Emerging Energy-Saving Technologies and Practices For The Buildings Sector: 2004 Introduction, Methodology, Results, Discussion, Next Steps & Recommendations, Analysis, References

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EXECUTIVE SUMMARY

E.1 CONTEXT, OBJECTIVES AND SCOPE

This report profiles emerging technologies and practices for the buildings sector in North America. The report is the result of an extensive collaborative study directed by the American Council for an Energy Efficient Economy (ACEEE) and involving government, utility, research institution and consulting personnel in the U.S. and Canada. This is the third assessment of emerging technologies and practices conducted in the past decade and builds on the experience and methodology refined under the two previous studies.

The scope of this study has been enhanced to reflect the interests of some of the collaborative sponsors and participants, which specifically has translated into reporting at the following levels of differentiation: i) a U.S. market perspective, ii) a Canadian market perspective; and iii) a California-specific focus. This document consolidates the results of the U.S. and Canadian perspectives into one report. The core report is referred to as the ACEEE version. Clearly integrated into the core report are the results of the Canadian specific analysis.

The concept of assessing emerging technologies (*e.g.,* a new air conditioner) and practices (*e.g.,* improved air conditioner installation procedures) for the buildings sector is driven by the need to effectively inform policy, program and research functions in government, utilities and the private sector to identify the best candidates for program development or for further technical development.

The adoption of emerging technologies and practices (T&Ps) is key for continuing to improve energy efficiency in the buildings sector while maintaining economic growth. This is a dynamic process in which T&Ps increase their market share and consequently, over time, evolve from newly adopted T&Ps to become mature T&Ps with significant market saturation. Fortunately, innovators continue to stay "ahead of the curve" and, indeed, introduce new T&Ps more rapidly than the market can assimilate them. Some have greater potential than others, so periodic, systematic evaluations of emerging T&Ps serve to identify the best candidates for program development.

The objectives of this study are:

- To identify new research and demonstration projects that could help advance high-priority emerging technologies; and
- To identify potential new technologies and practices for market transformation activities.

The analysis covers T&Ps applicable to the buildings sector in both the residential and commercial sectors. We define "emerging technologies and practices" ("T&Ps") as those which either: (a) are not yet commercialized but we judge to be likely to be commercialized and cost-effective to a significant proportion of end-users (on a life-cycle cost basis) by 2009; or (b) are commercialized, but currently have penetrated no more than 2 percent of the appropriate target market.

E.2 METHOD EMPLOYED

This study generated detailed profiles for 72 emerging T&Ps out of a possible candidate list of 198 measures. The method used to generate these profiles comprised the following steps:

Step 1: Develop Initial Measure Lists

Candidate T&Ps were taken from lists of emerging technologies developed for the 1998 study; existing databases and reports resident in the current study team files; recommendations from energy research organizations, major utility R&D departments, and state and provincial R&D institutions; recent conference proceedings; consultations with experts; and product and research announcements.

Step 2: Preliminary Sorting Of Measures Into Priority Categories

Low potential measures are those that are likely to have a cost of saved energy greater than current U.S. national average energy prices, or that can reduce U.S. and Canadian buildings energy use by less than 0.25 percent. High potential measures are likely to have a cost of saved energy less than 50 percent of current U.S. national average energy prices, and that can reduce U.S. or Canadian buildings energy use by 0.50 percent or more. Medium potential measures were neither "high" nor "low" potential, or measures for which little is known, so further analysis is needed.

Step 3: Selection Of Measures For Detailed Analysis

Seventy-two candidates were selected for detailed analysis as likely medium- and high-priority emerging technologies.

Step 4: Detailed Data Collection and T&P Profile Development

The T&P profiles report on the following categories: *the Market, the Base Case, New Measure Information, Savings Information, Cost, Likelihood of Success, Recommended Next Steps,* and *Notes* translating into 30 input parameters. Data was obtained in order to complete the 30 inputs in an EXCEL spreadsheet database. Based on these values, as well as a review of published literature on each measure and telephone conversations with researchers and manufacturers working on the different measures, written descriptions on each measure and their status and prospects were prepared (the T&P profiles).

A key quantitative output and indicator supporting the analysis and selection of priority T&Ps is the *Cost of Saved Energy* (CSE) which is defined as the levelized cost of a measure over its lifetime per unit of energy saved. It is calculated by assuming each measure is financed with a loan, with a term equal to the measure life and an interest rate equal to the discount rate, and dividing the annual loan payments by the annual energy savings. The CSE calculations are based on future mature measure cost estimates. The U.S. analysis uses a 5 percent real discount rate, where 5 percent is a figure commonly used by electric utilities for energy-saving analyses. The Canadian analysis uses a 10% real discount rate.

A second key quantitative output is the macro-market impact analysis. A spreadsheet model was developed to project market penetration and resultant energy efficiency improvements according to each T&P. A Canadian macro-market impact analysis was developed in addition to the U.S. market assessment.

A key qualitative output and indicator supporting the analysis and selection of priority T&Ps is the rating according to "likelihood of success". T&Ps were rated by the team according to the following criteria on a 5-point scale: 1 = very difficult to succeed; 2 = be hard to succeed; 3 = moderate chance of success; 4 = good chance of success; 5 = excellent chance of success; barriers appear to be clearly surmountable.

Step 5: Selection of High Priority Measures

All of the 72 T&Ps were rated according to 3 quantitative and qualitative values: potential market level energy savings, economic performance (cost of saved energy), and likelihood of success. The high priority measures show potential energy savings of at least 1 percent of projected residential and commercial energy consumption in 2020; a cost of saved energy less than half of current retail energy prices; and a likelihood of success rating of 3 or more.

Step 6: Comparison to Prior Emerging Technologies Studies

Many of the measures examined in the 1993 and 1998 ACEEE reports were re-examined in this study. For these measures we compared our findings with our expectations from prior work in order to see which technologies fared as well as expected, which fared better and which fared worse. In addition, for the 1998 high priority technologies that are not included in this study (which is the case if they now have more than a 2 percent market share or if their commercialization date is delayed beyond 2010), we looked at their current status in relation to our expectations.

Step 7: Summary of Related Canadian R&D Efforts

This step refers to the inclusion in the T&P profiles of a Canadian R,D&D situation assessment for buildings T&Ps. Observations are presented at the outset of each category of T&P, not at the level of individual T&Ps. In addition, where pertinent, some of the individual T&P profiles include specific observations unique to the Canadian context. The main source for these observations is information gleaned from a recent applications round to the NRCan Office of Energy Efficiency (OEE) for funding support of technology development under the auspices of the "Technology & Innovation" initiative.

Step 8: Estimate of Macro Market Impact in Canada

The macro market assessment for Canada included the same T&Ps used for the North American assessment. Three measures were dropped from the analysis, as was done for the ACEEE version:

- L2: Self-Commissioning Photosensors (combined with L5)
- S6: Commercial Cool Roofs (dropped, over 2% market share today)
- S7: Integrated Window/Wall Systems (dropped, no current work on technology)

Some measures targeted specifically at climates in the southern United States were found to have very little potential in Canada. These measures were not omitted from the analysis, but were instead included in the model and assigned an applicability level of zero.

A database was developed of all the macro drivers to calculate the market impact of the technologies. For each technology, these drivers included the following:

- Sector (commercial or residential) and building segments (e.g., office, retail, single-family dwellings, etc.) to which the technology would apply
- End-uses affected by the technology
- Energy used for those end-uses within the applicable building segments
- Fuel shares, specifically the allocation between electricity and non-electric fuels for the heating and domestic hot water end uses
- Applicability of the technology to each segment, e.g., the technical limitation on application of the technology
- Current penetration of the technology
- Potential penetration of the technology by the end of the study period.

The Canadian macro-market analysis includes energy savings and associated greenhouse gas emission reductions expressed as savings in the target year, 2020 relative to a "Business As Usual" base case projection of energy use.

The savings percentage and the factors that account for technical applicability and penetration are applied to the projected "Business As Usual" annual energy consumption for 2020. The total savings presented in the results section are projected energy savings in that target year. They are not accumulated savings.

E.3 RESULTS

Seventy-two T&Ps were studied in detail. Table ES-1 indicates the distribution of these T&Ps according to the categories of "high," "medium," "lower," "special," and "not a priority", based on 3 quantitative and qualitative values: potential market level energy savings, economic performance (cost of saved energy), and likelihood of success.

Table ES-1. Priority Levels and Distribution of Measures by Classification Parameters

Priority	Threshold for Savings	CSE, $/kWh	CSE, $/MMBtu (source energy)	Likelihood of success	Number of Measures
High	≥ 1.0%	≤ $0.0405/kWh	≤ $3.16/MMBtu	3–5	5–6
Medium	≥ 0.25%	≤ $0.081/kWh	≤ $6.33/MMBtu	3–5	20–27
Low	< 0.25%	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5	11–14
Special	>~0.05%	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5	10–19
Not a Priority		≥ $0.81/kWh	> $6.33/MMBtu	1–5	14–24
Total					**72**

The report documents the U.S. and Canadian macro assessment results separately. The Canadian results are summarized here.

The T&Ps with the greatest potential represent a variety of measure types, from changes in design practice to changes in technology. Changes in design practice offer the largest potential because the savings cut across all end uses, and because of the large number of buildings to which they can be applied. The large impact T&Ps also cut across energy end-uses as significant savings are available from advances in lighting, HVAC systems, motors, and appliances.

The top ten T&Ps, ranked according to macro-market energy savings, are as follows:

#1, PR3, Integrated Commercial Building Design LEED Level (30% > Code)

This T&P could save up to 176 PJ in the Canadian commercial sector by 2020. The greatest potential would be in offices (private and public) and retail buildings, because these segments represent the largest percentage of floor space in this sector.

#2, PR2, Ultra Low Energy Commercial Building Designs (50% > Code)

This T&P would generate significant savings for reasons very similar to those stated under PR1 but the savings per facility would be higher. As with PR3, offices and retail buildings represent the greatest potential.

#3, S1, High Insulation Technology (HIT) Windows (U<0.25)

HIT windows can save up to 20% of the energy used for heating and cooling residences and are technically applicable to any new homes from single family to apartments. Regionally, the greatest savings will occur where winters are the most severe, because nearly 85% of the energy savings are from space heating.

#4, D1, Advanced Appliance Motors

These motors can save up to 60% of the energy used by conventional motors and can be applied to all commercial pumps and to 20%-25% of residential appliances. The greatest potential is in the appliances used in single-family homes.

#5, H20, Advanced Condensing Boilers

These boilers can save up to 33% of the energy used by conventional boilers and they are applicable in all commercial buildings with hydronic systems. The greatest potential exists in offices and retails, because they represent the largest floor space with hydronic systems, but schools and health care facilities also offer large potential.

#6, L15, Scotopic Lighting

This T&P offers significant potential because lighting energy can be reduced by up to 30% in all commercial fluorescent lighting to which the technology is applied. The greatest potential is in offices and retail facilities, because of the large floor space in those categories.

#7, R1, Solid State Refrigeration (Cool Chips™)

This T&P offers a large potential because it could save up to 40% of the energy used for refrigeration and could apply to all commercial and residential refrigeration. The greatest potential is with refrigeration in single-family homes.

#8, W1, Condensing Water Heaters

This T&P offers a large potential because it could save up to 29% of the energy used for domestic hot water in all single-family and mobile homes with non-electric water heating. The greatest potential is in single-family detached homes, because they represent the largest number of dwelling units.

#9, A1, 1-watt Standby Power for Appliances

This T&P offers a large potential because it could save up to 60% of the standby power in all residential appliances and electronic equipment that have standby power. Penetration could be up to 100% of those appliances by 2020.

#10, L14, One-Lamp Linear Fluorescent Fixtures with High Performance Lamps

This T&P offers significant potential because it could save up to 42% of the lighting energy in all fluorescent lighting in offices, schools, and healthcare facilities.

Recommendations and Next Steps for Canada

The Canadian macro-economic analysis leads to the following set of recommended high priority measures, as listed in Exhibit E.2.

Exhibit E.2. Recommended High-Priority Measures for Canada

Measure	Name	Commentary
PR2	Comm. Construction 50%>Code	• This measure produces a higher level of savings per building and at a lower cost than PR3, but is not applicable to as many buildings.
PR3	Comm. Construction 30%>Code	• This level of improvement in design is more broadly applicable than PR2, and will result in a greater level of overall savings
D1	Advanced Appliance Motors	• This measure offers large potential savings in both the residential and commercial sectors, at very small incremental cost. • The motors are mainly used in other products, so it is the manufacturers who must adopt the measure. Because most of the pumps and appliances involved are marketed internationally, this will require collaboration with the U.S. and other countries.
H20	Advanced Condensing Boilers	• This measure offers considerable potential in commercial buildings with hydronic systems, at only a modest incremental cost. • Education for designers is an appropriate method for encouraging adoption of the measure.
L15	Scotopic Lighting	• This measure offers significant savings potential in commercial lighting, and is expected to have no incremental cost over conventional lighting. • The measure requires continued R&D and technology demonstrations.
R1	Solid State Refrigeration (Cool Chips™)	• This is a new technology, requiring more R&D to bring it to commercialization.
A1	1-Watt Standby Power	• Programs such as Energy Star, manufacturer incentives, and new standards are all appropriate ways to encourage adoption of this measure.
L14	One-Lamp Linear Fluorescent Fixtures with High Performance Lamps	• This measure offers significant savings potential in commercial lighting, with only modest incremental cost. • The measure can be encouraged through education of designers and changes to current incentive programs.

RÉSUMÉ

E.1 CONTEXTE, OBJECTIFS ET MANDAT

Le présent rapport dresse le profil des technologies et des pratiques émergentes dans le secteur du bâtiment en Amérique du Nord. Il découle d'une étude exhaustive concertée menée par l'American Council for an Energy Efficient Economy (ACEEE), en collaboration avec des employés du gouvernement, des services publics, des institutions de recherche et des experts-conseils des États-Unis et du Canada. Il s'agit de la troisième évaluation de technologies et de pratiques émergentes, effectuée au cours de la dernière décennie, fondée sur l'expérience et la méthode améliorées des deux études précédentes.

On a élargi le champ de la présente étude afin de tenir compte des intérêts de certains des commanditaires et intervenants qui œuvrent de concert, ce qui s'est traduit par les différentes approches suivantes : i) étude à partir d'une perspective du marché américain; ii) étude à partir d'une perspective du marché canadien; iii) étude à partir des spécificités de la Californie. Le présent document englobe en un seul rapport les résultats des études faites à partir des perspectives américaine et canadienne. On désigne par *version de l'ACEEE* le rapport principal. Les résultats de l'analyse relative au marché canadien sont intégrés dans ce rapport principal.

Le concept d'évaluation des technologies émergentes (p. ex., un nouveau climatiseur) et des nouvelles pratiques (p. ex., procédés d'installation de climatiseurs améliorés) dans le secteur du bâtiment est axé sur la nécessité de fournir aux responsables des politiques, des programmes et de la recherche au sein du gouvernement, des services publics et du secteur privé des renseignements pertinents qui leur permettent d'identifier de manière efficace les technologies et les pratiques émergentes les plus appropriées à l'élaboration de programmes ou au développement technique.

L'adoption des technologies et des pratiques émergentes est essentielle si l'on veut continuer à améliorer l'efficacité énergétique dans le secteur du bâtiment, tout en maintenant la croissance économique. Il s'agit d'un processus dynamique au cours duquel les technologies et les pratiques émergentes augmentent leur part du marché et, par conséquent, passent, au fil du temps, du stade de technologies et de pratiques émergentes récemment adoptées à celui de technologies et de pratiques complètement intégrées, atteignant un important niveau de saturation du marché. Heureusement, les innovateurs continuent d'avoir une « longueur d'avance » et d'offrir des technologies et des pratiques émergentes plus vite que le marché ne peut les intégrer. Certaines présentant plus de potentiel que d'autres, les évaluations cycliques et systématiques permettent de déterminer celles qui conviennent le mieux à l'élaboration de programmes.

La présente étude a pour objectif :

- de déterminer de nouveaux projets de recherche et de démonstration qui permettent l'amélioration des technologies émergentes de première priorité;
- de déterminer les technologies et les pratiques nouvelles possibles pour les activités liées à la transformation du marché.

L'analyse englobe les technologies et les pratiques émergentes applicables au secteur du bâtiment aussi bien résidentiel que commercial. Les « technologies et les pratiques émergentes » désignent : (a) celles qui ne sont pas encore commercialisées, mais qui, selon nous, le seront vraisemblablement d'ici 2009 et qui seront rentables pour une proportion importante d'utilisateurs finals (compte tenu du cycle de vie); (b) celles qui sont déjà commercialisées, mais qui n'ont pas atteint plus de 2 p. 100 de la part du marché visée.

E. 2 MÉTHODE UTILISÉE

Cette étude a permis d'établir le profil de 72 technologies et pratiques émergentes choisies à partir d'une liste initiale de 198 mesures. La méthode suivie lors de l'établissement de ces profils comprend les étapes suivantes :

Étape 1 : Élaboration des listes des mesures initiales

Les technologies et les pratiques émergentes examinées ont été sélectionnées à partir des listes élaborées lors de l'étude de 1998, des bases de données et des rapports contenus dans les fichiers de la présente étude, des recommandations exprimées par les organismes de recherche en matière d'énergie, des principaux services de R et D des services publics, les institutions de R et D d'États américains et provinciaux, des comptes rendus de conférences récentes, des consultations auprès des experts et des annonces au sujet de produits et de recherches.

Étape 2 : Premier tri des mesures par ordre de priorité

Les mesures à faible potentiel sont celles dont le coût de l'énergie économisée dépasse vraisemblablement les prix moyens de l'énergie aux État-Unis ou qui permettent de réduire la consommation de l'énergie des bâtiments aux États-Unis et au Canada de moins de 0,25 p. 100. Les mesures à potentiel élevé sont celles dont le coût de l'énergie économisée est probablement inférieur à 50 p. 100 des prix moyens de l'énergie aux État-Unis et qui permettent de réduire la consommation d'énergie des bâtiments aux États-Unis et au Canada 0,5 p. 100 au moins. Les mesures à potentiel moyen sont celles dont le potentiel n'est ni « faible », ni « élevé » ou des mesures au sujet desquelles on dispose de peu de renseignements et qui nécessitent une analyse plus poussée.

Étape 3 : Choix des mesures aux fins d'une analyse approfondie

Soixante-douze mesures ont été choisies afin d'effectuer une analyse approfondie des technologies émergentes présentant un caractère prioritaire élevé ou intermédiaire.

Étape 4 : Collecte de données détaillées et établissement des profils des technologies et des pratiques émergentes

Les profils des technologies et des pratiques émergentes portent sur les aspects suivants : *le marché, les cas de base, les données sur la nouvelle mesure, les données sur les économies, le coût, les chances de succès, les mesures à prendre recommandées* et les *remarques,* exprimées selon 30 paramètres. Les données ont été recueillies dans le but d'entrer ces 30 paramètres dans une base de données sous forme de feuille de calcul EXCEL. Des descriptions (profils des technologies et des pratiques émergentes) des différentes mesures, de leur statut et de leurs applications éventuelles, ont été rédigées à partir des données susmentionnées, des renseignements recueillis dans différentes publications sur chacune des mesures et des conversations téléphoniques avec des chercheurs et des fabricants qui travaillent sur ces différentes mesures.

Le *coût de l'énergie économisée* (CÉÉ), donnée quantitative et indicateur clé pour l'analyse et le choix de l'ordre de priorité attribué aux technologies et pratiques émergentes, désigne le coût moyen actualisé d'une technologie, par unité d'énergie économisée, réparti sur son cycle de vie. En admettant que chaque mesure soit financée par un prêt, dont l'échéance équivaut à la durée de vie de la technologie, et que le taux d'intérêt qui y est appliqué soit égal au taux d'escompte, le coût d'énergie économisée s'obtient en divisant les annuités par les économies d'énergie réalisées en une année. Le calcul du CÉÉ se fait à partir d'estimations de coûts de mesure future échue. Aux États-Unis, on utilise un taux d'escompte réel de 5 p. 100, représentant un taux couramment utilisé par les services publics d'électricité dans le cadre d'analyses d'économie d'énergie. L'analyse canadienne utilise un taux d'escompte réel de 10 p. 100.

L'analyse de l'incidence sur le macromarché représente le deuxième facteur quantitatif clé. On a élaboré une feuille de calcul modèle afin d'y représenter la pénétration sur le marché et les améliorations de l'efficacité énergétique qui en découlent, en fonction de chacune des nouvelles technologies et pratiques. On a également effectué une analyse de l'incidence sur le macromarché canadien en plus de l'évaluation du marché américain.

Le classement selon les « chances de succès » représente un facteur qualitatif et un indicateur clé dans l'analyse et le choix de l'ordre de priorité attribué aux technologies et pratiques émergentes. Ces dernières ont été classées par l'équipe qui a réalisé l'étude en fonction des critères suivants, selon une échelle à cinq niveaux : 1 = très faibles chances de succès; 2 = faibles chances de succès; 3 = chances de succès moyennes; 4 = bonnes chances de succès; 5 = excellentes chances de succès; les difficultés semblent tout à fait surmontables.

