ADVANCED HOUSES PROGRAM
PROGRAMME DE MAISONS PERFORMANTES

Advanced Houses Technology Assessment Summary Report

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NOTE

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EXECUTIVE SUMMARY

The Advanced Houses Program sponsored by CANMET/NRCan has been the most ambitious and successful demonstration of energy-efficient and environmentally responsible housing undertaken to date, either in Canada or internationally. This technology assessment study was undertaken to identify and analyze the most promising technologies emerging from the Program and to determine appropriate next steps for the federal government.

More than 40 candidate technologies were submitted to a Preliminary Assessment, involving a first screening based on energy and environmental benefits and a second screening based on business potential. Based on the resultant rankings and on input from participants at an industry experts' meeting, the following nine technologies were selected for Detailed Assessments: integrated heating/ventilating gas appliance; direct-vent, condensing gas, combination space/DHW systems; wall-mounted direct-vent gas water heater; advanced oil heating; small diameter, high velocity ducting; high performance motor/fan sets; energy-efficient windows; engineered wall framing; and exterior air barriers.

The Detailed Assessments involved modelling the incremental energy and environmental benefits in a variety of house types, fuels and regions; a costing analysis; an estimate of market penetration to the year 2020; the calculation of potential annual energy and greenhouse gas reductions; an analysis of market readiness and obstacles to adoption; and the identification of recommended action for accelerated commercialization.

The results indicate that by the year 2020, these nine technologies can significantly reduce national annual energy consumption by 214 PJ and greenhouse gas emissions by almost 9 Mt in new and existing housing (see table). These realistically achievable energy savings represent 15-19% of the projected total energy consumption in the low-rise housing sector in 2020.

These estimates are for the low-rise housing sector only. Many of the technologies also have applications in the high-rise residential and commercial sectors, increasing the overall potential savings. In addition, considerable export opportunities have been identified for most of these technologies.

Year	Annual Energy Savings (petajoules)	Annual CO_2 Reduction (kt)	Annual CH_4 Reduction (tonnes)	Annual N_2O Reduction (tonnes)
2000	14.5	673	17	48
2020	213.6	8,754	211	530

Potential Annual Savings From the Nine Most Promising Technologies

Energy-efficient windows offer by far the greatest potential energy savings and greenhouse gas reductions (104 PJ and 5.3 Mt of CO_2 annually by 2020), particularly due to their applicability to the existing stock. Advanced gas-fired mechanical systems represent the second most significant opportunity (68 PJ, 1.6 Mt). Together, high performance windows and advanced gas-fired mechanical systems represent more than three quarters of the total potential savings. Exterior air barriers (27 PJ, 1.4 Mt) offer substantial national potential. Efficient motor/fan sets (8 PJ, 393 kt) may justify mandatory minimum efficiency standards. Advanced oil heating (5 PJ, 33 kt) addresses a niche market. Other technologies contribute less energy savings but offer other benefits: engineered wall framing (1 PJ, 56 kt) conserves resources and small diameter, high velocity ducts facilitate cost-effective retrofits and fuel-switching.

These potential energy savings, greenhouse gas reductions and related business opportunities are only possible if accelerated market adoption is supported. It is therefore recommended that CANMET act as a catalyst with other stakeholders, immediately developing action plans and organizing government/industry dialogue groups to identify and remove barriers to adoption. Priority should be given to energy-efficient windows and advanced gas-fired mechanical systems.

Specific support activities have been recommended for each technology. These include undertaking joint R&D with manufacturers, assisting in overcoming regulatory barriers, linking manufacturers to export opportunities, integrating technologies with retrofit initiatives, promoting labelling programs and in some cases finding a Canadian manufacturer. In addition, the study makes several recommendations for increased information dissemination of the Advanced House technologies by CANMET.

RÉSUMÉ

Le Programme de la Maison performante, parrainé par CANMET de RNCan, s'est avéré la plus ambitieuse et la plus réussie des démonstrations d'efficacité énergétique et de responsabilité environnementale dans le domaine de l'habitation jamais entreprise jusqu'à maintenant, et ce tant à l'échelle nationale qu'internationale. La présente étude d'évaluation technologique a été réalisée dans le but de déterminer et d'analyser quelles sont les techniques les plus prometteuses du Programme de la Maison performante, ainsi que de préciser les prochaines mesures à prendre pour le gouvernement fédéral.

Plus de 40 techniques ont été présentées à l'évaluation préliminaire qui comprenait une première sélection fondée sur les avantages énergétiques et environnementales, de même qu'une deuxième sélection s'appuyant sur les possibilités commerciales. En se basant sur la classification des techniques ainsi obtenue et sur les renseignements fournis par les participants à une réunion des experts de l'industrie, on en est arrivé à une sélection de neuf techniques qui ont été soumises à une évaluation détaillée. Ces techniques se décrivent ainsi : appareil combiné de chauffage et de ventilation au gaz naturel; systèmes d'évent direct, de gaz de condensation et d'une combinaison espace-eau chaude domestique; chauffe-eau au gaz naturel à évent direct installé au mur; chauffage de pointe au mazout; système de conduits à petit diamètre et à grande vitesse; ensembles moteur-ventilateur à haut rendement; fenêtres à grande efficacité énergétique; charpentes de murs ouvrées; pare-vent.

Les évaluations détaillées prévoyaient la modélisation de l'énergie supplémentaire et des avantages environnementaux en ce qui a trait à divers genres d'habitations, de combustibles et de régions; une analyse des coûts; une estimation de la pénétration des marchés d'ici l'an 2020; le calcul des diminutions éventuelles chaque année de la consommation énergétique et des gaz à effet de serre; les dispositions et les obstacles des marchés à accueillir les techniques en question; l'examen des mesures recommandées pour en accélérer la commercialisation.

Selon les résultats obtenus, les neuf techniques retenues sont aptes, d'ici l'an 2020, à réduire substantiellement la consommation énergétique annuelle à l'échelle nationale de 214 PJ, et les émissions de gaz à effet de serre de près de 9 Mt, dans le habitations neuves et existantes (se référer au tableau). Ces objectifs d'économies d'énergie, qui sont réalisables, représentent de 15 à 19 % de la consommation énergétique totale que l'on prévoit dans le cas du secteur de l'habitation à faible hauteur en l'an 2020.

Les estimations qui suivent ne touchent que le secteur de l'habitation à faible hauteur. Un grand nombre de techniques pourraient également s'appliquer dans les secteurs résidentiel et commercial des habitations à grande hauteur, ce qui accroîtrait les possibilités d'économies globales. De surcroît, on a déterminé l'existence d'énormes débouchés d'exportation pour la plus grande partie de ces techniques.

Année	Économies annuelles d'énergie (pétajoules)	Réductions annuelles de CO_2 (kt)	Réductions annuelles de CH_4 (tonnes)	Réductions annuelles de N_2O (tonnes)
2000	14.4	673	17	48
2020	213.6	8,754	211	530

Économies annuelles possibles grâce aux neuf techniques les plus prometteuses

Sans aucun doute, les fenêtres à grande efficacité énergétique présentent les meilleures possibilités d'économies d'énergie et de réductions de gaz à effet de serre (avec 104 PJ et 5,3 Mt de CO_2 annuellement d'ici l'an 2020), en particulier si on les applique dans le cas des stocks actuels. Les systèmes mécaniques de pointe alimentés au gaz naturel constituent les deuxièmes meilleurs instruments d'économies (avec 68 PJ et 1,6 Mt). Ces deux dispositifs combinés permettent plus du trois quarts des économies totales possibles. Les pare-vent offrent, quant eux, des possibilités importantes d'économies sur le territoire canadien (avec 27 PJ et 1,4 Mt). Les ensembles moteur-ventilateur à haut rendement (avec 8 PJ et 393 kt) pourraient justifier l'élaboration de normes minimums d'efficacité obligatoires. Le chauffage de pointe au mazout (avec 5 PJ et 33 kt) relève d'un marché à créneaux. Bien que les autres techniques permettent moins d'économies d'énergie, elles offrent néanmoins d'autres avantages : les charpentes de murs ouvrées (avec 1 PJ et 56 kt) contribuent à économiser les ressources, alors que les systèmes de conduits à petit diamètre et à grande vitesse facilitent la modernisation et l'adaptation à de nouveaux combustibles d'une manière rentable.

La possibilité de ces économies d'énergie, de ces réductions de gaz à effet de serre et de ces occasions d'affaires ne pourra se réaliser que si l'on appuie l'adoption accélérée de ces techniques sur les marchés. Il est, par conséquent, recommandé que CANMET agisse en tant que catalyseur pour, de concert avec les autres parties intéressées, élaborer sans tarder des plans d'action et organiser des groupes de discussions entre le gouvernement et le secteur industriel afin de déterminer et d'éliminer les entraves qui empêchent l'adoption de ces techniques. Il faudrait accorder la priorité aux fenêtres à grande efficacité énergétique et aux systèmes mécaniques de pointe alimentés au gaz naturel.

On a fait des recommandations relativement à des activités de soutien dans le cas de chaque technique. Parmi celles-ci, mentionnons la réalisation de travaux de recherche-développement en collaboration avec les fabricants, l'aide en vue d'éliminer les barrières réglementaires, l'établissement de liens avec les fabricants pour l'exportation des possibilités, le regroupement des techniques avec les activités de modernisation, la promotion de programmes d'étiquetage et, dans certains cas, la recherche d'un fabricant canadien. En outre, l'étude contient plusieurs recommandations visant à élargir la diffusion par CANMET des renseignements concernant les techniques de la Maison performante.

Advanced House Technologies Assessment
Summary Report

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1. Introduction

The Advanced Houses Program has been the most ambitious and successful demonstration of energy-efficient and environmentally responsible housing undertaken to date, either in Canada or internationally. Characterized by an unprecedented level of industry participation and leveraged financing, the Program fostered the development of numerous innovative technologies which have the potential to drastically reduce energy consumption and greenhouse gas emissions from the housing sector, while creating the opportunity for domestic and export business growth.

This assessment of Advanced House technologies was commissioned by CANMET/NRCan, with funding from the Panel for Energy Research and Development (PERD), in order to identify the most promising technologies (according to CANMET priorities) emerging from the Program and to determine appropriate action by the federal government to capitalize on the opportunities presented.

Scanada Consultants Ltd. of Ottawa undertook the study, with a team consisting of Kevin Lee, Anil Parekh, Terry Robinson and Bob Platts. Tim Mayo served as CANMET's project manager, with Mark Riley, Robin Sinha and Tom Hamlin also providing input.

This document, "Summary Report: Advanced House Technologies Assessment", highlights the study's findings and contains the conclusions and recommendations. It is intended for broad distribution within the Canadian housing industry and the federal government.

