R. A. P. Transfer Grilles

To provide a well-balanced air distribution system, this home combines a single low central return with transfer grilles over each bedroom door. The mechanical equipment is located in a closet off the main hallway in the center of the plan. CARB specified Return Air Pathway (R.A.P.) Transfer Grilles, which have a baffle to reduce noise and light transmission. Under the Nebraska Certified Green Building Homes Program, the home receives credit for using transfer grilles in every "enclosed livable room".

R.A.P. Transfer Grilles with baffles exposed

Finished House with Transfer Grilles

Space Heating

The Nebraska Certified Green Building Homes Program also has requirements for the mechanical equipment installed in the home. The furnace was required to have a minimum efficiency rating of 90% AFUE. Since it is located within the living space, CARB recommended a sealed combustion furnace. Green Program credit was also given for locating the air handling unit within 15% of the horizontal center of the home's living space.

As shown on the right, the contractor installed a Bryant Plus 90 direct-vent, sealed combustion, condensing gas furnace (Model 350 MAV 024040) with an input of 40,000 Btu/hour. This unit has an efficiency rating of 93.7% AFUE. Due to the low cost of electricity in Nebraska, it is common to install electric heat pumps. Since the goal of this prototype is replicability throughout the entire state, CARB opted to install gas equipment. CARB wanted to resolve any issues associated with venting combustion equipment during the prototyping process.

Bryant Plus 90

Space Cooling

Another requirement of the Nebraska Certified Green Building Homes Program is a minimum Seasonal Energy Efficiency Rating (SEER) of 12 for the air conditioning system. Typically, SEER 10 equipment is installed in affordable housing. The 1.5 Ton Bryant condensing unit (Model 533GN 018) uses R-410A (Puron) refrigerant. R-410A refrigerant is chlorine-free.

1.5 Ton Condensing Unit

Programmable Thermostat

The heating, ventilation, and air conditioning (HVAC) system in this home is controlled by a programmable Bryant Thermostat. The programmable feature allows the homeowner to save energy by setting back the temperature during un-occupied periods. Shown on the right, CARB performed short-term monitoring of seven temperatures in the home for one week using temperature logging devices such as the one pictured next to the thermostat.

Domestic Hot Water

At a minimum, the Nebraska Green Program requires all gas water heaters have a minimum energy factor (EF) of 0.60 with ½" insulation on all water lines. There are also requirements governing water use throughout the home, such as low flow shower heads (2.5 gallons per minute or less) and low flush toilets (1.6 gallons per flush or less). Additional credit was given for installing the water heater in a central location in the home and selecting a power-vented unit.

To mitigate concerns about backdrafting, CARB recommended either a power-vented or a sealed combustion water heater. Since the goal of this project was to keep first costs low while increasing energy-efficiency and safety, the NE Energy Office opted to upgrade only to a power-vented water heater. A 40 gallon, power-vented, A.O. Smith Power Shot (Model GPSH 40 100) water heater was installed. This unit obtains combustion air from the living space but has fan-assisted exhaust. During construction, complications arose for providing adequate make-up air for this unit. The City of Lincoln has specific code requirements for make-up air when combustion appliances are installed in the home.

Ventilation System

Since this home is well-sealed, mechanical ventilation is extremely important. In this climate zone, CARB typically recommends an "Exhaust-Only" ventilation system using an upgraded bathroom exhaust fan and timer control. The Nebraska Certified Green Building Homes Program requires that all bathroom fans be Energy Star rated, have backdraft dampers, and be controlled by a timer.

To provide ventilation and local humidity control, an upgraded Broan bath fan (Model S80UE) was installed in the main bathroom. A Grasslin pin timer was remote-wired to the nearby mechanical closet to control the fan. A standard switch in the bathroom allows the homeowner to manually operate the fan as needed. The timer control turns the fan on for 40 minutes each hour to provide fresh air. The fan run-time for this home is based on compliance with the guidelines set forth by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) in *Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Low-rise Residential Buildings*.

Upgrade Fan & Timer

Energy Efficient Lighting & Appliances

The NEO is interested in reducing electrical operating costs for their low income families. This home features an Energy Star-rated dishwasher, the minimum appliance requirement for the Nebraska Certified Green Building Homes Program. All other appliances will be provided by the future homeowner. Additional program credit was given for the installation of a built-in microwave. Program credit would also be given if the builder had roughed-in for gas appliances, such as a gas stove or dryer. However, the builder did not opt to do so.

