High Performance Systems that Integrate Space Heating, Water Heating & Ventilation

Jamie Glouchkow, John Gusdorf, Skip Hayden, Anil Parekh, and Evgueniy Entchev, Natural Resources Canada

ABSTRACT

Through the ēKOCOMFORT™ Project, an industry and government consortium is facilitating the development of a new category of gas-fired products that efficiently integrate residential space heating, water heating, ventilation with heat recovery, and circulation. Six manufacturing teams have each been developing products aimed at meeting the same set of minimum performance specifications for these functions. To speed commercialization, common market infrastructure such as testing and educational materials were developed concurrently.

One key innovation is the integration of a wide number of components into a factory-engineered system with a single warranty. Advanced controls are required to optimize these multi-functioning products, enabling them to satisfy multiple demands at high efficiency. Integrating ventilation into the space-heating product has enabled the electrical cost of providing and distributing fresh air to be substantially reduced, while enhancing comfort and indoor air quality.

This paper focuses on the following project areas:

- Approach: This project takes a novel approach to concurrently developing products and market infrastructure that is integral to the way in which the products are being developed and how they perform.
- Target: The performance specifications.
- Products: A review of the manufacturing teams' technical approaches.
- Performance: An overview of new test protocols, how products performed under standardized lab testing, and how this relates to annual energy consumption.

Project Goals

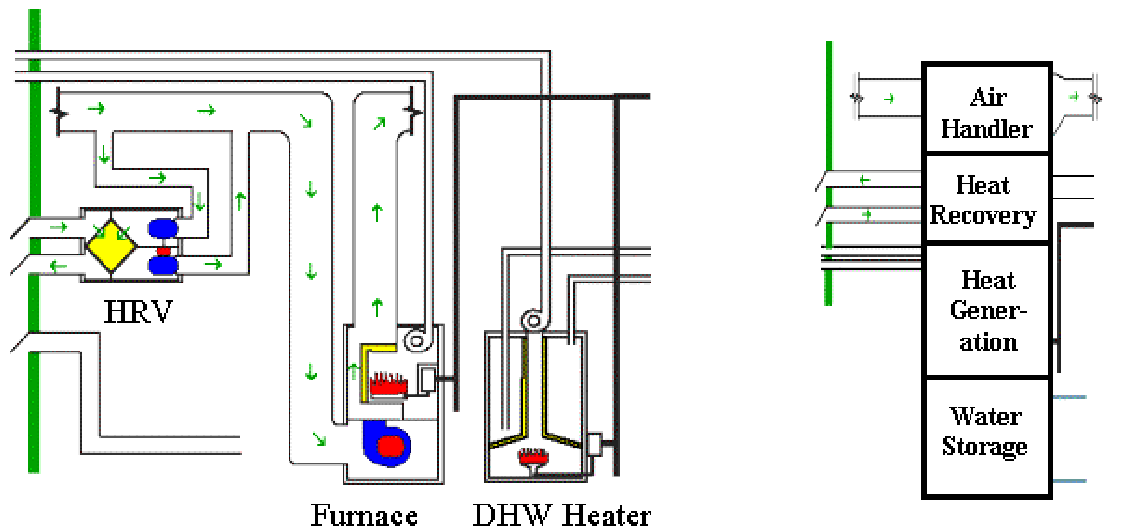
The goal of this project was to develop the foundation for a new class of residential products that efficiently provide space heating, water heating, ventilation and distribution throughout the home. The Consortium's challenges were to:

- Foster the creation of a critical mass of such products in the marketplace; and
- Develop a foundation of market infrastructure to enable such products to overcome existing market barriers and begin to be deployed.

The Consortium members had a shared desire to create a new home mechanicals option that:

- offers an integrated package that met their fundamental needs for home comfort and indoor air quality,
- was factory engineered as a system and came with a single warranty, and,
- efficiently consolidated loads to build a platform for further innovation such as integration of electrical power production and renewable energy sources. (Illustrated in Figure 1.)

Figure 1. Potential for Cost Effective Consolidation



From Traditional Best Practice… … to an Integrated Product

Opportunities & Barriers

Traditionally, each time a new HVAC market need is identified, a new single function product has been developed to meet that need. Today's marketplace is dominated by single function appliances such as furnaces, water heaters, exhaust fans, heat recovery ventilators, and air-conditioning units.