Étape 5 : Sélection des mesures à priorité élevée

Les 72 technologies et pratiques émergentes ont été classées selon trois valeurs quantitatives et qualitatives : les économies d'énergies possibles sur le marché, le rendement économique (coût de l'énergie économisée) et les chances de succès. Les mesures à priorité élevée laissent entrevoir des économies d'énergie potentielles de 1 p. 100 au moins de la consommation d'énergie résidentielle et commerciale prévue pour 2020; un coût d'énergie économisée inférieur à la moitié des prix de détail actuels de l'énergie et des chances de succès équivalentes à 3 et plus.

Étape 6 : Comparaison avec des études précédentes de technologies émergentes

Plusieurs des mesures figurant dans les rapports de l'ACEEE des années 1993 et 1998 ont été examinées de nouveau dans la présente étude. Ainsi, nous avons comparé, pour ces mesures, nos résultats avec les estimations fournies dans nos travaux précédents, afin de déterminer les technologies qui ont répondu à nos attentes, celles qui les ont dépassées et celles qui les ont trahies. Par ailleurs, en ce qui concerne les technologies très prioritaires qui ne sont pas contenues dans la présente étude (telles que celles dont la part de marché dépasse les 2 p. 100 ou dont la commercialisation a été repoussée au-delà de 2010), nous avons pris en considération leur situation actuelle par rapport à nos attentes.

Étape 7 : Résumé des efforts canadiens en matière de R et D

Cette étape concerne l'inclusion dans les profils des technologies et des pratiques émergentes d'une évaluation de la situation effectuée par organisme de R et D canadien en ce qui a trait aux technologies et pratiques des bâtiments. Les observations figurent au début de chaque catégorie de technologies et pratiques émergentes, et non au niveau du profil de chacune d'elles. Par ailleurs, on a ajouté aux profils distincts des observations propres au contexte canadien, le cas échéant. Les principales sources de renseignements proviennent de récentes demandes de financement présentées à l'Office de l'efficacité énergétique de RNCan (OEE), dans le cadre de l'Initiative d'innovation technologique.

Étape 8 : Estimation de l'incidence sur le macromarché canadien

L'évaluation des technologies et pratiques prises en compte lors de l'évaluation du macromarché canadien sont les mêmes que celles utilisées pour l'analyse du macromarché nord-américain. Trois mesures ont été ignorées dans l'analyse, à l'instar de la version de l'ACEEE :

- L2 : Photodétecteurs à commissionnement automatique (combinés avec L5)
- S6 : Toits commerciaux frais (ignorée, à peine plus de 2 p. 100 aujourd'hui)
- S7 : Systèmes intégrés fenêtrages/mûrs (ignorés, aucune recherche technologique en cours)

On a considéré que certaines mesures spécifiques au climat du Sud des États-Unis présentaient peu de potentiel au Canada. Elles n'ont pas été ignorées, mais on leur a attribué un niveau d'applicabilité nul.

Une base de données de tous les facteurs macros a été élaborée aux fins de calcul de l'incidence des technologies sur le marché. Pour chaque technologie, on compte parmi ces facteurs :

- le secteur (commercial ou résidentiel) et les catégories de bâtiments (p. ex, bureaux, magasins, résidences unifamiliales, etc.) auxquels la technologie s'appliquerait.
- les utilisations finales influencées par la technologie
- la forme d'énergie à laquelle recourent ces utilisations finales dans les catégories de bâtiments correspondantes
- parts des sources d'énergie, notamment celles de l'énergie électrique et de l'énergie non électrique destinées au chauffage des bâtiments et de l'eau
- applicabilité de la technologie pour chaque catégorie, p. ex., les limites techniques de l'application de la technologie
- la pénétration actuelle de la technologie sur le marché
- la pénétration éventuelle de la technologie sur le marché à la fin de la période d'étude

L'analyse macroéconomique du marché canadien comprend les économies d'énergie et la réduction connexe des émissions de gaz à effet de serre exprimées sous forme d'économies pour l'année cible de 2020, selon une projection d'un cas de base « classique » d'utilisation de l'énergie.

Le pourcentage des économies et les facteurs qui entrent en compte pour l'applicabilité technique et la pénétration sur le marché sont appliqués à la projection du cas « classique » de consommation annuelle d'énergie pour l'année 2020. Toutes les économies mentionnées dans la partie intitulée « Résultats » sont des projections d'économies d'énergie pour cette année cible. Il ne s'agit pas d'économies accrues.

E. 3 RÉSULTATS

Soixante-douze technologies et pratiques émergentes ont été étudiées en détail. Le tableau Es-1 indique le classement de ces technologies et pratiques nouvelles, en fonction des catégories suivantes : « priorité élevée », « priorité moyenne », « priorité faible », « priorité spéciale », « non prioritaire », selon trois valeurs quantitatives et qualitatives : les économies d'énergies potentielles sur le marché, le rendement économique (coût de l'énergie économisée) et les chances de succès.

Tableau ES-1. Niveaux de priorité et répartition des mesures en fonction des paramètres de classification

Priorité	Seuil des économies	CÉÉ ($/kWh)	CÉÉ, $/million de Btu (source d'énergie)	Chance de succès	Nombre de mesures
Élevée	≥ 1,0 %	≤ 0,040 $/kWh	≤ 3.16 $/ million de Btu	3–5	5–6
Moyenne	≥ 0,25 %	≤ 0,081 $/kWh	≤ 6,33 $/ million de Btu	3–5	20–27
Faible	< 0,25 %	≤ 0,081 $/kWh	≤ 6,33 $/ million de Btu	2–5	11–14
Spéciale	>~0,05 %	≤ 0,081 $/kWh	≤ 6,33 $/ million de Btu	2–5	10–19
Non prioritaire		≥ 0,81 $/kWh	> 6,33 $/ million de Btu	1–5	14–24
Total					**72**

Le rapport fournit des résultats de macroévaluation distincts relatifs aux États-Unis et au Canada. Les résultats canadiens sont résumés dans le présent document.

Les technologies et pratiques émergentes présentant le plus grand potentiel correspondent à une variété de types de mesures, allant du changement des pratiques relatives à la conception jusqu'au changement technologique. Le changement des pratiques ayant trait à la conception offre un potentiel plus élevé, car les économies qu'elles permettent de réaliser touchent toutes les utilisations finales et parce qu'elles s'appliquent à un très grand nombre de bâtiments. La forte incidence des technologies et des pratiques émergentes touche également les utilisations finales de l'énergie étant donné les économies considérables réalisées grâce au développement des systèmes d'éclairage et de CVC, des moteurs et des appareils électroménagers.

Voici les dix meilleures technologies et pratiques émergentes, classées en fonction des économies d'énergie de macromarché :

Nº 1. PR3 – Conception intégrée des immeubles commerciaux de niveau LEED (30 p. 100 > Code)

Cette pratique émergente permettra d'économiser jusqu'à 176 PJ dans le secteur commercial canadien d'ici 2020. Son plus grand potentiel réside dans les bureaux (secteurs privé et public) et les immeubles de magasins, car ces derniers ont le plus grand pourcentage de surface utile du secteur.

Nº 2. PR2 - Conception d'immeubles commerciaux à consommation d'énergie ultra faible (50 p. 100 > Code)

Cette pratique émergente permet des économies d'énergie considérables pour des raisons très semblables à celles données pour la catégorie PR1, mis à part le fait que les économies par immeuble seraient plus élevées. Quant à la catégorie PR3, les bureaux et les immeubles de magasins offrent le potentiel le plus élevé.

Nº 3. S1 - Fenêtres à haute isolation (U < 0,25)

Les fenêtres étanches de haute technologie permettent d'économiser jusqu'à 20 p. 100 de l'énergie utilisée dans le chauffage et la climatisation résidentiels et elles peuvent être techniquement adaptées à n'importe quel type de maison, allant de la maison unifamiliale aux appartements. Du point de vue régional, les économies les plus importantes sont réalisables dans les régions où les hivers sont les plus rigoureux, car environ 85 p. 100 des économies d'énergie proviennent du chauffage local.

Nº 4. D1 - Moteurs perfectionnés d'appareils électroménagers

Ces moteurs permettent d'économiser jusqu'à 60 p. 100 de l'énergie utilisée par les moteurs classiques et ils peuvent s'adapter à toutes les pompes commerciales ainsi qu'à 20 p. 100 à 25 p. 100 des appareils électroménagers résidentiels. Leur plus grand potentiel réside dans les appareils électroménagers installés dans les maisons unifamiliales.

Nº 5. H20 - Chaudières perfectionnées à condensation

Ces chaudières permettent d'économiser jusqu'à 33 p. 100 de l'énergie utilisée par les chaudières classiques et elles peuvent être installées dans tous les immeubles commerciaux équipés de systèmes de chauffage à eau chaude. Leur potentiel le plus élevé réside dans les bureaux et les immeubles de magasins, car ceux-ci représentent la plus grande surface utile dotée de système de chauffage à eau chaude; cela dit, les écoles et les établissements de santé ont, eux aussi, un grand potentiel.

Nº 6. L15 – Éclairage scotopique

Cette technologie émergente offre un grand potentiel, car la réduction de l'énergie consommée par l'éclairage peut atteindre 30 p. 100 dans tous les immeubles commerciaux utilisant un éclairage fluorescent et auxquels cette technologie s'applique. Son potentiel le plus élevé réside dans les bureaux et les immeubles de magasins, étant donné leur grande surface utile.

Nº 7. R1 – Réfrigération par semi-conducteurs (Cool Chips^{MC})

Cette technologie émergente offre un grand potentiel, car elle permet d'économiser jusqu'à 40 p. 100 de l'énergie utilisée pour la réfrigération et elle est applicable à tous les types de réfrigération commerciale et résidentielle. Son plus grand potentiel se trouve dans la réfrigération dans les maisons unifamiliales.

Nº 8. W1 – Chauffe-eau à condensation

Cette technologie émergente offre un potentiel élevé, car elle permet d'économiser jusqu'à 29 p. 100 de l'énergie utilisée pour l'eau chaude résidentielle dans toutes les maisons unifamiliales et les maisons mobiles non équipées de chauffe-eau électrique. Son plus fort potentiel réside dans les maisons unifamiliales isolées, étant donné le grand nombre d'unités de logement qu'elles représentent.

N° 9. A1 – Puissance en stand-by d'un watt pour les appareils électroménagers

Cette technologie émergente offre un grand potentiel, car elle permet d'économiser jusqu'à 60 p. 100 de l'alimentation de secours pour tous les appareils électroménagers et les équipements électroniques résidentiels qui sont dotés d'une alimentation de secours. La pénétration du marché de ces appareils électroménagers pourrait atteindre 100 p. 100 d'ici 2020.

N° 10. L14 – Appareils d'éclairage fluorescent linéaires à tube unique avec tube à haut rendement

Cette technologie émergente offre un grand potentiel, car elle permet d'économiser jusqu'à 42 p. 100 de l'énergie utilisée pour l'éclairage fluorescent dans les bureaux, les écoles et les établissements de santé.

Recommandations et étapes suivantes pour le Canada

L'analyse macroéconomique canadienne aboutit aux mesures à priorité élevée suivantes, énumérées dans l'annexe E.2.

DISCLAIMER

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PART 1: THE CORE REPORT

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

This report profiles emerging technologies and practices for the buildings sector in North America. This report is the result of an extensive collaborative study directed by the American Council for an Energy Efficient Economy (ACEEE) and involving government, utility, research institution and consulting personnel in the U.S. and Canada. This is the third assessment of emerging technologies and practices conducted in the past decade and builds on the experience and methodology refined under the two previous studies.

The scope of this study has been enhanced to reflect the interests of some of the collaborative sponsors and participants, which specifically has translated into reporting at the following levels of differentiation: i) a U.S. market perspective, ii) a Canadian market perspective; and iii) a California-specific focus. This document consolidates the results of the U.S. and Canadian perspectives into one report. The core report is referred to as the ACEEE version. Clearly integrated into the core report are the results of the Canadian specific analysis.

In 1993 and 1998 respectively, the American Council for an Energy Efficient Economy (ACEEE) and collaborating organizations published studies of emerging technologies (Nadel and others 1993; Nadel and others 1998). Each study profiled and analyzed approximately 100 technologies which had been recently commercialized or were expected to be commercialized over the next decade for application in the buildings sector. The studies examined technologies in the appliance, lighting, HVAC, water heating, drive power, office equipment, and miscellaneous end-uses. For each technology, likely costs, commercialization date and potential energy savings were examined, leading to a recommended set of high priority technologies with the largest potential for cost-effective energy savings.

These studies brought many technologies to the attention of utilities, government agencies (e.g., DOE and EPA), and other energy-efficiency professionals, and contributed to the advancement of energy efficiency in a substantial way. The first study (1993) contributed to such initiatives as the Consortium for Energy Efficiency's residential clothes washer and high-efficiency commercial air conditioner initiatives, the Department of Defense's incandescent replacement light bulb procurement, and EPA's involvement in Lawrence Berkeley National Laboratory's aerosol duct-sealant project. The second (1998) study pointed particularly to HVAC, lighting, and integrated design for new buildings as measures with the highest priority. Since the 1998 study was published, substantial progress has been made on quite a few of these measures. High-efficiency vertical-axis clothes washers are now produced and marketed by several manufacturers. Commissioning of existing buildings and aerosol-based duct sealing are receiving increased attention from program operators, building owners, and HVAC companies. Integrated new home design is incorporated into both the ENERGY STAR® Qualified New Homes program and the Building America program and tens of thousands of such homes are being built annually. Plus, many products featured in this study have entered the market including reduced-cost CFLs, ceramic metal halide lamps, “low leak” home electronics, compact fluorescent floor and table lamps, heat reflecting roofing materials, heat pump water heaters and new fuel cell and microturbine products.

Not surprisingly, the information in the 1993 and 1998 studies is now somewhat dated. Some technologies are now competing in the mainstream market and are no longer "emerging," others have faced difficulties in achieving substantial market deployment and adoption, and additional new technologies continue to be developed. Recognizing the need to update and expand upon the earlier work, several of the original sponsors and some new ones agreed to fund a new Emerging Technologies study. The consulting team for this study comprises the ACEEE, Davis Energy Group (DEG) and Marbek Resource Consultants, Inc. This study completely revises the earlier studies, starting with a new reconnaissance of technologies and practices. In addition, an even greater emphasis was placed on non-utility follow-up activities for each technology and practice (including both research and development, and commercialization/market transformation actions).

1.2 THE CANADIAN VERSION

Natural Resources Canada (NRCan) became a co-funder and collaborator in this study, through the CANMET Energy Technology Centre (CETC-Ottawa) Building Energy Technology Group. CETC supports Canadian federal government buildings energy management technology research, development and deployment. Participation in this study is considered to be a valuable building block in laying the foundation for a clear and rational selection of future science and technology (S&T) activities, particularly given CETC's strategic role vis-à-vis the federal Program of Energy Research and Development (PERD) and other collaborations with North American and overseas organizations.

As a result of the NRCan funding participation, this third ACEEE study is enhanced with a Canadian specific analysis. The specific Canadian "add-ons" are:

- The inclusion to the emerging technology (ET) profiles of Canadian performance impacts, specifically, a Canadian lifecycle costing and savings analysis and commentary on the Canadian market context.
- A Canadian estimate of the potential market energy and GHG impacts of the ET market penetration.

1.3 OBJECTIVES, OUTPUTS, SCOPE AND DEFINITIONS

The primary objective of this assignment is to establish a user friendly, updatable database and analysis of emerging energy efficient technologies for the Canadian buildings sector.

The secondary objectives of this study are:

- To identify new research and demonstration projects that could help advance high-priority emerging technologies
- To identify potential new targets for market transformation activities
- To gain new insights into the technology development and commercialization process by comparing 1998 expectations with 2009 realities (based on the ACEEE version).

The outputs from this study are:

- An emerging technologies and practices report
- An analysis of the potential micro and macro impacts of the emerging technologies and practices.
- Spreadsheets containing the data and analysis for each technology.

The project scope covers the residential and commercial sectors, including measures that are used in and on buildings. Both energy-saving technologies (*e.g.,* a new air conditioner) and practices (*e.g.,* improved air conditioner installation procedures) are included. The inclusion of technology and practice (T&P) "measures" was bounded as follows:

- T&Ps that save energy, including more efficient generation sources (e.g., fuel cells) and renewable energy sources appropriate for buildings are included.
- Load management measures, which only shift energy use from one time period to another, are excluded.
- Measures are included which save electricity, natural gas, oil, and propane.
- Measures that shift from one fuel source to another are included provided they save energy on a primary basis (e.g., electricity is evaluated based on the heat rate of power production) and are cost-effective to end-users on a lifecycle cost basis assuming national average energy costs.
- In order to keep the project scope to a manageable level, we needed to exclude measures with only long-term potential as well as measures that have already shown significant acceptance in the market.

For purposes of this study, "emerging technologies and practices" ("T&Ps") are defined as technologies and practices that are either commercialized but have less than a 2% market share in the relevant market, or that are not yet commercialized but are likely to be commercialized within 5 years (i.e., by 2009).

1.4 UNCERTAINTIES IN THE ANALYSIS AND OTHER CAVEATS

Readers should view the quantitative outputs of the report as indicative, rather than definitive. There is a considerable range in the quality of the input information and data. The criteria for determining the quality of the data include: precision, source (e.g., does it come from an independent authority?), basis for the data (e.g., does the data come from a small sample of research, development and deployment experience?). Since many of the technologies and practices covered, whether presently commercialized or not, are still just niche products, estimates of measure cost, savings, and commercialization date are generally imprecise.

In view of the data quality limitations, the results should be viewed as the midpoint of a range, with endpoints 10% to 50% higher and lower than the midpoint. The size of the range varies according to how the quality of the data was rated for each measure. In some cases data were obtained from several sources and there was general agreement between sources as to specific data values. Many of these cases included data obtained from independent analysts who do not have a vested interest in promoting a product.

Specifically, the data inputs were rated as follows:

- In cases that meet most of the criteria (designated by an "A" rating in the data quality field of the database), the range of likely values will generally be within 10-20 percent of the specific values listed.
- In still other cases, solid estimates were obtained from one source, or less precise estimates from several sources. In these cases (designated by a "B" or “C” rating in the data quality field of the database) the range of likely values is between the two extremes discussed above.
- In other cases, data were based on only preliminary estimates obtained from only one source, often a source with a vested interest in promoting the product. In these cases (designated by a "D" rating in the data quality field of the database), the range of likely values may be as much as 50 percent higher and lower than the specific values listed.

Furthermore, the results of the life-cycle costing and energy savings analyses were rounded to one significant digit—finer distinctions would be meaningless.

1.5 ORGANIZATION OF THIS REPORT

The report is comprised of 3 parts elaborated as follows

Part 1: Main Body of the Report

Part 1 reports on the study approach, method and results and is comprised of 5 chapters.

1. Introduction (this chapter)
2. Methodology: It includes step-by-step descriptions of the process and discussion of the different types of information and data collected on each measure. The assumptions specific to the Canadian market analysis are embedded in this section.
3. Results: It summarizes the results of the analysis and some of the trends that emerge from the research. The Canadian and ACEEE version results are presented separately. Additional ACEEE results are presented in Appendix A.
4. Discussion of the implications of the project: This chapter focuses on the implications of the Canadian analysis results.
5. This chapter includes recommendations, with an emphasis on steps to advance the highest priority technologies and practices.

Part 2: Technology Profiles

Part 2 comprises all of the T&P profiles consisting of approximately one-page summaries on each of the measures examined in detail in this study. The profiles describe the technology or practice, its current status, likely costs, savings, and commercialization date, and recommended next steps for advancing the measure. They are categorized and presented by technology grouping, e.g., lighting.

The Canadian context is integrated into the T&P profiles based on a review of recent submissions to the Technology and Innovation Fund.[1] The integration is organized as follows:

- The introduction to each T&P group (e.g., lighting, HVAC and so on) contains observations on the Canadian "context";
- Where pertinent, each of the individual T&P profiles contains observations particularly focused on market status and recommended follow-up.

Part 2 also comprises shorter descriptions (approximately one paragraph each) of additional lower priority emerging technologies that were screened out during the early stages of the project and for which more detailed research and analysis were not done.

Part 3: The Database

This section comprises a spreadsheet database and workbook with data input tables for each ET measure, key analytical assumptions, key market observations and the results of the quantitative analysis.

[1] In August 2003 the Government of Canada announced the Climate Change Plan for Canada, which included funding of $115 million over 5 years for the Technology and Innovation (T&I) research and development initiative. The T&I funds are targeted at five technology areas, including Advanced End-Use Energy Efficiency which addresses industry, transportation, integrated applications, and buildings & communities.

