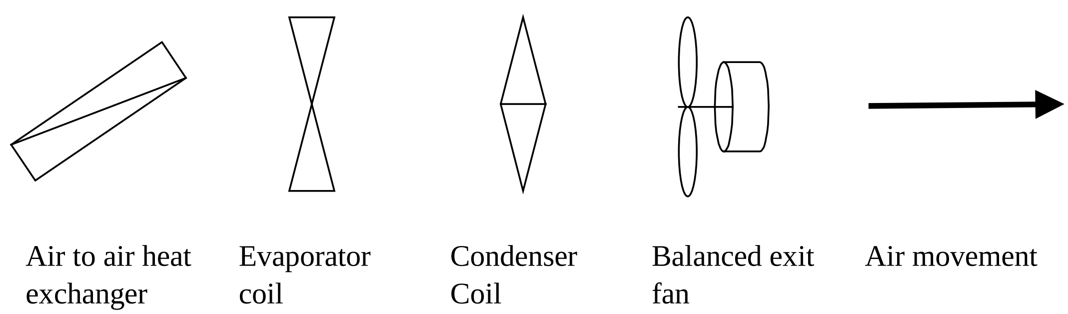
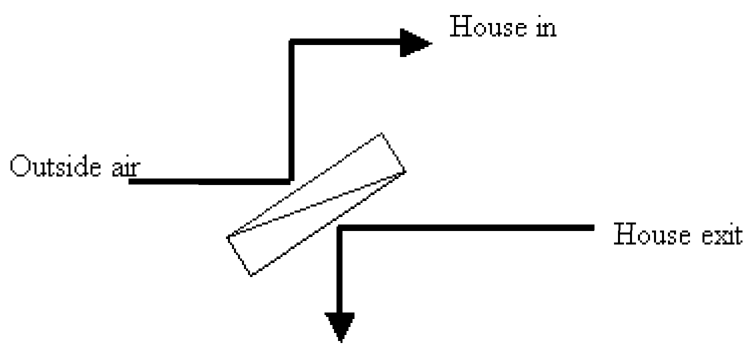


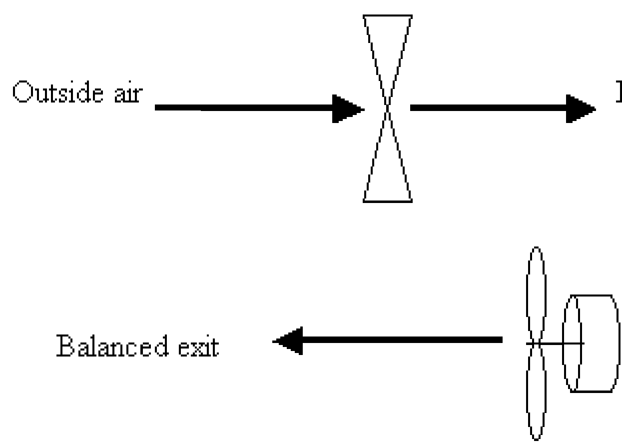
Figure 5.1.1. Symbols used in Table 5.1.1 Design Schematics

Table 5.1.1 Loads Met by Alternative Designs Under Average Summer Conditions

Design 1	Energy Recovery Ventilator			
	Balanced System		Double Ventilation Flow	
Location	Chicago	Charlotte	Chicago2	Charlotte2
Percent of Sens Load	6%	8%	13%	16%
Percent of Latent Load	17%	18%	34%	36%



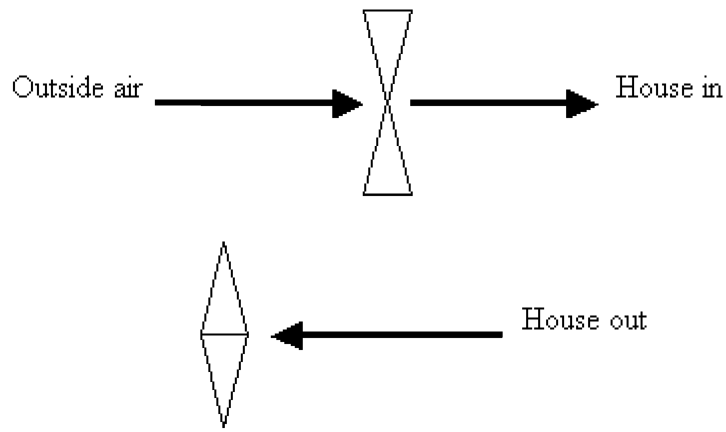
Design 2	Feed Only Outside Ventilation Air to Small Air Conditioner			
	Balanced System		Supply Only Double Flow	
Location	Chicago	Charlotte	Chicago2	Charlotte2
Percent of Sens Load	41%	34%	85%	68%
Percent of Latent Load	39%	36%	78%	72%



Design 3

Feed House Exhaust Air to Condenser

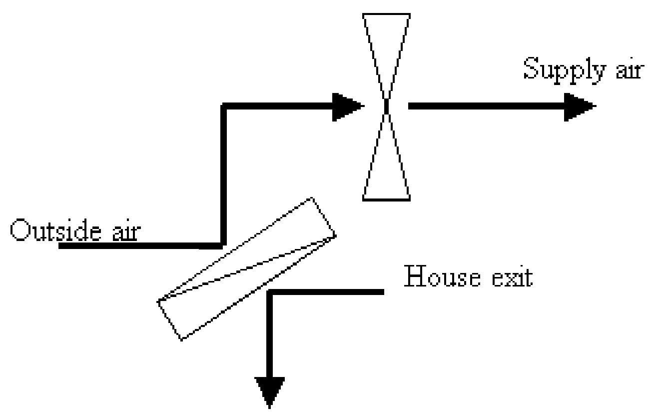
No advantage in moderate drybulb climates.