More detailed information on the assessment methodology and the results of the assessments can be found in a separately published report, "Supporting Documentation: Advanced House Technologies Assessment".

This introductory section provides an overview of the Advanced Houses Program, describes the objectives of the study and outlines the importance of the study's results to the Canadian housing industry and the federal government.

1.1 Canada's Advanced Houses Program

The Advanced Houses Program was a joint government/industry venture to demonstrate new levels of energy efficiency and environmental performance through innovative technologies. The Program was the first initiative taken by Energy, Mines and Resources Canada — now Natural Resources Canada (NRCan) — under the federal government's Green Plan.

The goals of the Advanced Houses Program were to fast-track the development and adoption of "green" technologies; to maintain Canada's international leadership in energy-efficient, environmentally-responsible housing; and to field test the industry's ability to meet a set of performance requirements which could feed back into the R-2000 Program.

The technical requirements were performance-based, building on the successful experience of the R-2000 Program, in order to encourage innovative and cost-effective responses from industry. Three areas were included: total purchased energy, environmental features and indoor health and comfort. The energy target was set at 50% of the R-2000 target, or roughly 52 kWh/m^2, and addressed all energy uses in the home. Environmental requirements addressed water consumption, CFCs, construction waste management, and the use of Ecologo and recycled products. Indoor environmental requirements addressed ventilation, indoor pollutant concentrations, noise and humidity control.

The Program was announced in August 1991 and was initiated with a national industry challenge, launched in partnership with the Canadian Home Builders' Association. Submissions had to include technical proposals, additional financial support, marketing and monitoring plans, strong project management and a high degree of innovation. Over 30 entries were received in the first stage of the competition. A Selection Committee identified 14 to proceed to the second stage, with 12 being selected. Ultimately, ten demonstration houses were built in 1992-94:

BC Advanced House	Vancouver, BC
Saskatchewan Advanced House	Saskatoon, Saskatchewan
Manitoba Advanced House	Winnipeg, Manitoba
Waterloo Green Home	Waterloo, Ontario
NEAT Home	Hamilton, Ontario
Innova House	Ottawa, Ontario
Maison Novtec	Laval, Quebec
Maison Performante	Laval, Quebec
EnviroHome	Halifax, Nova Scotia
PEI Advanced House	near Charlottetown, PEI

The Advanced Houses remained open to the public for a one year period, after which they were sold and occupied. Monitoring is currently nearing completion, with preliminary results indicating that most of the projects met their targets.

Each demonstration was led by a multi-disciplinary team which channelled the creativity, in-kind contributions and funding from a diverse range of industry and institutional players. Over $6 million in leveraged contributions complemented federal funding of approximately $3 million.

The success of the Advanced Houses Program has been given prominence internationally, particularly at the Innovative Housing '93 Conference and through the IEA Task XIII — Advanced Solar Low Energy Buildings. Considerable media attention has been received, most notably from Popular Science magazine. The results of the Program led to an upgrading and expansion of the R-2000 technical requirements in 1994.

1.2 Objectives of the Technology Assessment Study

The Program's decentralized, partnership approach led to several dozens of prototypical and innovative products and systems being demonstrated. Some of these new technologies are already mature and are gaining market share; others need further technical, regulatory, marketing or financial assistance to become successfully commercialized.

With the demonstration phase of the Advanced Houses Program completed, the next task is to accelerate the commercialization and adoption of these innovative technologies in order to reap the potential economic and environmental benefits.

To initiate this task, the Advanced Houses Technology Assessment was undertaken with the following objectives:

- to document, screen, assess and rank (according to CANMET's priorities of energy and greenhouse gas reductions) the innovative technologies emerging from the Advanced Houses Program;
- to identify the most promising technologies and undertake detailed technology assessments; and
- to identify the type of support which could be provided by CANMET and other stakeholders to accelerate the commercialization of these technologies.

Outputs arising from this study include an assessment framework, a preliminary assessment of over 40 technologies, a detailed assessment of nine of the most promising technologies and a set of recommendations for key support activities by the federal government.

1.3 Importance of Innovative Technologies to the Canadian Housing Industry

The Canadian housing industry is characterized by a great number of small manufacturers, suppliers, builders, subcontractors and related professionals. This fragmented structure, when compared to other sectors, such as the telecommunications or transportation industries, is both a strength and a weakness. On the one hand, this structure has enabled the housing industry to survive fluctuating demand cycles while producing a very cost-effective and regionally diverse product. On the other, individual industry players lack the concentration of financial and technical resources to undertake sustained R&D.

Partnership approaches to technology innovation therefore take on great importance. Joint industry/government initiatives, exemplified by CANMET's Advanced Houses Program, bring together diverse disciplines and spur the development and integration of new concepts, products and systems.

Such innovation is vital to the continued success of Canada's housing industry. This sector is one of the country's largest employers, yet is neither "high-tech" nor attracting highly educated workers — in other words, it is an industry which is potentially vulnerable to change from forces beyond its control. Innovation allows the housing industry to exploit new opportunities, to respond effectively to regulatory change, and to better compete during economically leaner times.

Federal government action to support the commercialization of energy-efficient and environmental innovations emerging from the Advanced Houses Program will produce the following specific benefits:

Meeting greenhouse gas targets: With Canada forecast to exceed — by 12% — our target of freezing greenhouse gas (GHG) emissions at 1990 levels by the year 2000, the availability of new energy-efficient technologies will facilitate significant reductions in the 20% of Canada's energy currently consumed by the housing sector.

Reduced resource dependency: Innovative technologies will reduce the intensive resource usage of low-rise housing, making the Canadian housing industry more sustainable.

Export opportunities: Building on Canada's reputation as a world-leader in cold-climate housing, new technologies will shift the focus of exports from raw resources to value-added products and will find markets in the northern U.S., Western Europe, Eastern Europe, Russia and the Far East.

Job creation: The introduction of new technologies to the housing market, the expansion of export markets and the replacement of resource-intensive technologies with value-added ones will create long-term employment in the manufacturing, distribution and building supply sectors.

Mainstream and retrofit application: While many of the technologies employed in the Advanced Houses were initially developed for leading-edge housing, a great number will find widespread application in conventional new housing and some will be applicable to the existing stock, thereby making retrofits more effective or affordable. These impacts, over time, will be very significant.

Affordable higher performance: Innovation leads to higher levels of energy and environmental performance at similar or lower costs, thereby making energy-efficient new homes affordable to a greater percentage of prospective homebuyers.

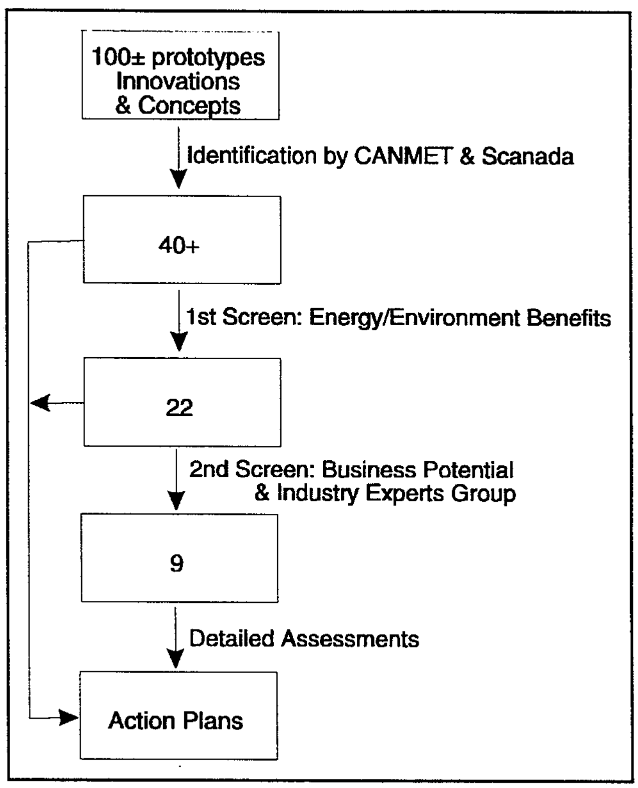
2. The Assessment Framework

The study's first task was to develop a defensible assessment framework in order to rank and analyze innovative technologies. This section summarizes the assessment procedures. A more detailed description is provided in Appendix A of "Supporting Documentation: Advanced House Technologies Assessment".

2.1 Overview of the Assessment Process

The assessment process consisted of the following steps:

- identification of more than 40 candidate technologies, in consultation with CANMET staff;
- Preliminary Assessments, involving a first screening based on energy and environmental benefits and a second screening based on business potential, to identify the most promising technologies;
- the holding of an experts' meeting to review the results of the Preliminary Assessments and assist in the final selection;
- Detailed Assessments of the nine most promising technologies to determine their potential impact.



2.2 Preliminary Assessments

Ideally, all candidate technologies should be subjected to a detailed assessment. However, since there were a great many innovative technologies emerging from the Advanced Houses Program, this was not financially feasible. Preliminary Assessments therefore provided a screening mechanism to assist in identifying the most promising technologies for detailed assessments. The Preliminary Assessments contained many of the elements of a detailed assessment, but by necessity were restricted to less comprehensive modelling. In order to facilitate ranking, numerical scores were developed, although it is recognized that no simple scoring system can accurately reflect the complexities of the housing industry.

1st Screening — Energy/Environment Benefits

CANMET requested that the first screening determine whether a technology had the potential for sufficient energy or environmental benefits to justify CANMET's interest within their Green Plan mandate.

Approach
The assessment of energy/environment benefits considered the impact of the technology in affecting energy consumption, greenhouse gas (GHG) emissions and other environmental performance in a typical new home and in a representative retrofit. Energy/Environment Benefit (EEB) points were awarded to rank and compare the technologies.

Energy/Environment Benefits =
Energy/GHG Benefits + Indoor Environment Benefits
+ Water/Resource Conservation + Other Benefits

Energy/GHG Benefits
At the Preliminary Assessment stage, reductions in energy consumption were taken as a surrogate for reductions in greenhouse gas and acid rain emissions (more comprehensive modelling of GHG emissions by region and fuel type were undertaken in the detailed assessments). Candidate technologies were assessed quantitatively on a scale from 0 to 10 EEB points, according to their potential impact on total house energy consumption. Percentage reductions were based on average energy use in representative new and existing homes, with 10 EEB points defined as a 20% savings in total energy consumption per house. It was possible for some technologies to score higher than 10.

The representative new home was defined as a conventional new home built to the current Ontario Building Code. For retrofit applications, candidate technologies were compared to conventional retrofits and replacements, which were usually assumed to be equivalent to conventional new technologies, with modelling undertaken on a representative 1950s home. In most cases, the EEB score was based on the new housing score. Ottawa was selected as the location for the preliminary assessment modelling, since its climate is close to the national average. Modelling was undertaken using HOT2000 version 7.