CHAPTER 2: METHODOLOGY OF 2004 EMERGING TECHNOLOGIES PROJECT

This chapter presents the methodology used in this project, methods designed to efficiently support production of three distinct reports:

1. A report analogous to the 1998 report on emerging technologies and practices for the buildings sector in the United States.
2. A report on the same technologies and practices built on the same data but adapted to a Canadian context.
3. A California-specific report. This includes revisions for climate-sensitive measures, and a supplement on five additional technologies.

In this project, we profiled 72 emerging T&Ps out of a possible candidate list of 198 measures. The method used to generate the profiles comprises the following steps:

- Development of initial measure lists
- Preliminary sorting of measures into priority categories
- Selection of measures for detailed analysis
- Detailed Data Collection
- Selection of High Priority Measures
- Comparison to Prior Emerging Technologies Studies
- Summary of Related Canadian R&D Efforts
- Estimate of Macro-economic Impact in Canada.

These steps are further elaborated below.

1. Development of Initial Measure Lists (the long list of candidates)

In order to develop a list of potential candidate measures meeting the project criteria, we used the following sources:

- Lists of emerging technologies developed for the 1998 study,
- Existing ACEEE, DEG, NRCan and Marbek databases and reports,
- Measure recommendations from energy research organizations including DOE and its national laboratories, EPA, EPRI, GRI, E Source, major utility R&D departments, and state and provincial R&D institutions. This included input from key Canadian officials involved in the buildings energy efficiency R&D community to identify candidate technologies and practices for consideration in the study,
- Recent conference proceedings and journals,
- Consultations with experts on particular end-uses including conversations with major equipment manufacturers and innovative smaller firms,
- Product and research announcement information received at ACEEE, DEG and Marbek.

This information was gathered through a literature search and phone calls to program managers at the organizations listed above.

2. Preliminary Division into Priority Categories

The initial candidate list totaled 198 measures. As a first step to narrow this list down to a more reasonable size, the measures were assigned to one of three preliminary categories: high-, medium- and low-potential measures, defined as follows:

- Low potential measures are those that are likely to have a cost of saved energy greater than current U.S. national average energy prices or that can reduce U.S. and Canadian residential/commercial energy use by no more than 0.25 percent, even when they have fully saturated appropriate markets.
- High potential measures are those that are likely to have a cost of saved energy less than 50 percent of current U.S. national average energy prices and that can reduce U.S. or Canadian residential/commercial energy use by 0.50 percent or more when they have fully saturated appropriate markets.
- Medium potential measures are those that fit neither the high nor low potential categories, or measures for which too little is known about them to quickly assign a category.

In addition, the T&P candidate list included several special cases, measures that would not save as much as 0.25%, but that should be considered for other reasons:

- "Lost opportunities": This refers to measures that can have a high impact in the new construction market. Because new construction is unlikely to account for more than 20% of the building stock over the project term, new construction measures otherwise could show no more than 20% of the effect of other measures. For many of these (e.g., glazing upgrades), the cost of retrofitting is much higher. We have considered these measures on an *ad hoc* basis.
- Measures that have great potential regionally, but limited or no impact for the U.S. and Canada as a whole. Typically, these are climate-sensitive HVAC products. For instance, a "cold-climate" heat pump that requires no resistive back-up at much lower temperatures than today's common products would be of value in northern regions. In the West and Southwest, air conditioners with evaporative condensers and high sensible heat ratios would have value, while the Southeast needs high efficiency latent heat removal, particularly in residential and light commercial buildings.

Measures were placed into categories based on findings from previous studies (including the 1993 and 1998 Emerging Technologies studies, several recent market transformation screening studies, other published work such as reports by DOE, EPA, EPRI, CRI, Platt's (formerly E Source), and national laboratories), and screening calculations conducted by the project team. High potential measures were automatically included on the list of measures analyzed under this project. Low potential measures were not researched further; but brief write-ups on these measures are included in the report.

The preliminary calculations conducted for this categorization relied on the following data sources: U.S. energy use and price data for 2003 from the Energy Information Administration's *Annual Energy Outlook 2003* report are used (EIA 2002). Canadian energy use and prices are taken from *NRCan's 2002 End-Use Energy Data Handbook* and Statistics Canada energy price information (NRCan 2002). For the California report, we use *California Energy Demand 2003-2013* published by the California Energy Commission (CEC 2003).

3. Select Measures for Detailed Analysis

The output from the previous steps was a draft list of 75 measures recommended for detailed analysis. This list, together with the list of measures that were not recommended for detailed analysis, was provided to the project advisory committee for review and comment. Based on this review process, California parties asked for (and funded) the additional work for Report 3.

4. Detailed Data Collection and T&P Profile Development

For each of the measures selected for detailed analysis and T&P profile development, over 30 data variables were collected and compiled in a database (see part 3 of this report). The data variables are grouped to provide qualitative and quantitative information on the following main categories: *the Market, the Base Case, New Measure Information, Savings Information, Cost, Likelihood of Success, Recommended Next Steps,* and *Notes.* Based on these values, as well as a review of published literature on each measure and telephone conversations with researchers and manufacturers working on the different measures, written descriptions on each measure and their status and prospects were prepared (the T&P profiles).

Part 3 of this report contains the EXCEL ET database with both the Canadian and U.S inputs. Canadian energy consumption and energy prices are used to conduct a Canadian macro-market impact assessment presented as separate set of results.

The specific database variables included in the ET database are:

Market Information:

1. Measure number (letter/number code shows end-use and sequential number for easy reference between report and database)
2. Measure name
3. Measure description (brief). One to two lines that expand upon name, e.g., central air conditioners with SEER of 14 or more
4. Market sector(s): (RES, COM, R&C, C&I, ALL)
5. End-use(s) COOK = cooking; COOL = space cooling; DISH = dishwasher; ELEC = home electronics (but excluding office equipment); HC = space heating and cooling; HEAT = space heating; LAUND = laundry; LIGHT = lighting; MOTOR = motor; OFFEQ = office equipment; REF = refrigeration; VENT = ventilation; WH = water heating; WSH = water and space heating; OTH = other)
6. Energy types (ELEC, GAS, OIL, G&O, SOLAR, ALL)
7. Market segments (NEW = new construction; RET = retrofit; ROB = replace on burnout; OEM = original equipment manufacturers

   NEW means new construction of a building, as a whole, and major renovation/major modernization projects

   RET covers activity in an existing building except those covered under ROB below. RET includes new practices in existing buildings as well as the replacement of functioning equipment with more efficient equipment

   ROB covers replacement of equipment or systems as a result of failure or tenant change-out

   OEM refers to equipment components (such as appliance motors and power supplies for consumer electronics) that are purchased by manufacturers rather than end users.

Base case Information:

8. Base case description (typical unit size and characteristics of current practice to which new measure is being compared). Our units of analysis varies by measure, depending on the most appropriate way to analyze each measure. Sometimes the analysis is for a piece of equipment such as a refrigerator, other times it is for a system, such as lighting systems, and still other times is for a whole building. The unit of analysis for each measure is specified in the base case description. For new construction and equipment replacement measures, the base case corresponds to typical new construction and equipment replacement practices in 2002/2003. However, in cases where future improvements in equipment efficiency are known due to finalized or near-finalized building code and equipment efficiency standards, we will use the new standards to determine the base case.

8a. Units for above (e.g., horsepower)

9. Base case efficiency

9a. Units for above (e.g., EER)

10. U.S. base case energy use. Energy use is calculated for typical operating conditions. For climate-sensitive measures, national average consumption was used if a measure is cost-effective nationally (on a LCC basis at projected 2020 measure costs and energy prices). If a measure is not cost-effective nationally (due to regional climate or energy price considerations), a subset of the country was explicitly defined and used uniquely for that measure. For measures that use both electricity and fossil fuels, separate numbers were listed for each energy source.

10b. Units for above (e.g., kWh, million Btu)

11. Peak energy use (based on 0.4%design temperatures in ASHRAE handbook, or available load shapes)
    a. U.S. summer peak (2pm, very hot summer day in St. Louis)
    b. U.S. winter peak (6pm, very cold winter evening in St. Louis)

New Measure Information:

12. New measure description (size and characteristics, for comparison to base case)

13. New measure efficiency

13a. Units for above (e.g., EER)

14. New measure U.S. annual energy use

14b. Units for above (e.g., kWh, million Btu)

15. Peak energy use (based on 0.4%design temperatures in ASHRAE handbook, or available load shapes)
    a. U.S. summer peak (2pm, very hot summer day in St. Louis)
    b. U.S. winter peak (6pm, very cold winter evening in St. Louis)

16. Current status of technology (COMM = commercialized; FLDTEST = field test; PROTO = prototype; RES = research)

17. Estimated date of commercialization (may be a range or an approximate figure, e.g., ”2003-2005" or ”~1995")

18. Estimated measure life (years). These are average installed lives in the field, not engineering lives in a laboratory. Available data (*e.g.,* ASHRAE Handbook, Applications, 2003) are of limited accuracy, but are often the best available.

Savings Information:

19. U.S. and Canadian electricity savings/year (of new technology relative to base case)
20. Peak demand savings (based on 0.4%design temperatures in ASHRAE handbook, or available load shapes)
    a. U.S. summer peak (2pm, very hot summer day in St. Louis)
    b. U.S. winter peak (6pm, very cold winter evening in St. Louis)

    For many technologies, there are better energy savings than demand savings data. In some cases, we have used available empirical correlations, as noted for each affected T and P.
21. U.S. and Canadian gas/fuel savings/year (of new technology relative to base case)

21a. Units for above (e.g., therms, gals., Btu)

22. Percent savings (of new technology relative to base case). Where a measure affects both electric and fossil fuel use, the percentage reduction in energy use was based on source energy savings using the projected national average heat rate for electricity generation in 2020.
23. Feasible applications are the approximate percentage of end-use applications for which each T&P is likely to be appropriate. This figure includes both technical and economic feasibility. "Feasible" means the fraction of technology and practice applications *nationally* that would be amenable to the improved T or P for the target market.
    For most measures, this is done on a national basis. But, if the target market is new construction in the southeast, % feasible applies to that percent of new construction in the southeast that is feasible. Any restrictions (*e.g.,* new construction only, limited regional applicability) were made as a coefficient in the calculated 2020 savings potential, not in the "feasible applications" parameter. Feasibility does *not* take into account the likely commercialization date of the technology (Variable 17) nor the rate at which the equipment or building stock turns over (Variable 18). See Appendix A for assumptions on T&P market applicability and penetration.
24. Annual U.S. and Canadian savings potential in 2020: GWh

24a. Annual U.S. and Canadian savings potential in 2020: trillion Btu (source energy)

For variable 24, potential energy savings were estimated for the U.S. using base case data by end-use from the Energy Information Administration's *Annual Energy Outlook 2003*. For Canada, potential energy savings were estimated using the June 2002 NRCan's End-Use Energy Data Handbook as the main sources for the baseline energy end-use profiles.

The formula for estimating the macro-market energy savings was to compute the product of projected energy use in 2020, for the affected end-use, times the energy savings of the feasible applications times the proportion of the market that could be impacted by 2020. The proportion of the market that could be impacted by 2020 was determined on the following basis:

- For retrofit measures, it was assumed to be 100%
- For replacement measures (measures which are installed when existing equipment needs to be replaced), this proportion was calculated assuming that sales between 2005 and 2020 are affected. For these calculations, we assumed gradually rising sales, with a 10% penetration rate for applicable markets in 2005, 20% in 2006, etc., rising to 100% in 2014 and continuing at 100% for subsequent years.[2] For replacement

[2] In the 1998 study we assumed 100% penetration in the first year of the analysis and thus savings in the 2004 study will generally be lower than savings estimated in the 1998 study.

measures not yet commercialized, the savings potential only includes sales after the date of commercialization and thus for measures commercialized after 2005, the ramp-up begins in the year of commercialization.

– For new construction measures, the same approach was used as for replacement measures except that savings estimates include only buildings built in 2005 or thereafter. Thus, the energy savings estimates essentially are for the technical and economic savings potential. Such savings may be achievable for measures with a likelihood of success rating of five (the maximum score) and for which full turnover of the stock will take place by 2020. For measures with a lower likelihood of success, penetration rates will probably be lower, but this difference is captured in the likelihood of success score and not the energy savings score. For measures that save one fuel but use more of another fuel (e.g., gas air conditioning which saves electricity but uses gas), energy savings are expressed in Btu, valuing electricity at 10,010 Btu/kWh. It should be noted that savings often overlap between measures and that savings across measures are frequently not additive. Also, given the many assumptions made in the calculations, these estimates should be viewed as approximate and not absolute. For this reason, national savings estimates will be rounded to the nearest GWh or trillion Btu.

25. Industrial savings indicator: A Yes/No variable was used to indicate if savings in industrial sector are likely to equal or exceed at least 25 percent of savings in residential and commercial sectors (from item above).

Cost Information:

26. Retail (consumer) incremental cost (relative to base case): This is estimated based on the assumption that the technology is established and has attained mature market costs. Costs are in 2003 U.S. and Canadian dollars. For commercial sector measures, costs are in quantities used in a medium-sized office/retail building; for residential sector measures, costs are in single-unit quantities.
27. Other direct costs/savings ($/year). This refers to other important costs included in the analysis (*e.g.*, additional or avoided maintenance costs and additional or avoided operating costs such as water, detergent, or use of a secondary energy source). The specific assumptions are included in notes and write-up for technologies and practices affected. This includes demand charge savings where these are significant. For fuel switching measures, the cost of the new fuel is included as a cost and the cost of saved energy is calculated in terms of the fuel that is displaced. For periodic costs in the future (e.g., maintenance every five years), costs were annualized, assuming a 5 percent real discount rate.
28. U.S. and Canadian cost of saved energy ($/kWh)

28a. U.S. and Canadian cost of saved energy ($/million Btu)

Variable 28 reflects both equipment costs and other direct costs/savings.

The *Cost of Saved Energy* (CSE) is the levelized cost of a measure over its lifetime per unit of energy saved. It is calculated by assuming each measure is financed with a loan, with a term equal to the measure life and an interest rate equal to the discount rate, and dividing the annual loan payments by the annual energy savings.[3]

[3] The specific formula used for Cost of Saved Energy is:

The CSE calculations are based on future mature measure cost estimates. The U.S. analysis uses a 5 percent real discount rate, where 5 percent is a figure commonly used by electric utilities for energy-saving analyses.[4] The Canadian analysis uses a 10% real discount rate.[5]

For measures that save both electricity and natural gas, we allocated costs proportionately to the two fuels based on the primary energy savings achieved and calculated CSE separately for electricity and gas. For measures that have annual operating costs or savings besides energy (e.g., reduced or increased maintenance costs), changes in annual maintenance costs were included in the costs calculations. For example, for a measure that increases maintenance costs, costs included in the total were annualized capital costs and the incremental increase in maintenance costs. In some cases, savings in other costs are greater than annualized measure costs and the CSE is negative. For these measures we insert the word "negative" in the CSE field because once a CSE is negative, the exact value is immaterial and often misleading (for example, if costs are negative, the CSE declines as energy savings decline). For measures that save one fuel but use more of another fuel, the CSE was calculated for the fuel being saved, but including the annual cost of the other fuel in the cost part of the calculations. For example, to calculate the CSE of gas air conditioning, costs include annual loan payments on capital costs, annual natural gas costs (valued at EIA projected values for 2020 but expressed in 2003 $), and incremental annual maintenance costs. As with the energy savings estimates, these figures depend on many assumptions and estimates and are highly approximate. Given the many assumptions made in the calculations, these estimates should be viewed as approximate and not absolute. For this reason, the CSE output was rounded to the nearest cent.

29. Data Quality Assessment: (quality/accuracy of data on each measure, rated on a A-D scale, where A=very good, B=good, C=fair, and D=poor). For an A rating, data needed to be available from several sources, with general agreement among these independent sources on specific data values. Many of these cases include data obtained from independent analysts who do not have a vested interest in promoting a product. For a B rating, solid estimates from one source, or less precise estimates from several sources. For a C rating, preliminary estimates were available from only one source, often a source with a vested interest in promoting the product. For a D rating, data are essentially a "guesstimate" with no source willing to support a firm number.

Likelihood of Success:

30. Major market barriers (brief list). Examples include third-party decision makers, high initial costs, and contractors unfamiliar with proper installation practices.

$$\frac{(\text{Measure Cost} \times \text{Capital Recovery Factor}) + \text{Annual Other Costs/Savings}}{\text{Annual kWh Savings}}$$

Capital Recovery Factor = ((1+D)L-1 × D) ÷ ((1+D)L - 1) where D is the discount rate and L the measure life.

[4] See for example PG&E, Annual Summary Report on DSM Programs in 1995 and 1996 and DOE, A Final Rule, Energy Conservation Program for Consumer Products: Energy Conservation Standards for Refrigerators, Refrigerator-Freezers and Freezers,@ April 1997.

[5] This value was provided by The Analysis and Modelling Group of Natural Resources Canada. A discussion on this variable can be found in Chapter 4, section titled "Discussion on key variables affecting the Analysis"

31. Effect of measure on customer utility (non-energy benefits and problems). Examples include cleans clothes better, increases worker productivity, or more difficult to maintain, etc.
32. Current activity promoting measure (a brief summary of who is doing what)
33. Likelihood of success rating (1-5 scale), where success is defined as penetrating at least 50 percent of feasible applications by 2020. Guidelines for these ratings are discussed further below.
34. Rationale for likelihood of success rating.

    Values for variables 33 were determined qualitatively for each measure according to the likelihood with which market and technical barriers can be overcome, using the 5-point scale indicated below. Significant non-energy benefits can also offset some of the barriers and improve the likelihood of success, so where these exist, the likelihood of success is increased by 1 point on the 5-point scale.

    1 = Will be very difficult to succeed; there are multiple major barriers that will be difficult to overcome.

    2 = Will be hard to succeed; there are major barriers to overcome and while some progress can be made, substantial barriers will likely remain.

    3 = Moderate chance of success; there are substantial barriers to overcome, some major barriers can be overcome, but others will likely remain.

    4 = Good chance of success; the barriers appear surmountable but will require extensive effort and time to overcome.

    5 = Excellent chance of success; barriers appear to be clearly surmountable.

The project team prepared initial estimates of likelihood of success ratings and shared these preliminary values with the project Advisory Committee for review and comment. Based on these comments, some of the ratings were revised. In this way, the ratings reflect the consensus judgment of the people working on the project.

Recommended Next Steps: This identifies plausible steps to support and increase the probability for market deployment and adoption.

Sources:

35. Using author/year format; multiple references are separated with semi-colons. If there is more than one source for a given author/year, a, b, etc. are used after the year (e.g., Suozzo 1997a, Suozzo 1997b).
36. Savings estimates
37. Peak demand estimates
38. Cost estimates
39. Feasible application estimates
40. Measure life estimates
41. Other key sources
42. Principal contacts (name, organization, phone number for people; sometimes includes

organization web page address).

Notes:

43. This section of the data sheet includes important comments such as key assumptions made to calculate some of the above values; more extensive notes are included in the written report.

5. Selection of High Priority Measures

In ranking measures we recognize that measure scores are inexact and that small score differences are meaningless. We also recognize that no objective ranking process can capture the full range of issues that need to be balanced in order to fully assess potential initiatives. However, ranking measures helps separate high priority measures from low priority measures. Ranking also allows consideration of other issues to be focused on a limited number of measures that appear to be high priority.

For this study, the T&P measures were divided into the following categories: “high,” “medium,” “lower,” “not a priority” and “special” categories, based on three factors: potential energy savings, cost of saved energy, and likelihood of success.

- High priority measures are those that meet the following three criteria: potential energy savings of at least 1 percent of projected U.S. residential and commercial energy consumption in 2020; a cost of saved energy less than half of current U.S. retail energy prices; and a likelihood of success rating of 3 or more.
- Medium priority measures are those with potential energy savings of 0.25 to 1.0 percent of projected residential and commercial energy use in 2020; a cost of saved energy less than current retail energy prices; and a likelihood of success rating of 3 or more.
- Low priority measures are those with potential energy savings of less than 0.25 percent of projected U.S. residential and commercial energy consumption in 2020, a cost of saved energy less than current retail energy prices; and a likelihood of success rating of 2 or more.
- Special measures are those that will not save as much as 0.25%, but are included because they are particularly important for new construction or in specific regions (details on this category were provided earlier in this Chapter).
- “Not a priority” measures are those with a cost of saved energy greater than current retail energy prices or a likelihood of success of 1. The differences among these priority categories are summarized in Table 1.