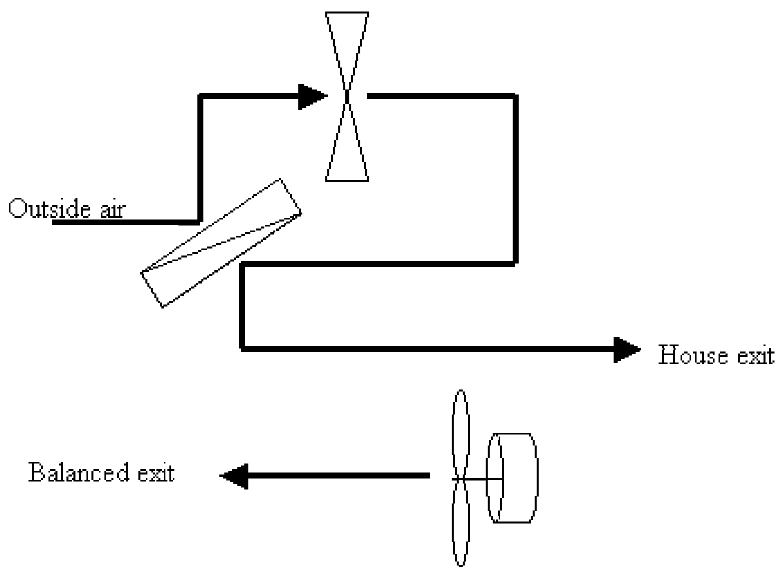
Design 4

Exchange House Exhaust with Ventilation Air to Small Air Conditioner

No advantage in moist climates



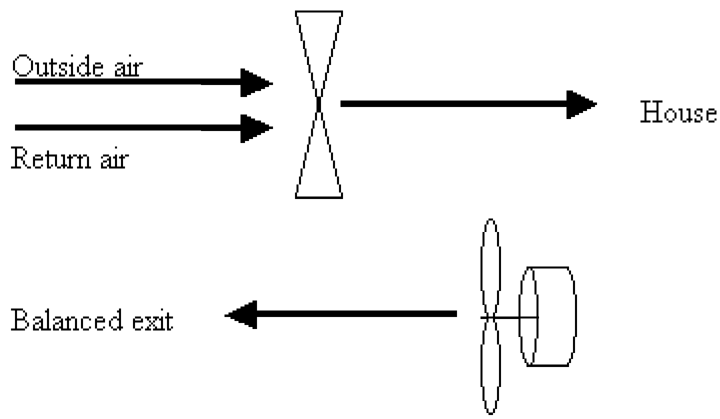
Design 5	Balanced		Supply Only Double Flow	
	Outside Air Through A/A HE to Small AC Evaporator from Evaporator through A/A HE to House			
Location	Chicago	Charlotte	Chicago2	Charlotte2
Percent of Sens Load	30%	25%	62%	51%
Percent of Latent Load	72%	68%	145%	136%



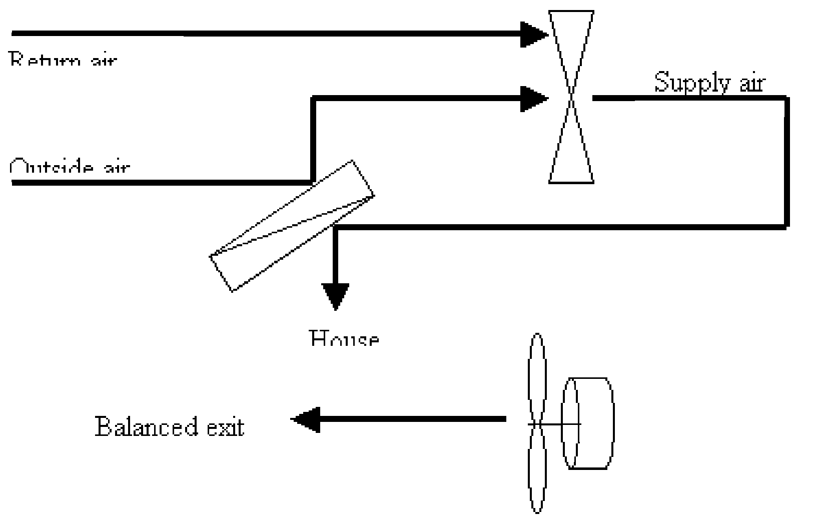
Design 6

Feed Outside Air Mixed with Return Air Directly to Small AC Evaporator

	Balanced		Supply Only Double Ventilation Airflow	
Location	Chicago	Charlotte	Chicago2	Charlotte2
Percent of Sens Load	159%	134%	156%	127%
Percent of Latent Load	93%	81%	117%	101%



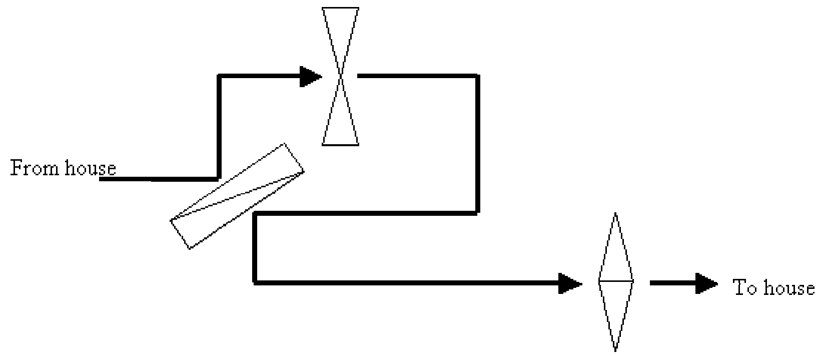
Design 7	Outside Air Through A/A HE, Preconditioned Outside Air and Return Air mixed and into Small AC Evaporator Supply from Evaporator through A/A HE to House			
	Balanced		Supply Only Double Ventilation Airflow	
Location	Chicago	Charlotte	Chicago2	Charlotte2
Percent of Sens Load	146%	125%	105%	110%
Percent of Latent Load	104%	98%	84%	140%



Design 8 Dehumidifier with internal A/A HE

No Ventilation air

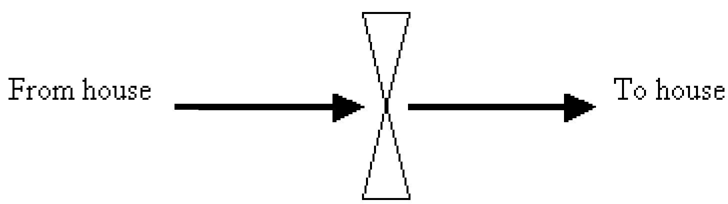
Location	Chicago	Charlotte	Chicago2	Charlotte2
Percent of Sens Load	-194%	-165%		
Percent of Latent Load	114%	99%		



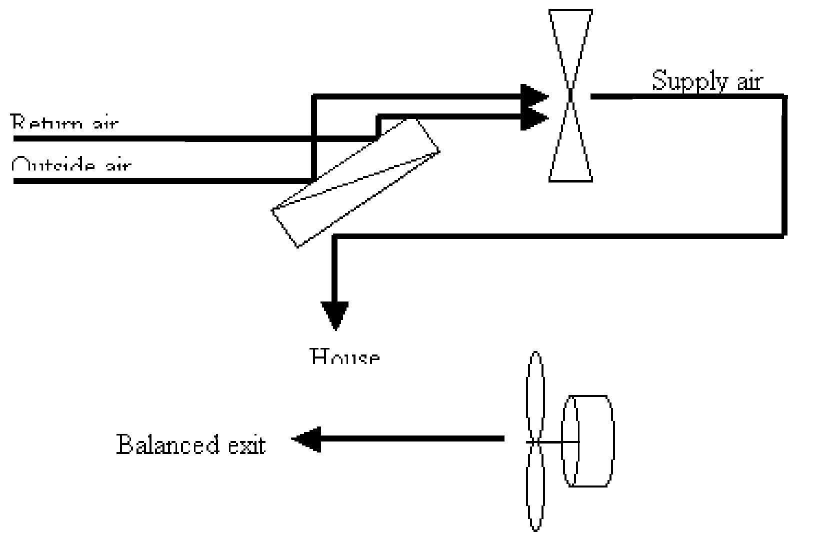
Design 9 Standard AC

No Ventilation air

Location	Chicago	Charlotte	Chicago2	Charlotte2
Percent of Sens Load	261%	256%		
Percent of Latent Load	100%	100%		



Design 10	Outside Air mixed with Return air. Mixed air through A/A HE and into Small AC Evaporator Supply from Evaporator through A/A HE to House			
	Balanced		Supply Only Double Ventilation Airflow	
Location	Chicago	Charlotte	Chicago2	Charlotte2
Percent of Sens Load	98%	83%	102%	84%
Percent of Latent Load	153%	137%	189%	174%



By this analysis three designs show promise, Designs 6, 7, and 10. All of these designs provide constant ventilation at ASHRAE Standard 62.2 levels. The ventilation air is tempered along with a small amount of return air. The units are designed to run continuously in the summer with a constant low wattage fan and a very small compressor (probably two speed or variable speed). Each of these designs will provide a base level of conditioning. For times of higher sensible or latent load each of these units will have to shift to a higher capacity.