Environmental Benefits
Indoor environment improvements and water/resource conservation were each assessed on a scale of 0 to 5 EEB points.

Indoor Environment: Technologies improving the indoor environment through ventilation, air cleaning or source control were assessed subjectively, with the maximum score defined as the virtual elimination of a significant contaminant. Considerations included emission rates, amounts of materials involved, associated health risks and length/frequency of exposure.

Water/Resource Conservation: Technologies easing the burden on water supply, wastewater treatment, landfill waste or natural resources were also assessed subjectively with the maximum score defined as a substantial reduction (i.e. 50%) in a significant resource usage.

Other Benefits
Other energy/environment benefits not falling under one of the categories outlined above, such as peak electrical load reduction, fuel switching opportunities, embodied energy (the energy associated with the extraction, production, transportation and installation of a material) or outdoor pollutant reductions, were assessed subjectively, with a maximum of 2 "bonus points" awarded.

Weighting
Since it is unlikely that a technology could offer benefits in both the indoor environment and resource conservation areas, the ratio of energy/GHG benefits to other environmental benefits is approximately 2:1 in this analysis. This reflects the importance placed on greenhouse gas reductions by CANMET and the Green Plan. Note that other agencies undertaking such assessments might have a very different set of priorities and would therefore need to select different weightings.

2nd Screen — Business Potential

The purpose of the second screening was to determine whether sufficient market potential exists for the technology to be economically viable, and whether the technology is at an appropriate stage of development where federal assistance would be beneficial.

Approach
The leading technologies emerging from the energy/environment screening were assigned a Business Potential Score which took into consideration the benefit/incremental cost ratio and the

size of the potential market segment. Less quantifiable factors, such as consumer and industry acceptance and market readiness were assessed subjectively.

Business Potential Score

Combining the Market Advantage (benefit/incremental cost ratio) and Market Segment Size, the Business Potential Score (BPS) represents a first estimation of a technology's potential for success in the Canadian market. Caution is urged when using such numerical scores, since they do not reflect the complexity of marketplace factors.

Business Potential Score =
Market Advantage (benefit/incremental cost ratio) × *Market Segment Size*

Market Advantage

The Market Advantage was defined as the benefit/incremental cost ratio, which provides a preliminary indication of the value of the technology, both to consumers and builders.

Benefits: The quantitative assessment of benefits was limited to the energy/environment benefits (EEBs) calculated in the first screening. Qualitative comments were also provided for consumer acceptance (lifestyle, health, comfort and perceived resale value) and industry acceptance (functionality and marketability).

Incremental Cost: The incremental cost over conventional technologies was determined from various sources or were estimated for prototype technologies. Where an innovative technology represents a new way of construction, the incremental cost had to consider the entire system, with some materials being added and others deleted. For retrofit situations, the incremental cost was calculated in comparison with a conventional retrofit or replacement. For technologies that cost the same or less than conventional practices, an incremental cost of $1 was assigned. This approach tended to polarize the assessments, making ranking easier but exagerating the differences among technologies, particularly where small or negligible incremental costs were involved.

Market Segment

The Market Segment Size was defined as the boundaries of the market to which a particular technology could be applied, representing an estimate of the upper limit of the potential annual market rather than the expected market penetration. In order to add new and retrofit applications, the existing stock annual market segment was expressed as equivalent annual housing starts. At the Preliminary Assessment stage, only a qualitative evaluation of the export potential opportunities was provided.

New Housing Market Segment: The size of the new housing market was taken as the average level of new low-rise housing starts annually over the past five years — approximately 125,000. Technologies which could be applied in all new houses were assigned this maximum market size, while those which are only applicable to certain fuel types or price ranges were assigned proportionately smaller market sizes.

Retrofit Market Segment: The size of the annual retrofit market was determined by the current volume of retrofit, replacement or related activity. For example, retrofitting an exterior air barrier could be undertaken in association with a siding replacement. Technologies which are generally not applicable in retrofits could still have a market in additions.

Market Readiness
Each technology was also categorized in terms of its market readiness, considering Canadian content, current status and level of success, whether there existed a natural "champion" (i.e. an owner or sponsor), and whether the technology was a marketable product or system rather than simply a good idea or concept. An initial identification was made of needs and barriers (e.g. technical, regulatory, marketing and financial) affecting commercialization. For those technologies which were not selected for the Detailed Assessment stage, some general recommendations were made for action by CANMET and other stakeholders to assist in accelerating commercialization.

Experts' Meeting

In recognition of the limitations inherent in any assessment system used to rank technologies, an Experts' Meeting was convened to review the results of the preliminary assessments and provide additional input to the selection process. Participants also completed a "ballot" with their recommendations for the most promising technologies.

2.3 Detailed Assessments

The purpose of the Detailed Assessment stage was to provide a comprehensive technical and market assessment of the most promising technologies and to formulate recommendations for action by CANMET and other stakeholders to accelerate commercialization.

Description
The basic characteristics of each technology were described, along with applications and advantages. Options for modifying the technology or integrating it with other technologies were explored. Key development issues were identified. Similar products available on the market were also identified and described

Energy and Environmental Performance
Where possible, actual field performance was verified and any installation or operation problems

were noted. Incremental energy savings on a per house basis were modelled — using HOT-2000 version 7 — on housing types representative of five construction periods, in five climate regions with two or three fuel types per region, for a total of 70 variations.

Costing Analysis/Market Potential
A costing analysis identified incremental costs, possible options for reducing such increments, pricing issues, installation and servicing costs, and factors impacting future costs and prices. An expected range of market penetration was estimated over five year incremental time periods from 1995 to 2020. The overall period of 25 years was chosen as a typical time frame within which new technologies mature in the Canadian housing market. Market penetration estimates were based on the study team's understanding of Canadian housing markets and assumed a reasonable level of R&D support, technology transfer and promotion by the federal government and other stakeholders. Applications in other sectors, such as apartment and commercial buildings, were noted but no attempt was made to quantify these other markets. Export opportunities were identified.

National Energy/GHG and Environmental Benefits
Based on the incremental energy savings by house type/region/fuel type and the estimated market penetration, the potential annual energy and greenhouse gas reductions in the low-rise housing stock were roughly estimated. Other environmental benefits were also documented for the stock. A detailed description of the modelling and projections is given in Appendix E of "Supporting Documentation: Advanced House Technologies Assessments".

Current Status and Barriers to Adoption
The current status of each technology's development and its market readiness were assessed, with sales levels noted and "success stories" documented. The need for a Canadian "champion" was examined. The barriers preventing innovative technologies from achieving their market potential were identified and characterized, including technical performance, regulatory barriers, infrastructure barriers, consumer acceptance/resistance and builder acceptance/resistance.

Recommended Action
Recommendations for accelerated commercialization were made, including key support activities which could be undertaken by CANMET and other stakeholders to assist the technology in overcoming any barriers to adoption.

3. Results of the Preliminary Assessments

Once the assessment framework had been approved by CANMET, Preliminary Assessments were undertaken on candidate technologies, using the two screening processes — energy/environmental benefits and business potential — described earlier. This section describes the general results of that screening. Further details and summary assessments for each of the various technologies examined can be found in Appendices B and C of "Supporting Documentation: Advanced House Technologies Assessment".

3.1 Energy/Environment Screening

Over 40 technologies were analyzed for their potential energy and environmental benefits. In consultation with CANMET staff, those technologies with high or moderate rankings — 22 in total — were selected for the next phase of screening.

The highest Energy/Environment Benefit (EEB) scores were achieved by integrated and advanced mechanical systems, reflecting the large potential for improvement which still exists over conventional practice. A variety of technologies, spanning building envelopes, HVAC components, appliances, home automation, renewables and innovative materials, were assigned high or moderate scores due to their significant energy and/or environmental impacts. Since CANMET had directed that the assessment be weighted toward energy and greenhouse gas reduction, environmental technologies which had little or no energy impact, such as recycled materials, or which addressed minor energy end uses, such as residential lighting, tended to have lower scores. The results of the Energy/Environment Benefits screening are summarized in Table 1. The original assessment sheets are included in Appendix C of "Supporting Documentation: Advanced House Technologies Assessment".

3.2 Business Potential Screening

In the second phase of the Preliminary Assessment, 22 technologies were analyzed for their business potential and categorized in terms of their market readiness.

The highest Business Potential Scores (BPS) were achieved by technologies which had equal or lower costs in comparison with existing technologies, while offering significant energy and environmental benefits. High rankings were associated with technologies which combined high energy/environmental benefits, reasonable incremental costs and broad market applicability. Technologies which had higher incremental costs or limited market segments tended to receive moderate rankings, while those characterized by both high incremental costs and limited markets obtained lower rankings. The results of the Business Potential screening are summarized in Table 2. The original assessment sheets are included in Appendix C of "Supporting Documentation: Advanced House Technologies Assessment".

Energy/Environment Ranking	Technology	
Very High	Ground source heat pump with integrated heat recovery ventilator Direct vent, condensing gas combination space and water heater Mid-efficiency gas furnace with integrated HRV Advanced oil heating/hot water with thermal storage	
High	Insulating exterior air barrier Home automation High mass masonry heater (1) Water-efficient fixtures package Engineered wall framing Triple-glazed high performance windows Double-glazed high performance windows Direct-vent gas range Demand-controlled ventilation (2) Poured-in-place CFC-free foam insulation Solar hot water pre-heating Solar hot water heater with direct-vent gas heater backup (3) Small diameter, high-velocity ducts Cellulose insulation	
Moderate	Sandwich foundation system EASE/laminated fibreboard exterior air barrier Cementitious roof tiles Low-emission cabinetry	
Low	Recycled rubber pavers PET recycled carpeting Recycled metal roofing Cellulose drywall Low-emission paints Concrete waffle panel foundation Alternative sewage treatment High-efficiency lighting	Water-efficient clothes washer Crushed glass drainage Cistern water storage Direct-vent gas clothes dryer PV-powered refrigerator Fibreglass batts with recycled glass Direct current motors (4) Electronically commut. motors (4)
Not scored	Wind turbine (5) Free cooling (6)	"Smartened" appliances (7)

Table 1. Results of Energy/Environment Screening

Notes:
1. The high ranking for the high mass masonry heater was based on its use as the primary heating system. Further assessment was based on its use as a secondary heating system, with a lower energy/environment ranking.
2. Demand-controlled ventilation was eventually evaluated in combination with home automation.
3. The gas back-up water heater for the solar system eventually emerged as a component worth further study as a primary stand-alone system (i.e. no solar component).
4. Higher efficiency motors were initially ranked low, since HOT-2000 only provides a credit of 300 kWh in annual energy reduction. Combining high efficiency motors with improved fans represents a significant breakthrough and eventually emerged — after the Experts' Meeting and discussions with CANMET — as one of the nine technologies meriting a Detailed Assessment.
5. No performance data was available for the wind turbine.
6. Free cooling was regarded as a concept rather than a marketable product.
7. "Smartened" appliances were evaluated as part of home automation systems.

