Evaluating Minnesota Homes
Final Report

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The Minnesota Department of Commerce

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Executive Summary

This report summarizes an examination of specific building performance issues in Minnesota homes built during a time of transition in building practices and energy code changes. It intends to evaluate the role these transitions play in improving housing to be more durable, safer, and energy efficient. This project was undertaken to evaluate and compare homeowner perceptions and the effectiveness of building envelope changes, combustion safety upgrades, and mechanical ventilation systems in homes built in 1994, 1998, and 2000.

A sample of 43 homes received performance testing and visual inspections. The homeowners were interviewed regarding energy use, comfort issues, indoor air quality, and mechanical system operation and maintenance. Utility usage was monitored and analyzed to quantify energy savings resulting from efficiency upgrades.

This study found that:

- Homes built under the Chapter 7672 and Category 1 codes are more tightly constructed than those built to Category 2 requirements by an average of 29%.
- The average 1998 home in this sample uses 21% less energy to heat than the average 1994 home.
- The average 2000 home in this sample uses 25% less energy to heat than the average 1994 home and 5% less than the average 1998 home.
- Mechanical ventilation systems of this sample set are meeting or exceeding the minimum airflow requirements of the new energy codes.
- Despite being less airtight, Category 2 homes in this sample are more susceptible to combustion safety issues than Category 1 and Chapter 7672 homes.
- Homeowners want and need more information and guidance regarding the operation and maintenance of their mechanical ventilation systems and how they affect the performance of their home.
- Incremental increased costs associated with energy code compliance amount to approximately 1-2% of the cost of the home.
- Savings in heating and cooling costs offset the additional expense for energy upgrades to comply with the energy code in most homes reviewed.

While this sample set is small and of limited use as a statistical predictor, the information collected provides valuable insight as to how some new homes are performing and as to what issues need further attention. Energy code requirements alone do not guarantee home performance, ensure indoor air quality, or improve attention to detail by builders and subcontractors. The building industry has a goal of providing homes that are safer, healthier, more energy efficient and offer better durability while providing affordability in owning, operating, and maintaining homes. With this in mind, builders and consumers are learning to understand the complexity of improving building performance. This creates a need for ongoing training for all facets of the homebuilding industry including building officials, subcontractors, manufacturers, and consumers.

Introduction

Minnesota's challenging climate dictates a systems approach to building which integrates energy conservation, management of combustion gases against the effects of depressurization from exhaust appliances, ventilation for indoor air quality, and prevention of water intrusion. Energy code requirements in response to these challenges have come under scrutiny, and little data exists as to actual performance of both new homes and existing housing stock. The purpose of this study was to examine and document how key construction details, operation, and maintenance variables affect the energy and indoor air quality performance of occupied homes, and to examine cost issues related to implementation of energy code requirements.

Study Objectives

- To examine the effectiveness of features installed in new homes to provide energy efficiency, protection against depressurization, improved indoor air quality, and increased building durability.

- To identify less costly methods that could have been used to achieve similar levels of energy efficiency, improved indoor air quality, and improved building durability.

- To determine the typical operation and maintenance behavior of homeowners and how operation and maintenance impact the energy use and air quality of homes.

- To prepare a report that can be used for future information and education projects.

Sampling Criteria

The sample size was limited to 40-45 homes due to the available project budget.

An independent data research firm was retained to obtain lists of building permits for homes issued in 14 Twin Cities metro area municipalities during periods in 1994, 1998, and 2000. A letter of solicitation was sent to 403 addresses inviting homeowners to participate in the study. 77 responses were received and all respondents were contacted by telephone. The study objectives, the nature of the field-testing, and the commitment involved were explained to them in further detail.

Because their participation was needed for the duration of the project, they were asked whether they planned to move in the next year and a half. We also asked whether they were currently involved in any litigation or dispute with their builder, which none were. Finally, they were asked whether they were available for house testing during daytime hours, including an initial visit of 4-5 hours. 43 homeowners agreed to participate.

The homeowners agreed to allow Shelter Source to conduct thorough performance testing of their residence in the winter of 2000/2001 and also to two subsequent visits, one to examine summer performance and one during the winter of 2001/2002. They also agreed to complete a homeowner survey during these visits, and they agreed to the release of energy usage data from their respective electric and gas utilities.

The sample was intended to include a cross-section of homes built to Category 2, Category 1, and Chapter 7672 energy code requirements. Of the 43 homes, 23 were built to Category 2 design, 15 to Category 1 design and 5 to the Chapter 7672 requirements. Six of the homes were built in 1994, 16 were built in 1998, and 21 were built in 2000.

Code Distribution by Year Built			
	Category 2	Category 1	7672
1994	6	0	0
1998	14	2	0
2000	3	13	5

The homes in the sample reflect a variety of sizes and styles, as well as both custom and production builders. Each grouping of homes by year contained 1 or 2 person households, families with children, and retirees. All but two of the participant homeowners were the original owners of their homes. Thirty were custom design/build homes, while 11 had purchased model homes.

Variables Being Measured

The following variables were measured and used to compare homes in the study:

- Effectiveness of Building Envelope
    - Air, vapor and thermal barrier continuity
    - Comparison of intentional and unintentional breaks in these barriers
    - Presence or absence of moisture problems
    - Presence or absence of comfort issues
- Ventilation and Mechanical System Effectiveness
    - Central ventilation system flows
    - Exhaust fan flows
    - Installation details
    - Homeowner maintenance issues
    - Occupant comfort and satisfaction
- Indoor air quality
    - Protection against depressurization
    - Relative humidity
- Energy Use Data
    - Comparison of total energy used for heating and cooling
    - Occupant satisfaction

Effectiveness of the Building Envelope

Airtightness of Sample Set

The airtightness of a building's envelope directly affects the comfort, energy efficiency, durability, indoor air quality, and combustion safety of the structure. Recent code changes have intentionally increased the airtightness of residential structures in Minnesota, but builders have been tightening their building envelopes, both intentionally and unintentionally for years. Reasons vary from homeowner demands for increased comfort and energy efficiency to reducing their liability exposure caused by moisture issues related to uncontrolled air leakage. With these changes comes a greater opportunity for depressurization in combustion appliance zones due to various types of exhaust fan operation. Despite the issues, information regarding the airtightness of new homes in Minnesota is relatively sporadic. One goal of this study was to gather data in this area.

Test Methods

A calibrated Minneapolis Blower Door and the Automated Performance Testing (APT) system from The Energy Conservatory were used to conduct the airtightness testing. Multi-point blower door tests were conducted according to procedures outlined in the "Minneapolis Blower Door Operation Manual for Model 3 and Model 4 Systems" and "Automated Performance Testing System Software User's Guide" from The Energy Conservatory. Multi-point tests were utilized to ensure accuracy and repeatability. Multiple multi-point blower door tests were conducted under windy conditions.

All of the "intentional openings" in the building envelope were sealed for the test. Class B flues were sealed in the mechanical room. The bottom of the vent was removed and the hole, or holes, where the furnace and water heater flues joined the class B flue were sealed on the inside of the class B flue. The bottom of the class B was than sealed in a similar fashion. Combustion air hoods, ventilation system intake and exhaust hoods, and PVC flues were sealed on the exterior. Dryer vents, exhaust fan hoods and other devices equipped with integral back-draft dampers were left in their normal operating state.

Test Results

The average year 2000 home in our study was 40% tighter than one built in 1994, and 28% tighter than one built in 1998 when the CFM per square foot of floor area is compared. The average Category 1 and 7672 home is 29% tighter than the average Category 2 home. This tends to indicate that recent changes in code language requiring increased air sealing have resulted in tighter buildings.

Airtightness Distribution by Year Cubic Feet Per Minute @ 50 Pascals			
CFM50	1994	1998	2000
1000 or Less	0	0	5
1001 to 1300	3	3	8
1301 to 1600	2	4	7
1601 to 1900	1	7	1
Over 1900	0	2	0
Total	6	16	21
Average	1,347	1,604	1,166

Airtightness Distribution by Year Air Changes per Hour @ 50 Pascals			
ACH50	1994	1998	2000
1.0 or Less	0	0	0
1.1 to 2.0	0	1	10
2.1 to 3.0	2	7	9
3.1 to 4.0	1	8	2
Over 4.1	3	0	0
Total	6	16	21
Average	3.71	2.97	2.14

Airtightness Distribution by Year CFM per Square Foot of Floor Area @ 50 Pascals			
CFM/Sq.Ft.	1994	1998	2000
0.24 or Less	0	0	3
0.25 to 0.30	1	1	8
0.31 to 0.40	1	6	8
0.41 to 0.50	0	6	1
0.51 and Over	4	3	1
Total	6	16	21
Average	0.52	0.43	0.31

The leakiest structure was a 1994 Category 2 home that tested at 0.75 CFM per square foot and 5.1 air changes per hour at 50 pascals (ACH50). The tightest home was a year 2000 Category 1 home. Blower door tests indicated that this structure was 0.20 CFM per square foot and 1.41 ACH50.

Infrared Scanning

Quantifying a building's air leakage is an important exercise because air leakage directly affects building performance. Determining the origin of the air leakage is equally important because the infiltration cannot be controlled until its origin is found. Partial-depth insulation, improperly installed insulation, or missing insulation also affects building performance in Minnesota's climate. The performance testing of this sample set was conducted during cold weather, with large temperature differences between indoor and outdoor conditions. This allowed for the integrated use of a blower door and infrared camera in an effort to identify both insulation voids and the origin of infiltration.

The infrared camera provides visual indication of temperature differences on building surfaces. For example, the framing members within a wall are clearly spotted during a scan because of the difference in the insulation value of the wood stud vs. the stud cavity. Wood studs conduct heat at a faster rate than the adjacent insulated cavities when there is a sufficient temperature difference.

Test Methods

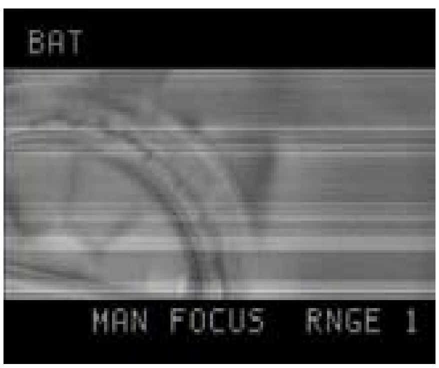
The infrared scanning was completed with an Agema Model 510 infrared camera. The images from the camera were recorded with a Sony Videoman 8 mm video recorder for later review. The tapes were played back through digital imaging software to capture the still pictures presented below.

Two infrared scans were conducted on each home. One was conducted before the airtightness testing process began, with the house in its normal state, in order to find any voids or compression of insulation within wall cavities. The second scan was conducted with the blower door depressurizing the house and drawing cold air from the outside.

Initial Scanning For Insulation Voids

Large dark spots in between framing members during the initial scanning indicate the settling or improper installation of insulating material. There were few obvious insulation voids found during the study. Areas that were expected to have problems, such as knee-walls and ceiling height transitions, were not found to contain serious voids or other installation issues. Those that were found are presented below.

The above images illustrate an obvious void and serve as a good example of what can be found with infrared imaging. The dark areas in the infrared image correspond to the cold surfaces caused by the missing insulation. This was in a 1998 home where a ventilation system was retrofit. The insulation was not put back in place properly after the exterior hood and flex duct for the ventilation system were installed.



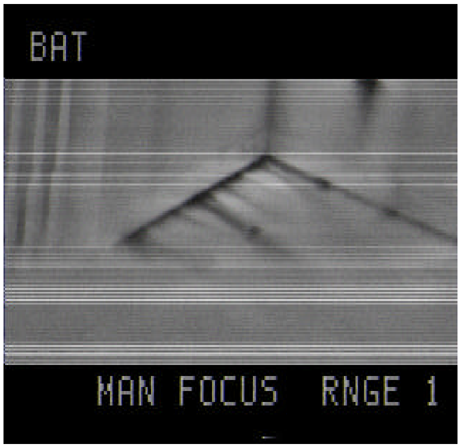
This infrared image shows an insulation void in the corner of the arched window in this 1998 home. This is a typical scenario for this detail due to the amount of framing members necessary to support this window and the small amount of space left to provide insulation, but this image would indicate that there is no insulation placed in that cavity.

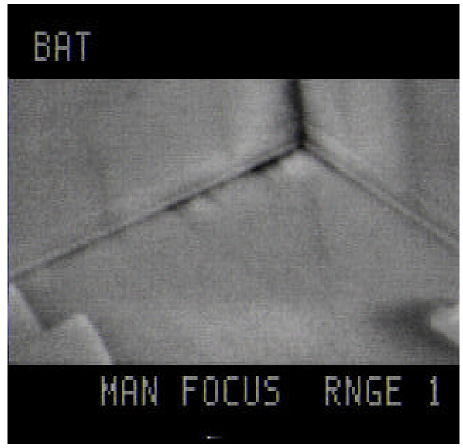
Careful installation of the insulation material, adequate air barriers, and wind-wash protection where applicable help to eliminate insulation voids and ensure the effectiveness of insulation. Insulation voids do occur in Minnesota homes and attention to detail during the framing and insulation process is necessary to avoid them.

Scanning Air Leakage

After the initial scanning of the inside surfaces of exterior walls and ceilings, the blower door was used to depressurize the home and draw cold air from the outside. The infrared camera can than identify temperature differences on interior surfaces caused by the cold outside air being drawn into framing cavities. The majority of the air leakage came from predictable areas. Those areas were: bottom plates, attic bypasses, exterior outlets, doors and windows, rim joists, cantilevered floor spaces, plumbing cavities, and framing cavities.

Bottom Plate Leakage

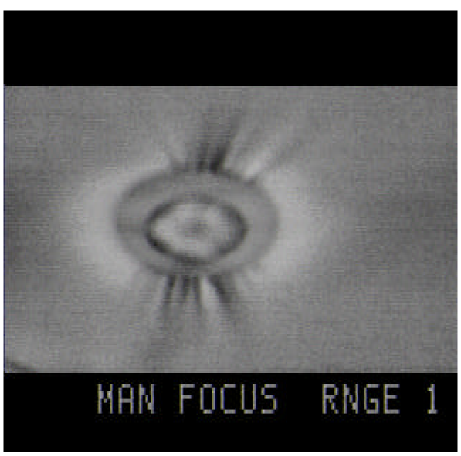




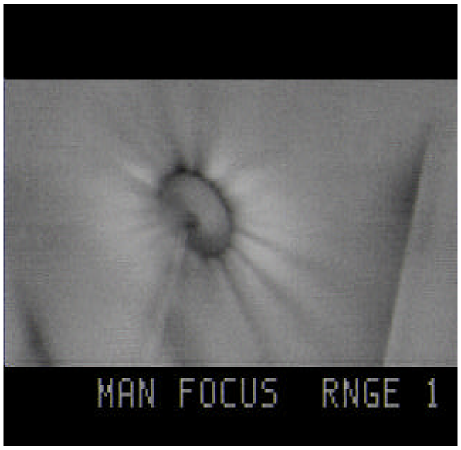
These pictures show air leakage from the crack between a sub-floor and bottom plate. Typically the leakage is greater in exterior corners of the floor due to the complex connection of the adjoining walls and the physical properties of wood to expand and contract with slight changes in moisture and temperatures. Using a plate gasket in between the sub-floor and the bottom plate or caulking the bottom plate to the sub-floor are two common ways of preventing this air leakage pathway.

Attic bypasses

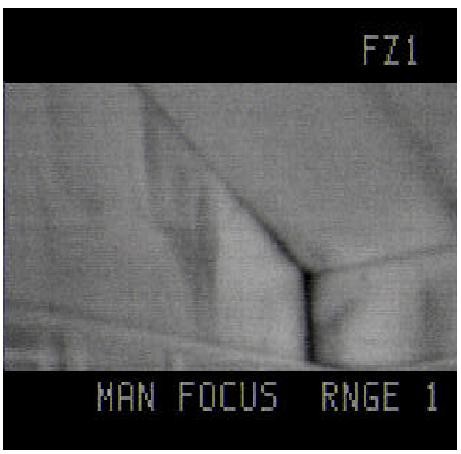
Attic bypasses can contribute to the formation of ice dams during winter months and are typically a large fraction of a home's total air leakage rate.

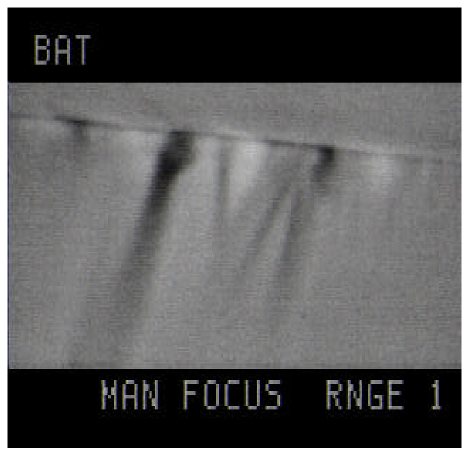


Air-leakage through recessed lights has a direct connection to the attic space. This picture shows cold air being drawn in from an unconditioned attic above the recessed light fixture. Most Category 1 and 7672 homes demonstrated better air sealing at this location. Increased availability of sealed recessed lights and careful installation are essential to the success of reducing air leakage at this detail.



Light fixtures and other fixtures such as speakers were also noted to have considerable leakage characteristics. This leakage was noted in 1994, 1998 and year 2000 construction.





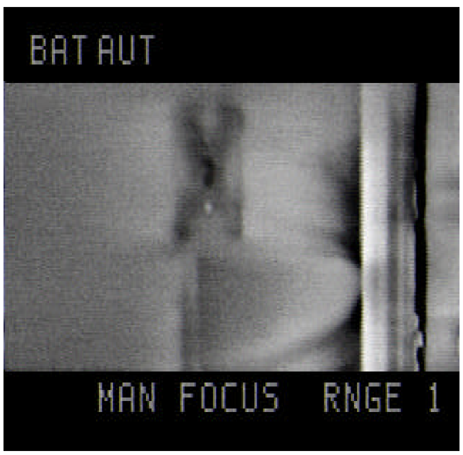
The pictures above show cold air (the dark plumes) from the attic leaking into interior wall cavities from the top plates. The cold air could be coming through unsealed wiring penetrations or through unsealed cracks between the sheetrock and top plates. Observe not only the darkened corners and edges of the top plate, but also the dark spots forming between the stud cavities. This migration of cold air is caused by an air path present in the wall cavity that is connected to the inside of the home. There was evidence of top plate leakage from all of the code types, but seemed to be less prevalent in year 2000 homes. The potential for this leakage is variable depending on the outside perimeter and the complexity of design. Homes with larger perimeters and complex features have more potential for leakage than more compact homes.

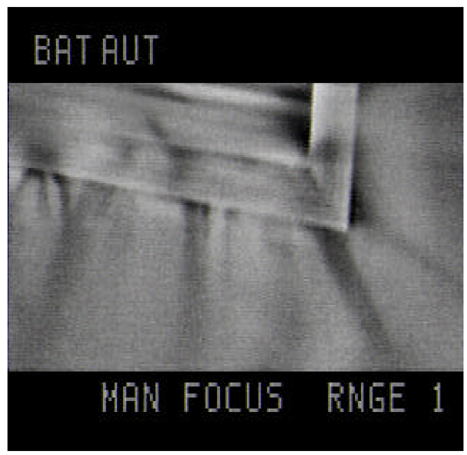
Sealing all the holes in the top plate with caulk or expanding foam and completely sealing the union of the sheetrock and the top plate will reduce the amount of air leakage between the attic and interior wall cavities. When the top plate is properly sealed the air path will be eliminated and thus reduce the overall air leakage rate.

Exterior outlets

Leakage from exterior electrical penetrations was expected to be more of a problem in the 1994 and 1998 homes than the year 2000 stock due to the increased use of sealed exterior outlet boxes. This was the case, but not to the degree expected. Some of the installations were well sealed; others leaked as much as regular boxes. Attention to detail is essential to the success of airsealing at this assembly.