Design 6 is the least expensive of the three. It requires no air-to-air heat exchanger. The return/outside air mix can be varied to provide some balance between sensible and latent capacity.

Designs 7 and 10 differ only in that the house return air is mixed with the outside air in two different places. In Design 7 the return air is mixed with the outside air as it exits the A/A heat exchanger. In Design 10 the return air is mixed with the outside air as it enters the A/A heat exchanger. A potential design could vary the proportion of return air mixed at the two locations.

Design 7 produces a close balance between meeting the sensible and latent loads. This design also has the best balance under conditions of higher latent or higher sensible loads.

Design 10 provides significantly higher latent capacities particularly at higher ventilation flows.

VI. CONCEPT RANKINGS

Three elements were integrated into the concept rankings. These elements were the market actors' perceptions as determined from the interactive presentations and written surveys, the analysis of market barriers based on individual market actor interviews (contained in Section VII), and the Proctor Engineering Group analysis of each concept.

6.1. Market Actor Surveys

Market actors surveyed included homeowners, architects, builders, building scientists/researchers, as well as HVAC contractors, distributors, and manufacturers. In the surveys, these market actors ranked the concepts in the following decreasing order of preference with respect to acceptability and cost.

Table 6.1.1. Market Actors' Perceptions

Acceptability	**Cost**
1. Low heat gain/loss windows	1. Reduced AC Size
2. Reduced infiltration	2. Roof color
3. Ventilation integration with air handler	3. Reduced surface area ductwork
4. Leakless ducts	4. Infiltration
5. Improved AC installation/maintenance	5. Shading
6. Higher AC efficiency and regional variations	6. Improved AC installation/maintenance
7. Roof color	7. Ducts in conditioned space
8. Air handler/furnace fan loss reduction	8. Ventilation integration with air handler
9. Reduced surface area ductwork	9. Leakless ducts
10. Shading (overhangs etc.)	10. Windows
11. Basementized crawlspaces	11. Fan loss reduction
12. Reduced AC size	12. Cathedralized attics
13. Ducts in conditioned space	13. Basementized crawlspaces
14. Heat and hot water integration	14. Heat and hot water integration
15. More use of thermal mass	15. More use of thermal mass
16. Chiller with hydronic delivery	16. Improved AC efficiency
17. AC and hot water integration	17. AC and hot water integration
18. Cathedralized attics	18. Chiller with hydronic delivery

6.2. Market Actor Comments

The market actor comments disclosed during the survey were helpful in producing the overall concept ranking. These comments are contained in Appendix C.

6.3. Overall Concept Ranking

In addition to the survey results that showed the market actors' perceptions of cost and acceptability, the team interviewed individuals and performed analyses to produce additional ratings of these criteria: estimated first cost, operational/maintenance costs, expected reliability, thermal comfort, peak load reduction, health and safety impacts, and major changes required for market actors. These factors were combined with the survey results to produce the overall concept ratings in Table 6.3.1. These ratings are not definitive. They are the result of equal rating of all the criteria.

There are a variety of views with respect to how much weight each criterion should carry. One view was that first cost should have double the weight of the others; another view was that peak electrical reduction should have a greater weight than thermal comfort. These ratings are largely subjective or are estimates. As priorities change the user of this information would be well advised to weigh the criteria as is appropriate to their situation. The raw data are contained in Appendix B to facilitate that process.

As the project progressed, additional options were suggested by participants. These options were added and evaluated. The items marked with * in Table 6.3.1 were added during the process and therefore were ranked by a lesser number of participants.

The first column of Table 6.3.1 is the overall ranking based on the total score. The third column is the total score out of a possible 81.

Table 6.3.1. Concept Ranking

Total Ranking Order	Concept	Total Score
1	Windows	60
2	Roof color and radiant characteristics	58
3	Closer HVAC sizing to load	57
4	Reduced infiltration with controlled ventilation	55
5	Ductless mini-split systems *	54
5	Sealed ductwork	54
5	Register placement/short duct design *	54
6	Expert system diagnostics *	53
6	Integrated heating, cooling, dehumidification, and ventilation	53

Total Ranking Order	Concept	Total Score
7	Basementized crawlspaces	52
7	Ensuring proper refrigerant charge	52
7	Reduced infiltration with ERV/HRV	52
8	Frostless heat pumps *	51
8	Advanced framing *	51
9	Matching each component to work at peak efficiency with the other components *	50
9	Evaporatively cooled condensers *	50
9	Improved aerodynamic air handler cabinet, blower, housing	50
9	Improved aerodynamic outdoor ac/hp units *	50
9	Exterior shading (e.g. Roof overhangs)	50
9	Higher SEER systems	50
9	Ensuring adequate evaporator airflow	50
10	Integrated cooling , heating and airflow design *	49
10	Combination space conditioning and water heating	48
10	Ducts in conditioned space	48
11	Radiant/thermal mass cooling	47
11	AC optimization for climate region *	47
11	ECM® motors *	47
11	Refrigerant metering devices *	47
11	Advanced adaptive-flexible thermostats *	47
12	Controls that closely match run parameters to efficiency characteristics *	45
12	Closer distribution system sizing to room and equipment demands *	45
12	Small-duct, high-velocity systems *	45
12	Dedicated Dehumidification *	45
12	Dedicated Ventilation *	45
13	Heat pump water heaters*	43
14	Cathedralized attics	42
14	Residential chillers	42
15	Desuperheaters *	40

The top four rated concepts are associated with load reduction and loss mitigation. These concepts are <u>relatively</u> easy to implement from the market actor perspective. There are large gains possible from simply applying current technology correctly.

VII. MARKET BARRIERS AND MOTIVATIONS

> Traditional economic theory assumes that human beings behave rationally. That is, that they understand their own preferences, make perfectly consistent choices over time, and try to maximize their own well being. This peculiar assumption has its roots in dusty essays like "Exposition of a New Theory on the Measurement of Risk" (from 1738) by Daniel Bernolli and scholarly tomes like *Theory of Games and Economic Behavior* by Mon von Neuman and Oscar Morganstern (published in 1944). ….
>
> The problem, of course, is that people don't always behave rationally. They make decisions based on fear, greed, and envy. … Economists understand this as well as anyone, but in order to keep their mathematical models tractable, they make simplifying assumptions. Then they try to adjust their equations by adding terms that account for "irrational" behavior.
>
> Huang, Gregory T. 2005

When a particular option is "obviously" the most rational choice yet it does not capture a major share of the market, this "market failure" is attributed to "market barriers".

Market barriers have been defined as "any characteristic of the market {…} that helps to explain the gap between the actual level of investment in, or practice of {…} and an increased level that would appear to be cost beneficial" (Ito, Joseph, Ralph Prahl, and Jeff Schlegel 1996). One issue is of course: cost beneficial to whom? Market barriers may occur for instance where the individual well being does not fully account for societal well being.

Rather than blind acceptance of "the market" therefore it can be useful to look at the motivations of the market actors and the market barriers.

7.1. Motivations

Market actors that can enable successful system optimization of residential HVAC systems include homeowners, architects, builders, building scientists/researchers, and HVAC contractors, distributors, and manufacturers. Critical factors in determining the viability of system optimization concepts include the underlying motivations of each of the market actors.

All of the market actors other than homeowners are primarily interested in the economic viability of their businesses. A business goal drives the adoption or development of a new system.

7.1.1 Homeowners

Homeowners are, first of all, interested in obtaining reliable comfort from their HVAC system. They are also interested in the health and safety of their family as well as their financial condition and security. They may be interested in reduced energy costs, convenience, and the environment.