CARB required that at least 70% of the lighting for the home be fluorescent rather than incandescent. At a minimum, the kitchen and bathroom were required to have fluorescent fixtures to meet the Nebraska Certified Green Building Homes Program requirements. The Green Program also prohibits the use of recessed can lights, unless the cans are air sealed and Insulated Contact (IC) rated. In addition, the program requires that the switches for the most efficient lighting be located nearest each door and all exterior lighting be photocell controlled. The builder received extra Green Program credit for installing compact fluorescent lighting fixtures for 50% of the fixtures in the home. See photographs below.

Bathroom Sconce
(2) 23 Watt Screw-in CFLs

Hallway Lights (3 Fixtures)
20 Watt Screw-in CFL in each

Bedroom Ceiling Fixture
Pin-Type Fixture (see photo on right)

Typical for 2 Secondary Bedrooms
(2) 26 Watt Pin-Type CFLs

Energy Modeling

Using Energy Gauge USA 2.3 software, the energy performance of the home was modeled and compared to the "Building America Research Benchmark Definition version 3.1". A summary of the Energy Gauge results is included in *Appendix A: Energy Modeling*. Based upon the installed specifications, the prototype will have an estimated 28% total energy reduction compared to the Benchmark. The Benchmark home has a HERS rating of 78.2, compared to 86.9 for the Prototype when modeled with Energy Gauge. The SEER 12 air conditioning system will reduce the cooling energy use by a projected 68% compared to the Benchmark. Installing compact fluorescent light bulbs in 70% of the fixtures is expected to decrease the lighting electrical use by 47% over the Benchmark. For further details, see *Appendix A*.

As part of the Building America Program, the Nebraska State Energy Project had a target goal of 40% total energy savings, as compared to the Building America Benchmark. It should be noted, however, that Nebraska currently has no state energy code requirements. One exception is affordable housing projects built using state funding, which are required to comply with the 2000 International Energy Conservation Code (IECC). Reasonably priced homes targeted at first time homebuyers are not required to meet an energy code. Recently, the 2003 IECC was adopted state-wide by Nebraska Legislature. Unfortunately, the effective date for the changeover is not until July 1, 2005. In the interim, the NEO has been providing training for code officials, builders, and others to help implement the new code.

This prototype demonstrates a significant improvement over standard construction practices across the state. Typical Nebraska housing construction specifications are shown in the Builder Section of the Energy Modeling. The Builder standard practice represents a typical affordable housing project, assuming that it meets the minimum requirements of 2000 IECC. The prototype will use approximately 24% less energy than typical Nebraska affordable housing.

An official HERS score for the home was provided by Bob Ruskamp of Lincoln Electric System, the HERS rater for this area. To meet the requirements of the Green Building Program, each home must be tested with a blower door and achieve a HERS score of 86.0 or greater. Using REM/Rate software, the final HERS score for the home was 88.1.

With a goal of keeping first costs low, this prototype was intended to demonstrate the most cost effective ways to reduce energy consumption. Using Energy Gauge, CARB modeled the additional savings provided by a SEER 14 air conditioner and a tankless gas water heater. When combined with the previously outlined specifications, the upgraded equipment increases the total energy savings by approximately 5%. Since this is a significant increase, Contractors were asked to provide cost estimates for the alternate equipment. The NEO used the cost estimates to determine the final project specifications.

Cost Analysis

A number of factors helped to keep the first cost of this project low, including: advanced framing drawings detailing the reduction in materials, minimized ductwork, a plenum truss to simplify the mechanical layout and installation, and complete drawings and specifications. CARB has already demonstrated the viability of advanced framing, mechanical ventilation, and compact duct systems in other prototype homes. However, these concepts were new to this builder and required on-site contractor oversight and coordination by CARB.

The builder provided a cost summary for this project, shown below. The projected sale price for this 1,250 ft^2 home is $147,000, which equates to $117.60/$ft^2$. In November 2004, this same builder sold a 1,336 ft^2 home in the same neighborhood for $138,375, a cost of $103.57/$ft^2$. Both homes had the same lot and impact fees and met the energy performance requirements of 2003 IECC. The 13.5% increase in costs is a result of increasing construction costs and the added cost of the green technologies and a higher energy performance goal. Despite the cost increase, this home is less expensive than many similar homes recently sold in the area that did not even meet the minimum requirements of the 2003 IECC.