Table 1. Criteria for T&P Measure Priority Ratings

Priority	Threshold	CSE, $/kWh	CSE, $/MMBtu (source energy)	Likelihood of success
High	≥ 1.0%	≤ $0.0405/kWh AND	≤ $3.16/MMBtu	3 – 5
Medium	≥ 0.25%	≤ $0.081/kWh AND	≤ $6.33/MMBtu	3 – 5
Low	< 0.25%	≤ $0.081/kWh AND	≤ $6.33/MMBtu	2 – 5
Special	>~0.25% but important for new construction or in specific regions	≤ $0.081/kWh AND	≤ $6.33/MMBtu	2 – 5
Not a Priority		≥ $0.81/kWh AND	> $6.33/MMBtu	1 – 5

6. Comparison to Prior Emerging Technologies Studies

Many of the measures examined in the 1993 and 1998 reports were reexamined in this study. For these measures, the ACEEE version contains a comparison of the study findings with expectations from prior work in order to see which technologies fared as well as expected, which fared better and which fared worse. In addition, for the 1998 high priority technologies that are not included in this study (which is the case if they now have more than a 2 percent market share or if their commercialization date is delayed beyond 2010), we looked at their current status in relation to our expectations. All of the 1998-2004 comparisons are summarized on a measure-by-measure basis. In addition, we examined these comparisons for trends across measures, particularly trends that teach useful lessons about the technology and practice development, commercialization and diffusion process. The results of this assessment can be found in Appendix A.

7. Summary of Related Canadian R&D Efforts

The Canadian context in the T&P profiles is expressed in two ways. As previously noted, at the outset of each T&P category we provide observations appropriate to that T&P category. Secondly, each individual T&P profile may include, on a case-by-case basis, specific observations unique to the Canadian context.

The observations of the Canadian context pertaining to the T&P profiles are drawn largely from a review of recent submissions to the Technology and Innovation (T&I) research and development initiative. In August 2003 the Government of Canada announced the Climate Change Plan for Canada, which included funding of $115 million over 5 years for the T&I initiative. The T&I funds are targeted for 5 technology areas, including Advanced End-Use Energy Efficiency which addresses industry, transportation, integrated applications, and buildings & communities. The Building Energy Technology (BET) group of CANMET Energy Technology Centre (the energy R&D arm of Natural Resources Canada) has been tasked with administration of the buildings and communities stream of the T&I initiative. In early 2004 BET issued a Request for Applications for "Phase 1" applications under this stream of the fund. Marbek conducted a review of these submissions in order to glean relevant material.

The T&I information reviewed by Marbek is presented in Part II of this report and pertains *only* to specifics, unique situations, and current R&D efforts in Canada as expressed in the T&I funding applications. It is also important to note that, since the T&I submissions were made to 'secure funding for R&D,' they highlight many opportunities and few challenges. As such, these Canadian observations need to be seen as preliminary in nature and lacking a full picture on the challenges facing the emerging T&Ps in the Canadian buildings sector.

8. Estimate of Macro-economic Impact in Canada

The method employed to derive the Canadian macro-market impact involved the following steps:

- **Review all of the profiles in the ACEEE ET inventory:**

The focus of this review was to determine which of the overall study T&Ps should be screened out of the analysis. The only measures completely eliminated from the Canadian analysis were those that did not survive the process of finalizing the ACEEE report. There were three measures that were dropped from the list late in the analysis process, each for different reasons. They were not resurrected for the Canadian version of the inventory. They included:

- L2: Self-Commissioning Photosensors (combined with L5)
- S6: Commercial Cool Roofs (dropped, over 2% market share today)
- S7: Integrated Window/Wall Systems (dropped, no current work on technology)

All remaining measures were retained in the analysis process. During the process of assessing applicability within Canada, some measures targeted specifically at climates in the southern United States were found to have very little potential in Canada. Most of these were air conditioning measures whose primary potential lies in hot, dry regions or hot, humid regions. **These measures were not omitted from the analysis, but were instead included in the model and assigned an applicability level of zero.** If more up-to-date information is found indicating that there is some potential for these measures, the Canadian analysis model can be changed accordingly. Some of these measures may be valuable for reducing peak loads during the air conditioning system, for utilities that experience capacity or distribution constraints during the summer. The following cooling/dehumidification measures fall in this category:

- H3: Heat Pipes for Air Conditioning Dehumidification
- H4: Free-standing Efficient Dehumidifiers to Augment Residential Central Air Conditioning
- H5: Hot-Dry Climate Designs
- S4: Attic Foil Thermal Envelope
- S5: Residential Cool Color Roofing
- W3: Heat Pump Water Heaters (space cooling is a major side benefit for cooling-dominated climates, but not for heating-dominated climates)

Some of the T&Ps were divided in two for the analysis. As an example, L11, LED Lighting, was split into L11a, Residential LED Lighting, and L11b, Commercial LED Lighting. As a result, the total number of T&Ps with applicability in the Canadian context was 68.

▪ **Compile macro-drivers for the analysis:**

A database was developed of all the macro drivers to calculate the market impact of the ETs. Readers can refer to the Part 3 database, specifically, the following worksheets: data, base energy and Canadian factors.

For each technology, these drivers included the following:

- Commercial and residential building segments (e.g., office, retail, single-family dwellings, etc.) to which the technology would apply and End-uses affected by the technology:

  Information on the applicable segments and end-uses, as well as the current penetration of the technology, was drawn in large part from the ACEEE version. It is assumed that the target markets are largely the same and that the current market penetration is also similar within North America.

- Energy used for those end-uses within the applicable building segments/Fuel shares, specifically the allocation between electricity and non-electric fuels for the heating and domestic hot water end uses:

  Energy consumption and fuel shares, by end use and building segment, were obtained from the End Use Database maintained by the NRCan Office of Energy Efficiency (OEE). Staff at OEE provided the supporting spreadsheets used to develop the summary tables on the OEE website. These supporting spreadsheets provided the detailed dis-aggregation required to conduct this analysis.

- Applicability of the technology to each segment, e.g., the technical limitation on application of the technology

- Current penetration of the technology

- Potential penetration of the technology by the end of the study period.

To establish values for technical applicability and potential penetration by 2020, Marbek drew on the information developed for the ACEEE report, previous technology profile projects conducted for NRCan, and extensive utility demand-side management studies conducted in the past two years.

▪ **Design simplified spreadsheet model to operate the analyses:**

The spreadsheet model is structured around the following central equation, using a lighting measure as an example:

$$Savings = \sum_{i}^{n} Svgs_{Unit} \times EnUse_{Lighting,i} \times Applicability_i \times (Pen_{2020,i} - Pen_{2004,i})$$

Where: Savings = Energy savings potential for this lighting technology (PJ)
i = the current building segment
n = the number of building segments to which this technology applies
$Svgs_{Unit}$ = Energy savings per unit (fixture, etc.) as previously estimated (%)
$EnUse_{Lighting,i}$ = Energy use for lighting in building segment i (PJ)
$Applicability_i$ = Estimated applicability of the measure in building segment i, accounting for saturation of the end use (e.g., what fraction of lighting is general fluorescent lighting), fuel shares, and technical limitations (%).
$Pen_{2020,i}$ = Estimated penetration of the technology in building segment i by 2020, accounting for new construction, stock turnover, and renovation (%)
$Pen_{2004,i}$ = Current estimated penetration of the technology in building segment i (%)

For technologies affecting both electricity and non-electric fuels (such as heating technologies), the savings potential was calculated in two parts. The electricity savings percentage and the non-electric fuels savings percentage were often not the same for a given technology – a fuel cell is an excellent example, saving considerable electricity but usually causing an increase in natural gas consumption. The energy use for each building segment was split into electricity and non-electric fuel energy using the fuel shares available from OEE. The remaining factors were the same for both calculations.

The spreadsheet model was used to sum the results for all building segments and end-uses affected by each measure.

Finally, appropriate factors were used to convert electricity savings and non-electric fuel savings into greenhouse gas emission reductions. The factors were taken from those used in the NRCan Federal House In Order (FHIO) program. Blended average emission factors were used for non-electric fuels in the residential and commercial sectors, based on the national fuel shares for each of the two sectors. The emission factors are:

- For electricity: 150.5 kg CO_2e per GJ of electric energy (or 150,500 tonnes CO_2e per PJ).
- For non-electric fuel consumption: 53.6 kg CO_2e per GJ for commercial (or 53,600 tonnes CO_2e per PJ) and 47.8 kg CO_2e per GJ for residential (47,800 tonnes CO_2e per PJ). The main source of difference between the two sectors is the greater proportion of wood used for heating in the residential sector: wood is considered to have a neutral impact on GHG emissions.

- **Express Results as Savings in the Target Year:**

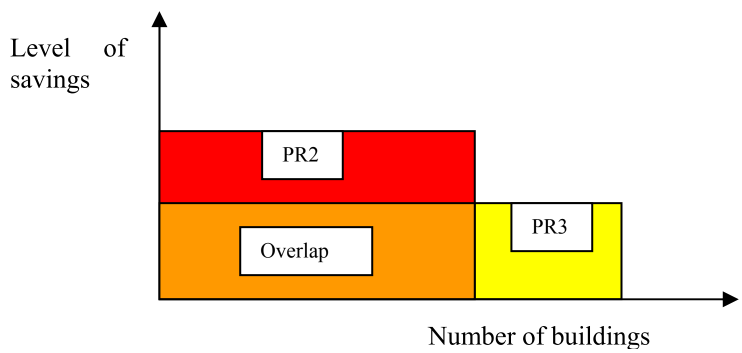
The main analysis outputs include energy savings and associated greenhouse gas emission (GHG) reductions. In both cases, these results are expressed as savings in the target year, 2020 relative to a "business as usual" scenario. Recent figures for annual energy consumption by building segment and by end-use were obtained from the OEE. These figures were segregated into electricity consumption and non-electric fuel consumption. Projected growth rates by building segment were used to develop consumption figures for buildings that will be constructed between now and 2020. The total of the current consumption and the consumption for these new buildings provide a “Business As Usual” energy consumption for 2020.

The savings percentage and the factors that account for technical applicability and penetration are applied to the projected business as usual annual energy consumption for 2020. **The total savings presented in the results section are projected energy savings in that target year. They are not accumulated savings.**

Similarly, the greenhouse gas emission reductions, calculated through the application of standard emission factors, are also reductions from the Business As Usual scenario for the single target year, 2020.

The results presentation includes subtotals for each major category of T&Ps, but these subtotals are notional only. No attempt has been made to avoid double-counting of energy savings and GHG reductions. For example, PR3, Integrated Commercial Building Design to 30% below code, and PR2, Ultra Low Energy Commercial Building Designs to 50% below code, would overlap approximately as shown in Figure 1.

Figure 1 Overlap Between Different T&Ps



CHAPTER 3: RESULTS

This chapter presents the results of the ET analysis. The results are presented as a set of decision parameters using a ranking of several parameters: energy savings, likelihood of success, CSE and, finally, looking at a combination of parameters.

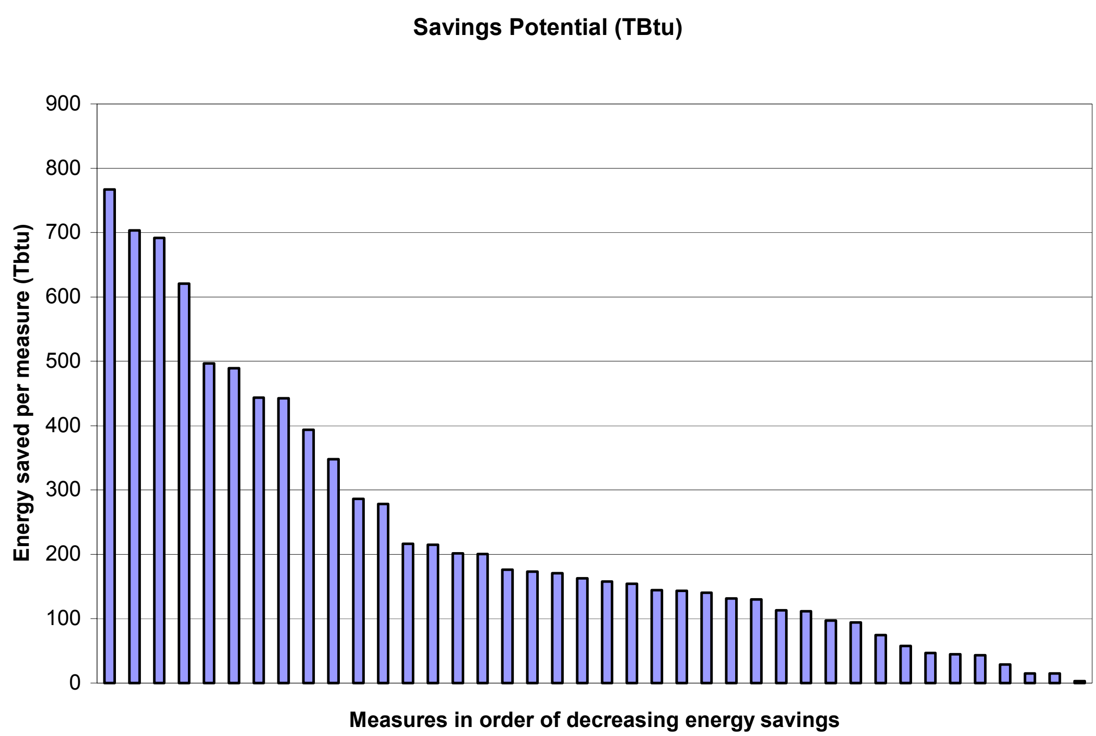
The results of the ACEEE version and the Canadian assessment are presented separately.

3.1 ACEEE VERSION RESULTS

The ACEEE version results are presented in this sub-section and in Appendix A. In this sub-section we present the results according to: energy savings, CSE, likelihood of success and a combination of these factors. Appendix A presents: a comparison of the 1993 and 1998 studies,

Energy Savings. In this study, the first parameter used to establish priorities is the quantity of energy that the measure could save in 2020. As indicated in Chapter 2, High Priority measures save at least 1.0% of total commercial and residential energy; medium priority more than 0.25% of the total, and low priorities show even smaller savings. Figure 3.1 shows energy savings by measure, from largest to smallest, exclusive of the "special" measures. "Special" measures should save at least 3% of energy use by new buildings or in specific regions.

Figure 3-1. Rank-ordered measures by total energy savings potential (without "Special" cases)

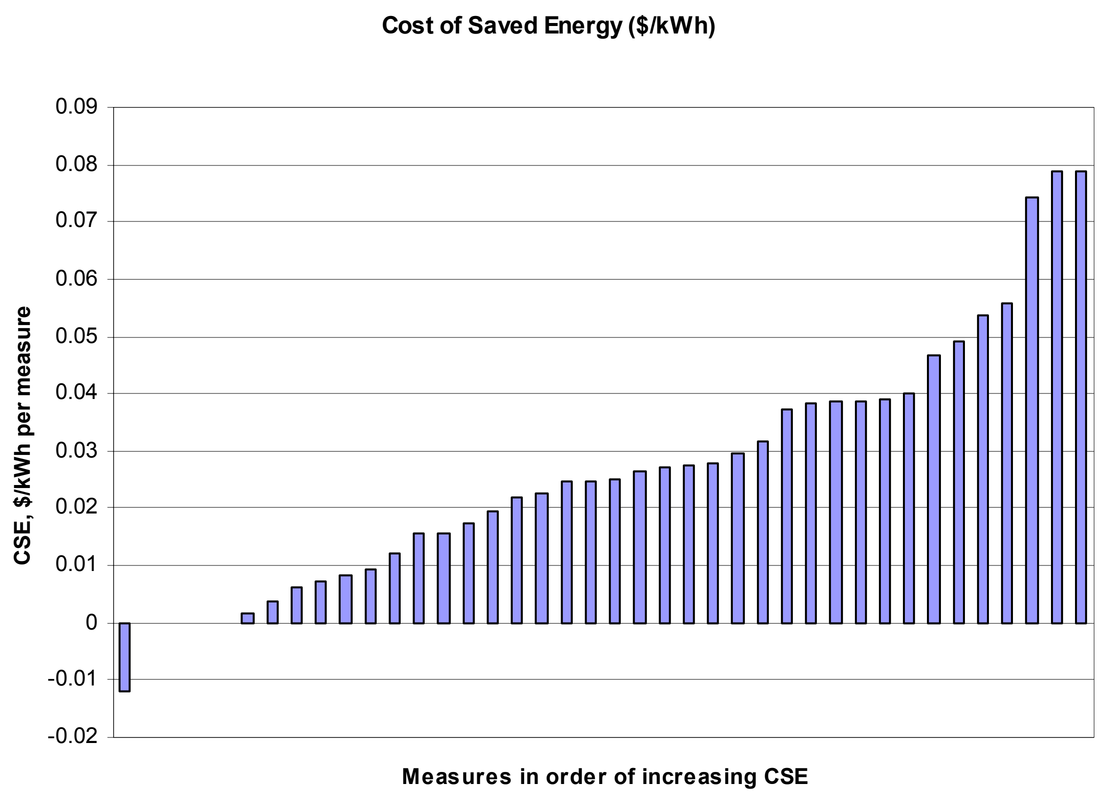


In terms of the study priorities, five or six measures are estimated to save at least 1% of commercial and residential buildings energy use in 2020 (given analytical uncertainties). These include automated building diagnostics, two HVAC measures (leak proof duct fittings, aerosol-based duct sealing), 1-watt standby power for electronic devices, and two practices: Integrated design practices (IDP) and LEED, with efficiency at least 30% better than Code.

Another 17 measures would save at least 0.25% but less than 1% of combined commercial and residential energy, as well as meeting all other criteria for Medium Priority. Seven Low Priority, two "Special" and five "not a priority" measures also had savings in this range, but were judged to have too low a likelihood of success or too high a cost of saved energy to receive High or Medium priority. The 1998 study identified 33 high and medium priority measures, compared with the 20 – 27 in this study (plus the 10 – 19 "Special" Measures this time). Thus, we have identified a comparable or larger number of large opportunities for savings.

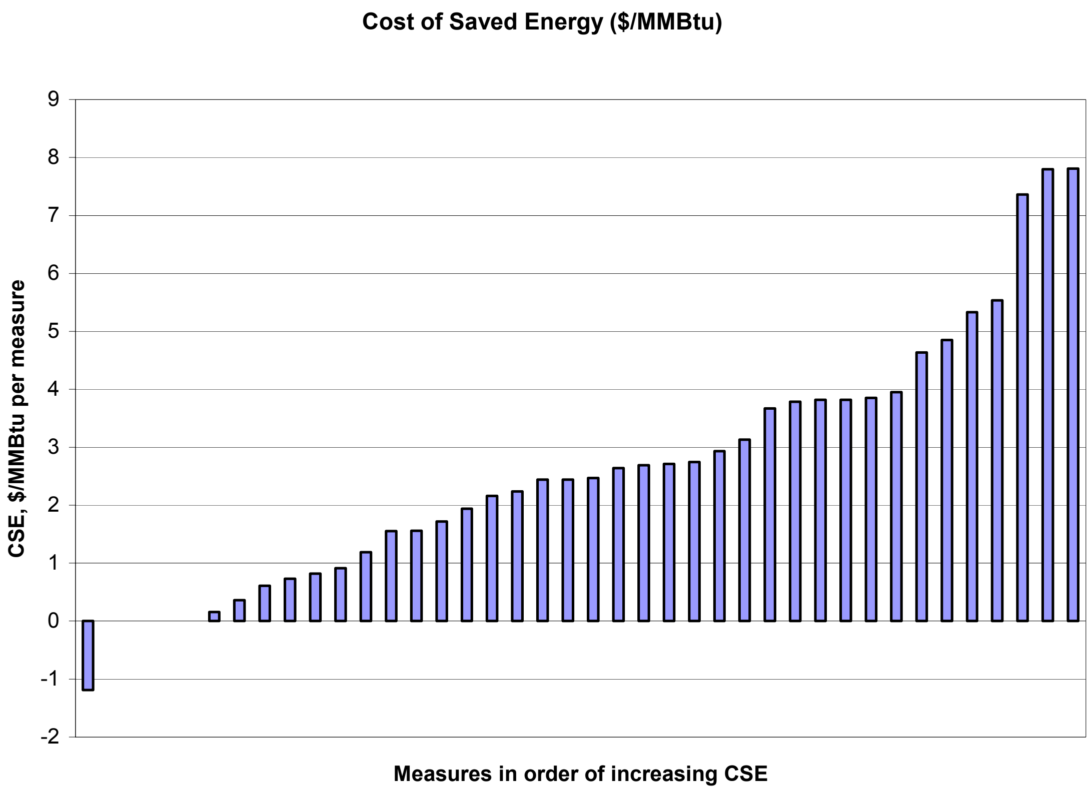
Cost of Saved Energy. The Cost of Saved Energy (CSE) is the second parameter used to prioritize measures. High priority measures have costs of saved electricity (CSE) less than half the average of 2002 electricity tariffs nationally, $0.041/kWh (This figure is the average of the national average for residential and commercial rates, by state, from EIA 2004). About 60% (40 of 69 measures with electricity use) have CSE < $0.41/kWh, the High Priority range (This number includes 11 "special" measures). For 16 others, $0.41/kwh < CSE < $0.081/kWh (Medium Priority range). That is, over three quarters of the electric measures studied have costs of saved energy less than the average electricity price in the US today. The distribution is depicted in Figure 3-2.