The homeowner is ill equipped to judge whether the HVAC system will provide the reliable comfort or the other benefits they desire. Their baseline is past experience—however, studies have shown that an efficient and highly effective residential HVAC system is the exception rather than the rule. The most common performance criteria for residential air conditioners are whether or not they produce cold air and whether they keep the house cool most of the time in the summer. The most common performance criterion for a heater is whether it produces sufficient heat in the winter to keep some significant portion of the house warm in the winter. The performance criteria for residential ventilation systems are even less well known to the average homeowner. Because of these baselines, only severe shortcomings in operating performance get a homeowner's attention.

7.1.2 Architects

As with other business-persons, architects are primarily interested in the economic viability of their businesses. They are interested in their customers' appreciation of their work and for some, the projection and display of artistic qualities. Some architects are interested in distinguishing themselves and may we interested in energy efficiency or "green" designs. The methods architects can use to increase energy efficiency may be in conflict with aesthetic or other requirements by their clients.

7.1.3 Builders

Builders are motivated by profit to provide homes at a price that will maintain a steady supply of new customers. Location, price, amenities, and other distinguishing features attract new customers. Marketing strategies for builders can include the use of energy-efficient technologies. Given the importance of comfort, health and safety to the customer, these areas have shown increased emphasis by some builders in the recent past. Builders also are motivated to avoid problems (including litigation) with the customers and with their contractors.

Programs such as the EPA's Energy Star and Build America provide visible signs of the special values of a home that can improve the builder's reputation and visibility. Builders are interested in new construction methods that will reduce total construction times and costs.

7.1.4 Building Scientists/Researchers

Building scientists and researchers are motivated by their status in the research community. They are also motivated by financial considerations such as a continuing stream of research funding. When the level of funding dwindles in a particular area they will switch to research in areas that are funded, even if their primary area of interest is left behind.

7.1.5 HVAC Contractors

HVAC contractors are motivated by financial considerations. There are HVAC firms that primarily focus on new construction and those that focus primarily on service and replacement. It is debatable which group will be most involved in newer designs. Designs integrated with the house design must be implemented within the new construction group, but they are more driven by volume and cost than the replacement/service contractor.

For the service/replacement contractor market share and revenue per transaction are of high importance. Being able to sell an upgrade is of high value. To the service/replacement contractor building customer trust and loyalty is of primary importance. In general, service calls are not profit makers. The profits come from selling replacement parts and from selling a replacement air conditioner when the current one is removed.

In general there is a greater value placed on the volume of customers served than the technical quality of the work done. There are a number of technicians and contractors that are motivated by pride to do superior work, but they feel constrained by a market place that does not value largely hidden superior performance.

7.1.6 HVAC Manufacturers

HVAC manufacturers are motivated by financial considerations. A large source of income comes from high volume sales of their least expensive products, which are designed to meet state and federal code requirements at minimal cost. Two thirds of their sales volume is replacement units. In that market they provide upgrade products for higher profits to the contractor, distributor, and themselves. Distinguishing upgrade products help provide ethical proof that their "builder grade" product is superior to other manufacturers products. A reputation for reliability and performance are important to the manufacturer to maintain sales of their products.

7.1.7. HVAC Distributors

The HVAC distributors too are motivated by financial considerations. They play a large role in the adoption of new technologies. They provide the access point for the contractor as well as the education in new technologies. Their financial motivation translates to sales; they primarily stock products that will get out the door quickly.

<u>References</u>

Eto, Joseph, Ralph Prahl, and Jeff Schlegel 1996. *A Scoping Study on Energy-Efficiency Market Transformation* by California Utility DSM Programs. Earnest Orlando Lawrence Berkeley Laboratory, Berkeley, CA

Huang, Gregory T. 2005. "The Economics of Brains" *Technology Review*, May.

7.2. Market Barriers

The motivations of the market actors need to be used to overcome a number of obstacles to introducing new designs and products. Some of these market barriers are listed in Table 7.2.1.

Table 7.2.1 Market Barriers to Full Implementation

Homeowner	Architect	Builder	Building Scientist/ Researcher
Information costs Costs of learning how to judge what equipment will best meet their needs and desires exceed the perceived benefits.	Information costs Costs of learning new and more effective design practices.	Information costs Costs of learning what needs to be done to obtain a more optimized combination of the HVAC system and the home.	Lack of champions Building scientists must find effective champions inside the HVAC and building industry.
Performance uncertainties For any but the standard designs, the performance may not have been proven sufficiently to make the homeowner comfortable with the purchase.	Performance uncertainties A new design carries risks of acceptance, cost, durability, etc. Performance should be improved but the extent is difficult to foresee.	Performance uncertainties Worries about durability, liability, and customer satisfaction.	Code restrictions New methods sometimes violate code although they benefit the home and its occupants; effort is required to lift the restrictions.
Asymmetric information/opportunism Difficulty in evaluating manufacturers'/contractors' /architects' /builders' claims.	Time costs New designs may require more time, increasing the cost of the work	Time costs Finding and/or retraining contractors and suppliers to successfully apply revised designs.	
Hassle costs Time required to find a contractor/ builder that is knowledgeable and proficient in the technology.	Organization practices or custom Architects have been leaving the HVAC design to the contractors for many years; it may be difficult to break out of the mold.	Organization practices or custom The current methods work, and we make money, so why change?	
Bounded rationality Comfort with better known, or common technology/contractor/ builder regardless of "objective" performance.	Design limitations Aesthetic requirements may make new designs more difficult to implement.	Code restrictions Builders may have to fight to lift code restrictions for some new designs.	
Hidden benefits The results of an effective HVAC system are unknown to the customer - a weak feedback loop for judgment of performance.		Quality assurance Extra cost of ensuring the work is done properly.	

HVAC Contractor	HVAC Manufacturer	HVAC Distributor
Performance uncertainties Will the new designs provide sufficient performance or will they cause more warranty and call back problems?	R&D costs Obtaining funding for integrated solutions may be difficult.	Information costs Costs of learning about and supporting new products.
Inadequate infrastructure Technicians are not skilled at new or more complicated designs. There is a lack of good technicians.	Marketing costs Newer ideas require effective marketing. The new product needs to compete with other products for the marketing dollar.	Asymmetric information/opportunism Distributors must be weary of product claims that exceed real life performance.
Organization practices or custom Within each local area there are certain customs that may conflict with the new designs.	Perceived gains less than actual Standard rating methodology (SEER, HSPF, AFUE) may not adequately capture the positive effects of the new design.	Demand Distributors stock items in current demand. Inventory of products with unknown demand is risky.
Hidden benefits The potential to provide higher profits and/or market share may not be obvious.	Complexity End users are reluctant to implement complex systems.	
Information costs The cost of training technicians to deal with new designs is perceived as high.		
Time costs Additional time will be required for some new and more complicated designs.		

VIII. CONCLUSIONS

The project evaluated many HVAC concepts that show considerable promise.

8.1 Load Reduction

Load reduction strategies and improved design/installation practices scored high on the list of concepts. Low solar heat gain windows, roofing with reduced heat gain characteristics, and reduced infiltration with controlled ventilation lead the list of load reduction strategies. In addition, basementized (sealed insulated) crawlspaces, advanced framing, exterior shading, and ducts in conditioned space were all within the top ten scores.