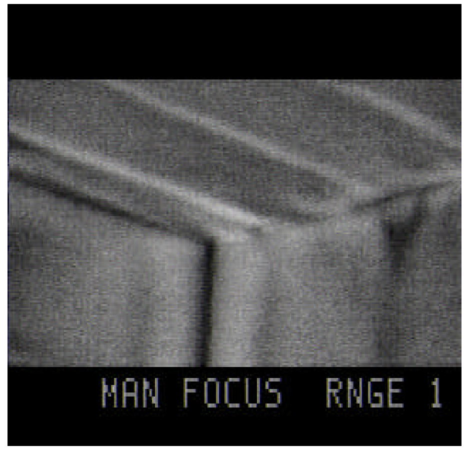
Doors and windows





Leakage around doors and windows can occur when the interior poly or sheetrock is not sealed to the rough openings. The leakage may go unnoticed by the homeowner because of the nature of the leak. Many occupants may simply think that the leak is from an improper seal at the door or window, not the installation. Sealing the vapor barrier or sheetrock to the rough opening of the door or window, insulating the cavity between the rough opening and the door or window, and properly sealing the exterior of the door or window frame to the exterior air barrier greatly reduces the potential for drafts at the doors and windows.

Rim joists and cantilevered floor spaces



These are shots of air leakage from floor cavities situated over attached garages. Both of the pictures are observed from adjacent kitchens. Note that the floor trusses are white because they retain heat longer than the un-insulated cavities around them that are getting washed with cold air. This was noticed in homes of all code types.

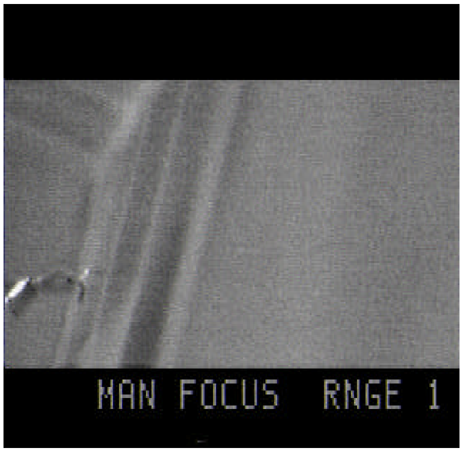
None of the homeowners in our study mentioned comfort issues that could be traced to this situation, but many homeowners believe that the cold feeling from this room in the winter is natural and to be expected because the room is over the garage. Sealed blocking above the garage common wall would reduce the amount of air drawn into the wall and floor cavities and isolate leakage from the cantilevered floor if it occurred.

The leakage shown here was observed from an unsealed rim joist in a Category 2 home. There are also air leaks noticeable above the patio door.

This staining is a common visual indication of rim leakage in a main floor rim of a 1994 home. The batt of insulation has been filtering infiltration for some time. Again, the proper sealing of the rim joist would prevent the air leakage from spilling into the basement.

This is a main floor rim joist in a year 2000 home. Notice the light coming in around the PVC pipe. The majority of the rim is well sealed with rigid foam and integrated with the polyethylene air/vapor barrier below it, but this penetration is a weak point.

Plumbing cavities



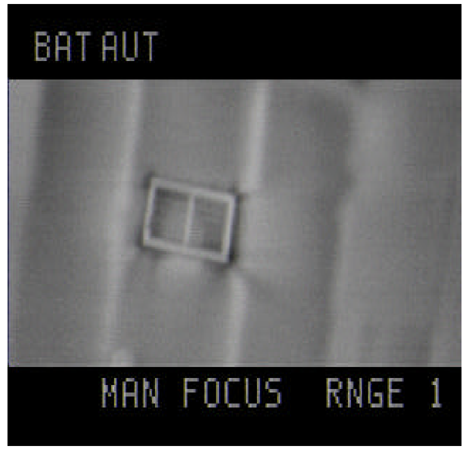
This is a second floor shower stall that is adjacent to an exterior wall and below an unconditioned attic. The object on the left of the picture is a showerhead. The white lines are warm studs, which are highlighted in black because of cold air filling the cavity.

As easily as the air can enter the wall cavity under test conditions, warm moist air can travel in the opposite direction during the winter. When this happens, accumulation of water in the wall cavity may occur due to condensation, challenging the systems durability.

Because of homeowner demand for windows in bathrooms, and the common layouts of bathroom floor plans, showers stalls on exterior walls are very common. The proper sealing of the vapor behind the shower stall is crucial and steps should be taken early during construction to ensure it happens.

Framing cavities and dropped soffits

Framed cavities on exterior walls are also problematic from an air sealing perspective. Framed cavities in this study included cantilevered fireplaces, cantilevered entertainment centers and dropped soffits.



Both of these pictures are framed fireplace cavities on exterior walls. Just as with the plumbing wall, the interior studs of these cavities appear warm when compared to the adjacent sheetrock. Had the cavity been sealed from exterior leakage, there would not be as significant a temperature difference and the dark areas would not be as evident.

This is a dropped soffit in the basement of a 1998 home with an air leakage signature similar to those of the framing cavities above.

In a general sense, noticeable leakage seemed to diminish from year to year, with the year 2000 homes having less obvious areas than the 1994/1998 homes. This is to be expected considering the increase in airtightness found via blower door testing. However, there are still some penetrations in the envelopes of new homes that will benefit from continued attention to detail during the framing, insulation, and sheetrock stages of construction.

Ventilation System Performance

One of the main goals of this study was to evaluate ventilation system performance within our sample set. Performance was based on the system's ability to deliver outdoor air to the indoor environment. The distribution of fresh air within the homes was not quantified, but this factor does affect performance and the potential for proper distribution was evaluated.

There are many factors that influence the performance of a mechanical ventilation system. The design of a system, its installation, its commissioning and homeowner education are factors that have the most affect on ventilation air delivery from the builder and mechanical contractor perspective. Homeowners affect the performance of their ventilation systems through proper maintenance and operation. All of the above factors were evaluated for this study.

One of the 1994 homes, nine of the 1998 homes and all but three of the 2000 homes had whole house ventilation systems. The 1994 house had a heat recovery ventilator that was installed at the time of construction. All of the nine 1998 homes had heat recovery ventilators. Six of the units were installed at the time of construction and three were later retrofit, with the homeowners citing window condensation as the main purpose for the retrofit. The year 2000 ventilation systems varied in design and installation. There were two decentralized exhaust-only systems, two energy recovery ventilation systems (ERVs) and 13 heat recovery ventilation systems (HRVs). All of the systems were installed at the time of construction. Balanced ventilation systems without heat recovery, centralized exhaust only systems or fully ducted balanced ventilation systems were not found in this sample set. By definition, all of the Category 1 and 7672 homes had mechanical ventilation systems and one had been installed in 6 of the 21 Category 2 homes.

Breakdown of Ventilation Types (# of Homes)*

	HRV	ERV	Exhaust Only	No Ventilation
1994	1	0	0	5
1998	9	0	0	7
2000	13	2	3	3

HRV/ERV Installation Types (# of Homes)*

Install Type	1994/1998	2000
Source Point	4	4
General	3	5
Volume, Return/Supply	3	3
Volume, Return/Return	0	3

* Detailed descriptions of each particular ventilation type can be found in appendix A.

Ventilation Air Delivery

The ideal ventilation flow rate is a compromise between providing acceptable indoor air quality, which tends to maximize airflow from the outside, and energy efficiency, which requires a minimized ventilation flow rate (IAQ Handbook, 2.9). For the purpose of this study, a "properly sized ventilation system" is defined as a system having a flow rate that would meet the requirements of chapter 7672.1000 of the Minnesota energy code. This chapter of the energy code is based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality" and the 1993 Ontario Ventilation Code. It incorporates as comprehensive an approach to calculating effective ventilation capacity as possible considering the thousands of pollutants, pollutant interactions and human physiological interactions that influence "acceptable indoor air quality". It is comprehensive in that it "considers chemical, physical, and biological contaminants that can affect air quality." (ASHRAE Standard 62-2001, 2.2)

Chapter 7672.1000 requires a total ventilation rate (TVR), in cfm, of 0.05 times the total conditioned floor area of the house. The total conditioned floor area includes the basement. For example, a system in a house of 3,000 square feet would be sized to be capable of providing 3,000 x 0.05 = 150 cfm of outdoor air. Code language recommends dividing the TVR into a people ventilation rate (PVR) and supplemental ventilation rate (SVR). The PVR is a minimum ventilation rate sized at 15 cfm per bedroom plus an additional 15 cfm and is usually designed to operate on a continuous basis. A three bedroom house would have a PVR of (3 x 15) + 15 = 60 cfm. The SVR is simply the difference between the TVR and PVR, 150 cfm – 60 cfm = 90 cfm.

Calculation of PVR, TVR and SVR	
House total conditioned floor area: 3,000 # of Bedrooms:	3
Total **V**entilation **R**ate = (Total conditioned floor area X 0.05) = (3,000 X 0.05) =	150 cfm
People **V**entilation **R**ate = (15 cfm per bedroom + 15) = (3 X 15) + 15 =	60 cfm
Supplemental **V**entilation **R**ate = TVR - PVR = 150 cfm - 60 cfm =	90 cfm

Ventilation systems installed in Category 1 and chapter 7672 homes are required to achieve the total ventilation rate and must be sized accordingly. They do not necessarily need to be designed to operate continuously at the people ventilation rate. It is a recommendation based on the fact that it is undesirable from both an energy perspective and an indoor relative humidity perspective for most homes in our climate to have continuous ventilation at a rate of 0.05 x the total conditioned floor area. However, all of the systems in this study had the capability of operating on a continuous basis at a smaller ventilation rate and did have added ventilation capacity for when a higher ventilation rate was necessary. This is why it was decided to convey the measured flow rates broken down into the PVR and TVR.

In homes using a decentralized exhaust-only ventilation approach, the PVR was met with a continuously running, quiet exhaust fan installed in a central location - the upstairs hallway in the three homes in this study. The TVR was then met by adding the airflow capacities of the remaining bathroom exhaust fans.

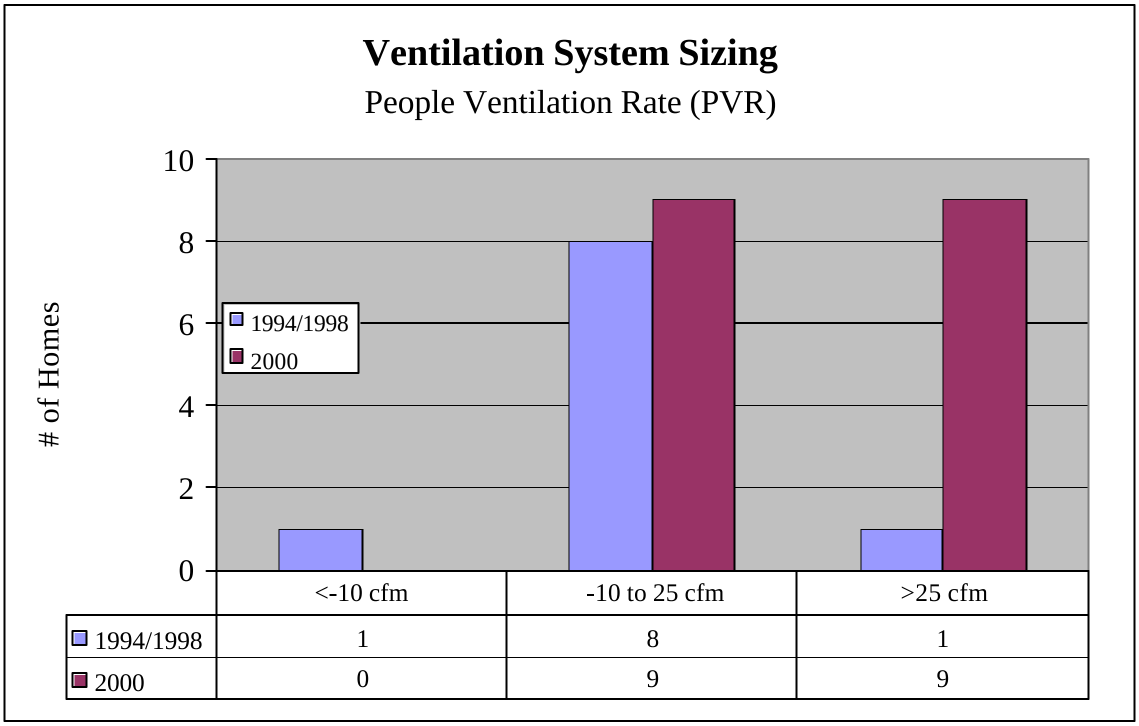
All of the HRVs and ERVs in this study had at least two-speed blowers. This allows them to operate at a low continuous speed to meet the PVR and at a higher airflow rate when necessary, i.e. when there is an increase in relative humidity, increased occupancy, disagreeable odors, etc. Only two of the homes utilized a balanced source point HRV/ERV system without additional exhaust fans. With this ventilation design the TVR in these homes would need to be met with the airflow capacity of the ventilation system at its highest speed. Other balanced ventilation design strategies may utilize the airflow capacities of additional exhaust fans to meet the TVR.

Test Methods

How the ventilation rates were measured depended on the type of system. The exhaust only ventilation systems, supplemental bathroom exhaust fans and individual draw points for balanced heat and energy recovery ventilation systems were measured using a properly calibrated Alnor Low-Flo balometer. Total system flow rates were measured at the exterior terminations (hoods) with the Alnor Low-Flo balometer or directly at the unit depending on the equipment type. Intake and exhaust flows and individual draw points were measured at all available blower speeds.

People Ventilation Rates

Two of the 10 (20%) 1994/1998 homes and 2 of 18 (11%) year 2000 homes with mechanical ventilation systems did not meet the recommended PVR. The 4 homes missed the PVR by 13 cfm, 9 cfm, 6 cfm and 3 cfm. 7 of the 10 (70%) 1994/1998 homes and 7 of the 18 (39%) year 2000 homes either met or exceeded the recommended PVR by less than 25 cfm. One of the 10 (10%) in the 1994/1998 dataset and 9 of the 18 (50%) whole house ventilation systems installed in the year 2000 exceeded the PVR by more than 25 cfm. This does not necessarily present a problem other than a slight increase in energy use. The systems that missed the design target ventilation rates still provide ventilation. Increased activity, larger families and other various site conditions can all contribute to variations in pollutant levels, but the PVR does not reflect this need for varying ventilation rates since it is based on the number of bedrooms. Even systems designed to the proper ventilation rate could be inadequate if adverse conditions existed.

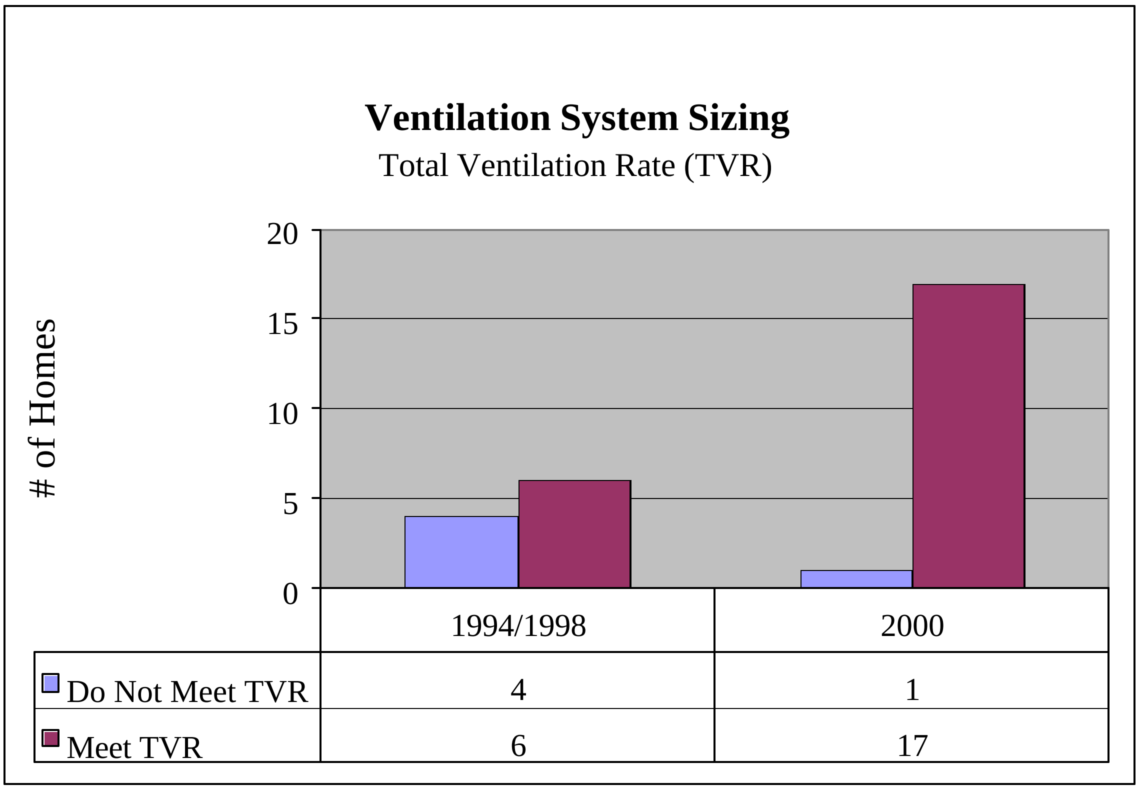


The largest difference between the rated PVR and actual PVR was a 1998 house that exceeded the recommended ventilation rate by 68 cfm. This HRV system was operating at 128 cfm on low speed although the minimum requirement for this 3-bedroom home is 60 cfm. Much lower continuous ventilation rates have been known to result in excessively low levels of relative humidity (RH) in Minnesota homes during the winter, but in this case the homeowners were satisfied with their indoor relative humidity. In fact, this was one of the 3 homes in the study where a ventilation system was installed to help solve a window condensation problem. The homeowners were satisfied with the ventilation system's performance and indicated that it had reduced window condensation. They did not indicate that low RH was a problem. RH monitoring equipment that was left at this home during the final week of February 2001 and the first three weeks of March indicated that this home maintained an average relative humidity of 26% during that period.

One homeowner in this study did not operate the HRV in his home because he felt it did "over-dry" the structure. The HRV was operating at 105 cfm on low speed, exceeding the recommended 75 cfm PVR by 30 cfm.

Total Ventilation Rates

The total ventilation rate (TVR) is the measured total ventilation capacity of homes with residential ventilation systems. This would be the sum of the measured people ventilation rate (PVR) and the total supplemental airflow capacity of the home, not including the kitchen range hood. In a house with a source-point balanced ventilation system not utilizing exhaust fans for spot ventilation, the TVR would be the measured high-speed flow of the balanced ventilation system. In a house with a general or volume balanced ventilation system strategy with separate exhaust fans for spot ventilation, the TVR would be the sum of the ventilation system's high-speed flow rate and the total measured exhaust capacity of the exhaust fans. In a house with a decentralized exhaust fan being used to meet the people ventilation rate and separate bathroom exhaust fans for spot ventilation, the TVR would be the total measured flow of all of the exhaust fans.



The four 1994/1998 ventilation systems missed the TVR by 52 cfm, 28, cfm, 28 cfm and 21 cfm. The year 2000 home missed the recommended TVR by 118 cfm. The average 1994/1998 home exceeded the recommended TVR by 63 cfm; the average year 2000 system exceeded the recommended TVR by 70 cfm.

All of the ventilation systems that did not meet the recommended TVR were source point balanced ventilation systems. Three of these systems did not have supplemental exhaust fans; one of the 1994/1998 homes had one supplemental exhaust fan. Of the 3 source point systems that did meet the TVR, one had one additional exhaust fan in the master bathroom and 2 of the homes had 3 additional bathroom exhaust fans. Only one of the source point ventilation systems in this study would have met the recommended TVR without added exhaust fan capacity.

Ventilation System Design

The above information highlights the need for the proper design of ventilation systems, especially balanced source point systems that utilize an increased amount of ductwork. The additional fittings, terminations and long duct runs that are necessary in a source point system greatly increase the equivalent duct length. The average equivalent length of a source point system is much higher than the average general or volume ventilation strategy. If a source point HRV/ERV system design does not account for this increased static pressure, it may not deliver the desired total flow rate or the amount of flow desired at each source point.

ASHRAE 62-2001 provides guideline ventilation rates for kitchens and bathrooms, the source points that produce the most pollutants, moisture and odors. ASHRAE recommends that bathrooms have 50 cfm of intermittent ventilation or 20 cfm of continuous ventilation. It recommends 100 cfm of intermittent ventilation or 25 cfm of continuous ventilation for kitchens.