Figure 3-2. Rank-ordered measures by cost of saved electricity



The CSE for source energy includes both direct use of natural gas on site, and the source equivalent energy of the fuel use at the power plant for electricity, using the projected 2020 national average heat rate, 10.10 kBtu/kWh. The distribution of the Cost of Saved Energy for source energy is shown in Figure 3.3 (again, without the "special" measures). The cost of saved energy for 33 of 75 measures is less than half the average of the 2001 and 2002 retail prices for the commercial and residential sectors, (which was $8.13/MMBtu, EIA 2004).[6] Another 13 "special" measures had source energy costs this low, too.

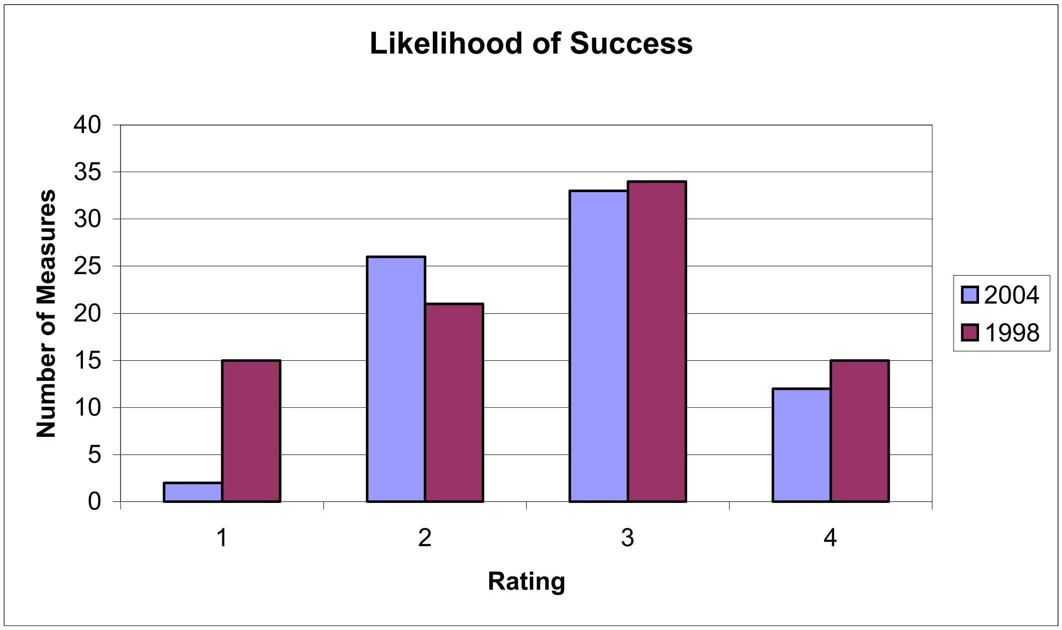
Figure 3.3. Rank-Ordered Measures by Cost of Saved Source Energy



Likelihood of Success (Rating). The third parameter we used to guide the decision on which measures would be grouped in High-, Medium-, and Low-priority measures was the estimated likelihood of success (LOS) or *Rating* of the measure. As noted in Chapter 2, LOS is based on analysts' judgment, combining considerations of major market barriers, non-energy benefits to purchasers; and current promotional activities. From these factors, we have estimated a LOS value (1 – 5; one being the least likely to succeed) and given a rationale (on the data sheets). Figure 3-4 shows the distribution of the Likelihood-of-Success parameter for this study and the 1998 precursor.

[6] Because EIA's gas and electric divisions present their data in somewhat different formats, our electricity data is from 2002. Our gas values average 2001 (relatively high retail prices) with 2002 (lower retail prices).

Figure 3-4. Distribution of the Likelihood-of-Success parameter for 2004 (left column in each pair) and 1998 (right column in each pair). The X-axis is the rated Likelihood of Success, and Y-axis is the number of measures with a given rating



The average value for 2004 is 2.8, *vs.* 2.6 in 1998, a very modest change in the analysts' estimate of likelihood of success.[7] The largest change is the great reduction of "1"-rated measures in this study, that is, those that are least likely to succeed. We attribute this change to more aggressive screening in initial stages of the project, based on the greater knowledge base from earlier work by this group and others. Table 3-1 summarizes definitions of Likelihood of Success ratings. In practice, no measure was recognized as belonging to Class 5 in either the 1998 or the 2004 study.

Table 3-1. Measures Rating Classes for Likelihood of Success

1 - Difficult; multiple major barriers to overcome
2 - Hard; major barriers to overcome
3 - Moderate chance; substantial barriers
4 - Good chance; barriers appear surmountable
5 - Excellent chance; barriers clearly surmountable

[7] Column heights are numbers of measures; averages are weighted (*Rating**number of measures). Since the distribution is categorical, not continuous, the term "average" is not to be taken in a strict parametric statistical sense. We quote it only to indicate the central tendency of the estimates of success.

Combined Effect. Table 3-2 summarizes the combined effects of the energy saved, cost of saved energy, and likelihood of success.

Table 3-2. Distribution of Measures by Classification Parameters

Priority	Threshold for Savings	CSE, $/kWh	CSE, $/MMBtu (source energy)	Likelihood of success	Number of Measures
High	≥ 1.0%	≤ $0.0405/kWh	≤ $3.16/MMBtu	3–5	5–6
Medium	≥ 0.25%	≤ $0.081/kWh	≤ $6.33/MMBtu	3–5	20–27
Low	< 0.25%	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5	11–14
Special	>~0.05%	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5	10–19
Not a Priority		≤ $0.81/kWh	> $6.33/MMBtu	1–5	14–24
Total					72

Notes:

To qualify in a given category, such as "High," a measure must qualify with *all* elements in the row. For example, High priority measures show potential energy savings of at least 1 percent of projected U.S. residential and commercial energy consumption in 2020; a cost of saved energy less than half of current U.S. retail energy prices; *and* a likelihood of success rating of 3 or more.

The column for "# of measures" in this study reflects analytical uncertainty about costs (and applicability) by giving a range of measures that can be included in each category, such as 5–7 high priority measures. Typically, ranges are extended downward by a small amount (<10%) to include more measures and respond to the uncertainties in the analysis.

A major distinction is that the column for "Number of measures" in this study reflects analytical uncertainty about costs (and applicability) by giving a range of measures that can be included in each category, such as 5 – 7 high priority measures. Typically, ranges are extended downward by a small amount (<10%) to include more measures and respond to the uncertainties in the analysis. This change in method also recognizes the increasing number of options that can have major regional impacts, or major impacts on new construction, but which have modest national impact because of their restricted spheres of influence.

Some Changes from 1998

For the present study, Table 3-3 shows the data that underlie our results.

Table 3-3. Rank-Ordered Measures by Cost of Saved Energy ($/kWh). Two letters such as "M/L" in the "Priority" column suggest borderline situations, given analytic uncertainties. An "X" in that column indicates that the measure is not a national priority (<0.25% savings forecast, high CSE, low likelihood of success).

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Rat-ing	Prior-ity
PR3	Int. Design Process (30% > Code)	620	1.31	$0.01	$1.20	3	H
A1	1-Watt standby power for home appliances	497	1.05	$0.02	$1.90	4	H
PR1	Advanced Automated Building Diagnostics	704	1.48	$0.04	$4.00	3	H/M
PR4	Retrocommissioning	443	0.93	$0.03	$2.60	3	H/M
H12	Aerosol-based Duct Sealing	443	0.93	$0.03	$2.50	3	H/M
H11	Leakproof Duct Fittings	489	1.03	$0.00	$0.40	4	M/H
L16	Airtight Compact Fluorescent downlights	393	0.83	($0.01)	($1.20)	4	M
O1	EZConserve Surveyor Software	286	0.60	$0.02	$1.70	3	M
H7	"Robust" A/C	278	0.59	$0.04	$3.80	3	M
L13	Residential CFL portable (plug-in) fixtures	216	0.46	$0.03	$3.10	3	M
L14	1-lamp fluorescent fixtures w/ high performance lamps	215	0.45	$0.01	$0.80	3	M
D2	Advanced Air-conditioning Compressors	200	0.42	$0.03	$2.40	3	M
L11b	Commercial LED lighting	176	0.37	$0.03	$2.90	3	M
H9	Adv. cold-climate heat pump/Frost-less Heat Pump	173	0.36	$0.05	$4.60	3	M
R1	Solid state refrigeration (Cool Chips™)	171	0.36	0	0	3	M
H18	CO_2 Ventilation Control	163	0.34	$0.03	$2.70	4	M
W3	Residential heat pump water heaters	158	0.33	$0.0218	$2.20	3	M
L15	Scotopic lighting	154	0.33	0	0	3	M
S5	Residential Cool Color Roofing	144	0.30	$0.04	$3.70	3	M
S1	High Performance windows (U<0.25)	144	0.30	$0.03	$2.70	3	M
A2	1 kWh/day refrigerator	140	0.30	$0.04	$3.90	4	M
L6	Low wattage ceramic metal halide lamps	130	0.27	$0.03	$2.80	3	M
H15	Designs for low parasitics, low pressure drops	94	0.20	0	0	4	M
D1	Advanced Appliance & Pump Motors; CW example	58	0.12	$0.00	$0.20	4	M
R3	Efficient Fan Options for Commercial Refrigeration	29	0.06	$0.02	$1.60	4	M
D3	Advanced HVAC blower motors	112	0.24	$0.04	$3.80	4	M/L
P2b	Commercial micro-CHP using Micro-Turbines	692	1.46	$0.05	$5.30	2	M/L
W4	Integrated Home Comfort Systems	43	0.09	$0.0382	$3.80	2	L/M
P2a	Commercial micro-CHP using Fuel Cells	767	1.62	$0.07	$7.40	2	L

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Rat-ing	Prior-ity
P1b	Residential micro-CHP using Stirling engines	201	0.42	$0.06	$5.50	2	L
H13	Microchannel heat exchangers	132	0.28	$0.02	$1.60	2	L
PR6	Better, Easier to Use, Residential Sizing Methods	113	0.24	$0.01	$0.70	2	L
L9	Advanced HID Lighting	97	0.21	$0.05	$4.90	2	L
L3	General service halogen IR reflecting lamp	74	0.16	$0.03	$2.40	2	L
PR7	Bulls-Eye Building Commissioning	47	0.10	$0.01	$0.60	3	L
S8	High Quality Envelope Insulation	15	0.03	$0.08	$7.80	2	L
H10-Com	Ground Coupled Heat Pumps	15	0.03	$0.00	$0.00	2	L
S3a	Electrochromic glazing for residential windows	3	0.01	$0.08	$7.80	2	L
R2	Modulating compressor for packaged refrigeration	45	0.09	$0.02	$2.20	4	L
H1a	Advanced Roof-top packaged air-conditioners	81	0.17	$0.04	$3.50	3	S
H1b	Advanced Roof-top packaged air-conditioners	81	0.17	$0.06	$6.00	3	S
PR2	Ultra Low Energy Designs & Zero Energy Buildings	199	0.42	$0.01	$0.60	2	S
S2b	Active Window Insulation, commercial	93	0.20	$0.02	$1.80	2	S
L5	Advanced daylighting controls	80	0.17	$0.02	$2.30	3	S
H8	Residential Gas Absorption Chiller Heat Pumps	41	0.09	$0.07	$6.60	2	S
H20	Advanced Condensing Boilers (Commercial)	23	0.05	$0.01	$0.60	3	S
H16	High-efficiency Gas-fired Rooftop Units	20	0.04	NA	$3.40	2	S
D4	Hi-Eff. Pool and domestic water pump systems	19	0.04	$0.03	$3.40	3	S
PR5	Low Energy Use Homes and Zero Energy Houses	199	0.42	$0.07	$6.60	2	S/X
H2a	Cromer Cycle Air-Conditioner - residential	21	0.04	$0.03	$3.10	3	S/X
H2b	Cromer Cycle Air-Conditioner - commercial	16	0.03	$0.07	$6.80	3	S/X
CR1	Hotel Key Card System	15	0.03	$0.01	$1.30	2	S/X
S9	Engineered wall framing	12	0.03	0	0	3	S/X
H19	Displacement Ventilation	11	0.02	0	0	3	S/X
H5	Residential HVAC for Hot-Dry Climates	11	0.02	$0.04	$4.40	4	S/X
H17	Transpired Solar Collectors for Ventilation Air	7	0.02	NA	$2.40	3	S/X
S3b	Electrochromic glazing for commercial windows	3	0.01	$0.05	$4.60	3	S/X
L7	Hospitality Bathroom Lighting	28	0.06	$0.04	$4.00	3	S/X
H4	CAC Dehumidifiers/free-standing dehumidifiers	5	0.01	$0.05	$4.40	3	X
L10	Hybrid solar lighting	270	0.57	$0.27	$26.30	2	X

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Rat-ing	Prior-ity
L11a	Residential LED Lighting	229	0.48	$0.11	$11.30	2	X
W1	Residential condensing water heaters	217	0.46	N/A	$6.40	2	X
P1a	Residential micro-CHP using fuel cells	171	0.36	$0.18	$17.40	2	X
W2	Instant. gas high-modulating water heaters	127	0.27	N/A	$8.30	2	X
H14	Solid state refrigeration for heat pumps	106	0.22	$0.16	$15.60	2	X
L8	Universal light dimming control device	97	0.20	$0.08	$8.10	1	X
H10	Ground Coupled Heat Pumps (comm.).	43	0.09	$0.13	$12.60	2	X
S2a	Active Window Insulation	41	0.09	$0.73	$72.20	1	X
S4	Attic Foil Radiant Barriers	27	0.06	$0.16	$16.20	2	X
H6	UV HVAC Disinfection	19	0.04	$0.57	$56.50	2	X
H3	Commercial HVAC Heat Pipes	8	0.02	$0.28	$27.30	2	X
L4	Cost effective load shed ballast & controller	1	0	$0.43	$42.90	3	X

Of course, savings often overlap between measures and savings across measures are frequently not additive. Also, given the many assumptions made in the calculations, these estimates should be viewed as approximate and not absolute. For this reason, national savings estimates are rounded to the nearest GWh or trillion Btu.

High Priority Measures

When we combine all three parameters [energy savings, cost of saved energy, and likelihood of success (rating)], only five or six measures meet all three thresholds (Table 3-4).

Table 3-4. High Priority Measures

PR1	Advanced Automated Building Diagnostics
PR3	Integrated Design Practices (30%> Code)
A1	1-Watt standby power for home appliances
PR4	Retrocommissioning
H12	Aerosol-based Duct Sealing
H11	Leakproof Duct Fittings

Two of these measures are almost exclusively residential (A1 and H11). Two are commercial (PR1 and PR4). The other two (H12 and PR3) are applicable to both residential and commercial structures. A1 is unique in this set because it concerns equipment used in buildings (electronics, appliances), much of which has relatively short life-times. The others are most likely to enter the market in new construction and major retrofits/remodeling projects, and thus will penetrate somewhat more slowly. PR1 is complementary to PR4, Retrocommissioning (Medium Priority), in that both intend to keep buildings working at the potential of the Design Intent.

Medium Priority Measures

In general, Medium Priority measures are those that could save at least 0.25% of projected 2020 buildings energy use, have a cost of saved energy <u><</u>$0.081/kwh or <u><</u>$0.633/therm, and have likelihood of success (Rating) of at least 3. By these criteria, we identify about 20 measures in the current analysis. All qualify through their electricity savings. Table 3-5 lists the medium priority measures. Of these, about half are primarily residential vs. primarily commercial, and four have major opportunities in both sectors. By technology type, the residential list includes an appliance (advanced refrigerator), and several HVAC/water heating measures. Although the list includes a number of commercial lighting technologies, there are also two that are more relevant for residential applications: CFL portable lights, and sealed CFL downlights. It is noteworthy that the CFL emphasis has shifted from the bulbs to measures that assure proper application and "lock in" savings by requiring CFLs instead of incandescents. Two measures are shell-related (advanced windows and cool roofs). Lighting dominates the medium priority commercial measures with five technologies, with the remainder including refrigeration, HVAC, and ventilation.

Table 3-5. Medium Priority Measures, in Order of Declining Energy Savings
Note that the three lowest measures are transitional Medium/Low

L16	Airtight Compact Fluorescent Downlights
L1	High Efficiency Premium T 8 Lighting (100 Lumens/W)
O1	EZConserve Surveyor Software
H7	"Robust" A/C
L13	Residential CFL Portable (plug-in) Fixtures
L14	One-lamp Fluorescent Fixtures w/ High Performance lamps
D2	Advanced Air-conditioning Compressors
L11b	Commercial LED Lighting
H9	Advanced Cold-Climate Heat Pump/Frost-less Heat Pump
R1	Solid State Refrigeration (Cool Chips™)
H18	CO_2 Ventilation Control
W3	Residential Heat Pump Water Heaters
L15	Scotopic Lighting
S5	Residential Cool Color Roofing
S1	High Performance Windows (U<0.25)
A2	1 kWh/day Refrigerator
L6	Low Wattage Ceramic Metal Halide Lamps
H15	Designs for Low Parasitics, Low Pressure Drops
D1	Advanced Appliance & Pump Motors; CW Example
R3	Efficient Fan Options for Commercial Refrigeration
D3	Advanced HVAC Blower Motors
P2b	Commercial Micro-CHP Using Micro-Turbines
W4	Integrated Home Comfort Systems

Special Case Measures

As noted earlier,[8] this study includes several "special" measures, including "lost opportunities" in new construction, and measures of great regional importance but limited national savings. One new construction "special" case also saves enough energy to warrant High Priority rating. This is Integrated Design, at levels 30% better than code (Measure PR-5). If the costs are assigned to primary energy, it would not meet the combined criteria, but it qualifies readily as an electricity-saving measure. Table 3-6 summarizes the Special measures. Roughly speaking, over 16 years of implementation between now and 2020, a new construction Special measure could save 15% to 20% as much energy as a national high priority measure (1%), since the building stock increases by a bit more than 1% per year. An analogous approximate case could be made for regional measures.

This relationship gives us a tool for comparing the importance of special measures to national ones, within specific regions or for new construction: Multiplying the national savings of Table 3-6 by about five will serve as a rough "rule of thumb." For example, it allows program operators in hot climates to consider the value of investing in modulating pool pump motors (D4) vs. a national measure that would save roughly 0.20% of 2020 national energy use. In this table, there is no clear break in estimated energy savings at levels below 0.09%, so local program considerations legitimately affect choices among measures of interest.

Table 3-6. Special Measures, in Order of Declining Energy Savings Potential
Bold marks measures that would also qualify as Medium priority, and italics those that save enough to qualify as Low priority on the basis of national savings

PR2	**Ultra Low Energy Designs & Zero Energy Buildings**	**0.42**
PR5	**Low Energy Use Homes and Zero Energy Houses**	**0.42**
S2b	*Active Window Insulation, commercial*	*0.20*
H1a	*Advanced Roof-top packaged air-conditioners*	*0.17*
H1b	*Advanced Roof-top packaged air-conditioners*	*0.17*
L5	*Advanced daylighting controls*	*0.17*
H8	*Residential Gas Absorption Chiller Heat Pumps*	*0.09*
L7	*Hospitality Bathroom Lighting*	*0.06*
H20	*Advanced Condensing Boilers (Commercial)*	*0.05*
H2a	Cromer Cycle Air-Conditioner - residential	0.04
H16	High-efficiency Gas-fired Rooftop Units	0.04
D4	Hi-Eff. Pool and domestic water pump systems	0.04
H2b	Cromer Cycle Air-Conditioner - commercial	0.03
CR1	Hotel Key Card System	0.03
S9	Engineered wall framing	0.03
H19	Displacement Ventilation	0.02
H5	Residential HVAC for Hot-Dry Climates	0.02
H17	Transpired Solar Collectors for Ventilation Air	0.02
S3b	Electrochromic glazing for commercial windows	0.01

[8] "Preliminary Division into Priority categories" and "Selection of High Priority Measures"

Lessons Learned and Implications of the Study

Perhaps the most important finding of this study is that the well of emerging technologies and practices continues to yield many very promising measures. Including "special" measures for new construction or regional applicability, we find more promising measures than in the 1998 study: the sum of high and medium in 1998 was 33, compared with 26-20 this time, but this study added 10-21 special measures that warrant serious consideration.

Of course, the reservoir is changing. Some of the measures that would result in the largest savings would also require the greatest changes in the present mode of operations. Combined heat and power at commercial and residential scales, using emerging technologies such as fuel cells and Stirling engines, could each save well beyond 1% of projected buildings energy in 2020, but they will require substantial changes in how most utilities do business and see themselves, as well as substantial cost reductions. Others, such as measures to assure ductwork integrity, will require that industry and consumers change the value they assign to energy distribution services – or embrace new thermal and ventilation systems that are inherently less leak-prone. Finally, retrocommissioning and advanced design practices illustrate the greater importance and potential we find for training, incentives, and other "humanware" services. This includes both front-end (design) and continuing (operation) services, intervening at the points where the investment will make the most difference.