Business Potential Ranking	Technology
Very High	Cementitious roof tiles (1) Low-emission cabinetry (2) Cellulose wall insulation (3) Sandwich foundation system Laminated fibreboard exterior air barrier
High	Small diameter, high velocity ducts (2) Water-efficient fixtures package Direct-vent, condensing gas combination space and water heater Mid-efficiency gas furnace with integrated HRV (4) Double-glazed high performance windows Insulating exterior air barrier (2) Direct-vent gas range Solar hot water heater with direct-vent gas heater backup (5)
Moderate	Poured-in-place CFC-free foam insulation Solar hot water pre-heating Advanced oil heating/hot water with thermal storage Sandwiched house wrap exterior air barrier (6) Engineered wall framing Triple-glazed high performance windows
Low	Home automation/demand-controlled ventilation Ground source heat pump with integrated HRV High mass masonry heater

Table 2. Results of Business Potential Screening

Notes:
1. Users have cited high installation costs, which would lower the ranking.
2. Users claim higher product costs than claimed by manufacturers, which would lower the ranking.
3. Varying opinions on incremental costs in comparison with fibreglass batts.
4. Actual field efficiencies not as high as originally claimed, which would lower the ranking.
5. The gas heater back-up for the solar hot water system eventually emerged as the component worth further study as a primary stand-alone water heater.
6. Evaluated in the energy/environment screening phase as part of EASE/laminated fibreboard exterior air barrier.

3.3 Experts' Meeting and Final Selection

Participants at the Experts' Meeting provided valuable input in challenging some of the assumptions made, particularly regarding incremental costs, field performance and market readiness, and this input was subsequently used by the study team to modify the selection of the most promising technologies. A consensus emerged that the subsequent Detailed Assessments should be undertaken more generically, going beyond the specific applications in the Advanced Houses.

Based on the ballots cast at the Experts' Meeting, written comments received from those who could not attend, the consultants' recommendations and input from CANMET staff, the following nine generic technologies were selected for detailed assessments:

Integrated heating/ventilating gas appliance
Direct-vent, condensing gas, combination space/DHW systems
Wall-mounted direct-vent gas water heater
Advanced oil heating/hot water system
Small diameter, high velocity ducting
High performance motor/fan sets
High performance windows (both double and triple glazed)
Engineered wall framing
Exterior air barriers (several systems)

3.4 Observations on the Use and Limitations of the Assessment Framework

The following observations relate to the development and implementation of the assessment framework for screening and evaluating innovative energy and environmental technologies.

1. **The screening process developed for this study proved to be useful in ranking a broad range of technologies and in identifying the most promising.**
   The Preliminary Assessments provided an initial ranking of technologies, which — despite the weaknesses inherent in any numerical system — was able to reflect client priorities, served to focus input from experts and assisted greatly in the final identification of promising technologies.

2. **Assessing energy impacts on a typical house provides a powerful screen.**
   Basing the first stage screening — the evaluation of energy/environmental benefits — on the percentage of energy reduction or environmental impact achievable in a typical new or retrofitted house effectively favoured those technologies which had the greatest potential impact.

3. **Assessing business potential may require a more qualitative approach.**
   The method used for the second stage of the Preliminary Assessment screening — the evaluation of business potential — tended to polarize the assessments excessively, since it was based on a benefit/cost ratio multiplied by the maximum annual market size. Where incremental costs were low or negligible, the business potential score became very large. A more qualitative assessment of market advantage may be a more realistic approach as a Preliminary Assessment.

4. The limitations of any screening process need to be well understood.
Even the most sophisticated assessment framework cannot match the real-world complexities of the housing industry and therefore the results of this study's Preliminary Assessments should not be regarded as a final verdict on the potential success of these technologies in the marketplace. Since a large number of technologies had to be examined in a compressed time frame, many simplifications were made in the preliminary assessment stage in comparison with the detailed assessments undertaken later. Field performance data was not yet available for many of the new technologies. Some of the ratings, such as indoor environment impacts, could only be assigned subjectively. The benefit/cost ratio was based only on energy/environment benefits and on rough estimates of incremental costs. Market segment boundaries were used as a surrogate for expected market penetration rates. Aspects such as consumer and builder acceptance, market readiness and potential obstacles could only be given a cursory qualitative examination. It should also be noted that there were a great many innovative technologies used in the Advanced Houses which for various reasons were not selected by CANMET and the consultant for assessment, but which may be worthy of further development.

3.5 Observations on Technology Opportunities

Based on this study's Preliminary Assessments of Advanced House technologies, the following general observations can be made regarding current and future technology opportunities. The most promising technologies selected for Detailed Assessments mostly fall within the categories of mechanical systems and building envelopes. Opportunities also exist in other areas, such as the indoor environment, eco-management and electrical end-uses.

Mechanical Systems: There is a large potential for improvement over conventional heating, cooling, hot water and ventilation systems, both in new housing and in retrofit/replacement situations. Higher efficiency equipment is now available for all fuel types, including oil and electricity. Anything other than sealed or power-vented appliances is incompatible with an energy-efficient, airtight envelope. Opportunities include:

- Integrated components to take advantage of system efficiencies and to better incorporate heat recovery and renewables;
- Mechanical systems based on ventilation needs rather than heating, particularly in low energy housing;
- Efficient delivery systems (i.e. fans and pumps) to complement efficient generation;
- Systems which take up less floor space, especially for export markets.

Building Envelope Systems: Building envelopes are quite well evolved in Canada, with the exception of foundations. High performance windows offer the single most important break-through in house energy performance, while most other innovations represent incremental improvements. Opportunities include:

- Multiple glazing strategies which avoid extra frame or wall thickness;
- Products which eliminate or reduce thermal bridging;
- Cost-effective methods of achieving airtightness;
- Alternatives to large dimension lumber;
- Integrating functional elements, such as air barriers and insulation, into a single product;
- Innovations in foundation systems.

Indoor Environment: Consumers are increasingly interested in healthy indoor environments. Opportunities include:
- Low-emission materials and equipment, accompanied by a comprehensive source control strategy and the availability of actual emissions data;
- Demand-driven ventilation, optimized to be delivered when and where it is needed in order to reduce the energy penalty.

Environmental Technologies/Eco-Management: There has been a recent explosion of environmental technologies in response to the landfill crisis, costs of wastewater treatment and concern over resource depletion. Opportunities include:
- Expanding housing applications for the large number and variety of innovative new building products incorporating waste or recycled materials, accompanied by greater availability of performance and cost data;
- Marketing and/or mandating water conservation, which is now a mature technology.

Electrical End Uses and Home Automation Systems: The absolute energy savings associated with these technologies are generally modest, but high electrical costs and peak demand are major issues in many regions. Some technologies, such as lighting, are quite mature, while others, such as home automation, are just beginning to tap into future potential capability. Opportunities include:
- Importance of parasitic losses and the need for more efficient fans and pumps;
- Addressing first-cost obstacles associated with more efficient equipment;
- Importance of real-time controls and home automation systems in influencing consumer behaviour and addressing time-of-day electrical rates.

4. Results of the Detailed Assessment

This section summarizes the results for the nine technologies studied. The full Detailed Assessments can be found in Appendix D in "Supporting Documentation: Advanced House Technologies Assessment".

Based on realistic estimates of market penetration and assuming a reasonable level of support by CANMET and other stakeholders to promote commercialization, it is predicted that these nine technologies will reduce national annual energy consumption by 214 PJ by the year 2020.

The projected energy savings for individual technologies are shown in Table 3.

Technology	**Annual Projected Energy Savings (PJ)**	
	By 2000	**By 2020**
High-performance windows	9.6	104.2
Integrated heating/ventilating appliance*	0.4	27.5
Exterior air barriers	1.8	27.3
Direct-vent, condensing, combination space/hot water heater*	1.3	20.9
Direct-vent, wall-mounted high-efficiency gas water heater*	1.2	19.6
High efficiency fans/motors	0.2	8.1
Advanced oil heating	---	4.9
Engineered wall framing	---	1.1
Small diameter, high velocity ducting**	---	---
TOTAL	14.5	213.6

Table 3. Projected Annual Energy Savings for the Most Promising Technologies

Notes: * These three gas systems were assumed to compete with one another for shares of the market. If one were to dominate the gas market, its contribution to national energy savings would be much higher than shown here. Under the assumptions of this study, the three gas technologies combine for a total savings by the year 2020 of 68 PJ.

** Small diameter, high velocity ducts do not contribute to energy savings. This technology was selected due to its potential to facilitate cost-effective retrofits and fuel-switching, thereby leading indirectly to greenhouse gas reductions in areas where peak electricity is thermally generated.

Current energy consumption in the low-rise housing sector is approximately 1112 PJ per year. Based on the growth rates used in this study, and assuming no further regulatory requirements beyond the 1995 National Energy Code for Houses and no further improvements to the existing stock, annual consumption would be 1395 PJ by the year 2020. NRCan's projections ("Canada's Energy Outlook 1992-2020: Update 1994") suggest a lower consumption rate of 1120 PJ by 2020, based on more stringent requirements for new houses and expectations that improvements to the existing stock will largely balance any increased demand due to growth between 1995 and 2020. Using these two estimates as upper and lower boundaries, then the projected energy savings of 214 PJ associated with these nine advanced technologies represent 15-19% of the estimated total energy consumption of the low-rise housing sector in 2020.

Note that the analysis for national savings of energy and greenhouse gas emissions is for low-rise residential construction only. Apartment buildings and other potential applications for the technologies are not included, thus estimates are conservative and may be well below the total potential savings that could be realized from accelerated deployment.

Furthermore, for gas technologies, propane applications offer an additional potential market but are not included in savings estimates. At present, the number of houses heated with propane is equal to approximately 1% of those heated with natural gas.

4.1 Energy Efficient Windows

Description

The most widely used technology in the Advanced Houses was the energy-efficient window. Of the technologies selected for Detailed Assessments, energy-efficient windows are projected to account for almost half (104 PJ) of the annual energy savings by the year 2020. All ten houses selected advanced window technologies along with passive solar design to meet their energy targets, using various combinations of multiple glazings, low-e coatings, inert-gas fills (argon or krypton), insulating spacers and low-conductivity frames. Combinations of fixed and hinged units were used, with windows ranging from double- to quadruple-glazed.

Status, Costs and Market Acceptance

Canadian manufacturers currently produce arguably the most energy-efficient commercially-available windows in the world. Windows used in the Advanced Houses have Energy Ratings (ERs) as high as 12 for fixed windows and 4 for hinged windows.