Significant advances in controls have enabled the growing international trend towards the development of products that serve multiple needs. Low mass boilers, instantaneous water heaters, and tank based water heaters are all being used in 'combo' applications to provide space and water heating. The focus on the development of residential combined heat and power (CHP) products extends this trend. As CHP savings result from the use of waste heat, residential CHP systems will need to build on systems that already integrate space and water heating to improve their economic viability.

The average Canadian new home has become tighter in each of the last four decades and should now have efficient effective mechanical ventilation that is distributed throughout the house. Integrating heat recovery ventilation into factory-engineered systems that supply multiple home mechanical needs has the potential to both reduce its associated first and operating costs.

The concept of a factory-engineered product that provided space heating, water heating, and ventilation needs had been around since at least the early 1980's. It was recognized that efficient integrated systems had the potential to cost effectively reduce greenhouse gas emissions (GHGs) in the Canadian marketplace.

Most industry efforts were going into the development of component products developed for one form or another of on-site integration. While many manufacturers recognized that fully integrated systems had great potential, how to get there was unclear. Without standards to test and rate such products, any manufacturer that might developing such a product would not be able to use performance effectively in their marketing. Thus they would not be likely to consider efficiency as a strong driver during their product development phase. It was recognized that no one manufacturer was likely to develop and launch a product when they had to overcome the full range of market barriers alone. A list of some of these barriers is as follows:

- no performance evaluation procedures or rating system for the complete system
- no way of rating performance in relation to existing products
- lack of critical mass of commercialized products (none)
- lack of field trial performance data and analysis
- lack of utility experience with such products
- no software modeling tools or design manuals
- lack of sizing or installation procedures (depending on technological approach)
- lack of knowledgeable builders, developers, installers, and building officials and lack of associated training

Project Approach

The intent was to get a new product class to the point where it could become self-sustaining and use existing channels to become a factor in the marketplace. The novel approach used to concurrently coordinating the development of both product and infrastructure is discussed here because it has defined the kind of products that have been developed and how these products are continuing to evolve. It is also of interest because the consortium stakeholders felt that it worked well and it could be applied to the development of other new classes of products. The associated budget was low enough that the government facilitation elements can be lead directly by researchers (as it was in this case) rather than at a broad program level.

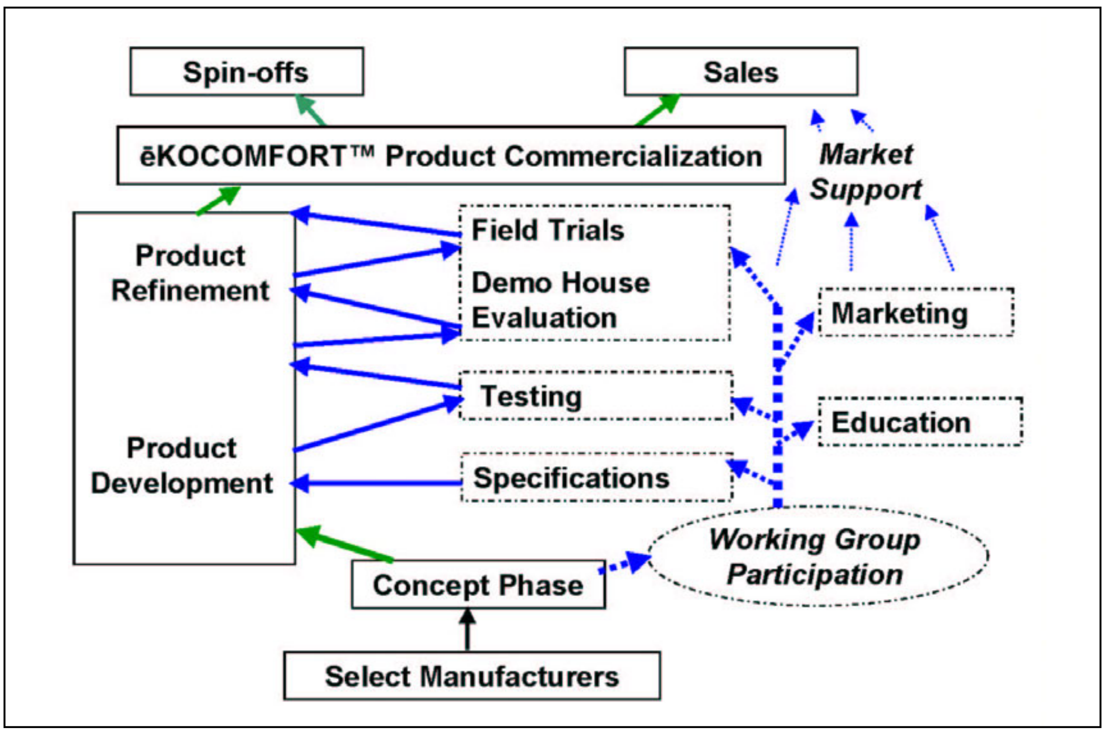
The following beliefs were fundamental to the development of the approach.