2410 SW Paul Whitehead Lane
Lincoln, Nebraska
Contractor: Ken Inness

Item	Cost
Lot	$23,000.00
Builder's Risk Insurance	$480.00
Foundation	$9,350.00
Excavation and Backfill	$1,011.00
Flat Concrete, Basement, Garage, Driveway	$6,255.00
Damp Proofing	$600.00
Framing Labor	$7,500.00
Framing Lumber, Roofing and Deck Material	$19,282.00
Brick for Columns	$250.00
Siding Material and Windows	$4,600.00
Entrance Doors	$1,796.53
Plumbing (Complete)	$7,225.00
Roofing Labor	$976.00
Treated Lumber for Deck & Foam for Bsment.	$1,900.00
Brick Labor	$950.00
Insulation	$1,630.00
Garage Door	$1,041.00
Siding Labor and Gutters	$3,919.00
Complete Drywall	$5,848.00
Complete Heating System	$5,620.00
Trim Labor	$1,900.00
Dumpster (Quantity = 1)	$102.71
Floor Coverings	$2,861.00
Complete Painting	$2,614.00
Counter Tops	$566.00
Appliances	$982.00
Cabinets	$2,362.00
Deck Labor	$1,500.00
Electrical Complete	$3,944.00
Door Knobs and Miscellaneous Materials	$900.00
Light Fixtures	$800.00
Miscellaneous Labor for Cleaning and Framing	$2,400.00
Sidewalk	$1,300.00
Sod and Grade	$1,200.00
Permit and Impact Fees	$3,300.00
Trim Material	$2,100.00
Base Project Cost	**$132,065.24**
Overhead and Profit	$14,934.76
Projected Sale Price of the Home	**$147,000.00**

The prototype home will remain on display until the Spring Parade of Homes Event sponsored by the Home Builders Association of Lincoln from May 8-15, 2005. This event will be used to promote the energy-efficient and green technologies in the home. As shown on the right, the tours will highlight not only the home's energy-efficiency but also the efforts made to recycle construction waste and install environmentally-friendly products and finishes. After the Parade of Homes, the prototype will be put on the market.

The builder for this home, Ken Inness, already has one buyer interested in having an identical home built in a different location. Ken is excited about this demonstration project and intends to incorporate all of these strategies into his standard practice. The only item he plans to change in the next iteration of the house is the plenum truss. To save space in the first floor, he plans to move the mechanical equipment and the laundry station to the basement and install the ductwork in the basement. Since Ken does not usually buy trusses, this will allow him to continue his standard practice of stick-framing the roof.

Performance Testing

At the completion of the project, CARB returned to Nebraska to evaluate the home through performance testing. Bob Ruskamp of Lincoln Electric System and Lynn Chamberlin of the Nebraska Energy Office provided assistance for the final testing. Representatives from local utility companies were also on-hand to learn more about the demonstration project and the testing process. The test plan included:

1. Air Infiltration Measurement using a Blower Door
2. Duct Leakage Measurement using the DuctBlaster
3. Air Handling Unit Airflow Measurement using the TrueFlow Grid
4. Room Airflow Measurements with an Alnor Low Flow Balometer
5. Pressure Differentials of Bedrooms using a Manometer
6. Pressure Diagnostics to determine Plenum connection to the Living Space
7. Combustion Air Zone (CAZ) Test to verify safe equipment operation
8. Bathroom Exhaust Fan Airflow Measurements using the Balometer
9. Set the Grasslin Pin Timer Control for the Bathroom Fan
10. Verification of Low e Windows
11. Lighting and Appliance Audit
12. Photograph the home using an Infrared (IR) Camera
13. Installation of HOBOS for a short-term test to evaluate temperature stratification

Air Infiltration

Using a Blower Door, the house was depressurized to measure the air infiltration rate. The leakage rate at 50 Pascals (Pa) was 655 cubic feet per minute (cfm), which is equivalent to a natural air change rate of 0.08 ACH. The effective leakage area (ELA) was 32.1 in^2. To determine the leakage of the plenum, CARB sealed off the registers connecting the plenum to the living space. With the plenum isolated, the home had a CFM_{50} = 613, ACH_n = 0.08, and an ELA = 31.1 in^2. The efforts to seal the envelope and plenum resulted in a tight house. CARB was satisfied that the plenum was not a significant leakage area in the home.