For the purposes of this study, two levels of energy-efficient windows were defined: high-performance windows, with double glazing, a low-e coating, argon fill and insulated spacers; and super-advanced windows, with triple glazing, low-e coatings, krypton fills, insulated spacers and a fibreglass frame. As mainstream construction practice now commonly makes use of improved performance windows, the incremental cost for moving from the industry-standard window to high-performance windows has been getting smaller. The move to super-advanced windows, however, still remains a significant jump in terms of capital costs.

While high-performance windows make inroads in new construction, the qualities that make super-advanced windows primarily a niche market technology in new construction contribute to their popularity in the retrofit market. Window replacement is one of the most important components of the housing retrofit market in Canada, with the repair and remodelling market for windows much larger than the market in new construction. The retrofit market tends to prefer high-quality window products and is less sensitive to cost than is new construction. In this market, windows are sold more on the basis of their thermal comfort, freedom of maintenance and aesthetics. There are remarkable economic opportunities in exploiting the use of energy-efficient windows in the housing retrofit market, probably greater than any other energy conserving measure at hand.

Builders and consumers are aware of the impact of energy-efficient windows on energy performance and reduced condensation, and even more conscious of the value placed on windows in housing sales. Improved window performance is therefore not difficult to sell, if incremental costs are minimized and performance can be guaranteed. However, while tests and standards are available to provide quality and performance assurance, there is currently a lack of widespread adoption in the industry of such guidelines. In order to accelerate the adoption of energy-efficient windows, a labelling program must be adopted universally.

Energy/Environmental Performance

The energy savings achievable from energy-efficient windows are not as high on a per house basis as those of some mechanical system upgrades, but their applicability to such a large market makes their potential contribution to national energy savings and greenhouse gas reduction almost as high as that of all of the rest of the technologies of this study combined.

Reduction in Energy Consumption Per House (space and DHW heating)				**Potential Annual National Energy Savings by Year 2020**	**Potential Annual Greenhouse Gas Emissions Reductions (CO_2 Equivalence)**
High-Performance Windows		**Super-Advanced Windows**			
New	**Retrofit**	**New**	**Retrofit**		
3.9%	10.1%	6.9%	12.2%	104.2 PJ	5348 kilotonnes

Table 4. Energy/Environmental Impact: Energy-Efficient Windows

The above projections are for the low-rise housing sector only. High-performance windows are also very applicable in the high-rise residential buildings, particularly in retrofits. Windows represent the greatest heat loss component in high-rise apartments, so the impacts of upgrading can be considerable. In the commercial sector, residential window technologies are generally not applicable in high-rise offices or other large buildings, but can be used in smaller niche markets (e.g. low-rise suburban offices and retail).

Recommendations

Stakeholders in the adoption of energy-efficient windows are numerous. All utilities looking to reduce peak loads and government agencies seeking energy consumption reductions will ultimately benefit from improved window performance. The Canadian Window and Door Manufacturers' Association (CWDMA) and the Siding and Window Dealers' Association of Canada (SAWDAC) represent the industry and are of course major stakeholders. Building officials would also benefit from adoption of standards and labels to facilitate their inspection operations. Given the tremendous energy and environmental benefits of increased energy-efficient-window deployment, CANMET should continue to work with stakeholders in the following ways:

1. Concentrate on gaining full adoption of CSA-A440.2 energy ratings in industry.
2. Continue technical support in areas such as analysis software development and performance test methods.
3. Explore cost reduction possibilities, such as use of lower grade krypton.
4. Encourage research in high-transmission low-e coatings, which would increase the energy benefits of moving from double to triple glazing.
5. Encourage energy-efficient specialty window products, as currently there is a lack of energy-efficient patio doors and skylights.
6. Disseminate information on energy ratings and the advantages of specific high performance technologies to the public. Promote health benefits of preventing mould growth through reduced condensation.
7. Link manufacturers to export opportunities.

4.2 Integrated Heating/Ventilating Gas Appliance

Description

The prototypical integrated heating/ventilating appliance (IHVA) used in the Waterloo Green Home was developed at the Canadian Gas Research Institute (CGRI). Three objectives guided CGRI in the development of the IHVA: to provide heating and mechanical ventilation with energy recovery in one highly efficient, compact and integrated unit; to eliminate problems such as defrost requirements to avoid icing of the heat recovery ventilator (HRV); to make the unit technically and economically attractive for both highly energy-efficient and conventional housing. The result is a mid-efficiency natural gas furnace with an integrated HRV that recovers heat from flue gases and exhaust air using a dual compartment regenerative rock bed.

Status, Costs and Market Acceptance

An example of a "success story" in the Advanced Houses Program, the IHVA was a concept in the lab when the program began, and the Green Home project provided a testing ground and promotional venue for this new technology. Further generations of the product are now being tested in the field and is near commercialization (it is expected to be available in 1996).

The integrated approach is an attractive alternative to using separate furnace and HRV units, and to two individual field installations and connection procedures. CGRI expects that the IHVA will provide lower capital and installation costs than the two separate components that it replaces.

Issues affecting adoption are primarily technical, as performance of the prototype system was below expectations and concern over purging of combustion products has been raised. If and when these are overcome, the advantages of the system should give the IHVA broad market appeal.

Energy/Environmental Performance

While the prototype unit installed in the Green Home achieved a lower efficiency than desired, a second generation prototype showed improved performance and CGRI anticipates that the final product should achieve a combined efficiency equal to or greater than the original estimates of 85 percent. Comparing this to separate units, HRV efficiency ranges from 60 to 85% and gas furnace efficiency ranges from 78 to 94%, so their combined efficiency would be 47 to 80%. The resultant energy/environmental impacts are shown in the table above, which assumes that the market is shared with the other gas technologies assessed in this study. Should the IHVA come to dominate the market, national energy and greenhouse-gas savings would be much higher.

Reduction in Energy Consumption Per House (space and DHW heating)		Potential Annual National Energy Savings by Year 2020	Potential Annual Greenhouse Gas Emissions Reductions (CO_2 Equivalence)
Average New Construction	Average Retrofit		
7.2%	24.5%	27.5 PJ	651 kilotonnes

Table 5. Energy/Environmental Impact: Integrated Heating/Ventilating Appliance

This technology is not widely applicable in other sectors. Limited opportunities exist in high-rise apartments which are being constructed or retrofitted with distributed gas systems.

Recommendations

Stakeholders for this technology include CGRI and gas utilities who can offer improved products to promote the use of gas. All high-efficiency gas furnace manufacturers could benefit from the development of the separate heat exchanger that can be integrated with other furnace units. CANMET should combine efforts with stakeholders to:

1. Disseminate information about IHVA technology and promote proper ventilation.
2. Address perception of air quality problems related to purging of rock beds.

3. Integrate efficient fan/motor technology into this and all forced-air system technologies.
4. Link to export opportunities.

4.3 Exterior Air Barriers

Description

Recognition that air barrier and vapour diffusion retarder (VDR) functions can be addressed by separate elements and materials is leading to the use of exterior air barriers as an alternative to the use of interior air barrier systems (e.g. polyethylene or airtight drywall). With potential installation, performance and cost advantages, exterior air barriers are likely a trend of the future, hence a system that emerges as a "winner" will have great market appeal.

Two systems used in the Program were assessed in this study. The system used in the Maison Novtec employed extruded polystyrene insulation panels as the air barrier, while the Maison Performante sandwiched an air barrier building wrap between two layers of fibreboard sheathing (the EASE system). A product which emerged concurrent with the Program, a fibreboard onto which a micro-perforated polyethylene membrane is laminated, was also assessed.

Status, Costs and Market Acceptance

The use of extruded polystyrene as an air barrier has undergone further development since its demonstration in the Maison Novtec, and now employs a gasketting system to seal joints. Still at the field-test stage, the system appears promising and cost competitive with more conventional air barrier approaches.

The EASE system faces the challenge of overcoming increased costs over conventional systems. The benefits of the approach must be weighed against the cost of the additional layer of sheathing.

The laminated fibreboard approach, although limited to regions without seismic restrictions on the use of fibreboard as sheathing, appears to be the least expensive of the three systems examined, with a slightly lower cost than conventional systems. According to the manufacturer, sales of the product are steadily increasing. The issue of tape durability needs to be addressed.

A major obstacle in the adoption of exterior air barriers is the resistance at the local building official level to VDR primers. VDR primers allow the elimination of polyethylene sheeting entirely, offering cost savings and facilitating construction. The exterior approach's advantages of avoiding interfaces with structural elements at headers and partition walls and minimizing penetrations of the air barrier by such things as electrical outlets, offer builders easier installation procedures and should make such systems popular with industry.

Energy/Environmental Performance

Reduction in Energy Consumption Per House (space and DHW heating)		Potential Annual National Energy Savings by Year 2020	Potential Annual Greenhouse Gas Emissions Reductions (CO_2 Equivalence)
Average New Construction	Average Retrofit		
2.3%	7.1%	27.3 PJ	1399 kilotonnes

Table 6. Energy/Environmental Impact: Exterior Air Barriers

The difficulty with assessing any air barrier system is that its performance is greatly dependent on the experience, skill and integrity of the builder and subtrades who install it. It is likely, therefore, that the systems that will perform the best are those that can be easily understood and implemented and avoid complicated detailing. In this light, exterior air barriers have several advantages in that they eliminate many of the problems and complications associated with penetrations through interior air barriers.

To assess the potential impact of improved airtightness systems, an airtightness level of 1.25 ACH_{50} was chosen, representing a performance mid-way between the R-2000 target of 1.5 and the Advanced Houses average of about 1.0. Even with the assumption that the market will be shared with more conventional interior systems, the resultant potential national energy savings attributable to exterior air barrier adoption are an impressive 27.3 PJ annually by the year 2020, with an associated greenhouse gas emission reduction of almost 1400 kilotonnes per year.

Some types of exterior air barriers also have broad applicability in other sectors. Extruded polystyrene can be used in high-rise apartments, both in new construction and in retrofits caused by cladding failures. Exterior insulation and air barrier systems are already in wide use in new commercial buildings.

Recommendations

Stakeholders in the accelerated commercialization of exterior air barriers include manufacturers, the R-2000 program, and HRV manufacturers (indirectly, as airtightness and ventilation go hand-in-hand). CANMET and other stakeholders should pursue the following:

1. Accelerate acceptance by building officials of VDR primers through regulations and education.
2. Explore and assist in the fast-track development of standards.
3. Disseminate information.
4. Set up full scale demonstration homes.
5. Promote export linkages.