While reduced loads are not integral to the efficacy of most of the HVAC concepts, they make the integrated heating, cooling, dehumidification, and ventilation systems more viable by producing a more stable load. They also make improved aerodynamics and duct design easier since the airflows are lower. In addition, they score high in market actors' perceptions.

8.2 Design and Installation Practices

Closer HVAC equipment sizing to loads, sealed ductwork, and shorter duct runs with improved register placement lead the list of improved design/installation practices. The top ten scores also contained expert system diagnostics, and ensuring proper refrigerant charge and airflow, as well as integrated design to provide cooling, heating and airflow.

8.3 Mechanical Systems

Mechanical systems with high scores included ductless mini-split systems as well as integrated heating, cooling, dehumidification, and ventilation systems. Many mechanical systems followed within the top ten scores including: ERV/HRVs coupled with reduced infiltration, frostless heat pumps, matched components to combined peak efficiency, evaporatively cooled condensers, improved aerodynamics (low watt draw per cfm) on both air handler/furnace and the outdoor AC unit, higher SEER, as well as combined space and water heating.

8.4 Adaptability

This project has convinced the investigators that the variety of interior and exterior weather conditions even at a single site calls for adaptability to obtain superior performance under the common conditions. Given the variety of building performance even when built by a single builder, the systems have to adapt to the situation presented by that building.

Adaptability calls for improved control systems, increased technician skill and "production" quality assurance. To the degree that the equipment is adjustable to the local situation, there needs to be verification that the adjustment has been properly applied before the technician leaves the site.

8.5 Favored Designs

Given the increased emphasis on ventilation, we favor concepts that combine mechanical ventilation, dehumidification, and sensible cooling. Two such designs are described as Designs 7 and 8 in Section V. These designs use and air-to-air heat exchanger to precool the ventilation air (or combined ventilation and return air), bringing it closer to its dew point. The precooled ventilation air and return air enter an evaporator coil that (through manipulation of the return and ventilation air volumes) can provide variable latent capacity according to the need. The supply air leaving the evaporator coil is passed through the air-to-air heat exchanger then delivered to the house. These systems can supply either balanced or unbalanced airflow as appropriate. The schematic of Design 7 is shown in Figure 8.5.1.

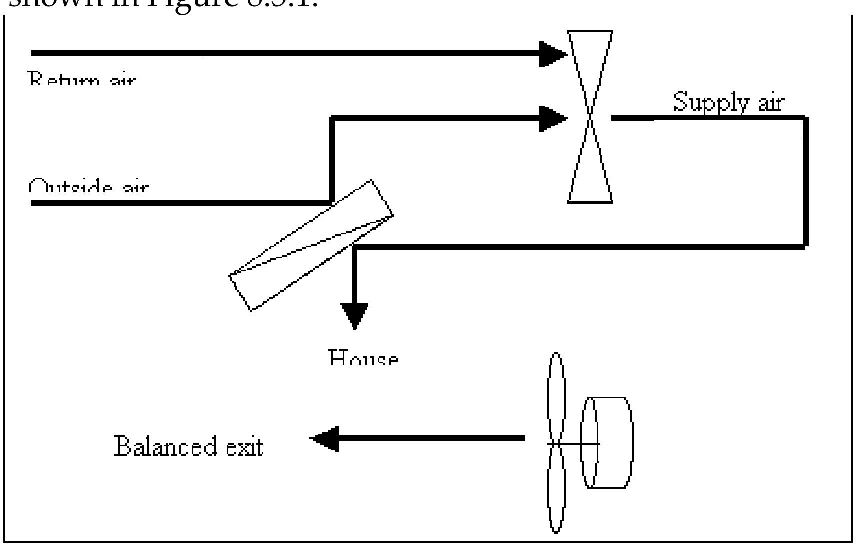


Figure 8.5.1 Design 7 – Variable Latent Capacity Ventilation/Conditioning System

Appendix A

Survey respondent information:

Name________________________________Company____________________________________

Address____

Phone______________________ Fax________________________Email_____________________

Please circle your interest group:

Architect	Builder	HVAC Contractor
HVAC Distributor	HVAC Manufacturer	Building Scientist/Researcher
Homeowner not in the above groups		Other______________________

Outlined below are several strategies available for optimizing HVAC in residential buildings. We are interested in feedback from market actors that can enable further implementation of these ideas, as well as suggestions for other strategies. In this survey we are asking for your initial perceptions of cost and acceptability of the concepts described. Your input will assist in rankings of the most practical and effective methods of HVAC optimization, which will pave the way towards further research on effective implementation programs.

Please fill out the survey and fax or mail to PEG (contact info at bottom of page), or email jpira@proctoreng.com for an electronic copy to submit. Thank you for your input!

Please Rank Cost and Acceptability from 1-5:	**Cost** 1=Low 5=Too High	**Acc.** 1=Easy 5=Impossible
1) Cooling Load Reduction		
Windows	_____	_____
Shading	_____	_____
Infiltration	_____	_____
Roof color	_____	_____

Many strategies have been developed over the years to minimize building loads. Energy-efficient windows significantly reduce solar gain. Use of shading, such as larger overhangs on homes, covered decks and awnings, and tree shading can mitigate loads. Better building practices can reduce infiltration—tighter homes result in less direct loss of cooling/heating capacities. Roof colors affect attic temperatures which in turn affect mechanical systems located in the attic. Lighter roofs can reduce attic temperatures, but new pigments available can reflect infrared energy while maintaining a darker, more aesthetically pleasing look.

Comments/Ideas____

____

Proctor Engineering Group
418 Mission Ave.
San Rafael, CA 94901
Phone: 415-451-2480 Fax: 415-451-2491
Email: jpira@proctoreng.com

____

2) Duct Loss Reduction

In conditioned space ____ ____
Cathedralized attic ____ ____
Basementized crawlspace ____ ____
Leakless ____ ____
Reduced surface area ____ ____

Although reducing duct losses can be considered an installation/maintenance issue, the potential savings are large enough to warrant its own category. Ducts typically lose 25-40% of the energy in the airstream from the indoor coil to the registers. This is due to leakage and conduction. Placing ducts in the conditioned space allows the losses to be captured to a useable space. Increasing insulation can reduce duct loss, as well as reducing the surface area by using smaller ducts with higher static pressures. Sealing all leaks in the ducts has great savings potential, whether by using mastic or rubber-sealed duct joints.

Comments/Ideas____

____

____

3) Ventilation Integration with Air Handler ____ ____

With the advent of tighter homes being built, mechanical ventilation becomes necessary to meet ASHRAE 62 standards of maintaining indoor air quality. A method of accomplishing this is to integrate a ventilation system with the existing air handler of the home. A common method is providing a fixed opening at the return plenum connected to outside air. The use of devices such as ERVs and HRVs can also be used to extract heat from exhaust air in order to precondition incoming air.

Comments/Ideas____

____

____

4) Dual-Path Ventilation ____ ____

An idea that has shown success in the commercial market is the separation of conditioning of outdoor air with that of indoor air. With the use of a separate coil for moisture removal from outdoor air, fine control of humidity levels can be achieved while satisfying the need for ventilation. A scaled-down version of such a system may be applied to the residential market.

Comments/Ideas____

____

____

5) Flexible Systems _____ _____

AC designs have been proposed that can vary capacity and the amount of moisture removal through varying airflows and the amount of outdoor air. These designs use variable-speed motors to achieve higher efficiency at part load.

Comments/Ideas____

____

____

6) Dedicated Systems _____ _____

Examples of dedicated systems include radiant cooling designs, dedicated ventilation and dedicated dehumidification systems. These systems isolate specific performance criteria and may be more efficient than other types of systems.