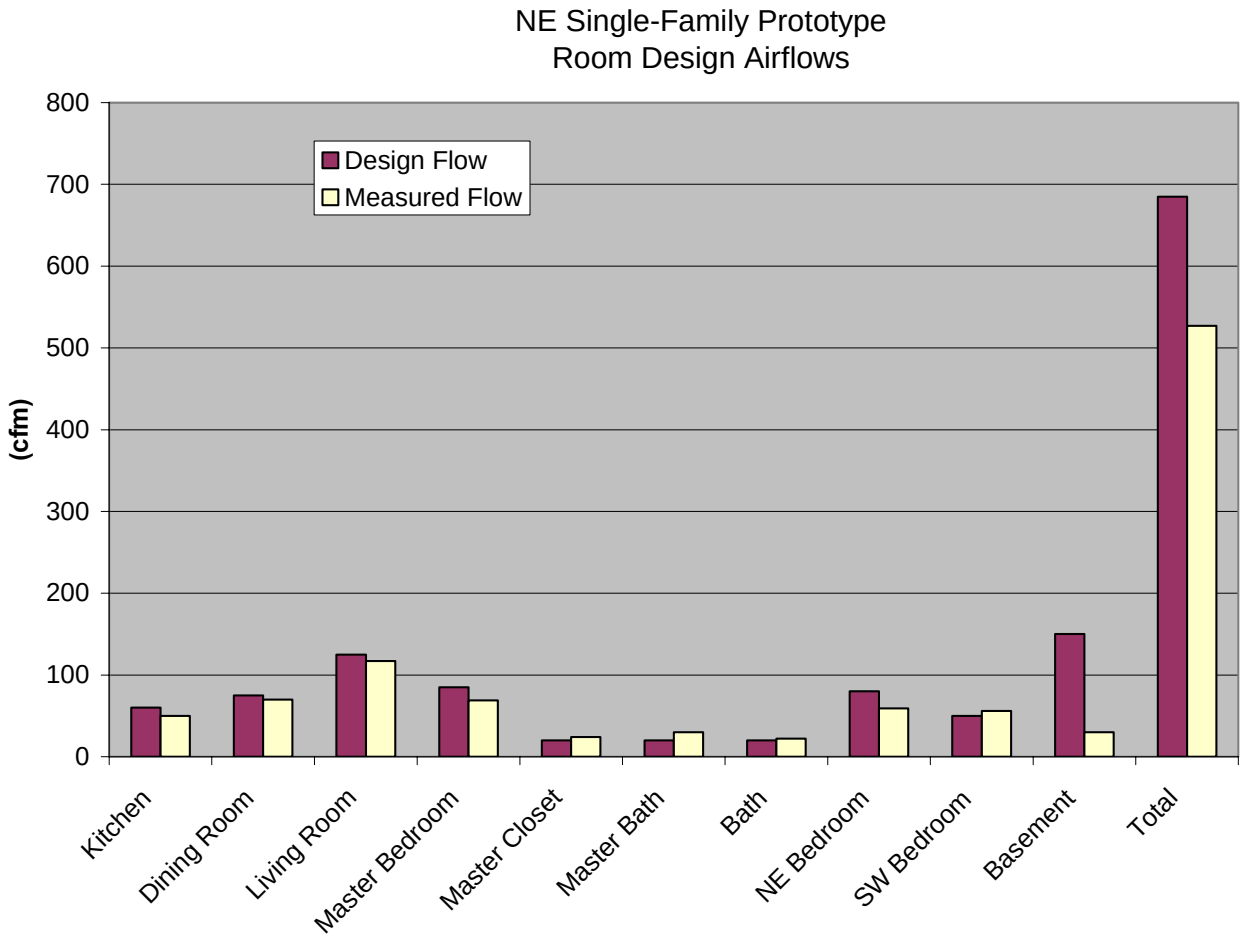
Duct Leakage
The total duct leakage for this home, measured at 25 Pa using a DuctBlaster, was 275 cfm. Of that leakage, 250 cfm was on the supply side and the remaining 25 cfm was return leakage. The return ductwork was isolated at the base of the air handling unit. Any leakage through the filter slot would be considered supply leakage in this scenario. Although there is very little return ductwork, the plenum box was not sealed prior to installation. Located in a small closet, there was no way to properly seal this ductwork after installation.