The charts below show the high and low speed flows for each of the ducted source point systems in this study:

House Code 1994-02

Source Point	Laundry	Kitchen	Master Bath	Main Bath	**Total**
High Speed	32	38	20	22	**112**
Low Speed	15	17	12	14	**58**

House Code 1998-02

Source Point	Basement	Kitchen	Master Bath	1/2 Bath	**Total**
High Speed	Grill Closed	52	39	43	**134**
Low Speed	Grill Closed	37	28	30	**95**

House Code 1998-09

Source Point	Basement	Kitchen	Master Bath	Main Bath	**Total**
High Speed	Grill Closed	24	32	33	**89**
Low Speed	Grill Closed	18	22	22	**62**

House Code 1998-14

Source Point	Laundry	Kitchen	Master Bath	1/2 Bath	Main Bath	**Total**
High Speed	27	20	38	44	32	**161**
Low Speed	13	10	22	22	18	**85**

House Code	2000-06					
Source Point	Basement Bath	Kitchen	Master Bath	Main Bath	Laundry	**Total**
High Speed	19	45	10	36	60	**170**
Low Speed	10	20	1	19	26	**76**

House Code	2000-07						
Source Point	Bsmnt Bath	Kitchen	Master Bath	Main Bath	Laundry	1/2 Bath	**Total**
High Speed	12	25	8	8	23	25	**101**
Low Speed	9	18	0	0	14	18	**59**

House Code	2000-08					
Source Point	Basement Bath	Kitchen	Master Bath	Main Bath	Laundry	**Total**
High Speed	25	21	18	9	22	**95**
Low Speed	19	15	12	8	18	**72**

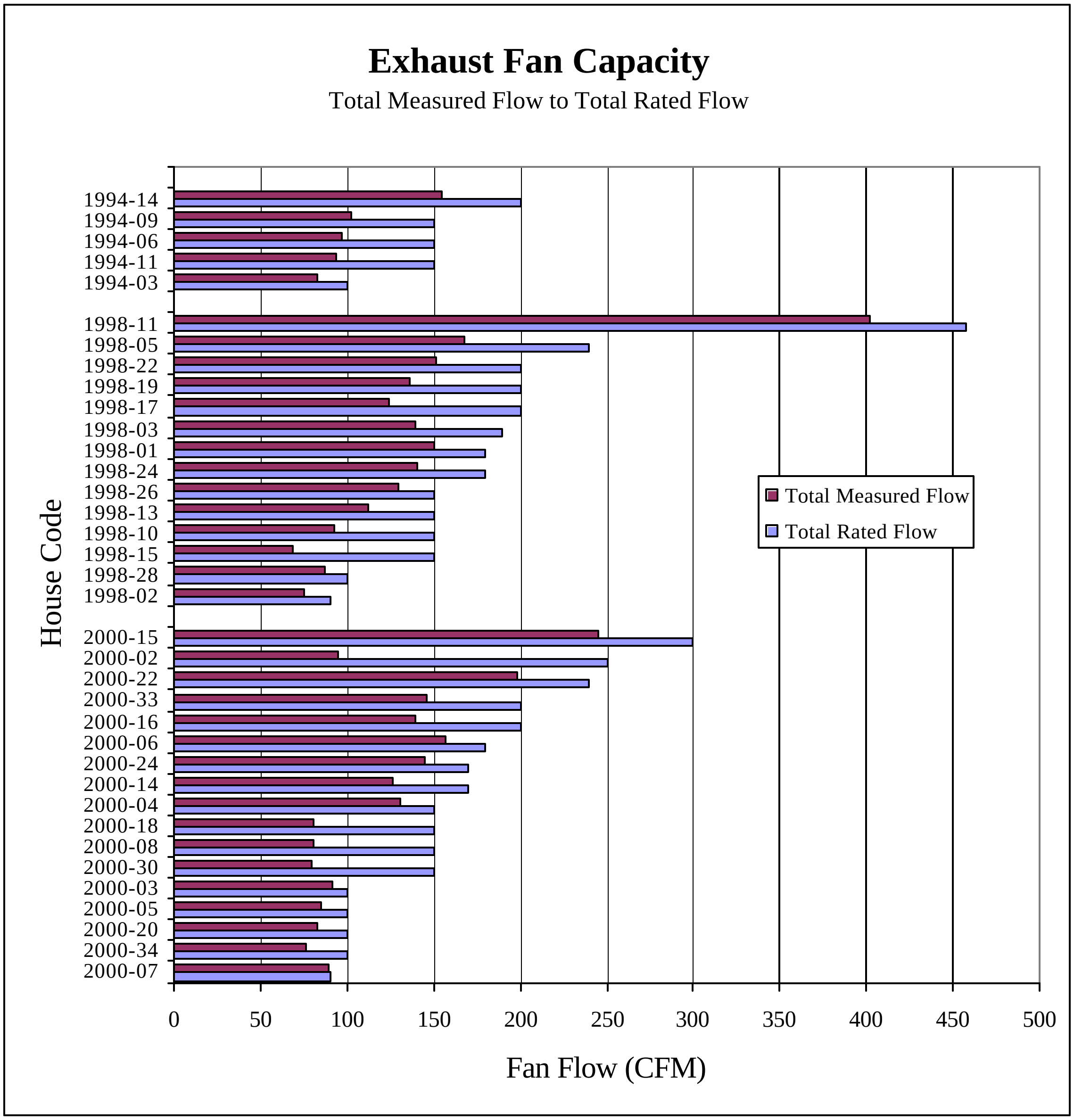
House Code	2000-10							
Source Point	Bsmnt Bath	Master WC	Master Bath	Bath #1	Bath #2	Laundry	1/2 Bath	**Total**
High Speed	58	10	18	12	15	9	12	**134**
Low Speed	33	6	9	6	9	5	8	**76**

Take note of the low master bath source point flow in house 2000-06. This was a rectangular rambler with the HRV in the basement on one side of the house and the master bathroom on the main floor on the opposite side of the structure. The equivalent duct length for this draw-point was more than double the duct length of the other source points but had the same 6” metal duct size.

A similar situation occurred in house 2000-07. The master bath and main bath draws were the only two draws located on the upper floor of this 2-story structure. The HRV was located in the basement. Long equivalent duct lengths are necessary to travel through the basement, up an interior wall cavity, into the floor space and up another wall cavity to reach the master and main baths. The long duct lengths are reflected in the amount of flow the HRV is able to draw from these two source points, but may also be a reflection of a lack of adjustment of airflow from other draw points via dampers.

Careful sizing of the HRV/ERV, in combination with careful duct design and adjustment of airflow from each exhaust point, will allow for the proper amount of airflow at each source point. It is important to realize that it may not always be practical to run a long length of duct to some remote source points. The addition of an exhaust fan may be necessary to meet ASHRAE recommendations.

Exhaust Fan Performance



Long equivalent duct lengths also affect the performance of bathroom exhaust fans. The chart above shows the total rated exhaust fan capacity compared to the total measured exhaust fan capacity for each home with exhaust fans installed. A home with four bathroom exhaust fans, each rated for 50 cfm, would have a 200 cfm total rated exhaust capacity. For example, house 1998-11 had 457 cfm of exhaust capacity. This included one 257 cfm rated in-line exhaust fan installed in a “smoking room” which was intended to provide intermittent exhaust, along with 4 bathroom exhaust fans rated at 50 cfm. The actual measured flow rate was 402 cfm.

The average measured exhaust capacity was 71% of the total rated capacity in the 1994 homes, 74% in the 1998 homes and 75% in the year 2000 data set.

Fresh Air Distribution

The basic premise of ventilation is to provide fresh, outside air to the occupants of a building. If that fresh air is only able to enter the house in one room, like a basement or mechanical room, and is not able to be transferred to an occupied space, it has less opportunity to be effective.

There are a number of strategies available to achieve effective distribution. The main component is a means for the fresh air to get to the habitable space. This can be accomplished through forced-air system ductwork, separate ventilation system ductwork, or separate individual room inlets. Once a path is established, the operation of the main furnace fan (air handler) or the mechanical ventilation system fan (HRV, ERV or exhaust) can provide the force necessary to move the fresh air from outside to the habitable space. This distribution also needs to be automatically controlled to operate either continuously or on a timed basis.

Since every home in this study had a forced air heating and cooling system, all of the ventilation systems had the capability to use the forced air system ductwork to provide ventilation distribution. There were no homes that had fully ducted mechanical ventilation systems or individual room inlets. This distribution capability was not utilized in most cases, however. Only 2 homes ran a continuous furnace fan and only 4 had a timed control device to operate the furnace fan to properly distribute fresh air. In other words, when there is no "call" for heating or cooling, there will be a lack of effective ventilation distribution in 21 of 28 (75%) homes in this subset. The effect of ventilation distribution could be demonstrated using tracer gas technology, but was not part of this study.

HRV/ERV Installation Issues

Of the 28 HRV/ERV installations in this study, one was found to not have any of the installation issues noted below.

HRV/ERV Installation Issues Encountered

	# of Homes	
Installation Issue	1994/1998 Installations	Year 2000 Installations
Not Balanced Within 10%	4	4
No Balancing Information	7	5
No Attempt to Balance	6	4
Control(s) Not Functioning Properly	0	1
Missing or Compressed Insulation on Cold-Side	3	3
Exterior Hoods Improperly Located	0	2
No Air Handler Interlock	3	6
No Trap in Condensate Tube	5	4

*Will not sum to total number of installations, installs usually had more than one issue

Balancing

The majority of the installation issues involved improper balancing, or lack of attention to detail when balancing, the HRV/ERV units. Balancing is an important step in the commissioning of these systems. It refers to the process of matching the fresh air intake flow of the system to within 10% of the stale air exhaust flow of the system. This is done in order to optimize recovery efficiency, maximize airflow and minimize house pressure imbalances created by the units.

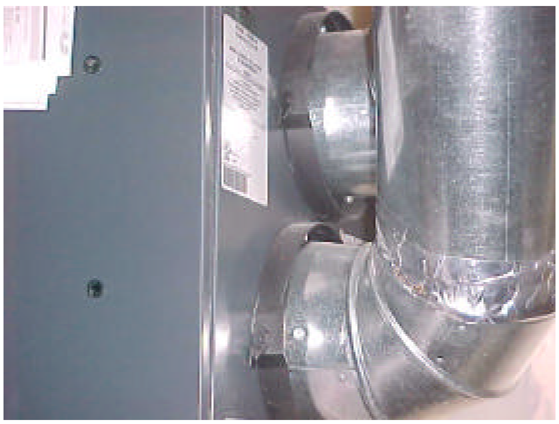
It is a common misconception that HRVs and ERVs are somehow “self-balancing”, but this is not the case. The variations in duct type, size and length on the intake and exhaust sides of the units make this impossible.

The balancing process is fairly simple and requires basic equipment to check the airflows. Every unit in this study, except the one unit installed in 1994, had balancing dampers on the intake and exhaust collars that the installer adjusts to balance the system after installation. The 1994 unit had balancing dampers installed separately at the time of installation. The balancing dampers are made to allow for a sheet-metal screw to be run into them in order to secure them in their balanced position. With the sheet-metal screw in place they cannot be accidentally adjusted and thrown out of balance by the homeowners at a later date. This makes for a good indicator of whether balancing was attempted, as well.

This is a picture of the warm side duct collars on a properly balanced HRV. Notice the dampers are screwed in place at the collar attachments and the metal ducts are sealed to the unit.

8 of the 25 (32%) HRV/ERV systems were not balanced - 4 of the 10 1994/1998 installations and 4 of the 15 year-2000 installations. This issue manifests itself in several different ways. The chart above indicates that 3 of the 1994/1998 units were not balanced, but 7 of the units saw no attempt at balancing. The 4 remaining units were “balanced by accident”. The balancing dampers were set wide open and not screwed in place. It is doubtful that the installer ever actually measured the airflows.

This picture shows the intake and exhaust balancing dampers on the duct collars where the metal ductwork is attached to the unit. Notice there are no screws in the dampers. These dampers could be accidentally adjusted and affect the operation of the ventilation system. Notice that there is a balancing sticker attached in the upper right corner although the system was never actually balanced.



This picture shows the balancing dampers on a year 2000 system as they were found - completely shut and reducing airflow and system effectiveness. No attempt was ever made to ensure that this unit operated properly after it was roughed in.

Another important aspect of a proper installation is the balancing sticker. This sticker gets attached to the unit after balancing and indicates the continuous, or low speed “people ventilation rate” and the high speed flow rate of the unit. 13 of the 28 (46%) systems had balancing stickers applied. 2 balancing stickers were applied to units where balancing was never attempted. One of the stickers indicated that the unit operated at its rated airflow on high speed for both the continuous ventilation rate and high speed flow rate, neither of which matched the measured flow. 5 stickers indicated that the unit was balanced at its rated airflow when it was actually moving 30 cfm to 90 cfm less than its rated flow.

Controls

The majority of the systems had controls that were operating as intended. One of the wall controls in a year 2000 home did not operate properly because it was not wired to the unit correctly. Another system was set at the unit to operate via a central wall control, but no central wall control was installed, the system was operating via homeowner interaction with the booster switches installed at the source points.

Flex Duct Issues

6 of the 28 (21%) installations had issues with the flex duct connection at the cold side of the unit. Since both the fresh air from outside and the exhaust air that leaves the unit are below dew point temperature most of the winter, it is important that any surfaces in contact with the cold air streams are insulated. All of the HRVs and ERVs in this study came equipped with flex duct collars that facilitate this process.

This picture is a good example of properly installed flex duct on the cold side of an HRV installation. The exterior of the flex is taped and tie-strapped to the outside of the duct collar. It can only be assumed that the interior of the flex duct is attached to the interior of the collar in a similar manner. The sharp bends in the flex duct will reduce the overall system flow rate and would benefit from getting at least 12” of straight duct length prior to the bend.

This installation left exposed metal ductwork on the cold side of the system. It is important that the insulation in the flex duct extends all of the way to the collar and that the flex/collar connection is sealed properly. If this does not occur, it is possible that condensation will occur throughout the winter at this connection.

Exterior Hood Location

2 of the 28 (7%) installations had improperly placed hoods. Intake hoods need to be placed where they will draw clean air. This should be at least 6’ from any exhaust hood, dryer hood or combustion vent and should be at least 18” off the ground. Exhaust hoods need to be placed away from other intake hoods or windows. The exhaust hood in one of the study homes was installed in the same rim cavity as the combustion air intake, creating a potential short circuit.

These are shots of the intake and exhaust hood locations of the other installation. The ventilation and dryer exhaust hoods on the right are about 4” of the landscape rock. The intake and combustion air hoods on the left are approximately 6” above the rock.

Air Handler Interlock

The air handler interlock is a control installed on HRV/ERV volume ventilation systems where the house exhaust air is drawn from the main duct system and the fresh air from outside is also supplied to the main duct system. (Please refer to appendix A for detailed diagrams of ventilation duct strategy information.) If the furnace blower (air handler) does not operate under this configuration, there may be poor ventilation and no fresh air distribution because it is possible for ventilation air to short-circuit inside the ductwork of the forced-air system. That is why the furnace blower should to be “interlocked” with the ventilation system so that it runs when the ventilation system is running. Only one of the nine volume ventilation systems utilizing this configuration had a furnace interlock.

Condensate Trap

HRV systems need a collection and drain tube system to allow for condensation from the heat recovery core to drain away from the unit. This condensate tube must be “trapped” as does any open drainpipe in order to prohibit the transfer of odors and other by-products from the floor drain into the ventilation system. Simply putting a loop in the line before it reaches a floor drain is all that is necessary. This was not done in 9 of the 28 installations.

This is a properly trapped condensate tube.

Homeowner Maintenance

Homeowners have a direct affect on the operation of their ventilation systems. These systems are by no means “maintenance free”. They have filters that need to be cleaned or replaced, heat recovery cores that need to be cleaned and intake hoods that need to be cleared of debris – all on a regular basis. Not completing the regular maintenance can result in problems like reduced airflow, wintertime heat recovery core freeze-ups, and even combustion spillage due to pressure imbalances.

HRV/ERV Homeowner Issues Encountered		
	# of Homes	
	1994/1998	2000
Intake Hood Plugged with Debris	5	2
Dirty Filters or Core	3	0

This is a typical plugged hood. Very little intake air is able to make it through the ¼” screen. The system will now have more exhaust capacity and could depressurize the structure.

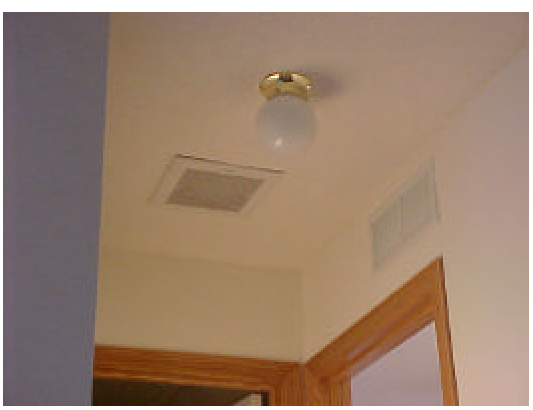
HRV/ERV Flows With Plugged Hoods			
House Code	Exhaust Flow High Speed	Intake Flow High Speed	Difference
1994-02	118	40	78
1998-05	145	118	27
1998-13	130	30	100
1998-19	174	99	75
2000-07	150	117	33
2000-12	130	72	58

Similar flow issues can arise if the filters and the heat recovery cores of these systems are not cleaned on a regular basis. Plugged intake hoods and dirty filters seem to go hand-in-hand and are part of an overall misunderstanding of proper maintenance procedure. The three systems above with the largest difference between exhaust flow and intake flow also had dirty filters. Just as a furnace filter needs to be replaced regularly to ensure the proper operation of the heating and cooling system, ventilation units need regular maintenance to maintain their ability to deliver fresh air.

Exhaust-Only Ventilation Systems

Three of the homes in this study had whole house exhaust-only ventilation systems installed. (Please see appendix A for more information.) The same builder built two of the homes.

One system did not meet the people ventilation rate requirement. This fan was moving 6 cfm less than the recommended PVR. The fan was rated for 70 cfm and was moving 69 cfm in a 4-bedroom home, which has a recommended PVR of 75 cfm. This was not an installation problem, but a design issue. A larger fan should have been specified and installed. All of the systems met the recommended TVR and all of the systems also met code requirements for system controls and fresh air distribution.



The three exhaust-only systems had the people ventilation fan installed centrally in a 2nd floor hallway. Each of the homes had open staircases that allowed for air movement from the main floor.

Each of the systems had a labeled people fan switch similar to this installed in the basement.

Each of the systems had a control to operate the air handler on the furnace at periodic intervals to distribute fresh air throughout the house.

As a whole, homeowners with exhaust only ventilation systems showed satisfaction with their performance. They did not indicate issues with noise or window condensation, as was expected, and the HOBO relative humidity data collected indicates that exhaust only systems maintained RH levels similar to those homes with balanced ventilation systems.

Indoor Air Quality

Numerous variables have an impact on indoor air quality: volatile organic compounds (VOC's), radon and other soil gases, carbon monoxide, moisture, biological contaminants such as mold and dust mites, particulates, smoke, and many other factors too numerous to mention. Therefore, a comprehensive strategy to reduce indoor air contaminants would involve much more than the addition of ventilation. It would also involve elements of source control, separation of zones, and improved filtration. In other words, ventilation alone cannot ensure a healthy indoor environment, but it is a critical component.

A comprehensive study of these variables and their interaction with occupants and the house system is beyond the scope of this study. However, increased airtightness and the addition of mechanical ventilation influence indoor moisture levels and pressure differentials. Because of these direct relationships, interior moisture levels, the potential for combustion spillage, and the air leakage from attached garages were evaluated. Each homeowner was also interviewed regarding their satisfaction with the indoor air quality of their home, since this concept is largely based on personal choice and perception.

Protection Against Depressurization

Testing was performed on each house to determine the potential for spillage or backdrafting of combustion products due to appliance zone depressurization. House systems that can contribute to depressurization include the operation of furnace air handlers and exhaust equipment such as dryers, range hoods, central vacuums, bathroom fans, etc. Two separate procedures were referenced to conduct this testing: the procedure outlined in the Minnesota Energy Code Chapter 7672.0900, subpart 8, section D and the Canadian General Standards Board 51.71-95 (CGSB) standard procedure.

The following maximum depressurization chart is from Minnesota Energy Code Chapter 7672.0900:

APPLIANCE	MAXIMUM DEPRESSURIZATION
Appliances with manufacturer certified negative pressure tolerance rating	The manufacturer-certified negative pressure tolerance rating
Direct vented appliance*	25 Pascals (0.10-inch water column)
Power vented appliance*	25 Pascals (0.10-inch water column)
Thermal mass wood-burning appliance*	15 Pascals (0.06-inch water column)
Closed controlled combustion wood burning appliance*	7 Pascals (0.028-inch water column)
Decorative wood-burning appliance	5 Pascals (0.02-inch water column)
Atmospherically vented oil and gas systems*	5 Pascals (0.02-inch water column)
Atmospherically vented water heater*	2 Pascals (0.008-inch water column)

* Without manufacturer-certified negative pressure tolerance rating.