- Market Infrastructure (test protocols, rating approach, field trials, market education etc) was required to enable manufacturers to invest in the development of efficient integrated systems with confidence in the potential for broad deployment.
- Market Infrastructure is best created when it can be tried with actual products and refined to make it work effectively.
- Multiple manufacturing teams would mitigate project risks where business as well as technical reasons might lead any one manufacturer to reduce or end their commitment over a multi-year project. Multiple teams also would help share the load of developing market infrastructure.

Minimum performance requirements were developed for each of the three basic product functions in terms of capacity, safety, comfort and efficiency. Through a Request for Participation process, 6 manufacturing teams were selected to each develop complying products. In return, NRCan agreed to facilitate the development of the testing protocol, evaluate and refine that protocol by testing the manufacturers products to its requirements at a third party testing laboratory, and monitor product performance both at the Canadian Center for Housing Technology (CCHT) and in residential field trials.

A consortium of manufacturers, utilities, associations, and a number of government agencies worked together to create the initial market infrastructure. (Please see the web site for a list of partners and some of the contributions that they made.) Figure 2 shows how the approach benefited the manufacturers.

Figure 2. Project Approach



The solid rectangles boxes on the left side of the figure show a typical product development path. The dashed boxes relate to the work of each of the five working groups. The arrows cryptically show the relationship they had with the commercialization process. Having a forum to discuss common non-proprietary product development issues and the various testing and demonstration exercises each provided manufacturers with opportunities to get independent feedback on their prototype's performance and ways towards commercialization. This helped them get past technical obstacles and keep efficient performance as a primary focus.

Performance Targets

The Project performance targets were based upon the philosophy that the first generation of emerging factory-engineered integrated systems should be able to perform functions as well as existing single function equipment. It was recognized that market dominant single function products have been optimized over a long period and that it did not make sense to set requirements for this first generation of integrated products to perform significantly better. Further optimization could come later. Using this approach, energy performance targets were set highest where there were the greatest advantages associated with integration.

To reduce first costs, most Canadian HRV installations provide fresh air to the furnace return plenum and the furnace fan must operate continuously to circulate fresh air throughout the house. In these installations, the furnace fan is often the largest consumer of electricity within the home (roughly 30%). These integrated systems were being designed to operate continuously and therefore needed to both provide and circulate fresh air efficiently. Electrical efficiency and the inclusion of heat recovery ventilation were two areas of primary focus in the performance requirements.

Most of the work had to take place within the 2.5 year timeframe within which the Technology Early Action Measures (TEAM) funding support was available. To be able to participate in the third party product testing and field trials, manufacturers focused primarily on integrating the best available existing components and developing controls to effectively operate them as a system. Time and resources were not available to develop new sophisticated equipment such as condensing boilers if they were not already available to each team.

Efficiency related performance requirements included:

- Minimum space heating AFUE of 81%. (The Canadian regulated minimum efficiency for a gas furnace is 78%)
- Minimum DHW energy factor of .75 (Regulated minimum for 50 gallon tanks is .58)
- Minimum sensible heat recovery efficiency of 60% (No regulations requiring heat recovery ventilation.)
- Maximum power consumption for high-speed ventilation mode (70 l/s) of 250 W. Typically an HRV would operate at roughly 100 W to supply and exhaust fresh air and a furnace fan with a standard PSC motor would operate in the 400 or 500 W range to circulate the fresh air throughout the house.