Comments/Ideas____

____

____

7) Reduced AC Size _____ _____

AC systems are commonly oversized for the building loads they operate under. Studies have shown oversizing averaging 47% greater than ACCA Manual J load calculations. Further education of contractors to properly size systems has the potential for lower initial and operating costs to the homeowner.

Comments/Ideas____

____

____

8) Improved AC Installation/Maintenance _____ _____

There is much room for improvement in the proper installation and maintenance of AC systems. Refrigerant charge is often suboptimal, and airflow is commonly inadequate to obtain peak efficiency of the air conditioner. This provides opportunities for energy savings through improved technician and homeowner education.

Comments/Ideas____

____

____

9) Fan Loss Reduction _____ _____

Fan/motor combination efficiencies in residential buildings are very poor, with values typically under 10% when including the air handler box in the system. In comparison, large engineered air handlers in commercial systems generally have efficiencies ranging from 60-80%, signifying the possibility of dramatic efficiency improvements in residential systems. Improvements are due to more efficient motors such as ECMs and turning vane design. Research in this field should be applied to both indoor and outdoor blowers.

Comments/Ideas____

____

____

10) Improved AC Efficiency _____ _____

The National Appliance Energy Conservation Act set a minimum SEER of 10 for air conditioners manufactured after 1992. An update to this act will increase the minimum SEER to 12 by 2006. The standards increase air conditioner efficiencies in general but provide a rating at only a specific set of conditions. The current barrier to using high efficiency units is cost, which should be mitigated as the higher standards become implemented. Also, design for specific conditions, such as evaporative condenser technology, can enable large increases in efficiency in certain markets.

Comments/Ideas____

____

____

Proctor Engineering Group
418 Mission Ave.
San Rafael, CA 94901
Phone: 415-451-2480 Fax: 415-451-2491
Email: jpira@proctoreng.com

11) Heat and Hot Water Integration _____ _____

Combining multiple appliances into one is an example of a system integration approach. Heat and hot-water integrated systems utilize the same heat source to both heat the conditioned space and provide domestic hot water.

Comments/Ideas____

____

____

12) AC and Hot Water Integration _____ _____

Another example of integration is capturing waste products to provide useful energy. The rejected heat from an air conditioner can be captured by a "desuperheater" and used to reduce water heating costs to nearly zero in summer conditions.

Comments/Ideas____

____

____

13) Chiller with Hydronic Delivery _____ _____

An advanced method of cooling a residential building is utilizing a separate chiller to circulate cool water throughout a home, with cooling coils to distribute the cold air to separate rooms in the house. This enables all refrigerant to be located outside of the house, which opens up the possibility of alternative refrigerants, and also makes installation easy, with no charge adjustment because of the package-unit design.

Comments/Ideas____

____

____

Proctor Engineering Group
418 Mission Ave.
San Rafael, CA 94901
Phone: 415-451-2480 Fax: 415-451-2491
Email: jpira@proctoreng.com

14) More Use of Thermal Mass _____ _____

The proper use of thermal mass to store and dissipate energy can significantly reduce heating and cooling loads in a building if designed properly. Some designs include concrete blocks located in ceiling panels that cool at night and absorb heat during the day.

Comments/Ideas____

____

____

15) Other _____ _____

Comments/Ideas____

____

____

____

16) Other _____ _____

Comments/Ideas____

____

____

____

Proctor Engineering Group
418 Mission Ave.
San Rafael, CA 94901
Phone: 415-451-2480 Fax: 415-451-2491
Email: jpira@proctoreng.com

Appendix B

Total Rank Order	Concept	Perceived cost	First cost	Operational/ Maintenance cost	Expected reliability	Thermal comfort	Peak load reduction	Health and safety impacts	Perceived acceptability	Major changes required for market actors	Total	Total less Perceptions	Ranking Order without Perceptions
1	Windows	4	3	8	9	9	9	5	6	7	60	50	1
2	Roof color and radiant characteristics	6	5	9	7	7	9	5	5	5	58	47	2
3	Closer HVAC sizing to load	7	8	7	5	8	8	6	4	4	57	46	3
4	Reduced infiltration with controlled ventilation	6	3	7	5	9	7	9	5	4	55	44	4
5	Ductless mini-split systems *	3	1	9	8	9	9	5	4	6	54	47	2
5	Sealed ductwork	5	3	8	6	7	8	8	5	4	54	44	4
5	Register placement/short duct design *	6	8	8	7	6	7	5	4	3	54	44	4
6	Advanced diagnostics *	3	3	8	9	9	9	6	3	3	53	47	2
6	Integrated heating, cooling, dehumidification, and ventilation	5	2	7	5	9	7	9	5	4	53	43	5
7	Basementized crawlspaces	4	6	9	5	6	7	7	4	4	52	44	4
7	Ensuring proper refrigerant charge	5	5	8	5	7	8	5	5	4	52	42	6
7	Reduced infiltration with ERV/HRV	6	3	8	4	7	7	7	5	5	52	41	7
8	Frostless heat pumps *	4	4	7	8	8	5	5	5	5	51	42	6
8	Advanced framing *	7	9	6	5	7	6	5	3	3	51	41	7
9	Matching each component to work at peak efficiency with the other components *	3	2	9	7	9	9	5	3	3	50	44	4
9	Evaporatively cooled condensers *	3	3	9	4	9	9	5	4	4	50	43	5
9	Improved aerodynamic air handler cabinet, blower, housing	4	3	9	6	7	9	5	4	3	50	42	6
9	Improved aerodynamic outdoor ac/hp units *	4	4	9	5	5	9	5	4	5	50	42	6
9	Exterior shading (e.g. Roof overhangs)	5	5	7	5	7	7	5	4	5	50	41	7
9	Higher SEER systems	4	3	9	5	5	9	5	5	5	50	41	7
9	Ensuring adequate evaporator airflow	5	5	7	5	7	7	5	5	4	50	40	8
10	Integrated cooling , heating and airflow design *	5	5	5	7	5	8	5	5	4	49	39	9
10	Combination space conditioning and water heating	4	4	9	6	5	7	5	4	4	48	40	8
10	Ducts in conditioned space	5	4	5	5	8	8	5	4	4	48	39	9
11	Radiant/thermal mass cooling	4	4	7	7	7	7	4	3	4	47	40	8
11	AC optimization for climate region *	3	4	8	5	6	8	5	4	4	47	40	8
11	ECM® motors *	4	3	9	7	5	6	5	4	4	47	39	9
11	Refrigerant metering devices *	4	4	6	4	7	7	5	5	5	47	38	10
11	Advanced adaptive-flexible thermostats *	4	4	7	5	5	6	5	6	5	47	37	11
12	Controls that closely match run parameters to efficiency characteristics *	3	2	9	4	7	9	5	3	3	45	39	9

Appendix B

12	Closer distribution system sizing to room and equipment demands *	4	4	6	5	6	5	5	5	5	45	36	12
12	Small-duct, high-velocity systems *	4	4	5	5	6	6	5	5	5	45	36	12
12	Dehumidification *	1	4	4	5	7	4	7	5	5	45	36	12
12	Ventilation *	4	4	4	5	4	4	9	6	5	45	35	13
13	Heat pump water heaters*	4	4	6	5	5	6	5	4	4	43	35	13
14	Cathedralized attics	4	4	5	5	7	7	5	1	4	42	37	11
14	Residential chillers	2	2	8	6	7	7	5	3	2	42	37	11
15	Desuperheaters *	3	4	6	5	5	6	5	2	4	40	35	13

Appendix C

Reduced AC Size

- Easy to sell to clients; hard to find a contractor that had trust in me seeing that everyone else did their job; had to bring HVAC contractor to EEBA conference

- Do we have to promote a constant indoor temperature for this to work?