The 7672 code has a depressurization limit of 2 pascals for atmospherically vented water heaters and there were 22 homes with one of these appliances in this study. The CGSB standard limits depressurization to 5 pascals for all atmospherically vented combustion equipment, but the depressurization limits they present "are based on the performance of typical vents during the heating season, and are not suitable for predicting summertime performance" (CGSB, 1). This standard goes on to note the following: "Fuel-fired hot water heaters connected to vertical chimneys pose a special problem when operated during the summer, in a tight dwelling. Even small amounts of house depressurization may be unacceptable, since flue gas buoyancy is reduced in warmer weather" (CGSB, 1). The stricter depressurization limits on atmospherically vented water heaters in the 7672 code account for summer conditions where the smaller temperature difference between the flue and outdoors weakens the draft potential for this type of appliance. Appliances that are less susceptible to spillage of combustion by-products, like direct vent or power vented appliances, have higher depressurization limits.

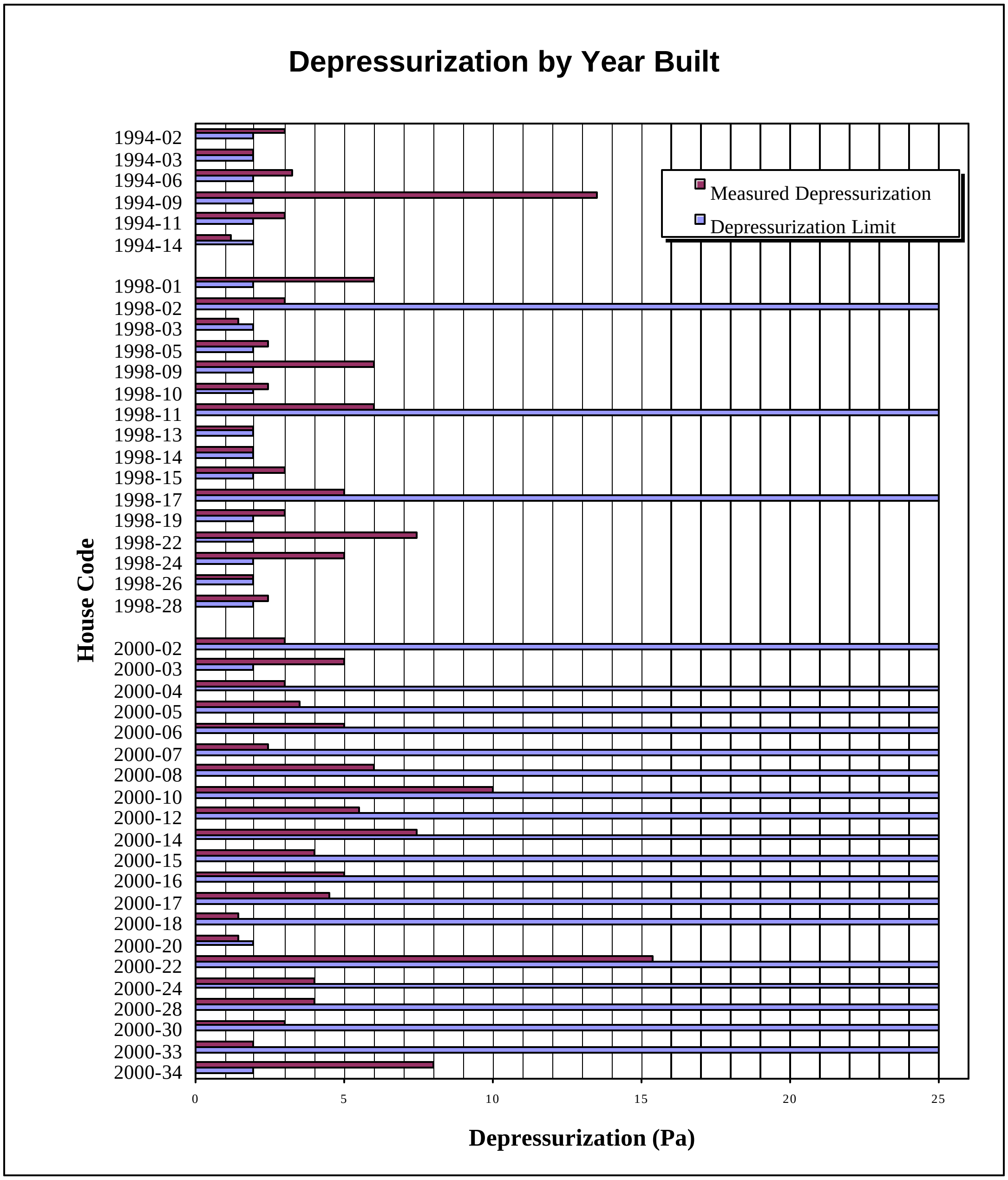
Test Method

The depressurization tests followed the procedures outlined in Chapter 7672.0900, subpart 8, section D. In order to achieve the highest levels of consistency, accuracy, and repeatability, the tests were conducted using the Automated Performance Testing (APT) System and TECLOG software from The Energy Conservatory. The APT system, which consists of the APT device and a laptop computer; is able to monitor, record and display up to 8 separate pressure differentials in real-time. During the test, the timing of specific events, such as when the air handler or exhaust devices were turned on or off, and other notable test data such as wind conditions and notes about house configuration were recorded for subsequent analysis.

For the purpose of this test, an appliance zone that maintains a negative pressure differential with respect to atmospheric pressure under test conditions is "depressurized." (An appliance zone that is depressurized by 3.0 pascals is –3.0 pascals with respect to atmospheric pressure, or outside.) An appliance zone that is depressurized beyond the "depressurization limit" of any combustion appliance housed in that zone fails the test. This indicates that the appliance zone has the potential to spill combustion by-products into that zone. Test results are tabulated below.

Depressurization by Year

HOUSE CODE	Code	Furnace	DHW	Fireplace	Depressurization Limit (MN Code)	Depressurization Limit (CGSB)	Appliance Zone Depressurization
1994-02	Cat 2	Induced Draft	1 - Atm. Vented	1 - Direct Vent	2.0	5.0	3.0
1994-03	Cat 2	Induced Draft	1 - Atm. Vented	1 - Direct Vent	2.0	5.0	2.0
1994-06	Cat 2	Induced Draft	1 - Atm. Vented	1 - Decorative Wood	2.0	5.0	3.3
1994-09	Cat 2	Induced Draft	1 - Atm. Vented	1 - Direct Vent	2.0	5.0	13.5
1994-11	Cat 2	Induced Draft	1 - Atm. Vented	1 - Direct Vent	2.0	5.0	3.0
1994-14	Cat 2	Induced Draft	1 - Atm. Vented	None	2.0	5.0	1.2
1998-01	Cat 2	Induced Draft	1 - Atm. Vented	None	2.0	5.0	6.0
1998-02	Cat 1	Sealed Comb	1 - Combo System	2 - Direct Vent	25.0	20.0	3.0
1998-03	Cat 2	Induced Draft	1 - Atm. Vented	None	2.0	5.0	1.5
1998-05	Cat 2	Induced Draft	2 - Atm. Vented	1 - Direct Vent	2.0	5.0	2.5
1998-09	Cat 1	Sealed Comb	1 - Atm. Vented	None	2.0	5.0	6.0
1998-10	Cat 2	Induced Draft	1 - Atm. Vented	None	2.0	5.0	2.5
1998-11	Cat 2	Sealed Comb	1 - Electric	None	25.0	20.0	6.0
1998-13	Cat 2	Induced Draft	1 - Atm. Vented	None	2.0	5.0	2.0
1998-14	Cat 1	Sealed Comb	1 - Atm. Vented	1 - Direct Vent	2.0	5.0	2.0
1998-15	Cat 2	Induced Draft	1 - Atm. Vented	None	2.0	5.0	3.0
1998-17	Cat 1	Sealed Comb	1 - Electric	1- Direct Vent.	50.0	20.0	5.0
1998-19	Cat 2	Induced Draft	2 - Atm. Vented	1 - Direct Vent.	2.0	5.0	3.0
1998-22	Cat 2	Induced Draft	1 - Atm. Vented	1 - Direct Vent	2.0	5.0	7.5
1998-24	Cat 2	Induced Draft	2 - Atm. Vented	1 - Direct Vent	2.0	5.0	5.0
1998-26	Cat 2	Induced Draft	1 - Atm. Vented	1 - Direct Vent	2.0	5.0	2.0
1998-28	Cat 2	Induced Draft	1 - Atm. Vented	1 - Direct Vent	2.0	5.0	2.5
2000-02	7672	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	3.0
2000-03	Cat 2	Induced Draft	1 - Atm. Vented	None	2.0	5.0	5.0
2000-04	Cat 1	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	3.0
2000-05	Cat 1	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	3.5
2000-06	Cat 1	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	5.0
2000-07	Cat 1	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	2.5
2000-08	Cat 1	Sealed Comb	1 - Power Vent	2 - Direct Vent	25.0	20.0	6.0
2000-10	Cat 1	Sealed Comb	1 - Power Vent	2 - Direct Vent	25.0	20.0	10.0
2000-12	7672	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	5.5
2000-14	Cat 1	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	7.5
2000-15	Cat 1	Sealed Comb	1 - Power Vent	2 - Direct Vent	25.0	20.0	4.0
2000-16	7672	Sealed Comb	1 - Electric	1 - Direct Vent	50.0	20.0	5.0
2000-17	Cat 1	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	4.5
2000-18	Cat 1	Sealed Comb	1 - Electric	1 - Direct Vent	50.0	20.0	1.5
2000-20	Cat 2	Induced Draft	1 - Atm. Vented	1 - Direct Vent	2.0	5.0	1.5
2000-22	7672	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	15.4
2000-24	Cat 1	Sealed Comb	1 - Power Vent	None	25.0	20.0	4.0
2000-28	Cat 1	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	4.0
2000-30	Cat 1	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	3.0
2000-33	7672	Sealed Comb	1 - Power Vent	1 - Direct Vent	25.0	20.0	2.0
2000-34	Cat 2	Induced Draft	1 - Atm. Vented	None	2.0	5.0	8.0


Depressurization by Year Built
Measured Depressurization
Depressurization Limit
House Code
1994-02
1994-03
1994-06
1994-09
1994-11
1994-14
1998-01
1998-02
1998-03
1998-05
1998-09
1998-10
1998-11
1998-13
1998-14
1998-15
1998-17
1998-19
1998-22
1998-24
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1998-28
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2000-17
2000-18
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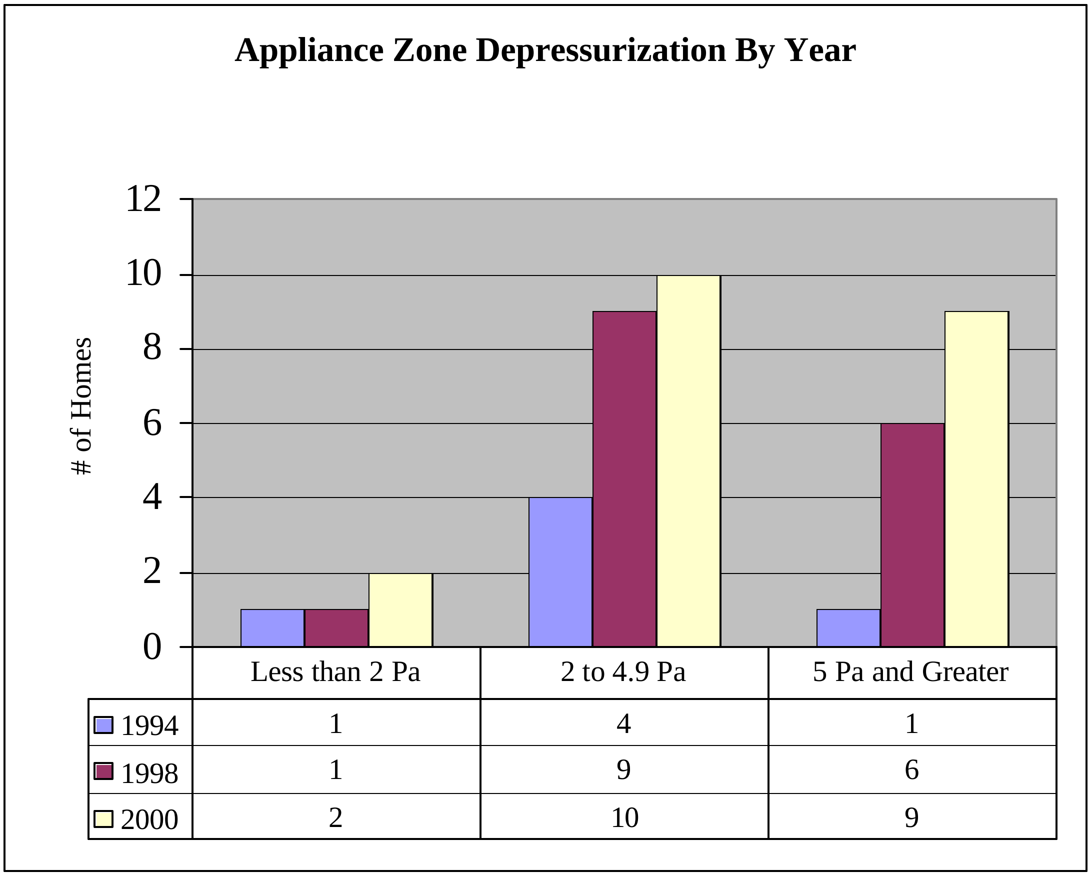
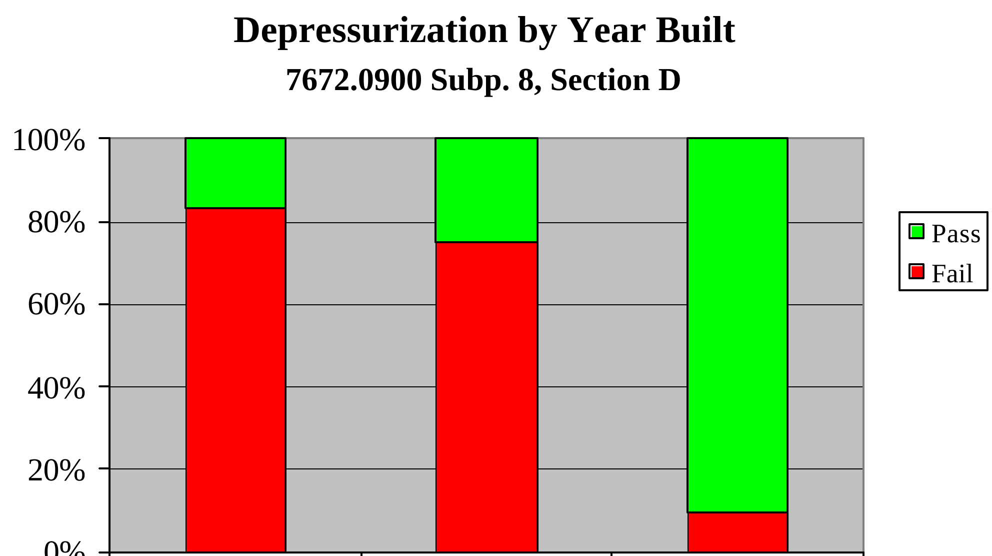
2000-28
2000-30
2000-33
2000-34
0
5
10
15
20
25
Depressurization (Pa)



	Less than 2 Pa	2 to 4.9 Pa	5 Pa and Greater
1994	1	4	1
1998	1	9	6
2000	2	10	9

Depressurization in this 43-house dataset ranged from 1.2 to 15.4 pascals. The average house was depressurized by 4.3 pascals. The average depressurization of the 22 homes with atmospherically vented water heaters (the appliance most susceptible to depressurization) was 3.9 pascals.



	1994	1998	2000
Pass	1	4	19
Fail	5	12	2

The combustion appliance zones (CAZ) in 19 of 43 tested homes (44%) were depressurized beyond their maximum depressurization limits as set by the chapter 7672 energy code with just the dryer and next largest exhaust device operating. All of the failures were in homes with atmospherically vented water heaters. Three of the 22 homes with atmospherically vented water heaters were depressurized by less than 2 pascals.

It is important to stress that this test can only identify the *potential* for spillage or backdrafting of combustion by-products. It does not actually detect spillage or backdrafting.

Temperature and Relative Humidity Monitoring

Temperature and relative humidity have a significant impact on the comfort and indoor air quality of Minnesota homes. Uncontrolled variances in these levels trigger negative responses from homeowners.

Increased wintertime RH levels are also a factor in the formation of window condensation and condensation on other interior surfaces. This window condensation is an especially well known home performance problem in our area due to our severe cold climate. A lesser known, but still valid, issue is condensation formation on interior surfaces. Areas with limited air movement, like closets, are especially prone to this problem, as are areas where the ability to provide full-depth insulation is compromised – such as top plates with shallow heels. This condensation formation has been known to provide conditions acceptable for mold growth and prematurely degrades building components.

Since window and wall condensation is a function of both RH and surface temperature, homes with low center of room RH are not guaranteed condensation-free windows or wall surfaces. But, in a house with controlled RH, at least one of the causative factors is reduced.

Test Methods

This study attempted to evaluate the homeowner's ability to control the relative humidity and temperature, mainly during winter weather conditions. This was done with the use of HOBO H08-003-02 temperature and relative humidity data loggers from Onset Computer Corporation.

A HOBO temperature (T) and relative humidity (RH) data logger is a small device that measures and records T and RH at set intervals for a set period of time. A typical HOBO monitoring strategy was to take T and RH readings at 4-minute intervals for a 2-week period.

Ten different H08-003-02 HOBO's were used for testing. They were set in a test house for the allotted time frame, the device collected data, the data was retrieved with a laptop computer and the HOBO was re-programmed and moved to another test house for another round of data collection. Time frames for data collection were between January and April of 2001, and between January and April of 2002.

HOBO's are small enough to be set almost anywhere in a house without being conspicuous. While the placement varied from house to house, they were normally set as close to the center of the house as possible, in a spot where it could not be disturbed. The placement could not be near a supply air vent or exterior door, or anywhere that would see regular localized changes in T or RH. Normally, it was placed on top of a main floor cabinet or on main floor shelving.