In some early combo applications, there were complaints regarding insufficient space and water heating capacities. Thus minimum capacity requirements were set in each mode of operation. Requirements were also set for temperature rise across the fan coil for comfort considerations. The complete set of performance requirements can be downloaded from the www.ekocomfort.com web site.

Product Development

The lead manufacturers took a diverse range of approaches to fulfilling each product function as they each came at the opportunity with a diverse range of core competencies. As the development of a three-way integrated product to meet such performance requirements had never been done before, there was no clear 'best' technological way of capturing the largest share of the potential integrated product market. The following table shows the range of approaches taken by the various manufacturing teams in their efforts to meet the product requirements.

Table 1. Variation in Technological Approaches

Product Approaches	Description
Configuration	Complete systems vary from 2 to 5 modules to be integrated together in the home. Some have chosen to eliminate the vertical supply and return plenums (as would be seen on either side of a traditional furnace) by using a horizontal air handler just below ceiling level. Others have taken a more traditional approach.
Burner Firing Rate	Varies between fixed firing rates of 18 KW (60,000 btu/hr) and 45 KW (155,000 btu/h) with one unit having a modulating firing rate between 9 KW (30,000 btu/h) and 26 KW (90,000 btu/h)
Burner	Two products are induced draft while three are forced draft; four have fixed firing rates while one is modulating
Integration of Space and Water Heating	Three products have a segregated boiler loop that provides the space heating and heats hot water via a heat exchanger. Two products are non-segregated and pump potable hot water to the air handler coils to provide space heating
Hot Water Storage	Varies from instantaneous (none) to 290 L (77 gallons)
Heat Recovery Ventilation	Some integrate HR ventilation with air handling while others provide the two as separate components with an additional fan to enable air to be exhausted directly from wet rooms.
Space Heating Coils	Heating coils ranged from 2 to 3 pass coils. One manufacturer chose to use the same coils for space heating and cooling with an additional heat exchanger in the cooling loop. The others took a more traditional approach with a secondary add-on coil in the ductwork to provide cooling.

Under the auspices of the Product Development Working Group (PDWG), NRCan facilitated efforts to find specific technologies that would enable all or most teams to improve their products' performance in meeting a specific need. One example of this effort relates to blower performance. The PDWG provided NRCan with a list of the various motor technologies that they were considering using in their products. NRCan used the Canada Mortgage and Housing Corporation (CMHC) 'Fanalyzer' to test these motors in a common air handler with the same blower and housing. The advantage of programmable DC motors became apparent given the order of magnitude reduction in energy consumption that could be obtained in continuous low speed mode to circulate fresh air. Electrical cost savings could also be made in heating and cooling mode.

NRCan also arranged an approach to let the group of SME gain faster access to the motors, as well as a workshop with one potential supplier to work out how best to program them for this application.

Two of the manufacturing groups contracted NRCan's Residential Integrated Energy Systems (IES) Laboratory to assist in the evaluation, troubleshooting and optimization of their prototypes, enabling them to improve performance and get ready for standardized testing according to the protocol and for field trials. Both groups made changes to their sub-systems, components, and controls logic as a result of their work with the IES lab.

The original timeline for product development was exceptionally aggressive. All manufacturers developed their original concepts and proposals based on this timeline and all found that there was considerably more work required in the initial phases than had been anticipated (with associated increases in their own costs and lengthening of their schedules).

These products are in their first generations and the manufacturers are focusing on further R&D to continue to improve performance, to value engineer, and to integrate additional features. While the first product is now commercialized, no manufacturing group would consider their product fully optimized. Descriptions of the individual products can be found on the www.ekocomfort.com web site.

Product Evaluation

The Product Evaluation Working Group developed a testing protocol to enable products to be tested to determine if they complied with the performance requirements. The protocol referenced existing standards where possible, and developed new clauses where it was not. The protocol is function based and was intended to evaluate the performance of a wide range of technologies in each operating mode.