Using the Blower Door and DuctBlaster together, CARB measured 25 cfm of total duct leakage to the outside. While the ducts were taped off, CARB also taped the three registers connecting the house to the plenum. A second DuctBlaster test was then performed. When the house was pressurized to 25 Pa with respect to outside, the isolated plenum became pressurized to 19.0 Pa with respect to outside and total leakage to the outside increased to 63 cfm. Since the plenum was isolated during this test, the plenum pressurization indicates a high amount of duct leakage into the plenum. Based on the minimal increase in duct leakage to the outside, the plenum is well-sealed.

Air Handling Unit Airflow
A TrueFlow Grid was used to measure the return airflow of the air handling unit. This air handling unit has a multi-speed fan, which adjusts the airflow depending on the mode of operation. The HVAC system was designed for 685 cfm, which is the Medium-Low fan speed. In Heating Mode, the measured airflow was 685 cfm. In Fan Only operation, the measured airflow was 831 cfm and this is close to the High fan speed setting of 895 cfm. Typically, the Fan Only Mode has the same airflow as the Cooling Mode. It was too cold outside to activate the condensing unit and measure the airflow in Cooling Mode.

Unfortunately, CARB could not locate any controls within the air handling unit to adjust the Cooling airflow down to a lower fan speed. For Heating, the airflow will be close to design. In Cooling Mode, the airflow will likely be higher than desired for a 1 ½ Ton air conditioning system. The high airflow will result in less dehumidification of the air, which may impact occupant comfort. The future homeowner may need to contact the HVAC contractor to decrease the Cooling airflow of the unit.

Room Airflow Measurements
Individual measurements of each register were taken with a Balometer. The total supply airflow measured was 527 cfm, which is approximately 77% of the 685 cfm design flow. At the HVAC Contractor's request, a supply register was added to the system to provide 150 cfm of air down to the basement. Excluding the basement, all the supply registers for the main floor were well-balanced and totaled 93% of the design airflows. Only the basement supply was extremely low. However, it was difficult to accurately measure the airflow of the basement register due to configuration. The figure on the following page shows the overall system balance, comparing design and actual supply airflows for individual rooms.



Pressure Differentials of Bedrooms

A manometer was used to evaluate the pressure differentials between each bedroom and the main hallway. Primarily, the intent of this test was to determine the performance of the transfer grilles. To prevent pressurization of individual bedrooms when the door is closed, CARB recommends a maximum pressure differential of 3 Pa.

The air supplied to the bedrooms is returned via both transfer grilles and door undercuts. As shown in the table below, the room pressurization increases significantly when the return paths are blocked. This increase is greatest for the Master Suite, which has three separate supply registers. When the door is closed, the pressurization is well below the 3 Pa threshold for all the bedrooms. With the door under cuts blocked, only the Master Bedroom slightly exceeds the maximum. Blocking the transfer grilles has the greatest impact on room pressurization.

Room-To-Room Pressure Measurements

Room	Door Open		Door Closed		Transfer Blocked		UnderCut Blocked	
	Supply CFM	Δ P	Supply CFM	Δ P	Supply CFM	Δ P	Supply CFM	Δ P
Master Suite	124	0	116	1.8	102	4.4	109	3.3
NE Bedroom	62	0	62	0.6	58	1.6	59	0.9
SW Bedroom	53	0	50	0.4	50	1.3	51	0.8

Notes:

1.) Master Suite Airflows include the Master Bedroom, Master Closet, and Master Bath

2.) Each bedroom with a Transfer Grille (TG) also has a 1 inch door undercut

Plenum Pressure Diagnostics

Using a manometer, CARB measured the pressure of the plenum with respect to the house throughout the testing process. Three transfer grilles were installed in the hallway ceiling to allow conditioned air from the living space to circulate through the plenum. Since the supply ducts are not insulated, CARB was concerned that humid air could get trapped in the plenum during the summer months and result in condensation. Although the ducts were sealed with mastic, the duct leakage tests found 275 cfm of leakage on the supply side. During normal operation, it is likely that the supply leakage would be enough to condition the plenum space and prevent condensation. However, the transfer grilles prevent the plenum from being pressurized with respect to the home. The tables below show a summary of the plenum pressure with respect to the house pressure, taken during various tests.

The plenum was isolated by taping off the three grilles connecting it to the living space. In this scenario, the registers were not sealed and the only connection between the living space and the plenum was the remaining leakage through the ductwork. As indicated in the tables below, when the house was pressurized using the Blower Door, the plenum also became pressurized. When the DuctBlaster was used in conjunction with the Blower Door to pressurize the ducts to 25 Pa, the plenum pressure was 19 Pa with respect to outside. With the house un-pressurized and the DuctBlaster pressurizing the ducts to 25 Pa, the plenum was almost 2 Pascals positive. However, when the plenum was open and connected to the living space, there was very little pressure difference between the two spaces. These results indicate a high level of duct leakage, despite the mastic sealing.