Including "special" measures in this study also illustrates another trend. While the earliest study (1993) could point to a relatively small number of technologies that each promised enormous savings, the present study, particularly in special cases, finds more broadly distributed savings that are, on average smaller. The 12 high priority measures in 1998 averaged about 824 TBtu per measure; the six highest priority measures in this study average about 540 TBtu per measure (Table 4-8). The total estimated savings from all measures is only three-quarters as large as in 1998. We believe that the analyses were systematically more conservative this time, accounting for much of the difference. *As noted earlier, this table treats the savings from individual measures as additive, which they certainly are not. Therefore, it should only be used for estimating the difference between the potential savings found in the two studies.*

Table 4-8. Aggregated Savings of source energy, 1998 and 2004
Note that the implicit assumption of additive savings is certainly not true

	1998	2004
High Priority Average Savings	824 (12 measures)	520 (6 measures)
Hi, Med, Low,	1239 (71)	852 (6640)
Hi, Med, Low, + Special		913 (2059)

However, there is another (pleasant) surprise in this study. Several measures assigned relatively high priority in this study were not available on the market for consideration in the 1998 study. These notably include "Super" T-8 lights and zone-level CO_2-based ventilation control, where critical research and development were nearly complete in industrial laboratories, but not yet announced.

3.2 CANADIAN MACRO-MARKET RESULTS

The results of the Canadian macro-analysis are presented in three different ways. Figure 3.5 graphically presents the measures in descending order of energy savings potential. Figure 3.6 graphically presents the measures in ascending order of cost of conserved energy. Table 3.7 shows the energy savings and GHG emission reduction potential for all 77 measures. Subtotals are shown for each category in the table, but as discussed above, these subtotals are notional only.

The results have been sorted, with the category showing the greatest total energy savings potential at the top. Within each category, the T&Ps are shown in descending order of energy savings potential.

Figure 3-5. Canadian Analysis: Rank-ordered measures by total energy savings potential

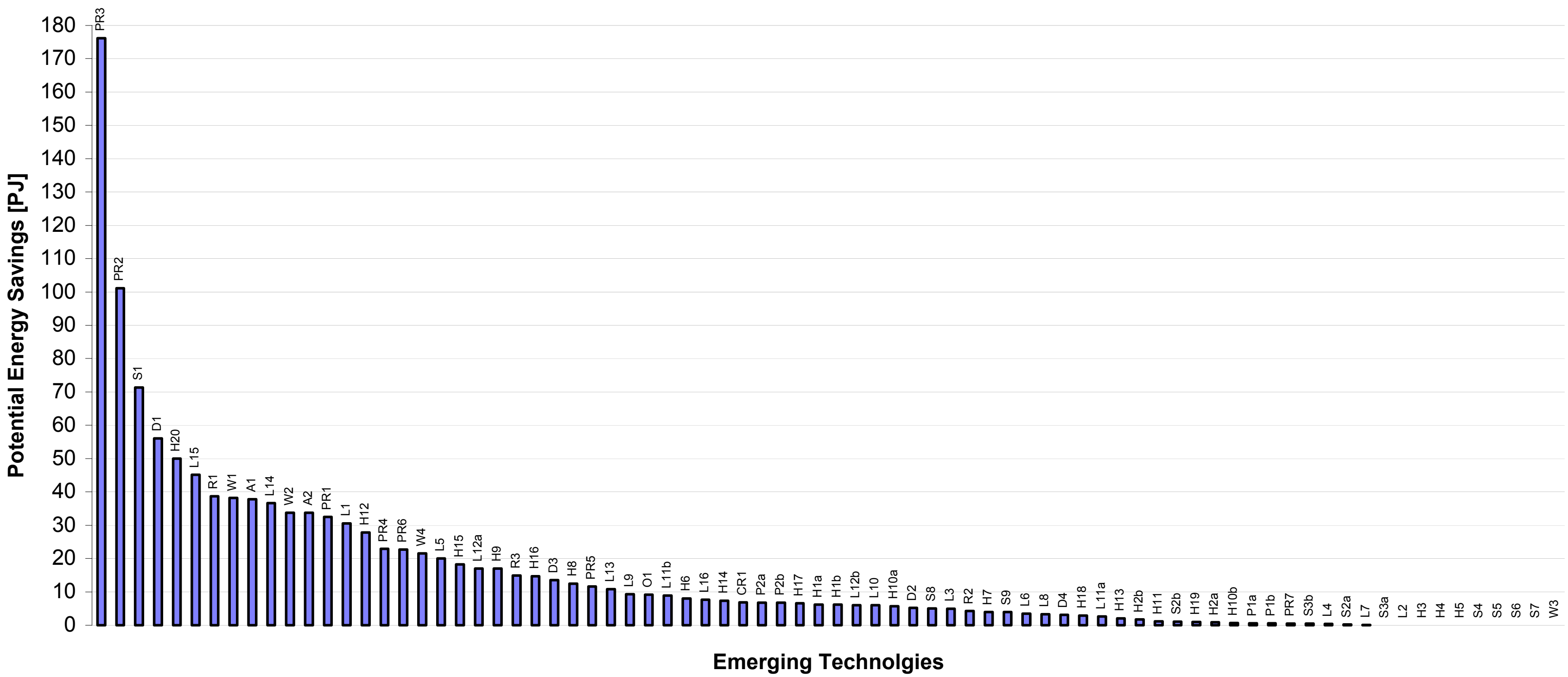


Figure 3-6. Canadian Analysis: Rank-ordered measures by cost of saved energy

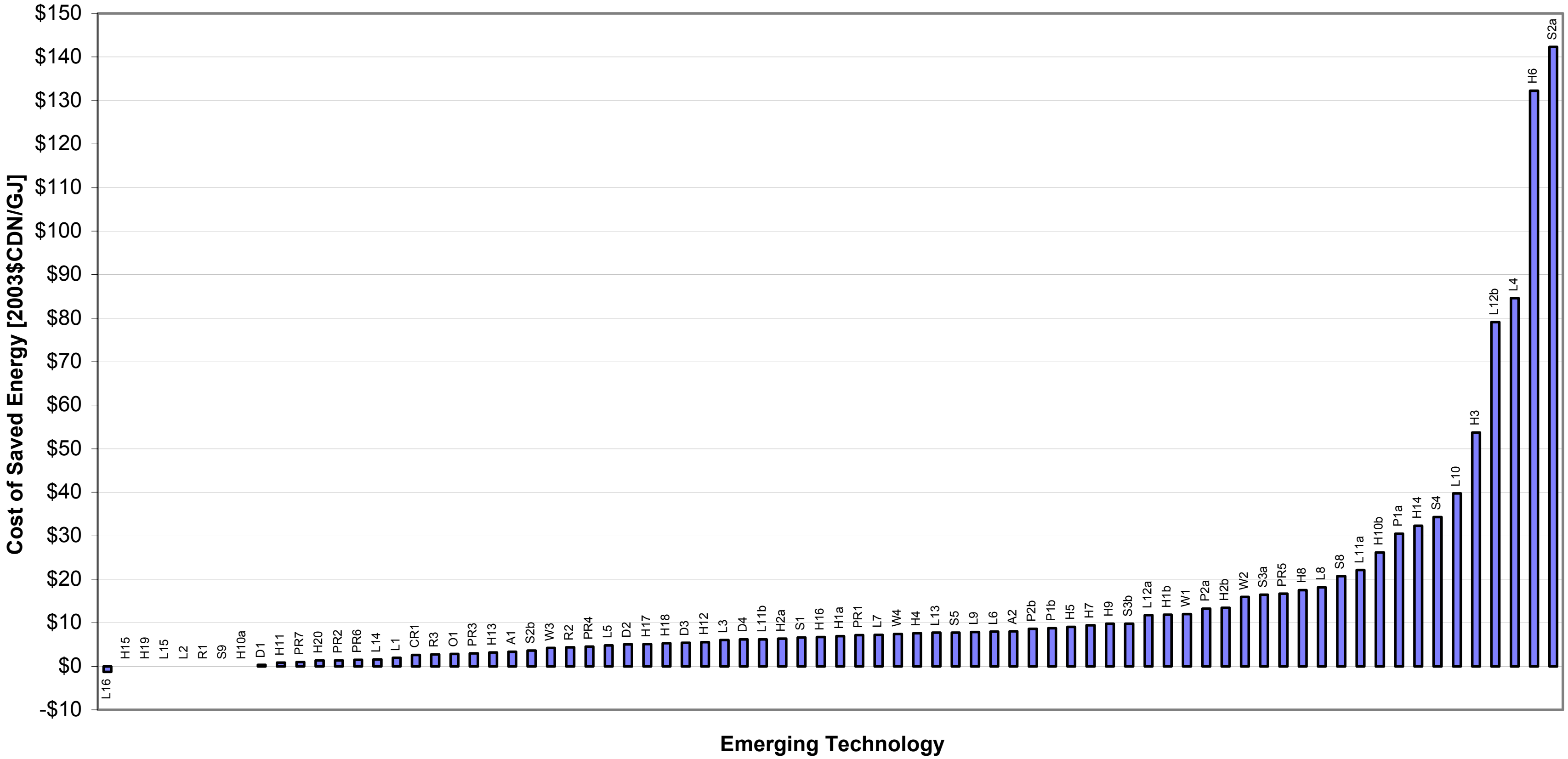


Table 3.7. Canadian Analysis: Total Energy Savings and GHG Reductions

Category	ET #	Description	Electric Savings (PJ)	Fuel Energy Savings (PJ)	Total Energy Savings (PJ)	GHG Reduction (1000 T CO2e)
Practice	PR3	Integrated commercial building design LEED level (30% > codes)	88.0	88.2	176.1	17,960
Practice	PR2	Ultra low energy commercial building designs (50% > codes)	50.6	50.5	101.1	10,320
Practice	PR1	Automated building diagnostics software (ABDS)	16.2	16.3	32.5	3,310
Practice	PR4	Retrocommissioning	11.4	11.5	22.9	2,330
Practice	PR6	Easier to use and more effective sizing methods for residential HVAC	0.6	22.1	22.7	1,150
Practice	PR5	Zero (net) energy houses, including houses with 50% + energy savings	3.8	7.8	11.6	940
Practice	PR7	Bulls-eye commissioning	0.5	0.0	0.5	80
Practice		**Subtotal**	**171.0**	**196.4**	**367.4**	**36,090**
Lighting	L15	Scotopic lighting	45.1	0.0	45.1	6,790
Lighting	L14	One-lamp linear flourescent fixtures w/ high performance lamps	36.6	0.0	36.6	5,510
Lighting	L1	High efficacy premium T8 lighting	30.6	0.0	30.6	4,600
Lighting	L5	Advanced/integrated daylighting controls (ADCs)	20.0	0.0	20.0	3,000
Lighting	L12a	Integrated skylight luminaire (ISL)	17.0	0.0	17.0	2,570
Lighting	L13	High quality residential CFL portable fixtures	10.8	0.0	10.8	1,630
Lighting	L9	Advanced high intensity discharge (AHID) light sources	9.3	0.0	9.3	1,400
Lighting	L11b	Commercial LED lighting	8.9	0.0	8.9	1,340
Lighting	L16	Recessed air-tight CFL cans	7.7	0.0	7.7	1,150
Lighting	L12b	Advanced, integrated skylighting design guidelines	6.0	0.0	6.0	910
Lighting	L10	Hybrid solar lighting	6.0	0.0	6.0	900
Lighting	L3	Halogen infrared reflecting A-line lamps	4.9	0.0	4.9	740
Lighting	L6	HID reflector lamp/ceramic metal halide	3.5	0.0	3.5	530
Lighting	L8	Universal light dimming control device	3.2	0.0	3.2	490
Lighting	L11a	Residential LED lighting	2.6	0.0	2.6	400
Lighting	L4	Cost effective load shed ballast	0.4	0.0	0.4	70
Lighting	L7	Hospitality bathroom motion sensor nightlight	0.1	0.0	0.1	10
Lighting	L2	Self-commissioning photosensors (combined with L5)	0.0	0.0	0.0	0
Lighting		**Subtotal**	**212.9**	**0.0**	**212.9**	**32,040**
HVAC	H20	Advanced condensing boilers (combined w W4)	0.0	50.0	50.0	2,680
HVAC	H12	Aeroseal or other spray-in/comprehensive residential HVAC duct sealing	15.3	12.6	27.9	2,900
HVAC	H15	Practices for design for low parasitics	18.3	0.0	18.3	2,750
HVAC	H9	Advanced cold-climate heat pump/frostless heat pump	17.0	0.0	17.0	2,560
HVAC	H16	High-efficiency gas-fired rooftop units	0.0	14.7	14.7	790
HVAC	H8	Small packaged advanced absorption chillers (~5 ton)/hybrid absorption & mechanical chiller	12.4	0.0	12.4	1,870
HVAC	H6	Ultraviolet germicidal irradiation (UVGI) for HVAC systems	8.0	0.0	8.0	1,210
HVAC	H14	Solid state refrigeration (Cool Chips TM) for heat pump applications	7.4	0.0	7.4	1,110
HVAC	H17	Solar pre-heated ventilation air systems (SolarWall TM)	0.0	6.6	6.6	350
HVAC	H1a	Advanced rooftop packaged AC (no economizer)	6.2	0.0	6.2	930
HVAC	H1b	Advanced rooftop packaged AC (w economizer)	6.2	0.0	6.2	930
HVAC	H10a	Geothermal heat pumps - commercial	5.7	0.0	5.7	860

Table 3.7. Canadian Analysis: Total Energy Savings and GHG Reductions (Continued)

Category	ET #	Description	Electric Savings (PJ)	Fuel Energy Savings (PJ)	Total Energy Savings (PJ)	GHG Reduction (1000 T CO2e)
HVAC	H7	Robust AC and HP	4.0	0.0	4.0	600
HVAC	H18	Ventilation controlled by IAQ indicators	2.9	0.0	2.9	440
HVAC	H13	Microchannel heat exchangers	2.0	0.0	2.0	310
HVAC	H2b	Cromer cycle air conditioner - commercial	1.7	0.0	1.7	260
HVAC	H11	Leakproof duct fittings	1.2	0.0	1.2	180
HVAC	H19	Displacement underfloor ventilation with low static pressure	0.9	0.0	0.9	140
HVAC	H2a	Cromer cycle air conditioner - residential	0.9	0.0	0.9	130
HVAC	H10b	Geothermal heat pumps - residential	0.6	0.0	0.6	100
HVAC	H3	Heat pipes for central air conditioning dehumidification	0.0	0.0	0.0	0
HVAC	H4	Free-standing efficient dehumidifiers to augment residential CAC	0.0	0.0	0.0	0
HVAC	H5	Hot-dry climate designs for residential HVAC	0.0	0.0	0.0	0
HVAC		**Subtotal**	**110.8**	**83.9**	**194.7**	**21,100**
DHW	W1	Residential condensing water heaters	0.0	38.2	38.2	1,820
DHW	W2	Instantaneous, gas-fired, high-modulating (ca. 10:1) instant water heaters	0.0	33.7	33.7	1,660
DHW	W4	Integrated home comfort systems	0.0	21.5	21.5	1,030
DHW	W3	Heat pump water heaters: with and without integral tanks	0.0	0.0	0.0	0
DHW		**Subtotal**	**0.0**	**93.4**	**93.4**	**4,510**
Shell	S1	High insulation technology (HIT) windows (U<0.25)	12.1	59.2	71.3	4,660
Shell	S8	Idiot-proof envelope insulation	1.0	4.1	5.0	340
Shell	S9	Engineered wall framing systems	0.7	3.2	4.0	270
Shell	S2b	Active window insulation (automated), commercial	1.1	0.0	1.1	160
Shell	S3b	Electrochromic glazing for commercial windows	0.5	0.0	0.5	70
Shell	S2a	Active window insulation (residential)	0.2	0.0	0.2	20
Shell	S3a	Electrochromic glazing for residential windows	0.0	0.0	0.0	10
Shell	S4	Attic foil thermal envelope (residential)	0.0	0.0	0.0	0
Shell	S5	Residential cool color roofing	0.0	0.0	0.0	0
Shell	S6	Commercial Cool Roofs (DROPPED, >2% market share today)	0.0	0.0	0.0	0
Shell	S7	Integrated window/wall systems (DROPPED - no current work on technology)	0.0	0.0	0.0	0
Shell		**Subtotal**	**15.6**	**66.5**	**82.1**	**5,530**
Drives	D1	Advanced appliance motors	56.1	0.0	56.1	8,450
Drives	D3	Advanced HVAC fan motors	13.6	0.0	13.6	2,040
Drives	D2	Advanced unitary HVAC compressors	5.3	0.0	5.3	790
Drives	D4	Hi-efficiency pool and domestic water pump systems	3.1	0.0	3.1	470
Drives		**Subtotal**	**78.1**	**0.0**	**78.1**	**11,750**
Appliance	A1	1-Watt standby power for home appliances	37.8	0.0	37.8	5,690
Appliance	A2	1 kWh/day refrigerator with linear compressor	33.7	0.0	33.7	5,070
Appliance		**Subtotal**	**71.5**	**0.0**	**71.5**	**10,760**
Refrigeration	R1	Solid state refrigeration (Cool Chips TM)	38.6	0.0	38.6	5,820
Refrigeration	R3	Efficient fan motor options for commercial refrigeration	14.9	0.0	14.9	2,240
Refrigeration	R2	Modulating compressor for packaged refrigeration	4.3	0.0	4.3	640
Refrigeration		**Subtotal**	**57.8**	**0.0**	**57.8**	**8,700**
Other	O1	Networked computer power management	9.1	0.0	9.1	1,380
Other	CR1	Hotel key card system	2.6	4.3	6.9	620
Other		**Subtotal**	**11.7**	**4.3**	**16.0**	**2,000**
Power	P2a	Commercial micro-CHP using fuel cells	6.8	0.0	6.8	1,020
Power	P2b	Commercial micro-CHP using micro-turbines	6.8	0.0	6.8	1,020
Power	P1a	Residential micro-CHP using fuel cells	0.6	0.0	0.6	90
Power	P1b	Residential micro-CHP using stirling engines	0.6	0.0	0.6	90
Power		**Subtotal**	**14.8**	**0.0**	**14.8**	**2,220**

Key Findings

Subtotals in the above table give only an approximation of the relative savings potential of the different categories. No "grand total" has been shown, because it would be considerably overestimated due to the double-counting of savings. Drawing broad conclusions from the table above, however, it is evident that the following categories offer great potential for energy savings:

- Improvements in practice
- Improvements in lighting efficiency, and
- Improvements in heating, ventilating, and cooling systems.

Discussion of the findings must focus primarily on individual measures. The top ten T&Ps, ranked according to macro-market energy savings, are as follows:

#1, PR3, Integrated Commercial Building Design LEED Level (30% > Code)
The T&P with the greatest energy savings potential, PR3, could save up to 176 PJ in the commercial sector in 2020. Total estimated energy use for the commercial sector in 2020 is approximately 1,485 PJ and this single T&P could thus save over 10% of the energy use in this sector. PR3 represents a major change in design practice, with savings across the board in both electrical consumption and non-electric fuel consumption. GHG reduction potential is nearly 18,000 tonnes of CO_2e. The estimated cost per GJ of conserved energy is Cdn$3.00.

The reason the potential is so large is that this T&P is technically applicable to all new construction in the commercial sector, perhaps with the exception of religious and recreational facilities. Uptake would take some time to accelerate, but with intensive support, it could be applied to 50% of the buildings constructed between now and 2020 in most categories. The greatest potential would be in offices (private and public) and retail buildings, because these segments represent the largest percentage of floor space in this sector.

#2, PR2, Ultra Low Energy Commercial Building Designs (50% > Code)
The T&P with the second largest potential is PR2, for reasons very similar to those stated above under PR1. The savings per facility would be higher, and the T&P is technically applicable to almost as many buildings as PR3. Estimated likely penetration in new buildings by 2020 was much lower, however: no more than 20% of offices, 15% of schools and retail, 10% of hotels and restaurants, and even fewer of the other categories. Total potential is therefore estimated as 101 PJ of energy and 10,000 tonnes of CO_2e. The estimated cost per GJ of conserved energy is Cdn$1.39 owing to the larger per unit energy savings (relative to PR3). As with PR3, offices and retail buildings represent the greatest potential.

#3, S1, High Insulation Technology (HIT) Windows (U<0.25)
This T&P represents a large potential, because HIT windows can save up to 20% of the energy used for heating and cooling residences and are technically applicable to any new homes from single family to apartments. Estimated maximum penetration in new homes by 2020 was 35%. Total potential is estimated at 71 PJ of energy and 4,700 tonnes of CO_2e. The estimated cost per

GJ of conserved energy is Cdn$6.64. The greatest potential is in single-family dwellings, because they represent most of the new housing construction. Regionally, the greatest savings will occur where winters are the most severe, because nearly 85% of the energy savings are from space heating.

#4, D1, Advanced Appliance Motors

This T&P represents a large potential, because these motors can save up to 60% of the energy used by conventional motors and they can be applied to all commercial pumps and to 20%-25% of residential appliances. Estimated maximum penetration by 2020 would be 80% of commercial pumps and 100% of those residential appliances to which they apply. Total potential is estimated at 56 PJ of energy and 8,500 tonnes of CO_2e. The estimated cost per GJ of conserved energy is Cdn$0.30. The greatest potential is in the appliances used in single-family homes.