4.4 Direct-Vent, Condensing, Gas Combination Space/DHW System

Description

A direct-vent, condensing gas water heater, connected to fan coils and a forced-air system, was used in five of the Advanced Houses. By replacing both the conventional water heater and furnace, it offsets some of the incremental costs of improved technology, simplifies the installation of gas piping and venting, and reduces the space occupied by mechanical systems. Its direct venting through a side wall eliminates the need for a B-vent and chase or chimney (offsetting costs further), and eliminates the risk of backdrafting and combustion spillage. The efficiency of such systems is rated to be in excess of 90 percent. Combination systems are an efficient and economically attractive method of providing heat without excessive oversizing for today's houses and their lower heating loads.

Status, Costs and Market Acceptance

At the design stage of the Advanced Houses, there was only one direct-vent, condensing, combination unit on the market. Other systems have since emerged and more are under development with various manufacturers. None, however, is manufactured in Canada.

At present, it is more common for builders to install combined systems by field assembling components than by purchasing a packaged system. The industry is developing system design guidelines, but there remains a need for appropriate performance data for components.

While some of the incremental cost of the packaged system is offset by replacing two systems with one, the improved technology still comes at a higher cost than conventional installations (an estimated minimum $1500 more). Current low-volume production is impeding cost reductions, thus higher market penetration in the future would reduce individual system costs.

The higher cost of the system is a barrier to wider adoption, as is the current lack of regulations concerning such systems. To aid building officials in inspecting combination systems, some gas utilities have developed guidelines for their design and installation, but nationally recognized guidelines are required.

For trades, the packaged approach simplifies some aspects of installation practice. Consumers and builders will appreciate the reduced floor space occupied by mechanical systems.

Energy/Environmental Performance

The recovery efficiency of condensing DHW units is over 90 percent and their seasonal efficiency is over 80%. However, some units are currently experiencing difficulty attaining predicted performance levels and remedial measures are being explored. Current air handlers in combination systems are not built with ECMs — this is an improvement which should be considered.

Reduction in Energy Consumption Per House (space and DHW heating)		Potential Annual National Energy Savings by Year 2020	Potential Annual Greenhouse Gas Emissions Reductions (CO_2 Equivalents)
Average New Construction	**Average Retrofit**		
25.5%	30.7%	20.9 PJ	492 kilotonnes

Table 7. Energy/Environmental Impact: Direct-Vent, Condensing, Gas, Combination Space/DHW System

It is estimated that the annual energy savings would be about 21 PJ by the year 2020. This is based on the assumption that the gas market will be shared with the two other gas systems in this study. Should either of the other two not reach production, or if this system comes to dominate the market, savings can be much greater.

While not widely applicable in the commercial sector, this technology may find some opportunities in multi-unit residential buildings which are being built or retrofitted with distributed gas.

Recommendations

Other than the foreign product manufacturers and prospective Canadian manufacturers, the primary stakeholders for high efficiency combination systems are the gas utilities, the Canadian Gas Association (CGA) and its technical arms, Gas Technology Canada (GTC) and the Canadian Gas Research Institute (CGRI). Another interested group would be the provincial government departments involved in energy. CANMET should work with Canadian stakeholders to achieve the following:

1. Develop national installation guidelines for combination systems to overcome regulatory barriers and a product directory to assist with component selection.
2. Integrate ventilation and efficient fan/motor units for complete system efficiency.
3. Facilitate modelling of combination systems in HOT2000 to facilitate and encourage use by leading builders.
4. Remove first cost obstacles through efficient production and high volume marketing.
5. Find a Canadian manufacturer.
6. Disseminate information to prospective manufacturers, builders and consumers for market push and pull.
7. Integrate into training programs of CGA, NRCan, HRAI and trade schools.
8. Integrate into demonstration projects for exposure.
9. Integrate into retrofit inititives at NRCan.

4.5 Direct-Vent, Wall-Mounted, High-Efficiency, Gas Water Heater

Description

This wall-mounted high-efficiency gas water heater is directly vented through the wall and is a sealed combustion appliance. Designed for use with a companion storage tank, it is capable of providing DHW or combined space/DHW heating with a forced air or hydronic system. It is not a condensing unit. Originally intended for retrofit applications, particularly for converting electric systems to gas by making use of the old storage tank, the system can now be purchased for new construction with a new tank included. The analysis below is based on its use as a combination space/DHW system.

Status, Costs and Market Acceptance

The product was placed on the commercial market in August of 1994, and sales have been steadily increasing since that time, with an affiliation with Union Gas enabling further research and development. With the original combination unit only appropriate for small heating load applications, of particular interest is the 100 000 BTU/h unit currently under development that would make the system applicable for larger-requirement new and retrofit installations.

The incremental cost of the system (over separate furnace and DHW) is estimated to be $1200, lower than that of the more common combination systems. In DHW retrofits making use of the old tank for storage, the incremental cost versus installing a new gas tank is estimated to be $200 for replacing an old gas system, $100 for replacing an old electric system.

Combination systems still meet with some resistance from building authorities, thus national guidelines for their installation are needed. Saving floor space and enhancing indoor air quality are two advantages this system offers to consumers. To broaden the scope of applications, development of a larger system must be seen to fruition.

As a floor-space-saving product, this technology has the potential to be popular in such export markets as Japan. Development of a system that removes the water tank from the floor would enhance such opportunities

Energy/Environmental Performance

The combination system's seasonal efficiency is 77% (according to the developer), making it one of the most efficient water heaters on the market. This translates to an average energy savings of over 20 percent in retrofit applications and over 12 percent in new construction. The potential annual energy savings shown in the table above are a conservative estimate—the market is assumed to be shared with the two other gas systems in this study.

This technology is not widely applicable in the commercial sector. However, the system's compactness creates opportunities in multi-unit residential buildings which are being built or retrofitted with distributed gas.

Reduction in Energy Consumption Per House (space and DHW heating)		Potential Annual National Energy Savings by Year 2020	Potential Annual Greenhouse Gas Emissions Reductions (CO_2 Equivalence)
Average New Construction	Average Retrofit		
12.2%	20.6%	19.6 PJ	463 kilotonnes

Table 8. Energy/Environmental Impact: Direct-Vent, Wall-Mounted, High-Efficiency, Gas Water Heater

Recommendations

The stakeholders with interest in this technology are the manufacturer(s), CGA/GTC/CGRI, gas utilities, propane suppliers and energy departments. Another set of stakeholders may be those involved in the export of manufactured housing, such as the Canadian Manufactured Housing Association. CMHC may also have a vested interest, as there exists the potential to convert rural and native housing from electricity-based systems to propane-fired systems, if such a conversion is found to be cost effective. CANMET should work with these stakeholders to achieve the following:

1. Disseminate information to natural gas utilities and propane suppliers.
2. Establish national combination system installation guidelines and improve information transfer to building officials.
3. Continue work on modelling of combination systems in HOT2000 to facilitate adoption of combination systems by leading builders.
4. Integrate heat recovery ventilation and high-efficiency fans/motors.
5. Integrate into NRCan's retrofit initiatives, such as demonstrations and information transfer.
6. Initiate collaboration between CANMET, CMHA, CMHC and manufacturer(s) for development of a modified product (removing all elements from the floor) for export.

4.6 High Efficiency Fans/Motors

Description

Inefficient fan/motor sets are still the industry standard in residential construction applications today. While even now this is causing excessive electricity consumption, as awareness of indoor air quality escalates further and continuous ventilation becomes more common, the need to integrate improved efficiency fans and motors into residential mechanical equipment will become still more important.

The best technology on the market today is the electrically commutated motor (ECM). Used in variable-speed blowers, these motors maintain the same high efficiency over their entire range of speeds, and hold airflow at specified levels regardless of static pressure, optimizing the use of energy in all situations. Competing with ECMs and presenting a less expensive alternative are adjustable-speed-drive (ASD) and switched reluctance motors, both AC technology. Although not as efficient as ECMs, variable speed AC motors, when combined with appropriate fan technology, offer significant savings over their conventional counterparts.

Status, Costs and Market Acceptance

In 1993, variable-speed blower motors represented 2.5 percent of sales and are expected to account for 7 percent within two years. Some industry representatives predict that they will become the standard within ten to twenty years. Currently, ECMs are used primarily in high-end furnace units.

The costs of fans and motors, purchased normally as elements of furnaces or HRVs, are difficult to isolate. Original equipment manufacturer (OEM) prices may be one third the cost of list prices obtained from manufacturers; trade prices may be two thirds of the list prices; and indications are that motors used most commonly in the industry may be sold as low as one fifth the list price. While higher-efficiency units are more expensive, many of the energy efficiency improvements currently being used, or being investigated and proposed, have the potential to reduce costs. A higher volume of production will have significant cost-saving implications. For instance, while ECMs are currently three to four times more expensive than conventional motors, manufacturers predict a 30 percent drop in their costs over the next few years.

As the 1995 National Building Code becomes adopted, continuous mechanical ventilation should become more common. The high energy consumption associated with inefficient air handling devices will come under greater scrutiny, and the marketplace will probably adapt by seeking fan/motor units of higher efficiency.

Energy/Environmental Performance

The table below shows the energy performance of two technologies — ECMs with backward-curved fans and generic high efficiency AC HRV motor/fan units with ASD. The potential national annual energy savings are predicted to be approximately 8 PJ by the year 2020.

Reduction in Energy Consumption Per House		Potential Annual National Energy Savings by Year 2020	Potential Annual Greenhouse Gas Emissions Reductions (CO_2 Equivalence)
ECM in Furnace	High-Efficiency AC Fans in HRV		
58.1% (vs. conventional fan)	12.3% (reduction in HRV energy consumption)	8.1 PJ	393 kilotonnes

Table 9. Energy/Environmental Impact: High Efficiency Fans/Motors

Efficient motor/fan sets are, of course, widely applicable in other sectors and in fact the impetus for their development arose in large buildings. Other sectors are already converting to more efficient equipment. The development of more efficient residential-scale fans and motors will find additional application in suite equipment for high-rise apartments.

Recommendations
The primary stakeholders in efficient fans/motors are the utilities, who can benefit from peak load shaving. The Canadian Electrical Association, in support of the utilities, is also a stakeholder. NRCan and CMHC, promoting energy efficiency and indoor air quality, both seek improved efficiency in residential fan/motor technology. Manufacturers can offer improved comfort qualities by incorporating variable-speed units (inherently more energy efficient) in all of their systems. With the high potential energy efficiency fans/motors have to reduce greenhouse gas emissions, CANMET and other stakeholders should:

1. Combine efforts with CMHC, where extensive study into this area has been undertaken.
2. Raise minimum efficiency standards for fan/motor sets, as other market incentives are not sufficient to increase adoption.
3. Establish a steering committee for overseeing testing, rating and labelling developments.
4. Demonstrate benefits through monitoring and testing of Advanced Houses and R-2000 houses.
5. Create EnerGuide ratings for fans/motors.
6. Continue ongoing work on HOT2000 to improve fan/motor modelling to enable leading builders to see the energy benefits of energy-efficient units.
7. Encourage the incorporation of high efficiency motors and fans in household applicances.