HOBO Temperature and Relative Humidity Monitoring

House Code	Ventilation System?	Temp Range	AVG Temp	RH Range	AVG RH	Test Dates
1994-02	HRV	67.7 to 79.4	72.0	23.6 to 57.8	35.9	04/12/02 to 4/23/02
1994-03						
1994-06		58.7 to 76.6	69.6	30.6 to 46.3	37.1	04/11/02 to 04/22/02
1994-09		58.7 to 69.0	63.7	28.3 to 53.0	43.9	04/29/02 to 05/13/02
1994-11						
1994-14		71.1 to 80.8	75.8	37.2 to 50.9	41.9	04/14/02 to 04/18/02
Averages			70.3		39.7	
1998-01	HRV					
1998-02	HRV	63.5 to 75.2	68.3	23.5 to 27.3	24.5	01/17/02 to 01/31/02
1998-03						
1998-05	HRV					
1998-09	HRV	63.5 to 83.7	73.6	28.7 to 61.8	39.6	04/15/02 - 04/20/02
1998-10		66.4 to 77.0	69.3	23.2 to 40.6	30.0	03/27/01 to 04/26/01
1998-11		71.8 to 78.0	73.8	29.6 to 39.8	33.0	02/01/02 to 02/25/02
1998-13	HRV					
1998-14	HRV	66.3 to 71.4	68.2	25.0 to 45.0	32.0	03/24/01 to 04/27/01
1998-15						
1998-17	HRV	65.0 to 74.3	69.6	24.9 to 35.0	25.0	03/10/01 to 04/11/01
1998-19	HRV	64.4 to 72.1	68.0	24.0 to 30.0	26.0	02/21/01 to 03/25/01
1998-22		62.9 to 72.5	68.4	24.7 to 44.7	32.1	04/19/02 to 04/30/02
1998-24	HRV					
1998-26						
1998-28						
Averages			69.9		30.3	
2000-02	Exhaust Only	65.6 to 75.2	71.1	23.5 to 26.3	24.0	02/01/02 to 02/15/02
2000-03		64.9 to 79.4	70.8	29.2 to 47.2	39.2	04/15/02 to 04/26/02
2000-04	HRV	66.3 to 71.1	68.3	31.5 to 52.0	37.8	01/18/02 to 02/01/02
2000-05	HRV	58.0 to 69.0	63.6	31.3 to 56.5	40.6	10/4/01 to 11/2/01
2000-06	HRV	64.9 to 74.5	70.6	23.8 to 43.5	32.3	01/22/02 to 02/05/02
2000-07	HRV	52,5 to 64.9	60.0	28.0 to 40.7	34.9	01/16/02 to 01/30/02
2000-08	HRV	68.3 to 74.5	71.8	25.7 to 36.2	30.6	01/17/02 to 01/30/02
2000-10	HRV	69.0 to 78	72.6	24.0 to 32.3	26.9	01/31/02 to 02/14/02
2000-12	HRV					
2000-14	ERV					
2000-15	HRV	64.2 to 80.8	72.7	23.8 to 49.8	33.7	03/21/02 to 04/19/02
2000-16	Exhaust Only	67.0 to 75.2	71.3	28.1 to 44.9	34.9	02/06/02 to 02/20/02
2000-17	HRV	67.7 to 74.5	69.8	23.7 to 33.7	26.3	01/17/02 to 01/30/02
2000-18	ERV	65.6 to 72.5	69.6	26.3 to 34.9	30.0	02/04/02 to 02/18/02
2000-20						
2000-22	HRV	69.7 to 75.2	72.0	23.9 to 42.2	30.6	02/08/02 to 02/22/02
2000-24	HRV	63.5 to 73.8	68.8	24.0 to 35.3	27.3	01/18/02 to 02/01/02
2000-28	HRV					
2000-30	HRV	68.3 to 77.3	71.6	23.6 to 32.5	26.2	02/08/02 to 02/22/02
2000-33	Exhaust Only	67.7 to 71.8	69.2	23.6 to 29.5	25.0	01/31/02 to 02/14/02
2000-34		62.9 to 79.4	70.3	25.6 to 58.1	43.9	04/07/01 to 05/10/01
Averages			69.7		32.0	

The average wintertime relative humidity levels in this sample ranged from 24.0% to 43.9%. 8 of the 43 homeowners in our study complained of low relative humidity during the winter. One was a year 2000 home which did not have a ventilation system and whose house was quite airtight, 0.28 cfm/square foot of floor area. Another was a homeowner with a tight home, 0.27 cfm/ sq. ft. built in the year 2000 that did not operate the ventilation system because it made the house too dry. Another homeowner who complained of dry winter conditions owned a home that was quite tight, at 0.28 cfm/sq. ft. of floor area, and the ventilation system's actual people ventilation rate (PVR) was 9 cfm less than the recommended PVR.

The ideal level of indoor relative humidity is a topic of debate, but it is generally in the range of 30% to 50% for human comfort. It is important to note that relative humidity is an important aspect of indoor air quality, but it should not be used as a guide to adjust the PVR. Humidity may need to be added or subtracted based on outdoor conditions, interior moisture load from building components and lifestyle, but the base ventilation rate should not change because of the many other pollutants in the structure.

Air Leakage from Attached Garages

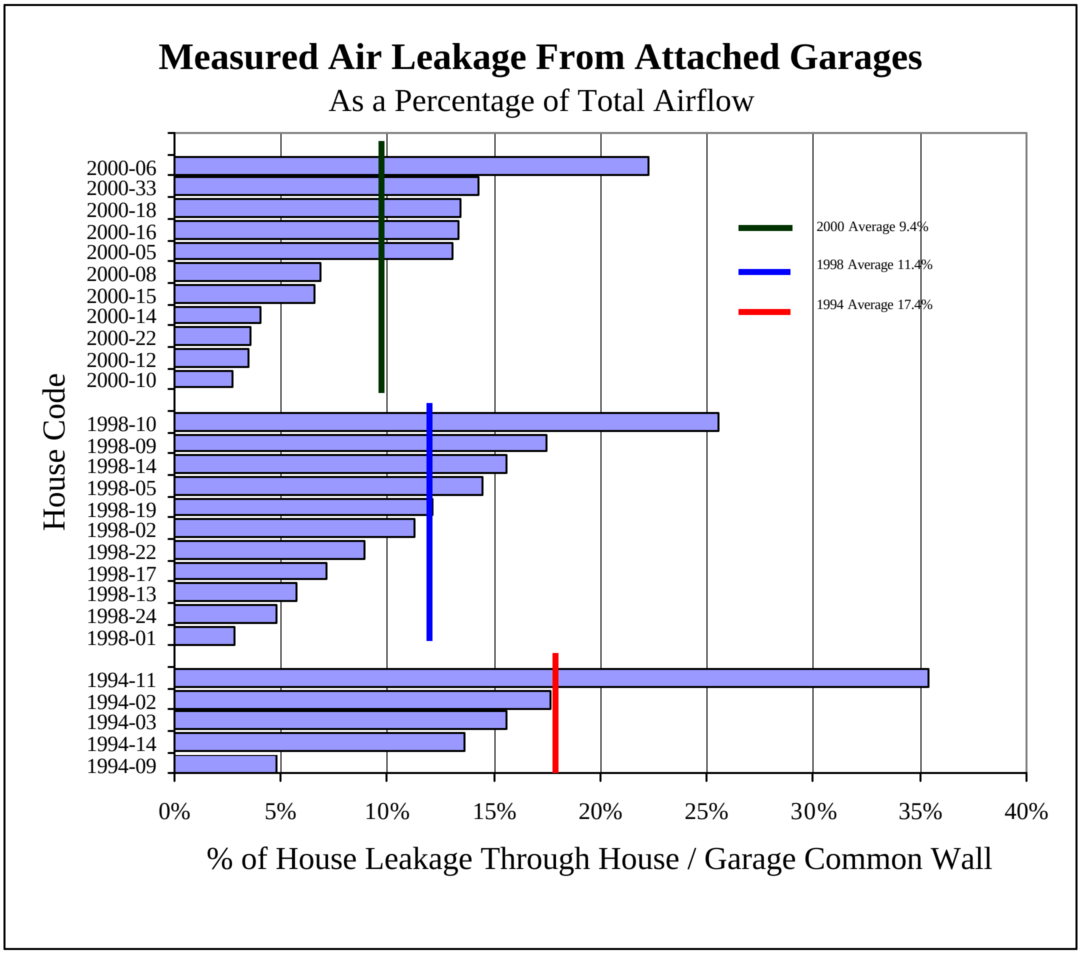
Code language has changed in recent years in an effort to seal air leakage from attached garages. These changes have occurred for a variety of reasons. People store hazardous products such as pesticides, herbicides, fertilizers, petroleum products and paint in their garage. This is also where we happen to park our cars and car exhaust can be a terrific source of carbon monoxide, especially when first started with a cold engine.

The more holes there are in the attached garage to house interface, the more opportunity there is for these pollutants to enter the living space. Testing was conducted to compare house to garage leakage in our separate sample sets in an effort to identify any trends.

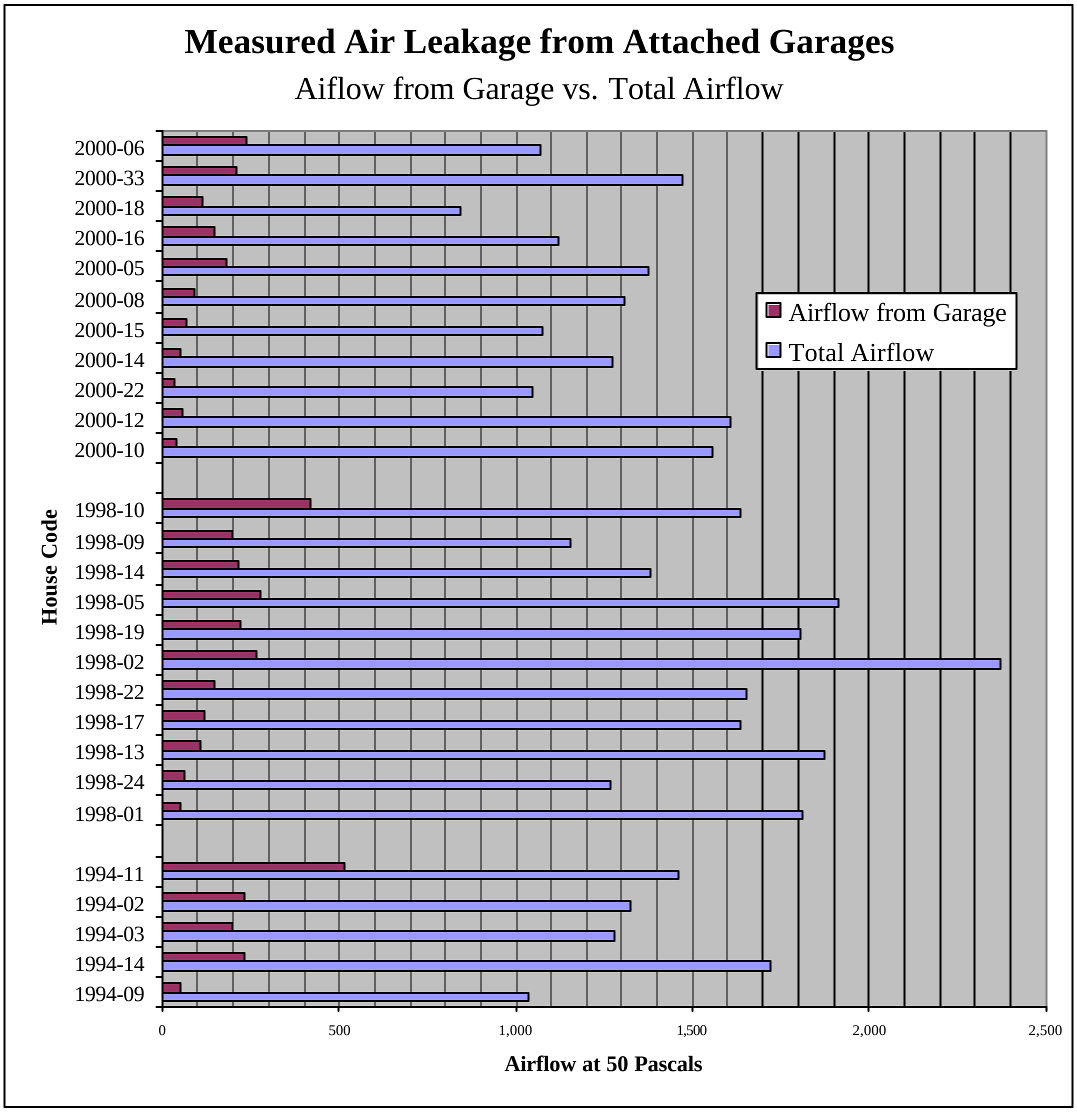
Test Methods

The air leakage through the common wall between homes and attached garages was tested using series leakage techniques as outlined in the "Minneapolis Blower Door Operation Manual for Model 3 and Model 4 Systems" from The Energy Conservatory. Data was analyzed using "Open a Door" software from The Energy Conservatory.

Test Results



This chart displays each home's measured garage leakage as a percentage of the total house leakage of its envelope. In home 1994-02, for example, 11% of the measured leakage from this home's envelope is entering the home through the garage wall interface. Notice the downward trend in garage leakage as a percentage of total envelope leakage from 1994 to 2000.


Measured Air Leakage from Attached Garages
Aiflow from Garage vs. Total Airflow
House Code
2000-06
2000-33
2000-18
2000-16
2000-05
2000-08
2000-15
2000-14
2000-22
2000-12
2000-10
1998-10
1998-09
1998-14
1998-05
1998-19
1998-02
1998-22
1998-17
1998-13
1998-24
1998-01
1994-11
1994-02
1994-03
1994-14
1994-09
0
500
1,000
1,500
2,000
2,500
Airflow at 50 Pascals
Airflow from Garage
Total Airflow

Garage Leakage by Code			
	Cat 2 (n=12)	Cat 1 (n=11)	7672 (n=4)
Average CFM50	209	144	82
% of House Leakage	13.5%	11.0%	8.7%

Garage Leakage by Year			
	1994 (n=5)	1998 (n=11)	2000 (n=11)
Average CFM50	247	189	113
% of House Leakage	17.4%	10.5%	9.4%

The charts above establish the average leakage rates in cubic feet per minute at the 50 pascal pressure differential used during blower door testing. Again, this indicates that air leakage from attached garages has decreased in recent years, reducing the potential for entry of hazardous air pollutants.

It is important to note that actual pollutant levels, homeowner exposure to pollutants, or the health effects of this exposure were all beyond the scope of this study. The goal of this exercise was to establish whether significant leakage from attached garages is occurring. This testing indicates that there are opportunities for air leakage from attached garages, the leakage is significant and further attention to this detail is warranted.

Homeowner Perceptions

47% of the participating homeowners said ventilation and indoor air quality features had been important concerns when they were planning and building their homes, and 39% described them as somewhat of a concern. Only 13% replied that ventilation and indoor air quality had not been much of a concern to them. However, only 32% reported having been given choices about ventilation options, while 68% had not.

When asked about their perception of the air quality in their homes, 71% said it was about what they expected, while 29% said it was better. Nobody reported indoor air quality that was not as good as expected, or indicated overall dissatisfaction. Six homeowners (14%) reported having some type of repairs or adjustments in response to air quality concerns. These included adding an HRV or exhaust fan, adding an ultraviolet air cleaning device, adding air filtration, and adding humidification.

Half of the homeowners reported that someone in the household has allergies, asthma, or other respiratory health issues. All of these conditions had been present prior to moving into their new homes; none had developed since moving in.

ENERGY USE ANALYSIS

Prism Method

Analysis of heating and cooling costs was undertaken using PRISM (Princeton Scorekeeping Method) Advanced Version 1.0 software. Originally developed for evaluating the energy use impact of installed conservation measures in existing homes, PRISM has several features which make it useful in the context of this study. Using utility billing data and average daily temperatures, it produces a weather-adjusted index of consumption called *Normalized Annual Consumption* (NAC) for each house (PRISM User's Guide 1). All homes in the study are heated with natural gas; NAC for heating is expressed in Therms (CCF) per year. Cooling NAC is expressed as Kilowatt-hours (KWH) per year.

Because we are comparing the energy performance of homes of various sizes, it is necessary to calculate the NAC in Therms (or KWH) per square foot of conditioned floor area per year.

Heating fuel consumption is often expressed in BTU's per square foot per Degree-day (BTU/SF/DD). To convert annual Therms per square foot to BTU/SF/DD, therms are multiplied by 100,000 (BTU/Therm) than divided by 7,541 (the annual heating degree-days for the 12 year history used in the PRISM analysis).

PRISM quantifies base-level consumption (energy used for purposes other than heating or cooling), allowing us to isolate heating and cooling costs for comparison. Base consumption is called a (*alpha*) and is expressed in Therms per day for heating and KWH per day for cooling (PRISM User's Guide 3).

PRISM generates its own reliability statistics: R^2 of the linear regression, and CV(NAC), the coefficient of variation, or relative standard error of NAC. An R^2 close to 1.0 and a CV(NAC) close to zero are considered ideal; PRISM authors recommend an R^2 greater than or equal to 0.7 and a CV(NAC) of less than or equal to 7% as cutoff points for determining reliability (PRISM User's Manual 4).

The PRISM program utilizes several different versions, called Regular and Robust, in both the heating and cooling models. The "Regular" version gives equal weight to all data points (each representing a meter reading). The Robust version detects "outliers" in the data and adjusts the amount of weight given to those data points (PRISM User's Guide I-8). All the PRISM runs in this study were initially run in the "Regular" version; those that failed to meet the reliability criteria were the run in the "Robust" version. For heating, all homes in the sample met the reliability criteria, while for cooling; only about half did so even after running them in "Robust".

Two energy use plots are produced for each PRISM run. The first, called an energy use time series, shows energy use per day for each billing period and is illustrated in fig.(1). *Alpha* (base usage) is shown by the dotted line; per day NAC is shown by the dashed line. The other plots Therms per day against degree-days per day, and is shown in fig. (2). Where CV(NAC) is low, indicating high reliability, all the data points are on or close to the line (PRISM User's Guide I-6).

Historical degree-day data dating back 12 years from the beginning of the study was obtained from the National Oceanic and Atmospheric Administration and the Minnesota State Climatology office. Utility usage histories were obtained from the respective utilities.

Heating

The study includes homes built in years 1994, 1998, and 2000. The six 1994 homes fall under Category 2. The 1998 homes include both Category 2 (14) and Category 1 (2) construction, while the 2000 homes include Category 2 (3), Category 1 (13), and Chapter 7672 (5).

A total of 23 Category 2 homes, 15 Category 1 homes, and 5 Chapter 7672 homes were examined.

Heating consumption for the 1994 homes averaged 4.60 BTU/SF/DD, with a high of 5.98 and a low of 2.54. The house that was 2.54 could easily be considered an outlier—the next lowest in the group was 4.19, and the standard deviation for the group was 1.19. If this house were not considered, the average for the group would be 5.02.

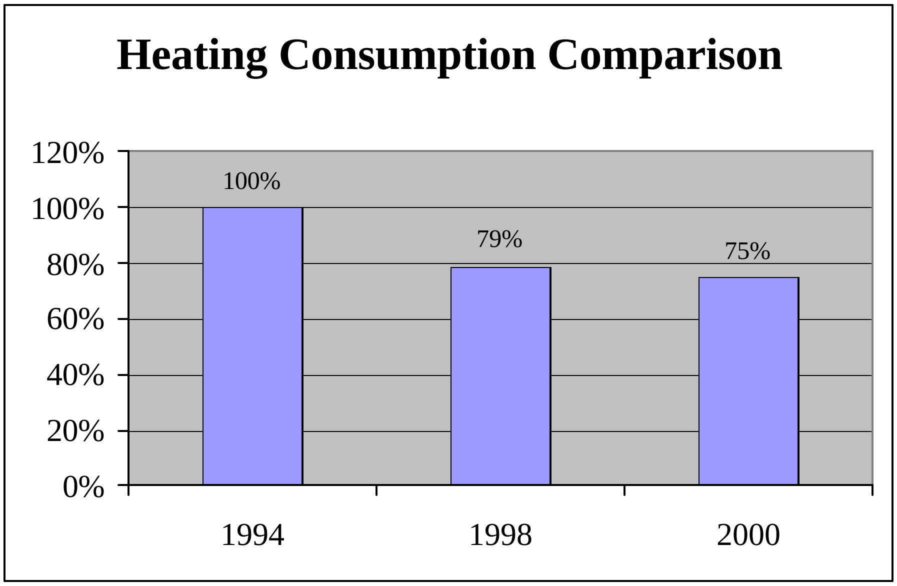
The 1998 homes averaged 3.62 BTU/SF/DD for heating with a high of 4.38 and a low of 2.44.

The 2000 homes averaged 3.45 BTU/SF/DD for heating with a high of 4.85 and a low of 1.44.

Viewed by category, the Category 1 homes averaged 3.20 BTU/SF/DD as compared to 3.95 for the Category 2 homes a difference of about 19%. About half of that difference could be attributed to differences in heating system efficiencies. All of the Category 1 homes have high efficiency furnaces while only 2 of the 23 Category 2 homes do.

Heating consumption is summarized in the following table:

	Lowest	*Average*	*Highest*
1994	2.54	4.60	5.98
1998	2.44	3.62	4.38
2000	1.44	3.45	4.85



A spreadsheet tabulating all the heating analysis data can be found in Appendix C.

A control group of homes not involved in this study was compared with the study sample. Heating usage data from 20 homes completed under the Xcel Energy *Premier Homes* program was run through PRISM, and yielded an average of 3.21 BTU/SF/DD—about the same as the average for Category 1 homes in the study sample. All homes in this program have high efficiency furnaces, direct-vent gas water heaters, heat recovery ventilation, and were required to meet an airtightness target of 0.24 CFM_{50} per square foot of floor area. The homes in this subset averaged 0.19 CFM_{50} per square foot of floor area.