#5, H20, Advanced Condensing Boilers

This T&P represents a large potential, because these boilers can save up to 33% of the energy used by conventional boilers and they are applicable in all commercial buildings with hydronic systems. Maximum potential penetration by 2020 was estimated at 60%. Total potential is estimated at 50 PJ and 2,700 tonnes of CO_2e. The estimated cost per GJ of conserved energy is Cdn$1.38. The greatest potential exists in offices and retails, because they represent the largest floor space with hydronic systems, but schools and health care facilities also offer large potential. Regionally, this T&P will have largest potential in areas with the most heating degree-days.

#6, L15, Scotopic Lighting

This T&P offers significant potential, because lighting energy can be reduced by up to 30% in all commercial fluorescent lighting to which the technology is applied. In several categories of commercial building, over 80% of the lighting is fluorescent. Penetration by 2020 could be up to 100% of commercial fluorescent lighting. Total potential is estimated at 45 PJ and 6,800 tonnes of CO_2e. This measure is expected to have no incremental cost over conventional alternatives. The greatest potential is in offices and retail facilities, because of the large floor space in those categories.

#7, R1, Solid State Refrigeration (Cool Chips™)

This T&P offers a large potential because it could save up to 40% of the energy used for refrigeration and could apply to all commercial and residential refrigeration. Penetration of 60% by 2020 was assumed to be possible. Total potential is estimated at 39 PJ and 5,800 tonnes of CO_2e. This measure is expected to have no incremental cost over conventional alternatives. The greatest potential is with refrigeration in single-family homes. Because this technology is farther from commercialization than most of the others in this list, there is greater uncertainty about the savings.

#8, W1, Condensing Water Heaters

This T&P offers a large potential because it could save up to 29% of the energy used for domestic hot water in all single-family and mobile homes with non-electric water heating. The technology therefore applies to 65% of single-family detached and attached homes. Penetration of up to 75% of those homes was estimated to be possible by 2020. Total potential is estimated at

38 PJ and 1,800 tonnes of CO_2e. The estimated cost per GJ of conserved energy is Cdn$12.00. The greatest potential is in single-family detached homes, because they represent the largest number of dwelling units.

#9, A1, 1-watt Standby Power for Appliances
This T&P offers a large potential because it could save up to 60% of the standby power in all residential appliances and electronic equipment that have standby power. Penetration could be up to 100% of those appliances by 2020. Total potential is estimated at 38 PJ and 5,800 tonnes of CO_2e. The estimated cost per GJ of conserved energy is Cdn$3.32. The greatest potential is in single-family detached homes, because they represent the largest number of dwelling units.

#10, L14, One-Lamp Linear Fluorescent Fixtures with High Performance Lamps
This T&P offers significant potential because it could save up to 42% of the lighting energy in all fluorescent lighting in offices, schools, and healthcare facilities. Estimated maximum penetration by 2020 is up to 65%. Total potential is estimated at 37 PJ and 5,500 tonnes of CO_2e. The estimated cost per GJ of conserved energy is Cdn$1.61. The greatest potential is in offices, because of their large floor space.

CHAPTER 4: OBSERVATIONS ON THE CANADIAN MACRO-ECONOMIC ANALYSIS

In Canada, the T&Ps with the greatest potential represent a variety of measure types, from changes in design practice to changes in technology. Changes in design practice offer the largest potential, because the savings cut across all end uses, and because of the large number of buildings to which they can be applied. There are also significant savings available from advances in lighting, HVAC systems, motors, and appliances. Lighting and heating measures tend to show the largest potential impact, because of the large amount of energy used for those end uses.

Savings potential in the commercial sector is dominated by savings in office buildings, followed by savings in retail facilities. In the residential sector, most of the savings will be obtained in single-family detached homes. In large part, this is because these segments dominate in terms of floor space or dwelling units.

Regionally, most of the T&Ps will apply equally to all areas. The major exceptions in the top-ten list presented in the previous section are Shell #1, High Insulation Technology Windows, and HVAC #20, Advanced condensing boilers, which will have the most potential in regions with the most heating degree-days, as well as Water Heating #1, Condensing Water Heaters, which has the most potential where natural gas is used most widely for water heating.

Clearly, there remains considerable potential for energy improvement in the Canadian economy. The "low-hanging fruit" has not all been picked. Specifically, the top ten list identified above, with the exception of W1, Condensing Water Heaters, and S1, High Insulation Technology Windows, all have attractive costs per GJ of conserved energy in comparison with currently prevailing Canadian energy prices. Technologies and practices identified in earlier studies have, in many cases, moved into the marketplace, but this list demonstrates that new, cost-effective efficiency measures continue to emerge to take their place.

Discussion on Key Variables Affecting the Analysis

As with any long-term forecast, the results of this analysis have some unavoidable uncertainty associated with the major assumptions and input variables. The major sources of uncertainty in the key input variables are discussed below:

- **Savings of the T&Ps:** The savings estimates used for most T&Ps are those developed as part of the ACEEE study. These are peer-reviewed values, and for the most part can be used with confidence for North America as a whole. To a limited extent, we have modified them to suit Canadian-specific applications. The task of "Canadianizing" the technology profiles is not complete, however. Areas of potential improvement are discussed below.

- **Energy Consumption for the End Uses:** The energy consumption by end use and building segment for current buildings is taken from OEE published figures. These can be used with good confidence. There is unavoidable uncertainty in the forecast of growth in the building stock to 2020, and the energy consumption associated with those new buildings.

- **Fuel Shares:** The fuel shares by end use and building segment are also taken from the OEE published figures for current buildings, and can be used with good confidence. They are assumed to remain unchanged between now and 2020. Many factors could intervene to change the mix of fuels used in Canadian buildings, but no attempt has been made to predict this change.

- **Applicability of the T&Ps:** Applicability estimates by building segment have been developed for each T&P, based on the Canadian context. These judgments are largely based on Marbek's experience and recent project work. The ACEEE applicability estimates combine technical applicability and potential market penetration, but were used for comparison purposes.

- **Potential Penetration of the T&Ps:** Potential penetration estimates for the T&Ps by 2020, by building segment, have also been developed based on the Canadian context. These judgments are based on Marbek's experience and recent project work. The ACEEE applicability estimates combine technical applicability and potential market penetration, but were used for comparison purposes.

- **GHG Emission Factors:** The factors used were those used in the Federal House In Order program. They are national figures, and do not reflect variations in fuel shares in different regions. The electricity factor is based on marginal generation, which uses natural gas-fired plants in most regions. Savings large enough to affect base load would require a different emission factor.

- **Real Discount Rate:** The real discount rate of 10% is significantly higher than the rate used in the US study. This will have the effect of increasing the number of T&Ps that are rejected because of high first cost and savings that are stretched out over a long period. For a T&P expected to save energy steadily over a long life, a real discount rate of 10% is equivalent to a simple payback of approximately 8.5 years. The 5% real discount rate used in the US would result in acceptance of a T&P with a simple payback as long as 12.5 years. Thus, a measure with a payback of 10 years, which would be included in the US potential, might be excluded from the savings potential in Canada.

Further Work on Canadianization

The technology profiles could be further modified to fit the Canadian context in two key ways:

- Further research is warranted on implementation cost for the T&Ps. The costs are presently based on currency conversion of the North America-wide values used in the ACEEE study.

- Research into the current status of the T&Ps in Canada was limited. A full-scale gap analysis would include research to assess penetration of the T&Ps in the Canadian marketplace, the current state of commercialization, and Canada-specific R&D efforts would be a valuable improvement.

- Finally, performance improvement estimates in the ACEEE study were based on average values for a generic building. There was a limited effort to account for different climate zones, and even more limited attention to different building types. A more robust approach would be to model the improvements offered by T&Ps for several major building types in several key Canadian climate zones. The results of this bottom-up estimation would then be summed into an overall estimate of the potential in Canada as a whole. Not only is this a more accurate approach, but it permits the results to be disaggregated, to identify the most promising building types and regions for individual T&Ps.

CHAPTER 5: NEXT STEPS AND RECOMMENDATIONS

This chapter presents our recommendations for the next steps for emerging technologies and practices. Table 5-1 briefly summarizes the ACEEE study's recommended next steps for the high- and medium-priority measures, as well as the "special" measures applicable to new construction or specific regions. Table 5-3 provides the recommended high priority measures for Canada with a commentary.

Table 5-1. Next Steps for High- and Medium-Priority Measures, and for Special Measures Applicable to New Construction or Specific Regions

Measure	Name	Savings Potential (% of 2020 R&C Energy Use)	R&D	Demonstrations	Testing	Education	Training	Financing	Incentives	New standards	Other
High Priority											
PR3	IDP LEED level (30% > Code)	1.31	X	X	X	X					Revise fee structure for designers
A1	1-Watt standby power for home appliances	1.05				X			X	X	ENERGY STAR
High - Medium Priority											
PR1	Advanced Automated Building Diagnostics	1.48	X	X							
H11	Leakproof Duct Fittings	1.03		X	X	X	X		X	X	Tightness Standards
PR4	Retrocommissioning	0.93	X	X	X	X	X		X		
H12	Aerosol-based Duct Sealing	0.93	X		X	X	X		X		R&D for best target housing types, business model
Medium Priority											
P2b	Commercial micro-CHP using Micro-Turbines	1.46	X								Resolve interconnection issues
L16	Airtight Compact Fluorescent downlights	0.83							X	X	Code revisions
O1	EZConserve Surveyor Software	0.60		X	X	X					
H7	"Robust" A/C	0.59	X	X	X	X	X		X		Develop consensus specification
L13	Residential CFL portable (plug-in) fixtures	0.46		X		X	X				ENERGY STAR
L14	One-lamp flourescent fixtures w/ high performance lamps	0.45				X	X		X		Phase out incentives for lesser products
D2	Advanced Air-conditioning Compressors	0.42									Regional incentives appropriate
L11b	Commercial LED lighting	0.37	X			X			X	X	revise rating methods
H9	Advanced cold-climate heat pump/Frost-less Heat Pump	0.36		X	X				X	X	
R1	Solid state refrigeration (Cool Chips TM)	0.36	X								
H18	CO2 Ventilation Control	0.34		X		X					
W3	Residential heat pump water heaters	0.33		X		X	X		X		Good ENERGY STAR specification
L15	Scotopic lighting	0.33	X	X	X	X	X				
S5	Residential Cool Color Roofing	0.30		X		X			X	X	
S1	High Performance windows (U<0.25)	0.30	X			X			X		
A2	1 kWh/day refrigerator	0.30							X		Upgraded ENERGY STAR
L6	Low wattage ceramic metal halide lamps	0.27		X		X			X		
D3	Advanced HVAC blower motors	0.24	X			X			X	X	
H15	Designs for low parasitics, low pressure drops	0.20		X	X	X	X		X		Revising Design Fee structures
D1	Advanced Appliance & Pump Motors; CW example	0.12							X		Standards (DW, furnaces)
R3	Efficient Fan Options for Commercial Refrigeration	0.06				X				X	Revise ENERGY STAR
Special											
PR2	Ultra Low Energy Designs & Zero Energy Buildings	0.42		X	X	X		X	X		
PR5	Low Energy Use Homes and Zero Energy Houses	0.42	X	X	X	X	X	X	X		
S2b	Active Window Insulation, commercial	0.20	X								
H1a	Advanced Roof-top packaged air-conditioners	0.17		X	X			X	X	X	Consider economizers, etc.
H1b	Advanced Roof-top packaged air-conditioners	0.17		X	X			X	X	X	Consider economizers, etc.
L5	Advanced daylighting controls	0.17	X	X		X					Productivity impact R&D
H8	Residential Gas Absorption Chiller Heat Pumps	0.09	X	X	X				X		
L7	Hospitality Bathroom Lighting	0.06	X	X	X	X			X		
H20	Advanced Condensing Boilers (Commercial)	0.05				X	X				
H2a	Cromer Cycle Air-Conditioner - residential	0.04	X	X	X	X					More work on climate limits of applicability
H16	High-efficiency Gas-fired Rooftop Units	0.04		X	X	X			X		
D4	Hi-Eff. Pool and domestic water pump systems	0.04		X					X		Regional incentives appropriate
H2b	Cromer Cycle Air-Conditioner - commercial	0.03		X	X	X					More work on climate limits of applicability
CR1	Hotel Key Card System	0.03		X	X						
S9	High Quality Envelope Insulation	0.03				X			X	X	
H19	Displacement Ventilation	0.02			X	X	X				Codes revision
H5	Residential HVAC for Hot-Dry Climates	0.02	X	X	X					X	Revise standard
H17	Transpired Solar Collectors for Ventilation Air	0.02		X		X			X		
S3b	Electrochromic glazing for commercial windows	0.01	X								

Measure-by-measure recommendations for the high-priority emerging technologies and practices are shown in Table 5-2.

Table 5-2. Next Steps Recommended for High-Priority Measures

Measure	Name	Next Steps
PR1	Advanced, automated building diagnostics	• Continued R&D, particularly on Open Interfaces for seamless integration with BAS • Field tests and monitoring for demonstrations
PR3	Comm. Construction 30%>Code	• Revised fee structures for mechanical designers • Dissemination of successful case studies to design professionals • Client education • Better software
A1	1-Watt Standby Power	• ENERGY STAR program for power supplies • Possible manufacturer incentive for using better power supplies. • Mandatory standard for power supplies
PR4	Retrocommissioning	• Better define approaches and appropriate applications for different approaches (e.g., for smaller buildings) • Benchmarking • Market Transformation programs with promotion, training, and incentives
H12	Aerosol-based Duct Sealing	• Raise consumer awareness of problems and savings • Utility Incentives • HVAC contractors taking on value-added service • Training and certification • Field tests in regions with basements and crawl spaces
H11	Leakproof Duct Fittings (transitional High-Medium, retrofit analogue to H12	• Raise consumer awareness of problems and savings • Utility Incentives • Performance-based codes and standards • Duct system integrity certification • Field tests in regions with basements and crawl spaces

Thus, we conclude that there are many opportunities for concerted action to accelerate the adoption of emerging technologies and practices in the near future. These new technologies and practices add to the available energy-efficiency resource and help replace opportunities that have been implemented in recent years. However, to some extent, implementation efforts will need to be more targeted to get more of the potential from more diverse but smaller (on average) reservoirs. We recommend that this research be repeated in about five years in order to update information on the technologies and practices identified in this report, identify new emerging measures, and assess progress on the opportunities profiled in this report. Through these periodic reports we can continue to identify -- and pursue -- promising new opportunities.

Recommendations and Next Steps for Canada

The Canadian macro-economic analysis leads to somewhat different conclusions. Table 5.3 shows the recommended high priority measures, with commentary.

Table 5.3. Recommended High-Priority Measures for Canada

Measure	Name	Commentary
PR2	Comm. Construction 50%>Code	• This measure produces a higher level of savings per building and at a lower cost than PR3, but is not applicable to as many buildings.
PR3	Comm. Construction 30%>Code	• This level of improvement in design is more broadly applicable than PR2, and will result in a greater level of overall savings
D1	Advanced Appliance Motors	• This measure offers large potential savings in both the residential and commercial sectors, at very small incremental cost. • The motors are mainly used in other products, so it is the manufacturers who must adopt the measure. Because most of the pumps and appliances involved are marketed internationally, this will require collaboration with the U.S. and other countries.
H20	Advanced Condensing Boilers	• This measure offers considerable potential in commercial buildings with hydronic systems, at only a modest incremental cost. • Education for designers is an appropriate method for encouraging adoption of the measure.
L15	Scotopic Lighting	• This measure offers significant savings potential in commercial lighting, and is expected to have no incremental cost over conventional lighting. • The measure requires continued R&D and technology demonstrations.
R1	Solid State Refrigeration (Cool Chips™)	• This is a new technology, requiring more R&D to bring it to commercialization.
A1	1-Watt Standby Power	• Programs such as Energy Star, manufacturer incentives, and new standards are all appropriate ways to encourage adoption of this measure.
L14	One-Lamp Linear Fluorescent Fixtures with High Performance Lamps	• This measure offers significant savings potential in commercial lighting, with only modest incremental cost. • The measure can be encouraged through education of designers and changes to current incentive programs.

As mentioned, the specific technologies and practices recommended for Canada differ somewhat from those recommended for the U.S., but the principle is the same. There is considerable scope for action to encourage adoption of these measures, and the resulting potential savings are significant. As more of these measures become commercialized and widely adopted, new technologies and practices will emerge to take their place. It will be appropriate, therefore, to conduct periodic updates of this research, to identify new targets for coordinated effort in the future.

PART 2: THE TECHNOLOGY PROFILES

INTRODUCTION TO CANADIAN CONTENT

The observations of the Canadian context pertaining to the T&P profiles (found at the beginning of each technology section) are drawn largely from a review of recent submissions to the Technology and Innovation (T&I) research and development initiative. In August 2003 the Government of Canada announced the Climate Change Plan for Canada, which included funding of $115 million over 5 years for the T&I initiative. The T&I funds are targeted for 5 technology areas, including Advanced End-Use Energy Efficiency which addresses industry, transportation, integrated applications, and buildings & communities. The Building Energy Technology (BET) group of CANMET Energy Technology Centre (the energy R&D arm of Natural Resources Canada) was tasked with administration of the buildings and communities stream of the T&I initiative. In early 2004 BET issued a Request for Applications for "Phase 1" applications under this stream of the fund. Marbek conducted a review of these submissions in order to glean relevant material.

APPLIANCES

CANADIAN SUMMARY

The market for appliances is largely similar between the U.S. and Canada, with only slight variations. There are 2 appliance ET profiles – stand-by power and for refrigerators – both are common appliance technologies in both the U.S. and Canada. There were no **appliance**-related submissions to the Canadian "Technology and Innovation" program funding.

A1 1-WATT STANDBY POWER FOR APPLIANCES

DESCRIPTION OF TECHNOLOGY

Standby power is the electricity consumed by end-use electrical equipment when it is switched off or not performing its main function. A wide variety of consumer electronics, small household appliances, and office equipment use standby power. Recent trends toward the incorporation of digital displays and other electronic components into white goods (i.e., major appliances), as well as the ongoing growth in the use of digital technology and devices, add to the list of products that consume standby power. The most common sources of standby power consumption include products with remote controls, low-voltage power supplies, rechargeable devices, and continuous digital displays. Although the amount of standby power consumed by an individual product is relatively small, typically ranging from 0.5 to 30 watts, the cumulative total is significant given the large number of products involved: an estimated 50 to 70 watts per U.S. house, or 5% of average residential electricity consumption (Meier 2002; EIA 2003).

CURRENT STATUS OF MEASURE

Currently available technologies, including more efficient power supplies and improved product designs, have allowed a number of existing products to consume 1.0 watt or less of standby power with no loss of functionality or user amenity. To date, these improvements have been adopted most readily for higher value products such as TVs, VCRs, mobile phones, and other portable technologies. The shift to high-efficiency components has been much slower for lower cost products. Digital cable boxes and satellite receivers are among the biggest consumers of standby power. Design improvements have led to reductions in standby power, but the1.0 watt standby target is not routine yet.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Annual energy savings from reduced standby power consumption vary widely depending on the product. At the household level, standby power consumption currently accounts for approximately 600 kWh per year, which could be reduced to less than 200 kWh (or more than 65%) if existing sources were replaced with products consuming 1.0 watt or less (Ross and Meier 2000). Efficient, low-loss external power supplies often cost manufacturers less than $1.00; the cost for internal power supplies in some products may be higher (Calwell and Reeder 2002). In some product categories (e.g., TVs and VCRs), there is no premium for products that consume less than 1.0 watt at standby.

KEY ASSUMPTIONS USED IN ANALYSIS

For this analysis, we assume electricity savings for a typical household in which most of the sources of standby power (15 products accounting for approximately 50W) are replaced with products meeting a 1.0 watt threshold for standby power—a savings of 265 kWh per year. Total incremental costs for end-user products is assumed at $2.00 per product—some larger or higher-value products will have a higher increment while others will have little or no incremental cost—for a total of $30.