4.7 Advanced Oil Heating System

Description
The oil-fired combination space/DHW heating system used in the Nova Scotia EnviroHome addresses the issue of short-cycling and the resultant inefficiency of oil systems when installed in today's lower-energy houses. Most of the components of the system are standard items, but the design is innovative and unique. A low mass cast iron boiler heats water which is stored in a well-insulated 60 gallon hot water storage tank. This configuration allows the boiler to remain off for several hours once the storage tank is up to the desired temperature, and permits longer firing times during operation for peak efficiency. Power venting prevents backdrafting. The system heats three "zones"—two fan coil units heat forced-air system zones, and the DHW tank acts as a third zone (eliminating the need for a burner in the DHW tank itself).

Status, Costs and Market Acceptance
The advanced oil system of the Envirohome appears to have overcome the oversizing, inefficiency and comfort problems often associated with conventional systems, but lack of a

champion is currently preventing deployment of this technology. CANMET's Energy Research Laboratories (ERL) continue to provide research support to the oil industry (which its typically small manufacturers cannot undertake) and is currently concentrating its oil heating activity on integrated systems, recognizing the potential for high efficiency and cost effectiveness.

It is estimated that a production level, less sophisticated system using the concepts of the EnviroHome system would have an incremental cost of approximately $700 over conventional oil furnace and water heater configurations. Technical issues are not a major impediment, and consumers currently using oil generally intend to stay with oil, while those using electricity tend to be seeking more economical methods of heating. The efficiency advantages of integrated oil systems have this technology poised to replace conventional oil systems, as well as electric DHW heaters and some configurations using electricity for both space and DHW heating, if a champion can be found.

Energy/Environmental Performance

Reduction in Energy Consumption Per House (space and DHW heating)		Potential Annual National Energy Savings by Year 2020	Potential Annual Greenhouse Gas Emissions Reductions (CO_2 Equivalence)
Average New Construction	Average Retrofit		
13.2%	16.2%	4.9 PJ	33 kilotonnes

Table 10. Energy/Environmental Impact: Advanced Oil Heating System

The low mass oil boiler system with an isolated highly-insulated hot water storage tank and fan coil air handler is estimated to have an equivalent steady-state efficiency for space heating of about 85 percent and an energy factor for DHW heating of 0.75. This level of performance can reduce household energy consumption by an average of over 13 percent in new construction and over 16 percent in retrofits. The potential annual greenhouse gas emission reductions are not extremely high as a national figure, but in regions where oil dominates, such as in the Maritimes, significant percentage reductions in local emissions are possible.

Resdidential-scale advanced oil systems are generally not applicable in other sectors.

Recommendations

The primary stakeholders in the commercialization of advanced oil heating systems are oil appliance manufacturers, the Canadian Oil Heat Association (COHA) and the major oil companies. CANMET should work with these stakeholders to:

1. Maintain or strengthen CANMET's R&D for the oil industry. Oil offers environmental benefits over electricity, but industry fragmentation prevents undertaking of R&D.

2. Find a Canadian manufacturer for the Advanced Oil Heating System — the technology is ready for the market but no manufacturer has seized the opportunity.
3. Encourage oil-fired appliance rental programs to reduce first costs for home buyers.
4. Integrate ventilation and efficient fan/motor units.
5. Link to export opportunities, particularly in Russia and Eastern Europe.

4.8 Engineered Wall Framing

Description

Today's marketplace is seeing a move away from conventional lumber framing practices as the industry looks towards more economical options and seeks methods which do not rely on old growth trees. Two Advanced Houses made use of resource-efficient engineered wood products (EWPs) as a more economical method of building thicker walls capable of accommodating more insulation. The Waterloo Green Home used I-joists and the Hamilton NEAT Home selected an open web-type joist. These products use less lumber than conventional members of the same size or strength, and reduce the use of large dimension lumber, making use of waste wood and weed woods.

Status, Costs and Market Acceptance

Forty-five percent of North American home builders are now using or are planning to use some form of engineered wood products, according to Home Builder magazine (Nov/Dec 1994). But while the conversion to engineered framing products continues, there has still been little application in residential wall assemblies. The increased depth of the members which provides a larger cavity for insulation is ideal for super energy efficient construction, as in the Advanced Houses, but represents too costly an expenditure for mainstream construction. Accordingly, to further capitalize on the environmental benefits of engineered wood products, a smaller-dimension line of products appropriate for wall construction is needed to render such applications feasible. The study therefore examined the implications of producing a 38x140 EWP stud, in either "I" or open-web form.

A EWP stud would offer the advantages of engineered wood products at a price which would make their use in mainstream construction feasible. It is estimated that the cost would be 30 to 60 percent higher than a conventional 38x140 SPF stud. Costs on a per house basis, however, could be considerably less than this, through the use of efficient framing and thanks to the improved performance of engineered wood products, eliminating warping, shrinking, etc. Eliminating backing required for warped studs and reducing call-backs for builders to fix popped nails could be very beneficial in reducing construction costs. This would also appeal to today's consumer seeking quality finishes and reduced maintenance. In terms of functionality, implementation would require no adjustments, with open web joists and punch out holes in I-joists even facilitating tasks such as wiring for trades. The environmental benefits of engineered wood framing along with those associated with blown cellulose insulation (a natural companion — see below) offer marketing advantages to builders as well. For all of these reasons, a product priced within the same range as conventional framing could be very well received.

Energy/Environmental Performance

Engineered wall framing systems have the potential to contribute extensively to resource conservation. A 241 mm (9.5") deep I-joist wall system, if made from parallel strand lumber, uses half the volume of wood of a 38x140 (2"x6") conventionally framed wall and one third the lumber of a double wall. Smaller dimensional members for use in walls closer to conventional thickness would use even less wood. Beyond the volumes of wood which would be saved, engineered framing products do not rely on old growth trees, but instead are made from waste wood and weed woods.

While the primary environmental benefit of engineered wall framing is resource conservation, it should also be noted that energy savings would also be realized by implementing such a system. In the case of the I-stud, the reduced thickness of the member at the web reduces thermal bridging, providing extra space for insulation. If one considers that the insulation likely to be used with such systems is blown cellulose (which appropriately fills the non-uniform cavity space created by engineered framing), the slightly higher thermal resistance of cellulose versus conventional fibreglass batts (an increase of RSI 0.0007/mm, on average) offers further energy efficiency improvement. The thermal resistance of a conventional 38x140 (2"x6") stud is approximately RSI 1.19, while the effective resistance of a 140 mm (6") deep I-stud with insulation between the flanges would be RSI 2.12. A comparable open web stud with galvanized metal webs and insulation blown between the flanges (after installation) could have an effective thermal resistance of about RSI 2.32. Based on the use of I-studs, these savings are reflected in the table below.

Reduction in Energy Consumption Per House (space and DHW heating)		**Potential Annual National Energy Savings by Year 2020**	**Potential Annual Greenhouse Gas Emissions Reductions (CO_2 Equivalence)**
Average New Construction	**Average Retrofit** (as house addition)		
1.7%	1.7% (of additional energy consumption)	1.1 PJ	56 kilotonnes

Table 11. Energy/Environmental Impact: Engineered Wall Framing

The above projections do not reflect the possible increased use of thicker, more energy-efficient walls, which can be built more economically with the availability of engineered wall framing than with conventional lumber or double stud walls. These projections also do not reflect market opportunities in other sectors. For walk-up apartments and small commercial buildings, particularly in Western Canada where there is greater structural use of wood, engineered wall framing can offer an alternative to masonry or steel frame construction.

Recommendations
Stakeholders in the development of EWP studs include the manufacturers, the cellulose industry (whose product is an ideal companion to EWP studs), the Canadian Wood Council, Forintek, and the APA-Engineered Wood Association. CANMET should work with stakeholders to:

1. Promote benefits of EWP studs and find a manufacturer.
2. Develop guidelines for EWP studs and assist in regulatory acceptance.
3. Disseminate information.
4. Prepare for export opportunities.

4.9 Small-Diameter, High-Velocity Ducts

Description
One of the most interesting technologies used in the Advanced Houses program for the distribution of heat and ventilation was tested in the Ottawa Innova House, with a system whose use was made possible by the improved envelope construction. It is a small-diameter (50 mm/2"), high-velocity flexible duct system that supplies air to outlets along the interior walls of the house. The small heat load associated with energy-efficient housing means air flow volumes can be lower, allowing the smaller ducts to be used.

Status, Costs and Market Acceptance
Although high-velocity systems have been used primarily for retrofitting forced air heating and air conditioning systems in the past, they are now being promoted in new construction as well. The only Canadian manufacturer is one of the newest competitors in this field and is the only company that is aggressively promoting its system for new construction.

Historically, the problem with high-velocity duct systems has been excessive noise, as whistling can occur due to the high speeds of the air. Baffles and other sound attenuating devices are being used to address this issue. The effectiveness of these measures is still uncertain.

While these systems offer some advantages with regard to comfort and distribution efficiency, they are currently more expensive than conventional sheet-metal duct systems. However, there exists the potential to optimize the design of the product and, in so doing, to possibly reduce its cost. The ducting currently available is insulated, but when ducting is installed inside the heated volume of the house, this insulation is no longer necessary, and its elimination could reduce manufacturing costs. The insulation layer also adds to the diameter of the ducting, thus its elimination would allow for an increase in the diameter of the tubing itself. Increasing the duct size from 50 mm to 75 mm in diameter would result in a product with approximately the same overall diameter as the insulated version (enabling installation in the same small spaces, such as interior partitions, and maintaining the ability to feed it within existing wall construction), but would provide a system whose air delivery capacity would be more than double that of the existing products. Such a development would also broaden its potential for installation to homes requiring larger volumes of air distribution. A smooth-bore product could also increase efficiency by reducing friction losses.

The small size of the ducts in high-velocity systems is particulary suited to manufactured housing, and accordingly this technology has good potential as part of a whole-house package for the export market. Applicable to both hot and cold climates (with its heating and cooling system capability), if integrated without insulation and within the building envelope, it can be part of a cost competitive package.

Energy/Environmental Performance

Optimizing design using shorter duct runs to interior outlets (especially appropriate in well-sealed and insulated construction) can improve air delivery efficiency. Installing all ductwork inside the envelope also ensures no heat loss from the distribution system to the exterior (leaky ducting outside the envelope, even just a few metres, can result in significant losses). It should be noted that these savings would however be partially offset by the increased power consumption of the blower because of high-pressure operation (emphasizing the need for high efficiency air handlers). The greatest energy and environmental benefits for these systems are found in retrofit applications, where fuel switching from electric to gas is facilitated by less labour-intensive and less disrupting installation procedures, and where the system can contribute to improving indoor air quality through ventilation. Projections of energy savings have not been undertaken, since this technology does not save energy directly, but rather facilitates fuel switching and energy upgrades. In those areas of the country where base or peak electricity is generated thermally, converting from electric baseboards to a natural gas furnace will lead to reductions in greenhouse gas emissions.