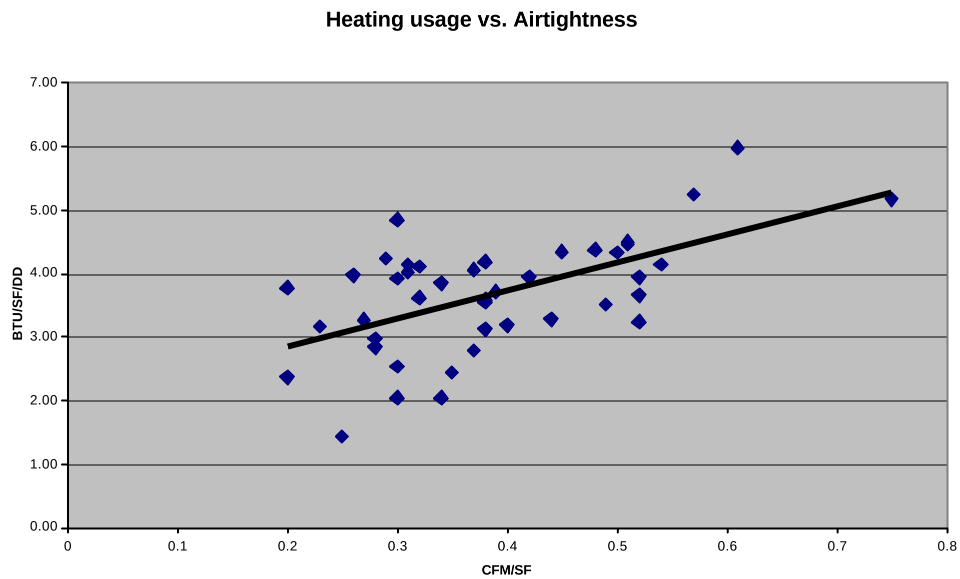
Variables Affecting Heating Fuel Use

Many variables can impact heating and cooling fuel usage, including building airtightness, insulation values, window selection, area, and orientation, shading, wind exposure, heating system efficiency, occupant lifestyle, indoor temperature, and thermostat set point.

Building Airtightness

One of the main objectives of this project was to evaluate the effectiveness of the interior air barriers. The best available means of quantifying this is by measurement with the blower door; test data is discussed at length elsewhere in this final report. Certain of the changes in the energy code have been directed toward a more continuous, sealed air barrier; the expected result being homes that are more airtight and therefore more efficient. Although other variables come into play, the data does tend to support the hypothesis: The Category 1 and Chapter 7672 homes in this sample, on the average, are tighter and use less energy than the Category 2 homes.

Heating consumption (BTU/SF/DD) was plotted against air leakage (CFM_{50} per square foot) for all homes in the study. The resulting graph is shown below; it illustrates a general upward trend in consumption as measured air leakage increases.



Heating System Efficiencies

Although not mandated by code, all of the Category 1 homes and all of the Chapter 7672 homes have "high efficiency"(90+% AFUE) furnaces. Of the 23 Category 2 homes, 21 have "mid-efficiency" (81-83% AFUE) furnaces. In addition to AFUE, other variables affecting heating system efficiency could include ductwork design issues, duct leakage and other distribution losses.

When participant homes were grouped by heating system efficiency, the "high efficiency" group had an average heating consumption of 3.29 BTU/SF/DD as compared with 4.07 BTU/SF/DD for the "mid-efficiency" group, a difference of about 19%. About half of this difference could be attributable to the difference in furnace efficiencies, with the other half being the result of other variables in house performance and/or operation.

Average Temperature

The indoor temperature has a direct impact on the amount of heat lost through the building envelope, and therefore on fuel consumption. With few exceptions, thermostat settings for heating varied by only a few degrees among the participating households, most being between 69º and 71º. The few that had noticeably lower average temperatures during monitoring periods did have somewhat lower consumption levels, but in most cases the difference in set points was too small to correlate with differences in usage. Solar gain, cooking, fireplace use, and other activities also affect average temperatures. While over 60% of homeowners in the sample reported setting back their thermostats regularly (manual or automatic), their usage did not appear to be lower as a group than those who followed a "set and forget" strategy.

Window Area and Orientation

Large window areas can impact energy use in several ways. Solar gain can add significant heat during the daytime, reducing the load on the heating system. Much heat can also be lost through window areas at night. Solar gain also can add to the cooling load in the summer.

Cooling

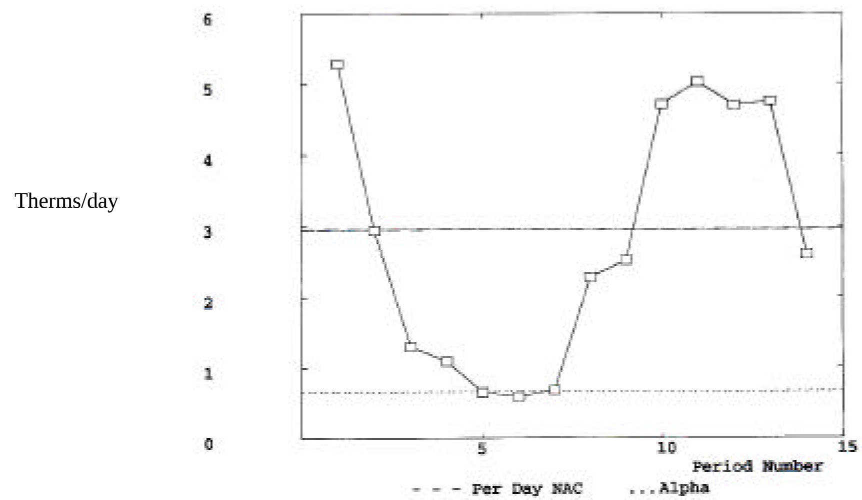
Because people's use of air conditioning varies dramatically, it is not surprising to find that cooling costs are more difficult to quantify and compare. Just as PRISM uses heating degree-days in its analysis of heating usage, it uses cooling degree-days for analyzing cooling costs. Humidity, however, has a large impact on comfort and on how we use air conditioning. With heating, by contrast, operator behavior is much more uniform. The thermostat setpoint may vary by a few degrees, but everyone heats their home for the duration of the cold season.

Less than half the homes in the cooling sample met the reliability threshold for PRISM.

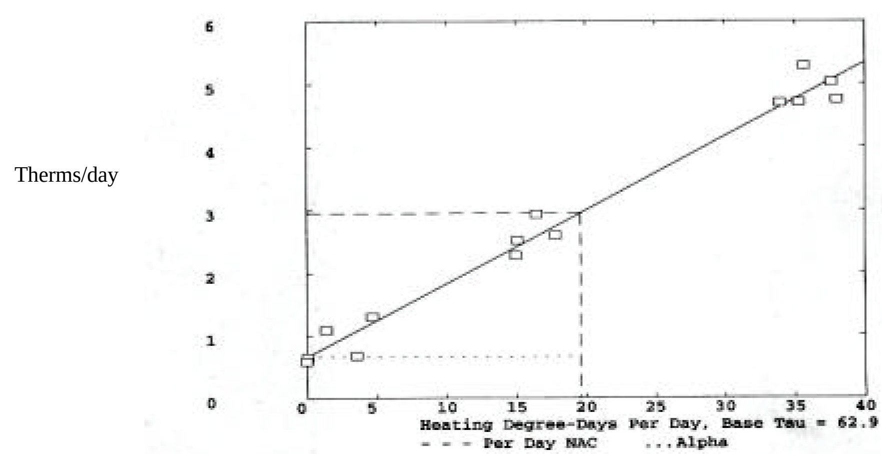
Of the households in this sample set, nearly 3 out of 4 homeowners say they keep the air conditioning on for all or most of the summer months. Others limit their use of air conditioning by choice, making their usage data of little use for comparison. Thermostat setpoints for cooling varied from 68-78º, with an average of about 75º.

Only data for homes where the homeowners reported that they keep the air conditioning running all or nearly all the time during the summer months, and which also met the PRISM reliability thresholds, is included.

Cooling costs are expressed in KWH per square foot (annual). The two 1994 homes averaged 0.51 KWH per square foot. The 1998 homes ranged from 0.20 to 0.54 KWH per square foot, averaging 0.28 KWH/sf, and the 2000 homes ranged from 0.20 to 0.59 KWH/sf, with an average of 0.35 KWH/sf.


Therms/day
Period Number
- - - Per Day NAC ...Alpha

(Fig 1)


Therms/day
Heating Degree-Days Per Day, Base Tau = 62.9
- - - Per Day NAC ...Alpha

(Fig.2)

Homeowner Interviews

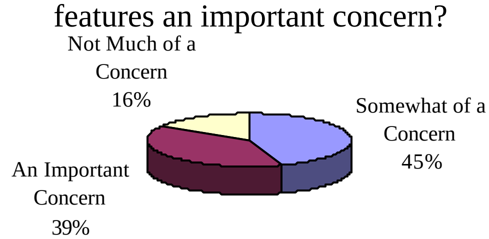
Considering the number of single family housing starts for the years 1994 (21,338), 1998 (25,001), and 2000 (25,549) this sample set is far too small to suggest that these numbers are indicative of the entire population of Minnesota homeowners. Many issues of comfort and satisfaction are subjective; sometimes two people in the same household don't even agree. Nevertheless, what this cross-section of homeowners told us about their perceptions and experiences with their houses serves to illustrate some of the issues facing homebuilders in today's environment.

Concerns and Choices About Energy Efficiency and Ventilation

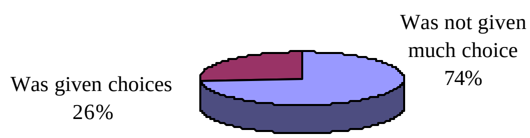
Homeowners were asked about their level of concern regarding energy efficiency features at the time they were planning and building the home. 39% responded that energy efficiency features had been an important concern, and 45% responded that energy efficiency features were somewhat of a concern. 16% responded that energy efficiency features were not much of a concern.

Asked about their level of concern regarding ventilation and indoor air quality features when they were building their homes, homeowners answered similarly. 47% said ventilation and indoor air quality features had been important concerns, and 39% described them as somewhat of a concern. 13% replied that ventilation and indoor air quality had not been much of a concern to them. However, when asked whether they had been given *choices* about energy efficiency features, 26% responded that they had, while 74% had not. Regarding ventilation options, 32% reported having been given choices, while 68% had not.

In building this home, were energy efficiency features an important concern?

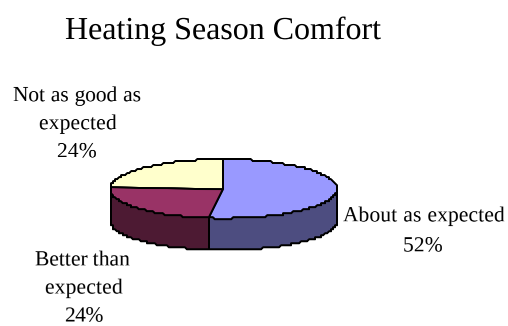


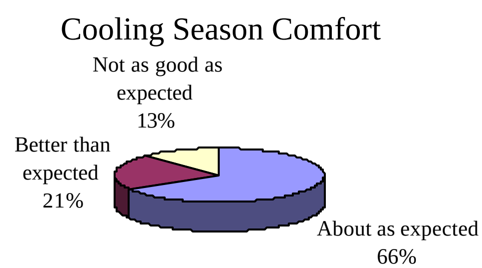
In building this home, were you given many choices about energy efficiency features?



Comfort Issues

About half of the homeowners said their experience with heating season comfort had been about as expected. About a fourth said it had been better than they expected, while the remaining fourth said it had not been as good as expected. As to cooling season comfort, 67% described their experience as about as they expected, while 21% said it was better than expected, and 13% said it was not as good.





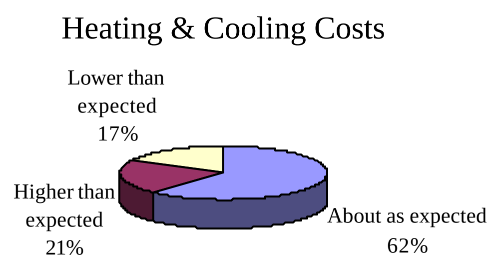
Eleven homeowners (26%) reported having made some type of repairs or adjustments since moving in to address comfort concerns. These included adding humidification, using a space heater in a cold bedroom, increasing air conditioner size, shutting off or limiting use of ventilation, balancing or reworking ductwork, and air sealing of building envelope leaks.

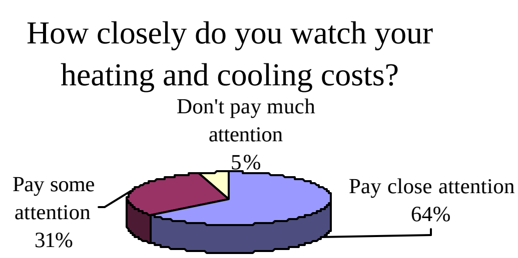
Heating and Cooling Costs

Asked about heating and cooling costs, 64% said they pay close attention and 31% said they pay some attention. Only 5% said they don't pay much attention.

62% of homeowners reported that their energy costs had been about as expected. 17% said they were lower than expected, while 9% said they were higher than expected.

Asked if they had noticed any changes in their fuel usage since moving in, 3 felt it had increased, 2 felt it had decreased, and the rest reported no change or weren't sure.





Mechanical Controls

55% of the homes had programmable thermostats, of which 78% of the owners reported using the setback feature regularly. The remaining 22% said they rarely or never use the setback feature. 45% of the homes had manual thermostats, of which 42% of the owners said they regularly set the temperature back, 16% said they occasionally do so, and 42% said they rarely or never do so. Overall, 62% of homeowners reported turning back the thermostat setpoint regularly, 7% did so occasionally, and 31% rarely or never did.

Somewhat surprisingly, only about a third of those homes that regularly utilized thermostat setbacks had heating consumption that was less than the average for their group (either by year built or "code type").

95% of homeowners described their heating/cooling system controls as "user friendly".

Only 75% of those with Heat Recovery or Energy Recovery Ventilation systems described those controls as "user friendly".

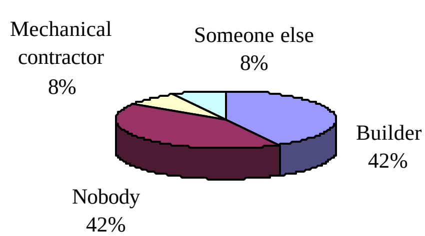
Eleven homeowners (26%) used a load control device such as off-peak electric water heating or air conditioning cycler.

Ventilation System Operation and Maintenance

Of those homeowners who have HRV's or ERV's, 10 (42%) reported not having done any maintenance (although all in this group had been in their homes for less than a year); 13 (54%) said they perform routine maintenance themselves, and 1 (4%) said they have routine maintenance performed by a contractor. Half had read their system's owner's manual and half had not.

Asked where they had received information about operation and maintenance of their ventilation systems, 42% named their builder, 8% named their mechanical contractor, and 8% named "someone else". 42% replied that nobody had explained it to them.

Who explained your ventilation system to you?



As for the operation of ventilation systems during the summer, 11 left it on all the time, 6 left it off all the time, and 1 ran it on an intermittent setting. The rest weren't sure, did not answer, or the question did not apply to them.

Homeowner Observations

Homeowners were shown a list of possible conditions and asked if they had experienced any of them (results shown in number of positive responses to each item).

	All homes	1994	1998	2000
Siding stains	6	1	3	2
Stucco stains or cracks	3	0	2	1
Ice dams	14	1	4	9
Condensation at basement walls	5	1	2	2
Exterior paint peeling/cracking	0	0	0	0
Water stains-interior walls or ceilings	3	0	1	2
Mold/mildew odors	1	0	0	1
Condensation on windows	12	3	2	7
Indications of excessive dryness	8	0	2	6
Moisture seepage	2	1	1	0
Temperature variations between rooms or levels	21	3	8	10
Cold floors	6	2	2	2
Drafts	5	3	2	0

Half the homeowners in each group cited temperature variations between rooms. Most of them described these as minor; one household was using a space heater in a cold bedroom. Of the homeowners who cited cold floors, one referred to a tile floor by a doorway, one mentioned a room over the garage, and the rest mentioned the basement floor.

Nearly all the homeowners who cited window condensation described it as minor, and said that it only occurred during extremely cold weather. Three homeowners had installed ventilation systems since moving into their homes, at least partly out of concerns over window condensation. Two homeowners who mentioned window condensation also mentioned excessive dryness as an issue.

Two homes encountered more serious moisture issues. Both were in Category 2 houses; neither problem was directly related to energy code considerations.

In the first, water had come into a wall as a result of ice damming compounded by sun exposure and a complex roofline. Ice dams are most frequently caused by leakage of warm air into an attic, which causes snow to melt on the roof, and subsequently refreeze as it runs down to the cold eave. Condensation often then occurs in the attic as the warm, moist air comes into contact with cold surfaces. In this case, ice was able to build up above the flashing for an adjoining wall system. Water got behind the flashing and ran down into an interior wall when the ice started to melt.

In the second situation moisture was discovered in walkout basement walls, and was caused by problems with the stucco application. The existing flashing details and only one layer of felt paper were reasons cited by the homeowner as reasons for the water events he was experiencing.

Although these cases are not energy code specific, they were significant enough to illustrate the critical importance of drainage plane details.

Cost Analysis

An objective of this study was to examine the cost of compliance with the Minnesota Energy Code. When the code was implemented in April 2000, the changes to improve the energy efficiency of the building envelope and the need to integrate that with the operation of the mechanical equipment raised concerns that this would increase cost and diminish home sales. In order to keep costs down, builders were reducing barriers to innovation by expanding and improving designs to stimulate technological advances. This section of the study investigates what contractors saw as their responsibility and the direction they took to achieve cost effectiveness.

Analysis Method

Ten general contractors were interviewed in person about their implementation of the Minnesota Energy Code. Four mechanical contractors were interviewed by telephone to obtain average costs for a variety of installations. Identities of the participating contractors were kept confidential for competitive reasons.

Aspects of Compliance

Topics of discussion with the builders and mechanical contractors were centered around the changes the code brings and the costs involved with the implementation of those changes. Two aspects of compliance were considered: changes to the building shell, including labor and materials; and the additional needs of the HVAC system, which also includes labor and any additional equipment.

Changes Made To Comply

Overall the builders indicated there were five phases of implementation:

1) Framing
2) Insulation
3) Windows
4) Electrical and Plumbing
5) Heating, Ventilation, & Air Conditioning (HVAC)

Between these five phases, the builders cited a total of 19 to 25 design changes necessary for code implementation:

Phase	# of Design Changes
Framing	5-7
Insulation	3-6
Windows	1-3
Electrical	2-5
HVAC	4-8

Research extended into exploring the five compliance levels and breaking down cost differentiation for the various changes mentioned above. Contractors provided information to specific applications and their related costs including labor and material. Some of the changes were minor process changes that involved neither added costs nor cost savings. The design changes cited below are more involved and were divided into six individual components:

1) Rim Joist
   a) Extruded foam on the exterior side of the rim
   b) Fiberglass insulation and extruded foam on the interior side of rim
   c) Spray foam on interior side of rim

2) Space Heating
   a) Induced draft furnaces
   b) High efficiency furnaces

3) Domestic Water Heating
   a) Atmospherically vented water heaters
   b) Power vented water heater

4) Combustion air

5) Ventilation
   a) Balanced ventilation (all models were HRV or ERV installed)
   b) Exhaust only ventilation

6) Make-up Air

Rim Joist

Some changes were made to the rim joist assembly for energy code compliance. The three different applications provided above are the typical installations but can differ from site to site.

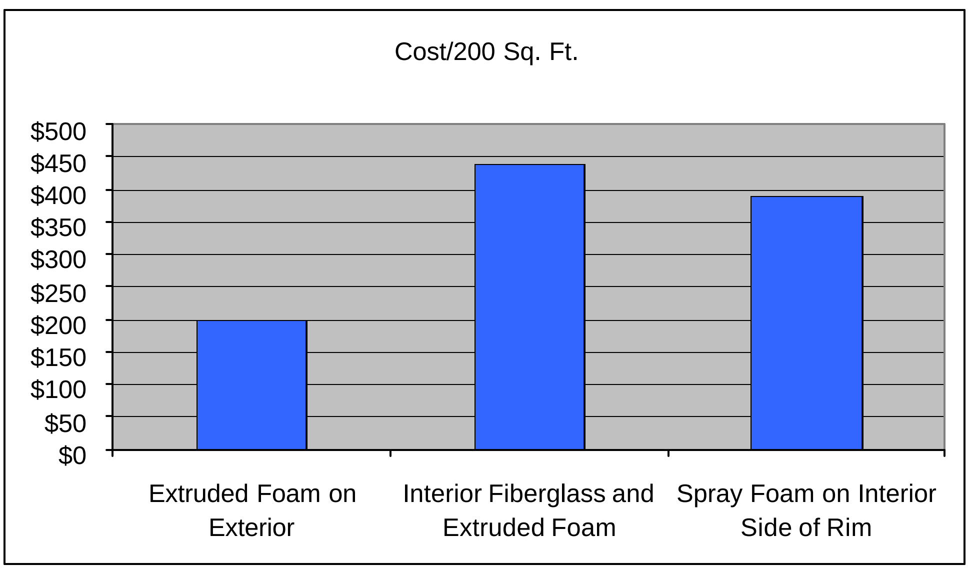
Rigid foam placed on the outside of the rim is the most utilized detail change. However, the builders still had some unanswered questions in regard to exterior deck attachment, whether insulation should be provided on the interior, and attention to the assembly and structural bearing of framing members.