Prototypes from four manufacturing teams were evaluated using the test protocol at Bodycote Materials Testing in Mississauga, Ontario. This made it possible to ensure that the protocol applied to a wider range of technologies. Efficiency and capacity performance aspects of the protocol are now being revised into a new CSA International Standard - P.10, Testing and Rating the Performance of Integrated Mechanical Systems.

Through the testing and evaluation process, manufacturers were able to have their product's performance benchmarked. Some of the testing was quite elaborate and beyond the scope of manufacturers capabilities to do in-house. Results alerted them to some issues as the early prototypes were tested. Product changes were made at the lab and performance improved. The completed test results enabled manufacturers to recognize where their products had market advantages. It also enabled them to determine priorities for further R&D to gain performance enhancements.

Three prototype products completed all testing. While individual results are commercial confidential for the particular manufacturer, key results are summarized in table 2.

Boilers are being installed with air handlers to provide space heating. There is no test standard to rate such systems. Each is rated independently at different operating conditions. As part of this protocol, engineered systems that included air handlers and boiler or water heaters as components were installed, commissioned and tested as a complete system using the manufacturers operating logic.

Space heating efficiency testing for furnaces is carried out at an output specified by the manufacturer (typically the optimal rate for steady state conditions). With factors of safety built into furnace sizing, the AFUE is typically determined at a point that it will not operate at in the home. Cycling is part of typical furnace operation. By specifying a required output of 14 kW, it forced some systems to cycle or modulate to meet the load during the testing. As a result, modifications were made to the test protocol to create a 'cyclic AFUE' test result for some products that could not be otherwise rated.

Table 2. Testing and Results

Description	Requirement	Performance
Efficiency		
Space Heating AFUE	AFUE or Cyclic Test 81% min.	All Meet
DHW Heating	EF 0.75 min	None meet, range 0.47 to 0.66
Ventilation	Sensible heat rec - min 60% @ 30 l/s	All Meet
Power Consumption	Max 575 W for full-load Heating	All Meet
	Max 250 W for Ventilation @ 70 l/s	None meet, range 257 W - 541 W
	Max 250 W for Ventilation @ 30 l/s	All meet, range 40 W - 200 W
Capacity		
System Loads	Satisfy System Load Table	All Meet
Space Heating	Minimum 14 kW capacity	All Meet
DHW Capacity	57°C/2.6 l/min/60 min	All Meet
	57°C/5.3 l/min/30 min	Most Meet
	57°C/11.7 l/min/10 min	Most Meet
	42°C/18.9 l/min/10 min	Most Meet
DHW First Hour rating	No required minimum	range 340 to 680 litre for 43°C Rise
Ventilation	70 l/s on H.Spd @ 100Pa Diff.	All Meet
	LT Vent. Reduction Factor < 10%	All Meet
General		
Size	Area < 1.5m^2; < 2.3 m high	All Meet
Filtration	MERV 10 required	All Meet
Control Integration	Space Heating and Ventilation	All Meet
Diagnostics	Main Floor Diagnostics	None had at lab
Burner Ignition	No Standing Pilot Permitted	All Meet
Ventilation - Defrost	No electric resistance defrost	All Meet
Start-up and Shut Down	Delayed fan startup for Heating	All Meet
Depressurization Spillage	Pass spillage test @ 50 Pa depress.	All Meet
Heating Supply Air Temp	Supp. Air Temp. Rise > 19°C	All Meet
Prioritization of Functions	DHW Priority if needed	One requires & has
Ventilation Controls	Low Speed 40-60% of High Speed	All 30/70 l/s

The DHW heating Energy Factor proved to be a particularly difficult target to make. As all but one of the systems were non-condensing, systems had to be very efficient in standby mode to make the target. By March 2004, three manufacturing groups have started projects to further improve their product's energy factors.

By integrating heat recovery ventilation into the air handler component, manufacturers can reduce the number of fan motors required to provide heat recovery ventilation. One manufacturer managed to utilize a single programmable brushless DC motor to provide both heat recovery ventilation and circulation, cutting the total consumption for both at low speed to 40 W, a factor of 10 lower than would typically be achieved using an HRV and a typical furnace circulating fan.