Tests with the Plenum Isolated

House Pressure	Plenum Pressurization*
-60.5 Pa	-48.1 Pa
-50.7 Pa	-40.7 Pa
-42.4 Pa	-34.3 Pa
-31.9 Pa	-26.3 Pa
-19.6 Pa	-16.4 Pa
25 Pa	18.5 Pa
25 Pa & Ducts at 25 Pa	19 Pa
0 Pa & Ducts at 25 Pa	1.9 Pa

* Plenum pressurization with respect to Outside

Tests with the Plenum Open

House Pressure	Plenum Pressurization*
-50.0 Pa	-48.8 Pa
0 Pa	0 Pa

* Plenum pressurization with respect to Outside

Combustion Air Zone (CAZ) Test

This home was tightly sealed to reduce air infiltration and save energy. In tight homes with atmospheric combustion appliances, there is a potential for backdrafting if adequate combustion air is not provided. Backdrafting occurs when a naturally-vented appliance loses the chimney effect, which normally carries dangerous combustion by-products (carbon dioxide, nitrogen dioxide and carbon monoxide) up the flue. Backdrafting can occur with furnaces, fireplaces, woodstoves, and water heaters when air pressure in the house is lower than outside air pressure.

The sealed combustion furnace in this home obtains combustion air from outside and vents the exhaust directly to the outside. This is the safest type of equipment for tight homes. The water heater is power-vented. Combustion air for the water heater is obtained from the space and it has a fan-assisted exhaust. Even in a very tight home, it is unlikely that a power-vented appliance would backdraft. However, CARB performed a worst-case depressurization test to verify combustion safety.

Using the standards set in the *2000 Minnesota Energy Code* as a guideline, CARB determined the depressurization of the home in the worst-case scenario. All of the exhaust fans were turned on, the Blower Door was used to exhaust 150 cfm to simulate a clothes dryer, and the water heater was turned on. This resulted in a house depressurization of -19.5 Pa. For a power-vented appliance, the *2000 Minnesota Energy Code* limits the maximum allowable depressurization to 25 Pa. This home falls within those safety guidelines. In addition, CARB used Bacharach Combustion Testing Equipment to verify that there was no spillage of combustion products in the mechanical closet.

Exhaust Fan Airflow Measurements

Using a Balometer, each bathroom exhaust fan was tested and the results are summarized in the table below. The results were consistent with test results of this same fan type installed in prototypes throughout the country. In each case, the fan drew less than 80% of the rated airflow. Also shown in the table is the reduced airflow measured during the CAZ worst-case depressurization test. When the house was depressurized to -28 Pa, with the water heater running and the Blower Door simulating 250 cfm of additional exhaust airflow, the fan flows decreased by an average of 30%. CARB expected a drop in airflow but wanted to verify that the "exhaust-only" ventilation strategy would still work in a tight home. Despite the decrease in airflow, the fans are still able to draw air from the home under extreme conditions.

Bathroom Exhaust Fan Performance

Location	Manuf.	Model	Rated CFM	Measured CFM	CAZ CFM
Main Bath	Broan	S80UE	80	63	45
Master Bath	Broan	S80UE	80	56	37

To minimize roof penetrations, the builder had originally tied the exhaust ducts for both fans into a single termination through the roof. Recognizing the negative impact all the elbows and impingements would have on the fan static pressure, CARB encouraged the builder to provide separate exhaust terminations for each fan. Shown on the right, the builder used a fitting to transition from the 4 inch fan outlet to 6 inch insulated flex duct. The duct was terminated directly out the roof with less than 5 feet of ductwork on each fan. Despite the extra efforts to reduce pressure drop, the fans did not achieve the Manufacturer's rated airflow.

Based on the measured airflow rate of 63 cfm in the Main Bath, CARB calculated the run-time of the fan required to meet the requirements established by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) in *Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Low-rise Residential Buildings.* To meet *Standard 62.2*, an intermittent fan in this home needs to operate for 40 minutes each hour. The pin timer control connected to the Main Bath fan, which can be set for 20 minute intervals, was programmed for this schedule.