Rim Detail by Year Built			
	1994	1998	2000
Batt Only	6	16	6
Batt & Interior Rigid Foam	0	0	1
Spray Foam & Batt	0	0	1
Exterior Rigid Foam & Batt	0	0	8
Exterior Rigid Foam Only	0	0	5

Cost and convenience seem to be the driving factors to this construction detail with a $1.00 per sq. ft. price. This price includes 1" of extruded polystyrene foam and labor cost.

Fiberglass insulation is still being installed on the interior of the rim in some cases, although it is not used as much as in the past. The assembly consists of the fiberglass to the interior and a fire rated air and vapor barrier sealed between each framing member. While deck attachment and structural bearing are not a concern, details relating to moisture entering the sealed cavity from the top of the concrete foundation wall could be a concern. The other drawback is the cost. The contractors indicated the price is over double the cost of the foam on the outside of the rim. Also, careful attention to detail is necessary when installing the fiberglass insulation and implementing an effective fire barrier.

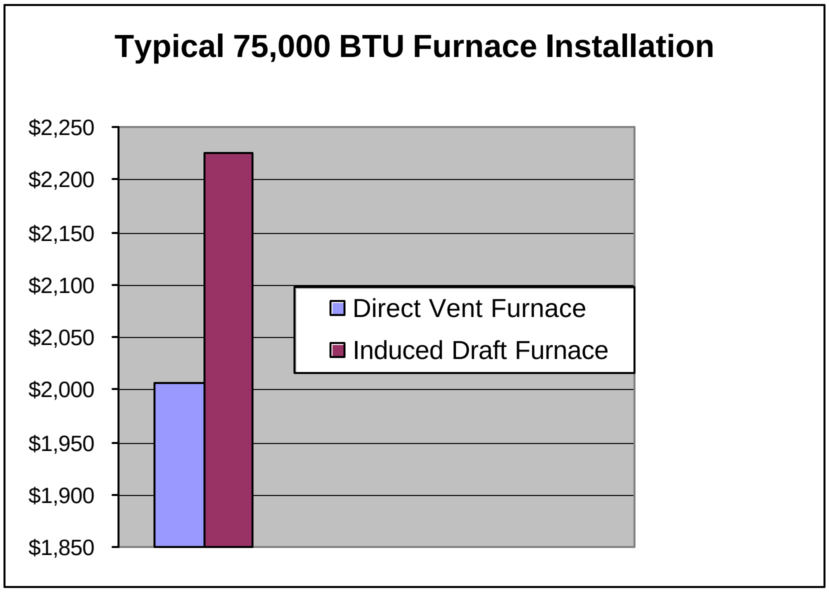
Spray foam insulation is gaining some acceptance for rim joist and wall installation, but is still relatively new to the industry. Minnesota builders are still weighing cost, application and energy savings for its acceptance. The builders who are installing it tout its effectiveness for air sealing, but still have to install a fire rated protection to the foam that is exposed to the interior. While the foam can be installed at $1.20 per sq. ft. (at R-11) there is an additional $0.75 per sq. ft. for fire rating (see graphs below).



Space Heating

Space heating appliances have been reviewed by builders and the difference in efficiency ratings and compliance with code seem to create a trend. A recent builders survey done by the Builders Association of Minnesota has shown that 78% of the builders install direct vent furnaces as opposed to induced draft. The finding in our research shows:

- Induced draft furnaces can be lower cost at purchase price per unit but the on-site venting for combustion gas relief can add 30% to that price. Other issues to consider are the possible make-up air installations that would be necessary to reduce pressure differences within the home from other exhausting equipment.
- Direct vent furnaces, while at a higher purchase price per unit have less on-site venting cost and can sometimes render the need for powered make-up air unnecessary. This seems to be more attractive to the builder both for cost and operation effectiveness (see graphs below).



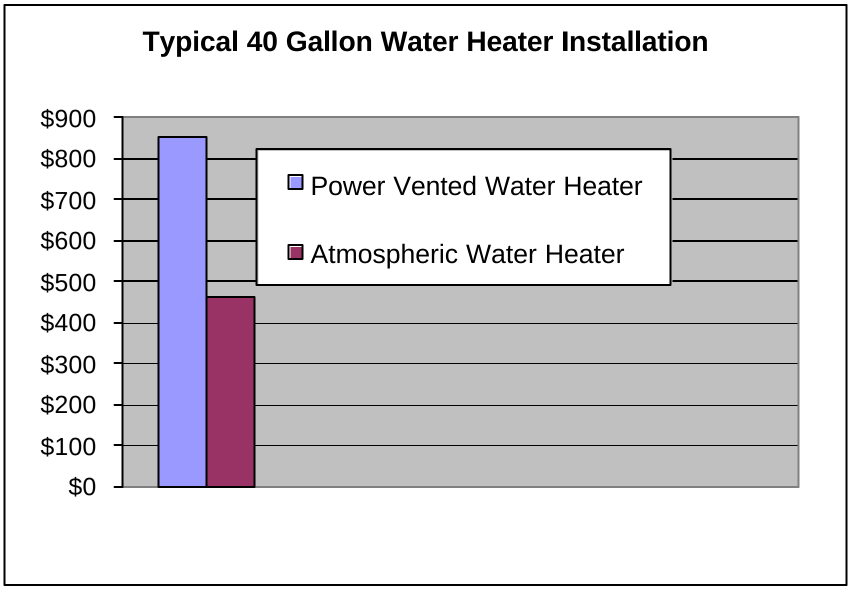
This installation cost includes only furnace and venting; ductwork was not included. The cost for the direct vent furnace could also be decreased by local utility rebates.

Domestic Water Heating

While water heating can differ from space heating equipment, the operational needs are closely the same.

Atmospherically vented water heaters will show a purchase price 40% lower than power vented water heaters. The addition of site installed venting equipment, either integrated with induced draft furnaces (which will reduce venting costs) or independently vented, will increase the cost by 10% to 30%. Builders believe there is a need to evaluate this water heating system to make sure operation will provide positive draft against increased negative pressures from exhaust appliances to comply with code.

While the purchase price of power vented water heaters is higher than atmospherically vented systems, the cost of venting and concerns about positive draft against negative pressure are decreased. Since there is a cost difference, though minimal, builders are showing a trend toward power vented systems (see graphs below).



If the atmospherically vented water heater uses a single purpose vent through the roof it will add $385.00 to the installation, mainly for costs involved with the construction of the chimney chase. Rebates from local utilities were not included.

Combustion Air

Combustion air is defined as the required amount of air needed for space heating and water heaters to turn fuel into heat. Requirements can depend on ACH measurement of the building, type of equipment, manufacturer's recommendation and the volume of the room the equipment is contained in.

This installation typically involves a flex duct extending from the outside into the utility room. Cost of this installation can run up to $150.00. This has, at times, been confused with make-up air.

Ventilation

Success in tightening homes has created a new set of concerns. There is general agreement within the industry that homes should have an air exchange rate of about one-third of an air change per hour. Air pollutants can build up in houses with air exchange rate lower than this. The chief concern is water vapor, which we typically refer to as humidity. Homes with high winter relative humidity often experience condensation on windows and concerns about potential mold growth.

When the Minnesota Energy Code was implemented, ventilation became a requirement in all new homes. Builders had two options for home ventilation, exhaust only and balanced. There are multiple ways in which this is being achieved (illustrations can be found in appendix A).

Exhaust Only
This system is typically a centralized exhaust fan either surface or inline mounted, operating 24 hours per day. The fresh air enters the building through the building envelope or a duct connected to the outside. This system costs builders $300.00 to $500.00. Most of the contractors indicated the success of this system relies on a quality fan.

Balanced Ventilation
This type of system is usually a heat or energy recovery unit. Builders reiterated the importance of balancing for optimizing the efficiency from their air change systems. Depending on the type of unit and installation design, the builders interviewed indicated that this ventilation installation costs between $2,200.00 and $2,800.00 per home.

Make-up Air

Make- up air is defined as any combination of outdoor and transfer air intended to replace exhaust air and exfiltration, as per ASHRAE Standard 62-2001. Make-up air is a requirement of the energy code when there is a large amount of exhaust fan capacity installed in combination with atmospherically vented combustion appliances.

Make-up air systems can be installed either as passive or powered to match exhaust flows. Passive systems will typically consist of a flex duct connected to the outside, which allows fresh air to enter the home while exhaust equipment is operating. The powered make-up air system is installed as an independent fan that will mechanically provide fresh air, and in some cases tempered air, while exhaust equipment is in operation. It is typically interlocked with range hoods with large exhaust capacities. The interlock assures that the make-up air system operates when the range hood is operating. The price of these systems can vary depending on passive or powered design and ranges from $150.00 to $3000.00. In homes where large exhaust systems are not installed and combustion appliances are sealed or direct vent types, a make-up air system may not be required.

Overall Cost

When the general contractors were asked about the total cost increase to bringing their homes into compliance with recent code changes, they said it added $1.00 to $1.15 per square foot. The builder indicated that the typical price range for a 3,000 square foot house in this discussion was between $300,00 and $350,000. Thus, the costs noted amount to approximately 1% of the total cost of the home.

3,000 square feet X $1.15 = $3,450
$3,450 / $300,000 = 1.15%

Builder Survey

As this project was reaching its conclusion, it was learned that the August 2002 edition of *Minnesota Builder,* from the Builders Association of Minnesota (BAM) will include a Mechanical and Ventilation Equipment Survey. For this survey, BAM builders were asked questions regarding the types of space heating, water heating and ventilation systems they were utilizing, along with much other information. 78 builders from Minnesota responded and a sample of the results are tabulated below:

Space Heating:

- 68% Sealed combustion
- 15% Power vented
- 13% Direct vented
- 2% Atmospheric

Domestic Water Heating:

- 65% Power vented
- 14% Direct vented
- 12% Electric
- 8% Sealed combustion
- 1% Atmospheric

Ventilation:

- 88% Balanced
- 12% Exhaust only

Summary

In the future, as technology advances through research and development, it is believed that costs will be driven down due to natural economic transitions involved with better productivity, better products, increased demand and volume purchasing. Of course, the builders that were interviewed indicated that they believe the most potential for improvement lies with proven research aimed at new products and installation procedures. In many cases Minnesota builders, in their endeavor to construct high performance homes, not only look to lower costs where possible but look to new technology to provide safer, healthier, and more durable homes.

Conclusions

Effectiveness of Building Envelope

This study indicates that the average building envelope in Minnesota has become increasingly airtight since 1994. This study also indicates that there is a correlation between increased airtightness and decreased energy consumption during the Minnesota heating season, although the increased use of high-efficiency furnaces, high-performance windows and other factors could also play significant roles. Although homes are getting tighter, observation, infrared scans and homeowner feedback indicate that the following construction details are still challenging:

- Cantilevered floors over garages
- “Bump-outs” for entertainments centers and fireplaces
- Rim joist penetrations
- Shower and tub enclosures along exterior walls
- Any other framed cavity adjacent to an exterior wall or attic

Homebuilders should continue to strive for air/vapor barrier continuity and maximum airtightness in the building envelope. Although there will always be other variables affecting building performance, this approach serves as a cornerstone to any effort to enhance energy efficiency, indoor air quality, homeowner comfort and building durability in this demanding climate. Although cries of “we’re building them too tight” can still be heard from skeptics, failure to achieve airtightness does nothing to ensure comfort, air quality or durability. Much of the fear and skepticism about modern building practices that lurks in the industry can be reduced by further education and demonstration of successes.

Ventilation and Mechanical System Effectiveness

As a whole, ventilation systems in Minnesota are being installed correctly and are meeting or exceeding recommended ventilation rates. Even the least-cost alternatives for complying with the mechanical ventilation requirements, the decentralized exhaust only ventilation systems, seem to be sufficient to control household humidity and prevent major air quality problems from occurring.

The installation deficiencies that were noted were relatively minor considering the fact that they were serving their intended purpose – delivering fresh air to the habitable space. However, the following installation issues deserve further attention:

- Attention to detail regarding the balancing of HRV and ERV systems
- Proper installation of cold-side flex ducts
- Increased awareness of methods available for ventilation air distribution
- Proper duct design and equipment sizing of source point balanced ventilation systems
- Commissioning of mechanical ventilation systems
- Builder and mechanical contractor responsibility for homeowner education regarding the operation and maintenance of mechanical ventilation systems

Indoor Air Quality

Despite the increased airtightness of the study homes constructed in 2000, they are less susceptible to combustion safety issues caused by house depressurization. This is due mainly to the increased use of power vented water heaters and direct-vent furnaces and fireplaces. The average monitored relative humidity of a subset of the study homes indicates that wintertime RH is within what is generally considered the human comfort zone, between 25% and 40%. This was the case for homes built in 1994, 1998 and the year 2000. Another envelope detail that has resulted in less potential for the entry of indoor air pollutants has been the increased airtightness of attached garages in Minnesota homes.

Homeowner Education

The vast majority of homeowners we interviewed told us they were interested and concerned about energy efficiency features and ventilation yet had few choices presented to them when planning their new homes. Some builders might be making the choices based on least-cost; others may be choosing upgrades (direct-vent furnaces and water heaters, balanced ventilation) because they believe these options result in a better product or demonstrate higher quality features. For consumers to make informed decisions, they need information and they need choices presented to them. They should at least be given the option of choosing upgrades that can provide them long-term benefits, and understand the costs involved.

Moreover, they need to receive more information and guidance about how to operate and maintain their mechanical systems.

Costs and Benefits

One expected benefit of energy efficient construction is reduced operating cost. Assuming an initial cost of about $3,000 for energy code related improvements, what would it take in heating and cooling savings to pay it back?

The average year 2000 home in this study used less energy for heating than its 1994 counterpart by a margin of 1.15 BTU/SF/DD. For an average sized new home of 3,850 square feet (as per this study's data), natural gas costs at $1 per therm, and an average weather year of 7,541 heating degree days would result in savings in heating cost alone of $333, a "simple payback" of about 9 years to recoup an upgrade cost of $3,000. A modest 5% per year increase in gas prices would bring the annual savings to $469, and reduce the payback time accordingly.

An even more compelling approach to this example is to apply the monthly energy savings against the increased payment if the efficiency upgrades as they are financed. On a 30 year, 7% mortgage, the difference in the monthly payment (for the additional $3,000) would be $21.25 ($255 annually). A $334 annual savings, or $27.83 per month, would yield a net *decrease* in monthly housing cost of $6.58. Again, as fuel prices rise, the savings grow.

What happens if the home is sold? A study published in the October 1999 Appraisal Journal concluded that home values increase by an average of about $20 for every $1 reduction in annual utility costs. Applying this multiplier to the above example, the resale value could be enhanced by about $333 x 20=$6,680. Even assuming half that rate of increasing value, the return at resale would still be about equal to the $3,000 initial investment.

Recommendations for Further Research

This study has provided a small amount of insight into the real-world effects of recent code changes on residential buildings, the people who live in them and the people who build them. However, improving whole-house building performance is an evolving issue with many complex interactions not evaluated during this study. The following items are offered as recommendations for further research:

Foundation Water Management

Moisture entering the home through foundation walls and slab floors is still a source for concern from an air quality and durability standpoint. Better understanding of moisture flows is necessary, as is the installation and material details that can reduce this moisture flow.

Flashing and Drainage Planes

Bulk moisture entering roof and wall systems are another concern from an air quality and building durability standpoint. There are still many questions in the local building industry regarding materials and material combinations that provide adequate moisture protection.

Avoided Costs

While health issues were not within the scope of this project, the question of avoided health care costs from building healthy housing stock is clearly one that deserves study and consideration. Half of the households in this sample had at least one family member with allergies or respiratory health issues, and almost nine out of ten had some concerns about their indoor air quality when they bought or built their homes. Research to document the long-term health impacts would require time and money, but would be a highly worthwhile investment of both.

Glossary

AFUE- Annual Fuel Utilization Efficiency; defines the efficiency of a furnace as the percentage of fuel entering the furnace that is converted to space heat.

Air barrier- "Material or combination of materials which are durable and installed at the warm side of the building envelope and continuously sealed to resist the passage of air and airborn moisture from a conditioned space into the building envelope". (Ch. 7672)

Acceptable Indoor Air Quality- air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.(ASHRAE definition)

Air Changes Per Hour (ACH) - The amount of air in a building that leaks out or is removed by a fan and is replaced by outdoor air, expressed as the number of times in an hour that the volume of air in the house is exchanged.

APT- Automated Pressure Testing System; a computer-controlled system for running and recording building performance tests. APT is a trademark of The Energy Conservatory, Inc.

Backdrafting- Reverse flow of combustion gases down the chimney of a vented combustion appliance, which is often caused by depressurization of the room where the appliance is located.

Building Envelope- "The elements of a building that enclose conditioned spaces through which thermal energy may be transferred to or from unconditioned speces" (Ch. 7672)

British Thermal Unit (Btu) - The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit; equal to 252 calories. Commonly described as the amount of heat in one kitchen match.

CFM- Stands for Cubic Feet per Minute. A measurement of airflow that indicates how many cubic feet of air pass by a stationary point in one minute. The higher the number, the more air is being forced through the system. CFM_{50} refers to CFM at 50 pascals of depressurization, a benchmark for comparing air leakage rates of houses.

Conditioned Area- Total floor area of a house that lies within the heated/cooled envelope (Differs from "total finished" or "total above-ground" footages that are commonly used in real estate).

Degree-Days – The number of degrees that the average outdoor temperature varies from a reference temperature (generally 65º) on a given day. Temperatures lower than the reference temperature are Heating Degree Days (HDD); temperatures that are higher are Cooling Degree-Days (CDD).

Depressurization- A negative air pressure differential induced in the dwelling unit relative to atmospheric pressure (CAN/CGSB-51.71-95)

ERV- Energy Recovery Ventilator; this type to ventilation is capable of reducing the moisture content of the fresh incoming air. As a result, this can reduce the load on air conditioning.

Exhaust-only Ventilation- A mechanical ventilation system in which a fan continuously exhausts air to the outside.

HRV- Heat Recovery Ventilator; exhausts stale air from the home, brings fresh air in from outdoors, and transfers heat energy from one air stream to the other.

KWH- Killowatt-hour; a unit of electric consumption indicating the total energy developed by a power of 1 kilowatt acting for one hour.

Mechanical Ventilation- Either "balanced" or "exhaust-only", a system that uses a piece of mechanical equipment to provide a continuous supply of fresh air to the house.

Pascal-a unit of pressure equal to one newton per square meter.

PRISM - Princeton Scorekeeping Method. A computer program for analyzing energy use data and normalizing it for weather. The following terms are used with PRISM:

> **NAC-** Normalized Annual Consumption—Weather adjusted annual energy use.
>
> **CV(NAC) -**Coefficient of Variation—Relative standard error of the NAC.
>
> **R^2 -** A reliability statistic, R^2 of the least-squares regression of consumption data vs. degree-days computed to best t value. Optimally, it will approach 1.
>
> **a** - (Alpha) Base-level consumption, in Therms or KWH per day, for uses other than heating or cooling (water heat, cooking, appliances, etc.)
>
> **t** - (Tau) Reference temperature; the average outdoor temperature at which the heating or cooling system comes on

Relative Humidity (RH)- The amount of moisture in a volume of air expressed as a percentage of the total amount of moisture that that volume of air can hold.

Spillage- The unintended flow of combustion gases from an appliance/venting system into a dwelling, primarily as a result of house depressurization. (CAN/CGSB-51.71-95)

Therm - A unit of heat containing 100,000 British thermal units (Btu). One hundred cubic feet (CCF) of natural gas equals one Therm.