An integrated system test was developed to evaluate the performance of the products while they are required to perform multiple functions concurrently. To ensure the system reaches equilibrium and that the HRV components do not experience frost related problems, a three-day test at – 25 °C was conducted.

With higher-powered fan equipment going into homes, the potential for depressurization to cause the spillage of combustion products is increasing. In the 2000 Minnesota Energy Code, there is a 'least restrictive' option for addressing concerns with the potential for combustion spillage. This option requires that combustion appliances be capable of withstanding combustion spillage at 50 Pa of depressurization. The associated web site notes that as there is currently no standard for 'sealed systems', equipment can be approved based upon the self-certification of the manufacturer. However, the web site strongly advises readers to review the posted letters from various manufacturers and decide for themselves whether they believe the associated products comply.

With tight Canadian home construction and trends towards tighter houses yet and higher powered exhaust equipment, the potential for higher levels of depressurization is increasing. This is increasing the demand on combustion equipment to withstand spillage. To address these issues, a depressurization test was developed. This test requires the product be installed in a test chamber. Its associated combustion venting system is connected from the unit and terminates outside the chamber. The chamber is depressurized by 50 Pascals and a call for heat is initiated. Based upon the CO_2 generated by the product at high fire, and the concentration of CO_2 in the chamber and surrounding area, a calculation is made to determine the percentage of combustion spillage. A spillage rate of 2 percent or less was deemed to be successful.

Three direct vent appliances and their associated venting systems each managed to pass the test. Fan positioning varied within these systems as one had a draft inducer and two used a forced draft approach. In some instances, both the burner and the venting system had to be switched or specifications adjusted to be able to comply with the performance requirements.

Field Trials

Two early prototypes were installed and monitored under simulated occupancy during the heating season at the Canadian Centre for Housing Technology (CCHT) research houses. This monitoring was carried out around the same time that these products were evaluated according to the testing protocol. The work at the two facilities complemented each other as they found different areas of interest with these products. Evaluation by NRCan experts at the CCHT led one manufacturer to change his approach to both combustion venting and internal piping and associated controls.

CMHC is currently leading a field trials sub-project. Products from five manufacturing teams have been installed in homes in Ontario in Nova Scotia. One of each of these products is being monitored and the remainder are being audited. The first ēKOCOMFORT Consortium manufacturing team to commercialize their integrated system have also installed their system in Manitoba and Alberta. CMHC will have a public report on this work by the end of 2004.

Education and Marketing

The education and marketing component of this project were key elements in gaining stakeholder interest and early field trial sites. These elements included: the name and logo; the www.eKOCOMFORT.com web site; an Innovative Building Program (conducted at the first show where the products were displayed and aimed at gaining trials with early adopter builders); a promotional video; and logistical support to the development of articles by the trade press. In some cases, this was also helpful in gaining support from the manufacturers' marketing and management elements for the work of their technical staff in continuing their efforts to develop integrated products.

Energy Consumption and Greenhouse Gas Reductions

The most legitimate way to compare performance is probably based upon the third party lab testing as it gives the most comparable results to those of other products in the marketplace. As the protocol used standardized terms to the greatest extent possible, it enables annual energy simulation and comparison with those of benchmark technologies under the same operating loads.

The analysis could easily become an exercise in permutations and combinations as there are many factors that provide the needed context for the results to have meaning. Parameters include: selecting equipment based upon the four different prototypes tested; different baseline technology options that would otherwise serve the same function (eg space heating – furnace, boiler or combo); multiple fuel sources (as an oil derivative already exists); multiple house archetypes; varying occupant loads; and varying climates.

For illustration purposes, benchmarking was carried out with these standardized choices: the house was the 2,300 ft2 R-2000 test house at the CCHT (design heat load 17 kW); occupant set points and loads were taken as the defaults in the HOT2000 energy simulation program (eg 225 l/day of DHW use), and mechanical ventilation was taken to be operating continuously at the minimum ventilation capacity specified by CAN/CSA F326-M91 Residential Mechanical Ventilation Systems (70 l/s for this house); and the electricity consumed was assumed to have been derived from coal fired generation.