This technology is also applicable in those high-rise apartments which are incorporating ventilation or forced air heating or cooling systems.

Recommendations

Stakeholders in the diffusion and adoption of this technology are the ventilation industry (who can use this technology to penetrate unventilated existing housing), utilities (electric utilities who can shave peak loads by facilitating "off-electric" retrofits and gas utilities who can take up that extra market), HRAI, the CHBA Renovators' Council and the manufactured housing sector (particularly exporters). CANMET should work with these stakeholders to:

1. Develop an optimized 75 mm duct product, with cost and broader market advantages.
2. Address sound attenuation concerns through testing of existing installations.
3. Seek adoption by gas utilities as part of their efforts to expand markets.
4. Gain support from CMHA for further development.
5. Promote use in retrofit projects through dissemination of information.

5. Conclusions and Recommendations

The Advanced Houses Program succeeded in providing a testing and demonstration ground for over 100 innovative and/or prototypical "green" technologies. This study documented and screened approximately 40 of these technologies and undertook detailed assessments on nine of the most promising. This section provides conclusions and recommendations regarding the potential impacts of the technologies studied and the federal government actions required to acclerate commercialization and adoption of these technologies.

5.1 Implications of the Detailed Assessment Results

1. **Accelerated adoption of the most promising Advanced House technologies can reduce national energy consumption in the low-rise housing sector by 15-19% by the year 2020.** The technologies used in the Advanced Houses Program have the potential to have a major impact on Canadian energy consumption and to greatly reduce the impact of housing on the environment. Estimates of market penetration in the low-rise residential sector for the nine technologies assessed — based on a reasonable level of R&D support and information transfer by CANMET and other stakeholders — show that significant energy savings are possible, as shown in the table below. The projected annual savings of 214 PJ by the year 2020 represents 15-19% of the estimated total energy consumption of 1120-1395 PJ for the low-rise housing sector in 2020. Also, it should be noted that many of the technologies are applicable in high-rise residential and commercial buildings, therefore resulting in further savings.

Year	Annual Energy Savings (petajoules)	Annual CO_2 Reduction (kt)	Annual CH_4 Reduction (tonnes)	Annual N_2O Reduction (tonnes)
2000	14.5	673	17	48
2020	213.6	8,754	211	530

Table 12. Potential Annual Savings From the Nine Most Promising Technologies

2. **High-performance windows offers by far the greatest potential energy savings.** Of the nine technologies analyzed for potential energy savings to the year 2020, high performance windows provide roughly the same impact as the other eight combined, underscoring the importance of this recent performance break-through. Accelerating market uptake, particularly in the existing stock, should therefore be a priority for CANMET program and policy development. Ensuring adoption and implementation of the window labelling program is seen as an essential first step.

3. **Advanced gas-fired mechanical systems represent the second most significant energy savings opportunity.**
   Advanced gas-fired systems, such as the combination space/DHW heater, the wall-mounted direct-vent water heater and the integrated heating/ventilating appliance, represent a strategic area for CANMET's R&D, with considerable savings possible in the long term. Their combined impact by 2020 is estimated to be about 68 PJ annually or three-fifths the savings associated with high performance windows. Integrated mechanical systems clearly represent the future trend.

4. **Exterior air barriers, efficient motor/fan sets and advanced oil heating also offer substantial potential.**
   Three other technologies merit priority treatment. Exterior air barriers provide a cost-effective alternative for achieving airtightness and ranked third overall in this analysis with a projected annual saving of 27 PJ by 2020. Efficient motor/fan sets (8 PJ/year) also offer significant potential, possibly justifying regulatory action in the form of mandatory minimum efficiency standards. Advanced oil heating (5 PJ/year) can make a substantial impact in a niche market. Other technologies will have smaller impacts. Engineered wall framing offers lower energy savings on a per-house basis, but also offers significant resource conservation benefits. Small-diameter, high-velocity ducting is not a direct source of energy savings, but is a facilitator of energy retrofits and fuel switching through reduced construction costs.

5.2 Recommendations for Accelerated Commercialization

Recommendations for accelerated adoption of the nine most promising technologies are listed in each of the detailed assessment sections. Common themes for action by CANMET and other stakeholders are summarized as follows:

1. **Immediately develop action plans and organize government/industry dialogue groups to accelerate the adoption of the most promising technologies identified in this study, particularly energy-efficient windows and advanced gas-fired mechanical systems.**
   The projected energy savings and greenhouse gas reductions associated with the nine technologies given Detailed Assessments are significant, but will not be achieved without a reasonable level of R&D support, information dissemination and promotion undertaken by the federal government and other stakeholders. For some of the technologies, there are enough groups with vested interests to enable advancement of product development and commercialization without extensive financial support. However, CANMET needs to act as a catalyst in bringing stakeholders together through dialogue groups to take advantage of current opportunities and steer support activities. IRAP will likely be a key participant. In some cases, a Canadian "champion" needs to be found and assisted to proceed with research, development and manufacturing prior to CANMET pursuing accelerated commercialization. In other cases, proponents need to be assisted with product refinement, performance testing,

overcoming regulatory obstacles or developing domestic and export marketing strategies. Two particularly important areas are energy-efficient windows and advanced gas-fired mechanical systems, which together represent more than three quarters of the total potential savings associated with the nine technologies in this study. As a first step, CANMET should reconvene the participants from the Experts' Meeting to review the study's findings and discuss the next steps for priority technologies.

2. **Pursue joint R&D with manufacturers and other stakeholders.**
   CANMET needs to use the results of this study to assist in setting its residential R&D priorities and in influencing the direction of PERD strategic planning. Several technologies (e.g. integrated heating/ventilating appliance) need to overcome technical performance obstacles. Others (e.g. direct-vent, condensing gas combination space/DHW system) need R&D to become more cost effective.

3. **Assist the industry in overcoming regulatory obstacles.**
   Some of the innovative technologies are experiencing resistance or unnecessary extra costs due to poor understanding on the part of building officials. CANMET should act as a facilitator in addressing these obstacles. For example, acceptance of VDR paints needs to be secured as part of the shift to exterior air barriers and installation guidelines need to be developed for combination heating/hot water systems.

4. **Aggressively disseminate information about the Advanced House technologies.**
   A major finding of the study was that while the Program succeeded in incorporating a vast number of innovative energy efficient and/or environmental technologies into its houses, little is known about them, especially outside of the main coordinators of the project. Project team members from one house are not familiar with those technologies used in the others. While this report assessed to some degree many of the technologies of the Program, there still remain many others which should be documented. A simple **listing of all of the environmental products** (and manufacturers) that were used in the program should be completed and made available. **Reports on each house**, in any form, would be beneficial. **Brochures and pamphlets on specific Advanced House technologies** are also called for to disseminate information. Information should be incorporated into **R-2000, HRAI and other training** programs. A **newsletter** for Advanced House technologies should be considered. **Advanced House technology seminars** should be continued and expand to other target audiences. A survey of participants at the 1994 series found that 85 percent would use or encourage others to use Advanced House technologies and 89 percent found the information helpful in their work. Seminars geared towards different audiences should be developed and presented to important groups including: builders and trades; manufacturers and suppliers; building officials; technical schools, colleges and universities; and possibly to home buyers as well as home owners (who can consider retrofit options).

5. **Link Advanced House technologies to export opportunities.**
   Almost all Advanced House technologies have export potential, and it is recommended that CANMET assist manufacturers in identifying and pursuing such opportunities. One option is the Housing Export Centre, which is currently being established by CMHC.

6. **Include Advanced House technologies in retrofit initiatives.**
   Assessments of the technologies show that in many cases there is a much greater potential for energy consumption reduction in Canada through retrofitting existing houses than in improving new construction. It is recommended that retrofit initiatives be supported and pursued and that Advanced House technologies be integrated into such activities, including consumer education. CMHC/NRCan's current Reno-Demo projects provide an immediate example. Particular attention needs to be given to exploiting the window and furnace replacement markets to avoid lost opportunities.

7. **Seek out other ongoing demonstration projects to promote the integration of Advanced House technologies.**
   Other demonstration projects and programs could provide venues for further exposure of Advanced House technologies to builders and consumers. Examples include the EnviroHome demonstrations, the R-2000 program and CMHC's Healthy Housing projects.

8. **Consider mandating minimum efficiency requirements where necessary.**
   Several promising technologies are facing market resistance due to higher first costs, in spite of reasonable payback periods and cost effectiveness. NRCan should pursue, through its implementation of the Energy Efficiency Act, the mandating of minimum efficiency requirements for certain products, such as motors, fans and lighting.

9. **Continue upgrading HOT2000 to reflect CANMET priorities and facilitate modelling of Advanced House technologies.**
   As CANMET seeks to promote such improvements as continuous ventilation and combination space/DHW systems, work on HOT2000 should continue to allow the accommodation of innovations in this area. Currently, the software does not account for the performance advantages of ECMs which could reduce energy consumption for continuously ventilated houses. Combination space/DHW systems, seen as an excellent way to reduce energy consumption, are not an option on the current version and must be modelled using separate system approximations. Ongoing work in these areas should be accelerated to reflect the trends emerging from the Advanced Houses and to allow early adopters of innovative technologies to realize the full benefits.

10. **Update and support rating and labelling systems.**
    The importance of supporting window rating and labelling has already been noted above. Consideration should be given to making such labelling mandatory in order to create increased demand for high performance windows. Rating and labelling systems for all

mechanical equipment are also necessary to provide consumers with information and to substantiate performance claims. The EnerGuide HVAC rating system is a step in the right direction, but will need to be adjusted if it is to truly promote energy efficiency in HVAC systems. The adjusted fuel utilization efficiency (AFUE) will be used to rate systems, but this AFUE should include fan and motor energy consumption. Fans and motors are also in need of their own rating/labelling system. Furthermore, if combined mechanical systems are indeed the trend of the future, a labelling system which allows the comparison of an integrated system to a combination of individual HVAC components is required. If the market is to make the logical step to combination systems, EnerGuide should be used to facilitate and accelerate such a move.

11. Complete the monitoring and documentation of the Advanced Houses.
The Advanced Houses have presented an important opportunity to monitor, test and assess prototypical technologies, as well as many other innovative products. Due to a lack of funding, this opportunity is not being fully seized. In order to advance commercialization of these technologies, such information is essential. In performing assessments in this study, such information was not always available. Monitoring and testing of the Advanced Houses must be completed and documentation of the results must be made available.