Vapor Barrier/Retarder- a material that prevents the passage of moisture in its vapor state

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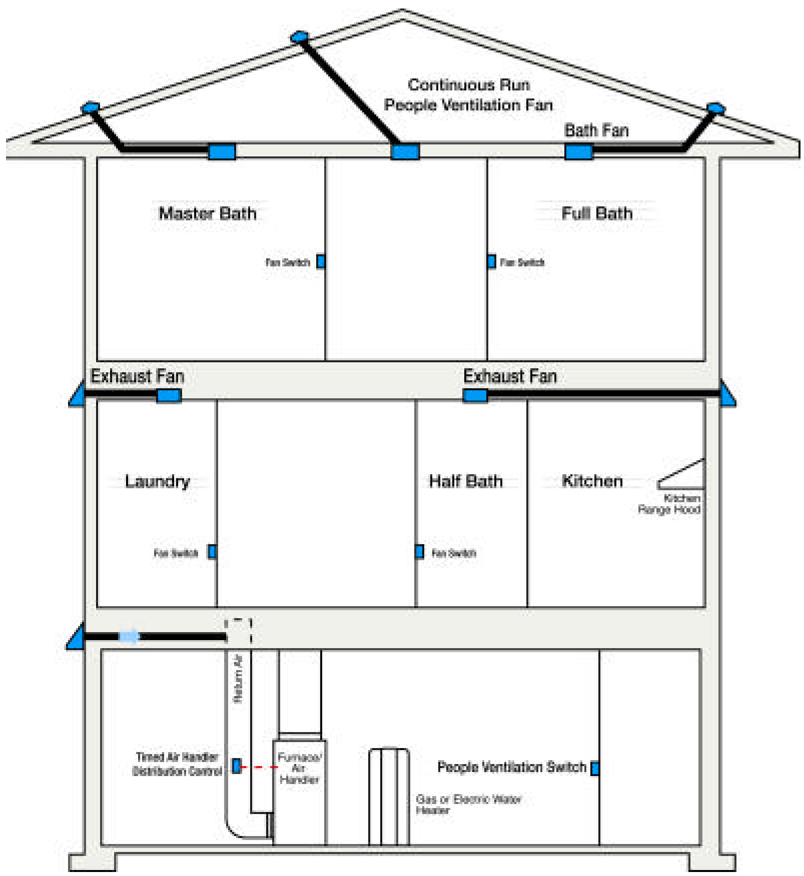
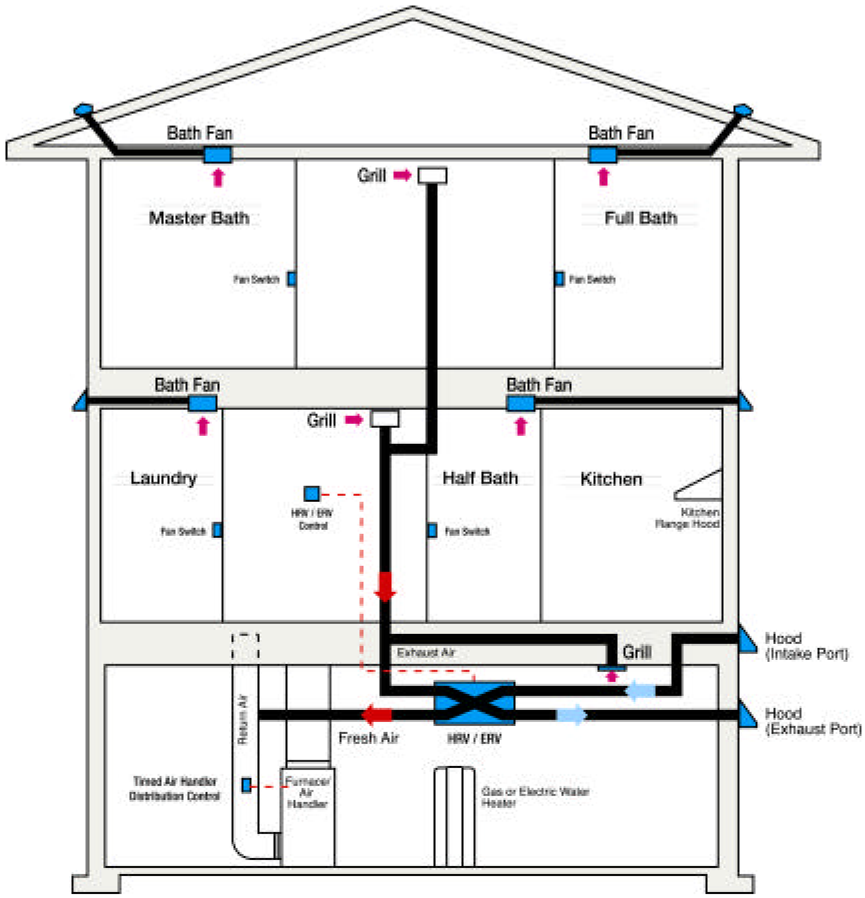
Appendix A

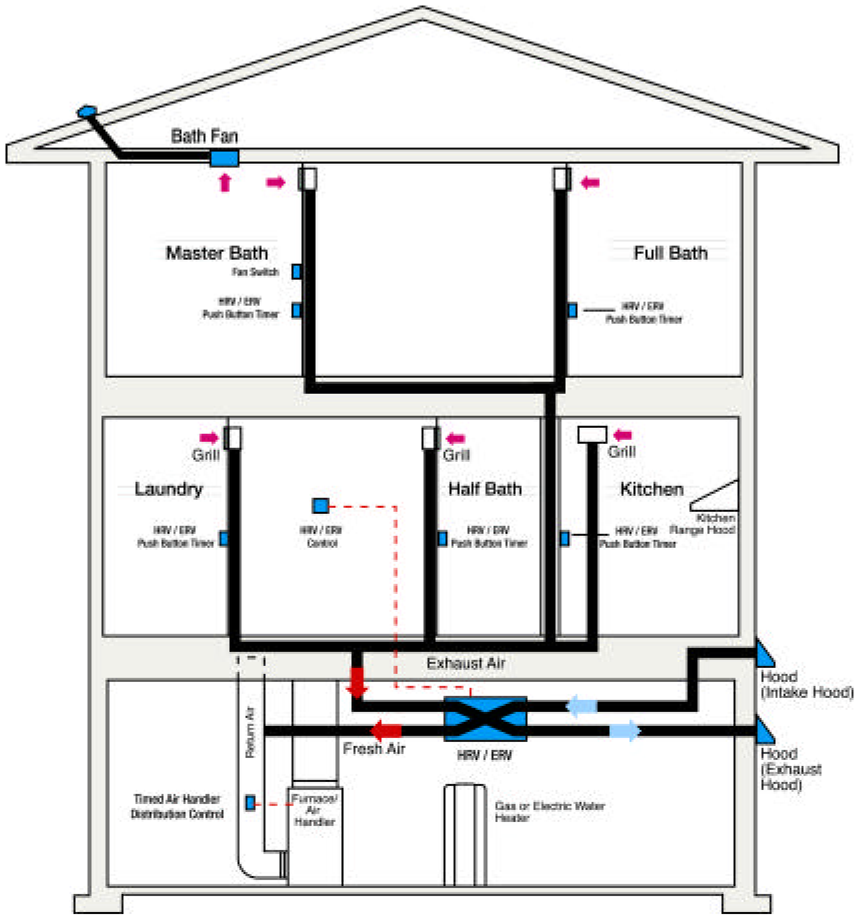
Ventilation Strategy Diagrams



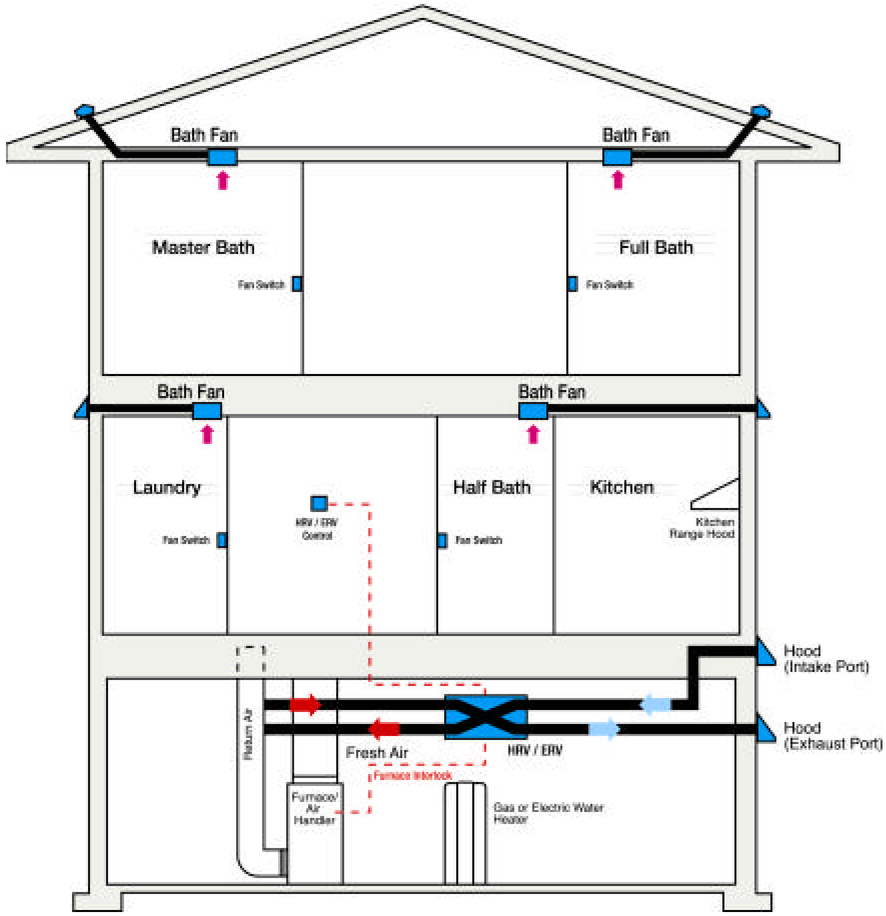
Decentralized Exhaust Only



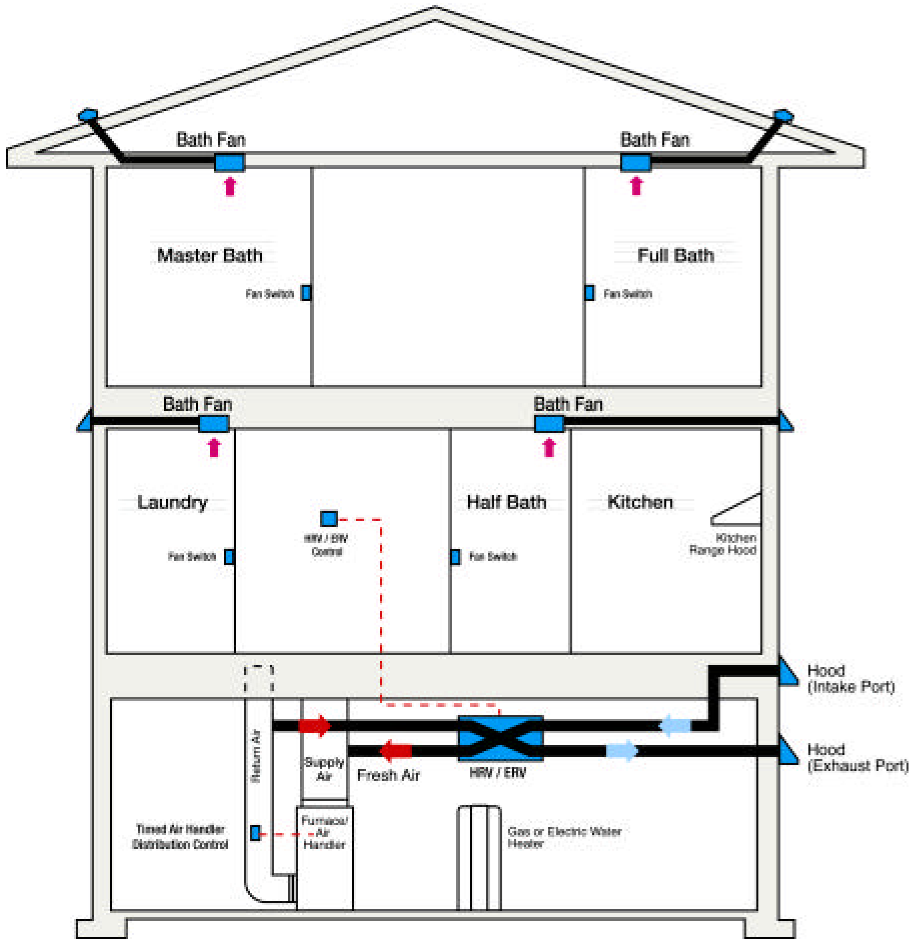
Balanced with Heat Recovery - General Ventilation Strategy



Balanced with Heat Recovery – Source Point Strategy



Balanced with Heat Recovery – Volume Ventilation Strategy, Return/Return



Balanced with Heat Recovery – Volume Ventilation Strategy, Return/Supply

Appendix B

Appliances Broken Down by Year

Furnace Type	1994	1998	2000
Induced Draft	6	12	3
Direct Vent	0	3	18
Combination System (Direct Vent)	0	1	0

Water Heater Type	1994	1998	2000
Atmospherically Vented	6	13	3
Power Vented	0	0	16
Electric	0	2	2
Combination System (Direct Vent)	0	1	0

Fireplace Type	1994	1998	2000
None	1	7	3
Direct Vent	4	9	18
Decorative Wood Burner	1	0	0

Filter Type	1994	1998	2000
Standard	3	7	12
Standard Pleated	1	3	3
6" Pleated	0	2	3
Electronic Air Cleaner	0	2	1
Filtrete	2	2	2
UV Scrubber	0	2	0

* Some homes had more than one type of filtration

Range Hood Type	1994	1998	2000
Recirculation Type	5	11	13
Exhaust Hood	1	4	8
Downdraft	0	1	0

Central Vacuum	1994	1998	2000
In Basement	0	0	2
In Garage	0	2	1
None	6	14	18

Appendix C

PRISM Tabulated Data

PRISM Data by Year

HOUSE CODE	Code	Htg eff.	SQ. FT	NAC	CV(NAC)	R2	ALPHA	BETA	TAU	CFM/SQ.FT	ACH	HTG NAC	HTG NAC/SF	BTU/SF/DD
1994-02	C2	81	3450	1345	1.60%	0.993	0.7	0.2	61.3	0.38	2.88	1089.5	0.315797101	4.19
1994-03	C2	81	2112	1281	2.50%	0.975	0.9	0.2	59	0.61	4.23	952.5	0.450994318	5.98
1994-06	C2	81	2232	1102	3.90%	0.937	0.6	0.1	64	0.57	4.08	883	0.395609319	5.25
1994-09	C2	81	3460	954	3.60%	0.962	0.8	0.1	56.2	0.3	2.16	662	0.19132948	2.54
1994-11	C2	81	2855	1261	2.30%	0.967	0.8	0.1	60.4	0.51	3.83	969	0.339404553	4.50
1994-14	C2	81	2299	1043	1.80%	0.995	0.4	0.1	61.2	0.75	5.1	897	0.390169639	5.17
1994 avg.			2735						60.35	0.52	3.71		0.347217402	4.60
1994 median			2577						60.8	0.54	3.96		0.339404553	4.50
1998-01	C2	81	4834	1808	1.00%	0.997	0.9	0.2	62.9	0.37	2.3	1479.5	0.306061233	4.06
1998-02	C1	92	4608	1927	2.60%	0.979	2.2	0.2	53.5	0.52	3.08	1124	0.243923611	3.23
1998-03	C2	81	3298	1275	1.00%	0.997	1.1	0.1	60.1	0.49	3.58	873.5	0.264857489	3.51
1998-05	C2	81	4220	1856	2%	0.991	1.3	0.2	56.9	0.45	3.14	1381.5	0.327369668	4.34
1998-09	C2	81	2762	1004	2%	0.989	0.5	0.1	60.7	0.42	2.93	821.5	0.297429399	3.94
1998-10	C2	81	3129	1146	2%	0.995	0.7	0.1	60.5	0.52	3.77	863.5	0.275966763	3.66
1998-11	C2	92	4614	1784	1.30%	0.996	1.5	0.2	55.2	0.38	2.72	1236.5	0.26798873	3.55
1998-13	C2	81	4800	1819	4.90%	0.943	1.3	0.2	55.9	0.39	2.76	1344.5	0.280104167	3.71
1998-14	C2	92	4002	1101	3.60%	0.926	1	0.1	63	0.35	2.49	736	0.183908046	2.44
1998-15	C2	92	3342	1265	5.40%	0.917	1.2	0.2	56.4	0.44	3.18	827	0.247456613	3.28
1998-17	C1	92	4742	841	5.80%	0.941	0.3	0.1	59.6	0.34	2.38	731.5	0.154259806	2.05
1998-19	C2	81	3745	1784	1.30%	0.996	1.5	0.2	55.2	0.48	3.15	1236.5	0.330173565	4.38
1998-22	C2	81	4315	1527	1.40%	0.995	1.4	0.2	57.5	0.38	2.64	1016	0.235457706	3.12
1998-24	C2	81	4300	1667	2.90%	0.982	0.8	0.2	59.9	0.29	1.83	1375	0.319767442	4.24
1998-26	C2	81	2636	1079	2.50%	0.982	0.7	0.1	62.9	0.54	3.8	823.5	0.312405159	4.14
1998-28	C2	81	2500	1072	2.60%	0.981	0.7	0.1	62.4	0.5	3.54	816.5	0.3266	4.33
1998 avg.			3865						58.9	0.43	2.96		0.273358087	3.62
1998 median			4111						59.8	0.43	3.01		0.278035465	3.69
2000-02	7672	92	4028	1395	3.80%	0.949	1.5	0.1	57.1	0.37	2.64	847.5	0.210402185	2.79
2000-03	C2	81	2240	922	3%	0.978	0.7	0.1	60	0.52	3.67	666.5	0.297544643	3.95
2000-04	C1	92	3827	1236	1%	0.998	0.8	0.2	59.9	0.27	1.82	944	0.246668409	3.27
2000-05	C1	92	3400	1036	3.90%	0.961	0.6	0.1	61	0.4	2.56	817	0.240294118	3.19
2000-06	C1	92	3421	1404	4.10%	0.947	1	0.1	63.6	0.31	2.07	1039	0.303712365	4.03
2000-07	C1	92	4280	1313	1.70%	0.992	0.8	0.1	63.7	0.23	1.66	1021	0.238551402	3.16
2000-08	C1	92	3860	1561	2.00%	0.992	1.2	0.1	56.1	0.34	2.31	1123	0.290932642	3.86
2000-10	C1	92	6151	2163	4.40%	0.752	4.1	0.2	49	0.25	1.76	666.5	0.108356365	1.44
2000-12	7672	92	5066	1754	1.00%	0.998	0.5	0.2	68.1	0.32	2.28	1571.5	0.31020529	4.11
2000-14	C1	92	4275	1819	5.30%	0.949	0.7	0.2	60.9	0.3	1.79	1563.5	0.365730994	4.85
2000-15	C1	92	4138	1677	3.90%	0.941	1.2	0.2	66	0.26	1.87	1239	0.29942001	3.97
2000-16	7672	92	3680	1090	2.90%	0.987	0	0.1	64.9	0.3	2.12	1090	0.296195652	3.93
2000-17	C1	92	2714	995	1.70%	0.992	0.4	0.1	63.4	0.31	2.33	849	0.312822402	4.15
2000-18	C1	92	4133	813	2.40%	0.98	0.2	0.1	59.4	0.2	1.41	740	0.179046697	2.37
2000-20	C2	92	3290	1153	4.50%	0.93	0.7	0.1	60	0.32	2.14	897.5	0.272796353	3.62
2000-22	7672	92	5201	1772	3.10%	0.979	0.8	0.2	61.5	0.2	1.37	1480	0.284560661	3.77
2000-24	C1	92	3390	909	1.10%	0.997	0.5	0.1	60.8	0.28	2.01	726.5	0.214306785	2.84
2000-28	C1	92	5189	1203	2.20%	0.986	1.1	0.1	61.1	0.3	1.5	801.5	0.154461361	2.05
2000-30	C1	92	2678	1125	2.30%	0.977	1.1	0.1	62.6	0.38	2.71	723.5	0.270164302	3.58
2000-33	7672	92	2893	1303	3.00%	0.966	0.9	0.1	64.1	0.51	3.52	974.5	0.336847563	4.47
2000-34	C2	81	2766	731	5.20%	0.952	0.3	0.1	52	0.28	1.72	621.5	0.224692697	2.98
2000 avg.			3839						60.7	0.32	2.16		0.25989109	3.45
2000 median			3827						61.0	0.30	2.07		0.272796353	3.62