Two integrated systems were selected, these being the first product commercialized, and a subsequent one that we expect to be commercially available within two years. The two benchmark systems selected were as follows.

A. A common code-based system including a furnace, fired tank water heater and an exhaust fan based ventilation system. This is representative of common practice throughout much of Canada from Ontario west.
B. A boiler-based system with an air handler for space heating, tankless coil for hot water, a simplified HRV installation that uses the air handler for circulation. (This

would be the most similar type of installation that is currently being put together as discreet components in homes.)

For HOT2000 inputs for four systems were essentially based upon Table 3.

Table 3. Parameters for Simulation

Element	Commercial Integrated System	Expected Next Generation	Benchmark Systems From Above	
			A	B
Space Heating - AFUE	83%	92%	78%	80%
DHW Heating - Energy Factor	0.47	0.8	0.58	0.3
Ventilation - Sensible Heat Recovery	58%	60%	0%	60%
Total System Power Consumption				
At full heating load	575 W	495 W	715 W	920 W
For high speed ventilation (70 l/s)	260 W	250 W	575 W	620 W
For low speed ventilation (30 l/s)	40 W	40 W	525 W	615 W

The electrical power consumption is often considered in terms of the furnace fan in circulation mode. The total system power consumption also includes: the standby power for any controls, valves and other components for each of the individual appliances; combustion air fans and pumps (for combos) in heating mode; and HRV fans. The largest component of the benchmark system power was still the 505 W HOT2000 default for PSC motors.

Table 4. Energy Use and GHG Savings

Element	Integrated System	Expected Next Gen	Benchmark Systems	
			A	B
Total Electrical Consumption (kWh)	2,158	1,952	4,823	5,102
Total Gas Consumption (m3)	3,242	2,647	3,465	3,605
Associated GHGs (Annual kg CO_2)				
Electrical Consumption	2,374	2,147	5,306	5,612
Gas Consumption	6,118	4,995	6,539	6,803
Total Associated GHGs	8,492	7,142	11,845	12,415

While these are estimations based upon one set of assumptions, the important item to recognize from this is that it is not only the primary energy use in gas fired heating systems that has significant GHG implications. Well-sealed and comfortable Canadian homes require continuous efficient ventilation and distribution. Typical current practice using a furnace fan to circulate the fresh air provided by an HRV or fan can have a significant impact on GHG emissions.

Furthermore, a systems approach is required to address total residential mechanical electrical consumption that also includes pumps, burner fan motors, controls, electronic ignition, damper motors etc. Rating the total electrical consumption of the total product in each operating mode has already led manufacturers to make changes to their first generation products and should lead to more efficient products in future generations.

Conclusions, Status and Next Steps

This project has developed the first foundations of an infrastructure for integrated products that efficiently provide space heating, water heating, ventilation and circulation. An ēKOCOMFORT manufacturers council has been established at the Heating, Refrigeration and Air Conditioning Institute of Canada that currently has seven members. The Council is open to other manufacturers and can expect to gain new members as existing manufacturers begin to achieve market success with their integrated products.

Concurrent development of products and market infrastructure proved to be an effective strategy in developing a new class of products. One manufacturing team has commercialized a product that integrates all the base functions, four have had their initial prototypes evaluated according to the testing protocol, and five have products in field trials. Manufacturers are developing second-generation products to improve performance based upon learning from their first generation prototypes and products.

The testing protocol developed for integrated products has proved effective in testing and rating their performance. It is currently being developed into a new standard, CSA P.10 for Testing and Rating the Performance of Integrated Mechanical Systems. Once the standard is developed, a process for certification will need to be established. Test results on the first generation of products being commercialized through this initiative has shown that the product class has the potential to reduce the GHG emissions associated with space heating, water heating, ventilation and circulation.

References

Natural Resources Canada, 2002. *Laboratory Evaluation of Advanced Integrated Mechanical Systems (AIMS).* Ottawa, Ontario. Note: available for download from www.ekocomfort.com.

State of Minnesota, Office of Technology, Department of Administration, 2000. *Sealed Combustion Appliances.* http://www.state.mn.us/cgibin/portal/mn/jsp/content.do?contentid=536894726&contenttype=EDITORIAL&agency=NorthStar