- Need to work closely w/ builder and HVAC contractor to build agreement on strategy and avoid conflict

- Contractors are not convinced; Past practice prevents down sizing

- HVAC Contractors will do this if they are not liable

- Lowers the cost but makes the builder and HVAC comtractor open to comfort complaints; Risky unless the installation is closely monitored and tested

- Best: use Manual J and D to design and select equipment; worst: rules of thumb; The oversized system is often an insurance policy; oversizing makes up for install defects/ poor design. The builder doesn't want that phone call

- Concerns about homeowners who demand ability to keep house @ 60 * F

- Education/training->marketing

- Very good idea, sometimes hard to implement (stubborn contractor or homeowner)

- Free cost reduction but difficult to get HVAC contractor to go for it

- Better envolope all the time increase air handler output reduce furnace & AC size

- Best: longer runtimes to reduce moisture in humid climates; worst: homeowner preferences; reduced AC size saves $ on initial cost

- Easy to show calcs and justification, but poor field installation offsets performance

- Functional integration is best; worst is to only change windows; unless previous windows were very leaky, windows don’t make enough difference in the NW

- Question: 1950- no insulation; 1 ton- 400 sq ft; 2002 r-14/30 1 ton per 400 square ft. Why?

- Best: base HVAC load on Manual J load calcs; worst: 400 ft2 per ton, 20 years in business experts

- Possible problem with air flow, loud factory for cooling

- Best: size by the numbers; worst: size by rules of thumb

- Best: cost savings, lower airflow, smaller duct systems; worst: hvac contractor losing money / opposition; lack of knowledge of builder and leaving the decision making /

liabilty with HVAC contractor as opposed to actually sizing it according to load. Builders need support.

- Good to downsize; not good when insulation and building problems occur

- I'm talking to contractors now--many that say Manual J calcs are done--actually 'game" the calcs to meet code + rebate requirements. Need to find a better/ simpler way to right-size systems.

- Compensate installer for lost mark up, incentivise smaller units by higher markup, give trips to Hawaii

- You can educate, but if the system doesn't cool adequately, complaints will be aimed at the contractor--- therefore oversize is safer liability-wise unless excess energy use is discouraged

- AC companies make money off size of HVAC

- My design people use precise sizing from Manual J & D/Wrightsoft designs. Builders are very responsive to reducing HVAC size.

- In new construction it is viable, retrofit is much tougher.

Improved AC Installation/Maintenance

- best idea: simplify home owner responsibilities; worst: no verifications after install
- best: simpler installs (I.e. package units)
- Install check is great!
- Need strong training/tech support mechanism for technicians, or some automated method of monitoring
- Many HVAC contractors still fight us on this even when we tell them that this is an extra w/ extra $
- best: ongoing monitoring (black box)
- best: better equipment operation; worst: difficult and time consuming to monitor/train/etc.
- best: black box--good idea to monitor/test ducts; worstL black box--needs further data
- best: monitor installation w/ expert call-in system
- best: black box; help homeowner change filter
- HVAC contractors that do a better job charge more - builders like low bidder
- black box is great idea
- charge, airflow, eq less sensitive motor, equipment, monitor install, monitor perf.
- best: black box/installation; These must work together and require homeowner participation
- use TXV to eliminate superheat check!

- place in accessible loaction for maintenance and filters; many units in back corner of crawlspace/attic w/ access panels turned towards back
- best: proper heat/load calc w/ SP and FR and equipment selection; worst: inqualified or bad HVAC contractor
- best: check charge; What TV commercial? ("I'm here to fix your refrigerator") maybe it doesn't show in all markets
- best: install thermostatic expansion valve in AC unit; Consider the possibilty of selling the service that an a/c set provides for a monthly fee, HVAC contractors retain ownership of equipment and is responsible for operating it.
- best: mastic! Hard duct trunks based on Manual D; worst: cramped flex ducts with undersized return; Give your rough-in and trim/startup checklists they need to sign to document failures and shortcomings
- Must train tech. on sizing materials and charging methods
- best: regularly scheduled service by qualified technician; worst: no filter change
- best: great idea; worst: applicability, availability; who would monitor? Need easy method to verify correct installations. Love Black Box
- works good with good building procedures; watch out for problems to cool down and maintain; Black box- when and how often is it calibrated for effectiveness
- We need to show contractors the revenue opportunity w/ pressure diagnostics + air flow corrections. Then they will follow the $. Talking to contractors on this subject as well.
- Only obstacle is inertia
- Call backs will be reduced and be good for homeowners but not profitable for HVAC contractors.
- adds to labor time

Cooling Load Reduction

- Windows--code does it; What is the advantage of shade screen versus Low E?
- We've had good success moving builders to low-e windows in most markets
- Reflectivity and emissivity (cool roof technology) are important; windows have caused big load reductions in our area (Sacramento); roof color is not a good idea
- roof color must be aesthetically flexible-- don't know cost
- shading options typically not supported by homebuyers and builders; Believe issue of incrementally high cost of windows is becoming less of an issue because of success of different market pull efforts such as EnergyStar, Building America, MASCO's EFL, NFRC, etc...
- latent load reduction: windows easiest; shading is most effective but hardest to implement (biggest industry change); Shading means intelligent design and it costs $ for architectural shading devices
- #1: infiltration; #2: shading, windows; sun and heat sensored glass shading (cost 5)
- windows are easy and very effective; infiltration can require training and a learning curve; tile roofs work better than asphalt shingles in home; but there are load issues.

- infiltration-- must reduce towards 0; best practice is to include latent loads and shading; promote solar screens; design to include porch, awnings
- best: external shading; worst: interior shading; shades inside the structures such as light blinds reflect the heat inside the house allthough slower but it still gets in the house, bring awning back?!
- best: infiltration-- pressures/balancing; roof color may have deed restrictions
- best: shading, roof color
- shading is good, but is more subject to aesthetic considerations
- use the best envelope possible-- track downsizing; worst: use bad components, poor supervision, oversize AC to hide faults; Should have someone who isn't interested in selling bigger units do the Manual J calcs and trade-offs
- will increase comfort heat/cooling; reduce cooling size for humidity control
- best: dehumidification w/ tight envelope; worst: leaky envelope w/ oversized AC
- roofs-- flat unvented?; best: windows; Shading? Solar screens or overhangs? Curtains on inside?
- windows reduce ultra violet rays (protected); unrated windows create heat; could your collect some energy from the windows to power house
- Shows common sense isn't that common!
- Curb appeal or party talk rules what happens
- Start a new fashion craze for different house shapes & colors.
- they will reduce heat loss and gain and will be overall more comfortable living conditions and cost effective.
- With (California) AB970 energy credit for low E glass the cost is not high. Cool roofs may be harder to sell. Good point about complex inorganic roof pigments that reduce 25% at solar noon.
- in new construction in California strategic shading speaks against the economy of scale.

Duct Loss Reduction

- I've put all my ducts in conditioned space (furdowns) for about 13 years. This year we had a house burn. My observation was that the furdowns created a raceway for the fire to spread through the house.
- best: SDS w/ terminal fitting seal
- Can be in conditioned or semiconditioned space; best: Conditioned space supply and return; ducts above ceiling but isolated from outside
- Prefer larger duct for lower fan power
- Duct design is a service that some builders will pay for, but again requires a lot of interaction w/ builder and mech. contractor to succeed. Ideally, long-term the mech. contractor would be trained to design ducts and builder would be willing to invest more in installed cost of ducts.
- High velocity ducts increase energy use for fans - conservation is not achieved

- Ducts sealed with actual rubber seems so obvious that the current state (using duct tape or mastic) is hard to believe
- should be airtight ducts
- best: ducts in conditioned space; worst: leakless is not available yet!; In Sacramento builders have had trouble with Duct in conditioned space. Permitting and code enforcement
- best: put in conditioned space--allows best opportunity for EE and cost reduction/"cascading"; worst: reduced surface area?--likely to encounter resistance from builder, hvac contractor
- best: leakless no inside insulation; If ductwork is sealed, conditioned space doesn't matter if ducts are insulated
- increases airflow to rooms and allows for reduction in size but takes more work; if ducts are tight and flex is is stretched out, reduced surface area
- snap ducts!! Sounds good
- best: 100% duct sealing in any space and regardless of surface area; worst: leaky house and duct; HVAC contractor needs to plan for and include one extra day for drying, because once installed some seams cannot be gotten to
- best: ducts in conditioned space
- this should be standard operating procedure for all installations
- best: follow manual D installation guidelines and test; worst: duct tape, pull straps; need to promote programs that test ductwork at rough-in
- yes, keep load on conditioned air; yes, because to keep run time on equipment, also low utility bills.
- leak control is standard in Tucson; worst idea: in conditioned space; lack of skilled labor, education by hvac contractors, house design
- best: using right materials and workmanship; worst: no education; bad materials
- Tight + right ducts- trying to get distributive ownership by contractors. At least have them "walk the ducts" --> Again revenue opportunity.
- customers/ buyers unaware
- hard to retrofit
- it will not look glamorous to homeowners, to see duct work in the envelope.
- Our HERS raters must work with HVAC leadman to assist their installation practices to insure proper duct sealing. California energy credit makes tight ducts affordable. I have inspected many cathedral dense pack insulated houses that were loose at the top plate.
- Tightening ducts seems to be do-able. The other two require alterations to plans and special considerations.

Fan Loss Reduction

- best: reduced duct friction; worst: flexible duct
- best: all steel or smooth duct/ as short as possible; fan area should be completely sealed (use older style pants and turning veins, radius corners)

- best: centrally located air handler or furnace; worst: sprawling house where architect has not planned or left room for duct runs; we need functional intergration from very beginning, not after plans are drawn
- optimized duct system design should be standard operating procedure
- best: use reduced surface area to facilitate airflow; worst: long snakey flex with undersized ducts
- design duct system and installation clearness (use Manual D), proper size R/A & S/A
- lower static is the most practical
- Contractors like to sell air due to higher margins.
- Use DC motors that have high cfm/ watt yield. Get away from AC with its bad VA to watt ratio (pf or pf or cos phi for the educated.)
- amazing that we do not do this already

Improved AC Efficiency

- best: evaporative condensers
- Codes are helping, as is builders' desire to have EnergyStar labels, which will often require mechanical upgrades
- best: using manufacturers data to select efficiency at site specific conditions; worst: using SEER to determine eff.; EER not much better; HVAC contractors hat is put on in design stage. Take that hat off use the graphs available from manufacturers to "design"
- best: regional AC designs
- best is design for regional conditions
- most cost-effective-- Freus unit? (to address issue of SEER rating problems in hot climate location); Where "cost effective" is relative to large kWh savings achieved, "cost" may be considered a bargain!
- they're out there
- use TXV like before; definitely a good idea to design different units based on geographic latent/sensible loads
- best: reduce heat gain by improved sealing and insulating and ventilating; worst: low cost hvac people who cannot possibly do quality at quoted prices; most builders know when the price they get is too low for quality work; they need to take bids from the best for the best to get the best. Hank (ACCA) says "Quality /comfort costs money"
- regional test is a great idea
- best: SEER 95
- best: use ECM motors/TXVs/right sizing; Use EER, not SEER / regional design sensible vs. latent
- best: find food regional design solutions; worst: base design on SEER alone; further educate contractors/builders on options and improvements
- yes, all new homes are, built with A/C only. Keep low utility bills. Good for health reasons

- how high? Diminishing return above 12; if other measures (above) are taken care of, this becomes secondary; 12 is very good!
- By 2006 manufacturers, HVAC contractors & consumers will be on board with higher efficiency benefits & costs will be less!
- Why didn't California motivate builders to use 12 SEER equipment in 2005 prior to the 2006 NAECA requirement by offering a Title 24 credit for 12 SEER installations?

Ventilation Integration with Air Handler

- If you use a fan to move fresh air, tie it into the main blower motor.
- best: when coupled w/ damper and fan-only operation capability during periods when heating/cooling not required
- Very important, need to deal w/ heating climates, chilling of heat exchangers
- yes
- cheap way to provide fresh air; improves IAQ
- best: ERV w/ standalone humidifier in closet; worst: trying to dehumidify w/ AC unit in hot, humid climate
- best: Fancycler
- I prefer to separate ventilation w/air handler in favor of using smaller fan running 24 hrs. to get ventilation rather than running big air handler fan intermittently
- High costs; can be an installation nightmare!
- already done quite a lot in newer condition homes--but lots of bad installations
- Ventilation with fresh air is cost effective and easy.

Heat and Hot Water Integration

- Done on 3 homes. Hot water system delivers warmer air to the vent than an air/air heat pump.
- Little space heating needed in Arizona
- Cheaper for builder but what are the real energy savings except where coupled w/ hydronic radiant floor system? (obviously higher cost to builder/buyer) Good opportunity for use of solar thermal systems in mild heating climates?
- best: boiler w/ heat exchanger + radiant; good
- works in a cooling climate--inexpensive, but need to watch out for thermosyphoning; not flushing system will cause copper shavings to clog check values and hot water will rise to heat coils durring cooling season.
- proper size H.W.T. also vaiblty Air handler, and parts. also blower sizing for A/C condenser matching air handler
- Pushing an elephant upstairs!

AC and Hot Water Integration

- Potential for problems w/ simultaneous heating & cooling due to thermosiphoning

- cost effectiveness is low; solar with extra storage works better but also may not be cost effective.
- best: desuperheater on AC w/ SEER <= 12.0
- too complex for homeowner

Chiller with Hydronic Delivery

- good idea
- Bringing this to residential scale will be many elephants!
- commecial ideas may not work on a smaller scale

More use of Thermal Mass

- Hard to find out what to expect from mass.
- Yes!--Minimal cost when amortized through mortgage
- Requires intimate knowledge of mass principles and appropriate placement of mass and appropriate use of glazing.
- Better chance-- obviously only on new construction
- Dead easy, cheap

Other

- AC PV; inverter problems still an issue
- There is a new heat-pump water heater on the market--"Watter Saver"--hopefully will be successful. Could be installed near/adjacent to refrigerator to utilize waste heat from refrigerator as well as other sensible and latent kitchen loads (oven,stove,people)
- time of use load controller
- Should create a marketing graphic toward complete HVAC system performance- One that gives consumers something to ask for (and understand) and creates new opportunity for contractors.
- Look at foiled siding products of late sears-masonite, Lp composite, EIFS and wonder how it is that producers can push products, they choose and impede others from progress in SEER, a AC's etc.
- biggest problem is the home builders associations.