Canada-specific assumptions: This measure applies only to appliances with standby power (excludes dishwashers, dryers, washers, refrigerators), which is assumed to be 25% of the total residential appliance end-use. Penetration by 2020 is assumed to cover new construction and the existing stock reaching 99% of the stock. Source: Consultant estimate based on Canadian residential end-use analysis studies that show miscellaneous electrical appliances (excludes white goods) account for 1,500 to 2,500 kWh/year in a typical household (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

EPA has developed ENERGY STAR® labeling programs for many of the consumer electronics products with standby power. TVs, VCRs, telephony products, DVDs, and home audio equipment currently set maximum standby power at one-watt or will move to a one-watt level by January 2005. For white goods, DOE has committed to incorporating standby power into all test procedures. Minimum efficiency standards for power supplies are also under consideration at the federal and state levels. Internationally, the International Energy Agency is working to develop a coordinated response in cooperation with industry. Chief among the remaining barriers to wider availability of products meeting a 1-watt standby threshold are product diversity (including many low-value products) and the existing OEM supply-chain for commodity power supplies and other components. Continued efforts to promote product labeling, standards for power supplies, and international coordination on products with global markets are promising vehicles for increasing the acceptance of products with low standby power consumption.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

A2 ONE KWH/DAY REFRIGERATOR WITH LINEAR COMPRESSOR

DESCRIPTION OF TECHNOLOGY

Under current US appliance efficiency standards, the maximum annual energy use of 20 ft^3 US refrigerators is 496 kWh/yr, or 1.36 kWh/day, with energy use scaled by formula for larger and smaller units. In 2004, ENERGY STAR will require 15% better performance, about 422 kWh/yr (1.16 kWh/day). Reaching the metaphoric "magic mile" of 1 kWh/day (365 kWh/yr) means improving the baseline efficiency by 26%. Two pathways for achieving the goal are continued incremental design changes (*e.g.,* thicker walls), or very large changes in key components. This might mean vacuum panel instead of foam insulation, or modulating linear compressors.

CURRENT STATUS OF MEASURE

Oak Ridge National Laboratory employed an incremental approach involving doubling door insulation thickness, substituting efficient DC motors for AC, improving compressor efficiency, and changing from (timed) automatic defrost to adaptive defrost, and achieved 1.16 kWh/day; with further improvement to 0.93 kWh/day by using vacuum panel insulation around the freezer compartment, although the latter showed payback longer than the expected life of the refrigerator (Vineyard and Sand, 1997). Large changes are exemplified by the LG implementation of SunPower-developed free-piston linear compressors, which are inherently modulating output devices. The LG side-by-side unit, now being sold outside the US, saves 30% relative to the US minimum efficiency standard, and will be marketed in the US beginning in January, 2004 (Hollingsworth, 2003). Because of the small number of moving parts, there is little reason to expect shorter life than conventional compressors.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

In LG design work, direct substitution of the linear compressor for a reciprocating unit reduced energy use by 24% in a 24 ft^3 side-by-side refrigerator/freezer. Optimizing the design for the modulating linear compressor with HFC-134a led to a 47% reduction in energy use. This efficiency level is likely to require using separate evaporators for the freezer and refrigerator, which will directly improve efficiency and also reduce frost control issues in the freezer section. The expected reduction for a smaller unit would be less, but a 40% reduction would still yield 300 kWh/yr, or 0.82 kWh/day. SunPower asserts that the technology will have rather consistent efficiency in sizes from 10W to 5 kW. Vineyard and Sand (1997) estimated manufacturer's cost of $53 to achieve 1.16 kWh/day, but much more ($134) to include vacuum panel insulation. Unger (1997) suggests that the linear compressor (when mature) may be less expensive than the components it replaces. LG reports that their 2004 models that introduce the linear compressor to the U.S. market will reduce energy consumption 30% without split evaporators, and show no significant price increase relative to their reciprocating compressor models.

KEY ASSUMPTIONS USED IN ANALYSIS

For the package, we assume an incremental manufacturer cost of $2, based on information from LG. This translates to $4 incremental cost to the consumer, using Vineyard and Sand's 2:1 cost multiplier. Adding split evaporators would increase consumer costs further, by $50 - $60 (EPA 1993).
Canada-specific assumptions: This measure applies only to refrigerators, which are assumed to be half of the appliance end-use. Penetration by 2020 is assumed to reach 90% of the new and existing stock single detached and attached housing and 70% of the apartments and mobile homes. Consultant estimate based on Canadian residential end-use analysis studies that show refrigerators accounting for the largest consumption of all appliances (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

In the trade press, LG has expressed willingness to license the linear compressor technology to competitors. As a competitive market emerges, market transformation programs are likely to be highly cost-effective, based on the low cost of saved energy in this highly competitive market. Tax credits pending in the 2003 federal energy bill would provide incentives for models 15% and 20% better than the current standard; a utility or public benefits program incentive for at least 30% better performance would encourage production of models with both linear (or other modulating) compressors and dual evaporators. In turn, these will prepare the ground for efficiency standards requiring consumption less than 1 kWh/day.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

CONTROL SYSTEMS

CANADIAN SUMMARY

Several T&I submissions pertained to **building control systems** including personal environmental control (PEC) and perimeter control systems. Below is a summary of Canadian implications of these projects.

Current Canadian Status of Technologies

Self-learning algorithms are being developed in Canada for personal environmental control (PEC) and perimeter control systems; these algorithms are being extended to both manual input and automatic control situations. Enhanced feedback and response in 'responsive buildings' is also being developed in Canada, where buildings can react to external signals (e.g. energy source prices or instructions from utilities) and internal signals (e.g. load, occupant programming, system efficiencies, remaining energy, etc.).

Canadian Opportunities & Challenges

Canadian PEC and perimeter control innovations are increasing the thermal and lighting customisation and controlled-technology choices for individual workspaces and other areas of buildings, including the balance between natural (solar) and artificial (powered) heating/cooling and lighting. Canadian government and industry is also working toward open standards for PEC, rather than single-source proprietary technology, which has not been a successful route in the past in working with PEC manufacturers. As 'responsive building' technologies mature and better data is available, ongoing refinements can be made to enhance peak efficiency.

CR1 HOTEL KEY CARD SYSTEM

DESCRIPTION OF TECHNOLOGY

To reduce hotel/motel lighting and HVAC energy use, several products are coming to market that minimize usage during unoccupied periods through the use of the key card. The key card systems achieve this goal through different methods. One approach controls energy consumption through the door key card and additional sensors that determine guest occupancy. The second is a stand alone unit that determines occupancy through a dedicated key card system; if the guest is present the card is in the reader and if not the guest has the card and energy consumption is minimized.

CURRENT STATUS OF MEASURE

Key card systems have become universal in the hospitality industry due to the benefits of increased room security through reprogrammable key cards. Energy management features that control room HVAC and lighting operation represent the next logical step in key card evolution. Messerschmitt produces a system by which a central computer determines occupancy status and adjusts energy consumption accordingly. It keeps the temperature of the room constant at a minimal comfort level until a guest requests a more comfortable temperature. It will also hand over control of lighting when the guest is in the room and turn off lights when guests are not present (Messerschmidt 2004). Reth Ireland manufactures one of the stand-alone systems. When a guest enters a room he or she must insert the key card to control lighting and HVAC. The card is also used as the key card for the door, so as the guest leaves, the card is removed and room lighting and HVAC is switched to setback mode (Chen 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Key card products have the potential to considerably reduce room HVAC and lighting energy use. However, this is primarily a new construction measure since it is expensive to retrofit systems with the hardware and wiring to a central office computer. The incremental cost of adding the energy management features to the key card system is about $25 per room (personal communication with D. Chen 2003). Additional wiring requirements to interface the key card system with the HVAC and lighting circuits is estimated at an additional $75 per room.

KEY ASSUMPTIONS USED IN ANALYSIS

Monitored motel room HVAC and lighting energy consumption with conventional packaged terminal heat pump equipment was found to be roughly 9.5 kWh per ft^2 per year at one site (DEG 2000). Based on detailed lighting fixture monitoring at ten hotel rooms (Page and Siminovitch 2000), we estimate roughly 60% of lighting energy usage occurs during the 9 AM to 4 PM period when rooms are generally not occupied. Based on key card control, we project a 33% reduction in lighting energy use. HVAC energy use is more difficult to quantify due to the unpredictable nature of how room units are controlled (DEG 2000). Estimating a 20% HVAC savings potential, overall room savings of 25% are projected. Installation costs are estimated at $100 per room above the cost of the key card door lock system.

Canada-specific assumptions: This measure is restricted to hotels (excludes restaurants), which are estimated to be 70% of the segment energy use. Penetration by 2020 is assumed to reach 90%. Consultant estimate based on breakdown of sub-segments in the commercial sector (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Due to the fact that most of the key card systems are currently manufactured overseas, market penetration in North America may be slow. Education of large hotel/motel organizations is critical in improving their understanding of where energy use is occurring within their establishment. A case study with a side-by-side comparison of motels with the key card system and without, would be useful in quantifying the savings potential of the system.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

WATER HEATING

CANADIAN SUMMARY

Several T&I submissions pertained to the category of **water heating** including various integrated systems. Below is a summary of Canadian implications of these projects.

Current Canadian Status of Technologies

Over 90% of Canada's hot water supply in the buildings sector is still generated using 1980s technology, although efficiencies have slowly increased over the past 25 years. Today, Canadian industry associations and manufacturers are researching and commercialising various integrated systems combining water heating and solar thermal and/or HVAC and/or power systems, such as the Canadian ēKOCOMFORT™ system. Many of these related water heating projects are currently being done solely in Canada or complementary to international work; an example is innovative gas-fired integrated systems being developed solely within Canada, putting Canada in a leading position and opening up international business opportunities. These R,D&D projects support Natural Resources Canada's Office of Energy Efficiency and industry standards development activities. It is estimated that Canadian receptors for these water-heating technologies currently exist or will exist by 2015. Design criteria are also being defined for extended storage (days, weeks, or even months) of solar thermal energy so the heat can be used to better supplement or satisfy both domestic hot water and space heating loads in Canadian climates year-round.

Canadian Opportunities & Challenges

With the increasing recognition of Canada's solar resource, solar thermal supplementary systems, (including integrated solar thermal systems), are gaining more market acceptance in Canada; this will be complementary for some water heating technologies and a threat to others. All emerging water heating technologies may need to comply with a new "P.10" home mechanicals standard, which is currently being developed by the Canadian Standards Association (CSA) to: 1) align minimum efficiency requirements for products that use different technologies to serve the same function and 2) eliminate poorly performing products from the marketplace.

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W1 CONDENSING WATER HEATERS

DESCRIPTION OF TECHNOLOGY

Conventional storage water heaters have energy factors in the range of 0.6, meaning they waste 40% of the input energy. Condensing boilers can capture over 90% of the input energy. Condensing units capture almost all of the heat value of condensing flue gas water vapor to liquid (about 10% for natural gas). More importantly, their forced draft burners eliminate off-cycle heat transfer to the flue. As expected from the additional and improved components, condensing boilers have a substantial first cost premium.

CURRENT STATUS OF MEASURE

Condensing residential water heaters are currently available from Laars Heating Systems, Polaris, and Voyager. All are typically installed as combination space and water heating units. Neither FEMP nor ENERGY STAR have water heating programs, although it was under consideration by the latter.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The 34 gallon, 100,000 Btuh Polaris (Model PG10 34-100-2NV) sells for $1800 plus installation. Because of its high recovery rate, we consider this unit equivalent to a larger conventional storage unit (we assume 80 gal). We estimate $1100 current incremental costs in residential applications. On the standard test cycle, gas consumption is reduced by 42% ($94 per year), after subtracting $8/yr for electricity used.

KEY ASSUMPTIONS USED IN ANALYSIS

We estimate an installed price of $600 for a base model (EF = 0.60 in 2004), and $800 incremental price for the condensing unit when products become more widely available. We assume that fuel *use* is proportional to the ratio of energy factors, *e.g.,* 0.60/0.93. Then the combustion efficiency (95% advertised for both Polaris and Lennox CompleteHeat) multiplied by the "standby efficiency (100-5-1.5=93.5%) is an estimated EF of 0.89 as a water heater. Based on these assumptions, condensing water heaters are cost-effective where projected natural gas prices are higher than $0.64/therm, so they should be attractive to all relatively large hot water users.

Canada-specific assumptions: This measure is restricted to natural gas and propane water heaters, which represent 65% of the total DHW energy use. Penetration by 2020 is assumed to reach 75% for W1 and W3, and 5%for W4. The estimate of portion of residential DHW met with natural gas and propane water heaters was derived from Canada's Energy Use Data Handbook (NRCan 2004).

RECOMMENDED NEXT STEPS

Even at the high incremental cost assumed for the condensing water heater, it is a cost-effective solution at today's gas prices for the *average* consumption pattern assumed by the DOE test procedure for most consumers (e.g. for a typical family of four). In addition, the combination of high efficiency and high recovery rate should make these ideal for light commercial applications such as commercial kitchens with dishes and silverware, some locker rooms, and some coin laundries. Condensing water heaters are a good candidate for programs to that increase customer awareness (*e.g.,* FEMP) and for gas utility incentive programs, since cost reduction will follow from sales volume increases. *See also,* W-4, Integrated Home Comfort Systems, which deals with products such as the Lennox "CompleteHeat" and the Canadian ēKOCOMFORT™ program, which involves several additional manufacturers.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

W2 INSTANTANEOUS, GAS-FIRED, HIGH-MODULATING (CA. 10:1) INSTANT WATER HEATERS

DESCRIPTION OF TECHNOLOGY

In Canadian and U.S. single family houses, storage water heaters are almost universal. The "instant" or "tankless" water heater is more popular in other countries. These units use a very high capacity gas burner or electric resistance element and sophisticated controls to heat water on demand. Because there is no tank, these units are small, and are frequently wall-hung. Conventional (100 amp) residential wiring can only support very small electric demand water heaters (up to about 1 gallon/minute (gpm) at 12 kW power supplied), but available gas water heaters, at ratings up to 199,000 Btuh, can support needs in some whole-house installations, at about 3 gpm (DOE 2003). Advanced units use water mixing valves and/or modulating burners with electronic controls to maintain constant outlet temperature despite (seasonal or other) variations in inlet temperature and variable demand (*e.g.,* number of faucets open, and to what extent).

CURRENT STATUS OF MEASURE

Currently, instantaneous gas water heaters comprise 1% of the U.S. market for house-scale water heaters (DOE 2003). DOE estimates that sales of these units are around 50,000 per year and sales are growing at 30 to 50% per year (DOE 2003). DOE explored an ENERGY STAR labeling program for water heaters in 2003, which could have included instantaneous gas water heaters with energy factor (EF) of .82 (DOE, 2003), but decided against proceeding (DOE 2004).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The EF proposed for ENERGY STAR was 0.82 for this technology. Comparing a unit with .82 EF with a 40-gallon tank (commonly used in residential homes) with .594 EF (federal minimum energy standard in 2004), energy savings are 28%. Greater savings would be attained if these units replaced oversized tanks in commercial applications (because of lower standby losses not accounted for by the rating method). Instantaneous gas water heaters currently cost $350-$2000, depending on capacity (Btuh) and features. Incremental cost is currently high – typically $900-$1000 for a whole-house unit.

KEY ASSUMPTIONS USED IN ANALYSIS

A typical U.S. home uses a 40-gallon water tank. Our baseline is the 2004 minimum efficiency 40 gallon storage water heater (EF=0.59). About 54% of residential homes use gas water heaters (Census 1999). We assume a mature market price of $600; it is almost twice that today. At $600, the cost of saved energy for residential units ($8.32/MMBtu) is greater than the current cost of gas for the default consumer in the test procedure, but it would be less than $6/MMBtu if the incremental cost fell to $400. Since instantaneous gas water heaters currently in the market have maximum 3 gallons per minute capability, we assume that the units would be used in applications with high average use but low peak demand. For these applications, the average cost of saved energy drops to $5.90/MMBtu at 1.4 times the default daily use, and $4.13/MMBtu at twice the default usage. Thus, they would be cost-effective for many larger families and small commercial applications. For example, commercial buildings 10,001 to 100,000 sq.ft. in size have the least natural gas intensity usage for water-heating (40.2 cf/sq.ft.) (CBECS 1999). These buildings consume approximately 39% of total natural gas for water-heating in the United States. To be conservative, our analysis is based on residential applications, with estimated 60% of installations feasible.

Canada-specific assumptions: This measure is the commercial sector restricted to natural gas water heaters. Their share ranges from 30% to 80% of the DHW energy use. Penetration by 2020 is assumed to reach 75%. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

An ENERGY STAR endorsement would assist instantaneous gas water heaters to stand out in the market as a viable alternative to higher energy-consuming units. It may also encourage manufacturers and vendors to put more effort into developing and marketing lower cost units. Consumers need further education on the most appropriate uses of these units. Gas utilities may find this market attractive for efficiency programs directed at commercial users. It is also expected that price reductions would follow increasing sales.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

W3 HEAT PUMP WATER HEATERS: WITH AND WITHOUT INTEGRAL TANKS

DESCRIPTION OF TECHNOLOGY

The typical US house today uses an insulated storage tank and heats water with a gas flame or electric resistance element. The former suffers large standby losses through the flue, and the latter has inherent inefficiencies of electricity generation. The heat pump water heater uses a vapor-compression refrigeration cycle, like a refrigerator or air conditioner, and the COP largely compensates for primary electricity conversion losses. HPWHs are commonly installed in basements, where they take heat from the air at a relatively low temperature, and reject the heat at a higher temperature to the water tank; placement for slab-on-grade houses varies with climate. In the process, most units also cool and dehumidify the basement, which can be valuable. Efforts to commercialize the technology have waxed and waned for decades. Current U.S. annual sales are estimated as a few thousand units per year (Sachs 2002).

CURRENT STATUS OF MEASURE

Within the past few years, several manufacturers abandoned the market, and the only large-scale utility program for residential HPWH in the continental US was suspended after 4000 installations, largely because utility funding was disrupted (DOE 2002). However, two new residential products have been introduced, and there is substantial interest now. The "Watter$aver" from ECR International is designed to "drop in" to the same space as an existing 50 gallon resistance water heater, and can be installed by a single trade. Its certified EF is 2.4 (GAMA 2003), compared with 0.95 for the best resistance units. NYSERDA offers $300 incentives for this unit. The alternative, an add-on unit, is exemplified by the Nyle Specialties Nyletherm 110 heat pump water heater. It is a wall-hung, 7000 Btuh auxiliary unit designed to supplement an existing water heater by replacing the primary resistance element. Its power requirement, 7.25 amps at 120 v., can be met by a conventional wall socket. The unit is new, and there are no independent performance data yet. In the commercial sector, HPWH has not grabbed a big market. However, the DOE recently awarded United Technologies Corp. to develop systems with higher water-delivery temperatures and wider operating range for commercial uses (DOE 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The incremental cost of an integrated heat pump water heater today is in the range of $900 - $1000 (Johnson 2003). At average electricity prices ($0.078/kWh), this would be a four year simple payback. The add-on HPWH will likely have similar costs and benefits, but certified ratings are not yet available. In a mature, competitive market, the purchase price (without installation) will be about the same as that of the separate technologies, approximately resistance water heater plus a room air-conditioner, or about $500 - $600. Installation should be the same cost as for a resistance water heater, unless a condensate pump and installation are required ($100).

KEY ASSUMPTIONS USED IN ANALYSIS

We assume: (1) The HPWH displaces 30% of all resistance water heaters but no gas water heaters [estimated fraction of customers with electric water heaters and demand at test measure assumption, 66.3 gpd (DOE 2002), rather than national average about 44 gpd (TSD Figure 10.1)]. (2) Field EF = 2.4, compared with 0.9 for electric resistance water heater. (3) Calculation using methods of the GAMA Consumer Directory. (4) Incremental installed cost of $800.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

The first cost is high, and the products are not widely available. We recommend the following steps, *in parallel:* (1) Continued field demonstrations. If successful, progress toward rebates and contractor training as early MT promotion. (2) Disseminate information (technology, availability, savings calculation methods) to potential large-scale buyers, as FEMP is doing. (3) Work to be sure that ENERGY STAR residential programs encourage use of heat pump water heaters by uniformly providing incentives for EF>2.0, once the technology is well-proven and readily available.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

W4 INTEGRATED HOME COMFORT SYSTEMS

DESCRIPTION OF TECHNOLOGY

Over the next decades, improved construction will decrease residential HVAC loads, but raise the importance of mechanical ventilation. The results will be higher water heating loads relative to space heating loads, and the addition of ventilation loads. Integrated appliances that provide space heat (and cooling), hot water, and ventilation services promise higher efficiency, lower costs, one-trade installation, and smaller space requirements. Already, space heating and water heating are the two largest energy uses in the average house (RECS 2003). For high-efficiency fossil-fuel equipment, the core appliance is usually a high efficiency, fast-recovery, water heater. It provides space heating by a water-to-air coil in an air handler that replaces the furnace, and may also integrate a ventilation function. The Lennox CompleteHeat system exemplifies this approach. The American Water Heating "Polaris" high-recovery, condensing, water heater is also frequently installed with a hot water coil and air handler integrated by the contractor. Integrated systems can also be built around space-conditioning heat pumps, either using a desuperheater to make hot water while the system runs, or as a full condensing water heater option. Both approaches are rare with air source heat pumps, but most residential ground source heat pumps have desuperheaters that may provide half the water heating on an annual basis.

CURRENT STATUS OF MEASURE

Thorne (1998) estimates that the penetration of combined systems is less than 2% of US houses, and that the number of high-efficiency units is much smaller. Lennox CompleteHeat is marketed as a premium product, with many options (humidifier, heat recovery ventilator, etc). It is considered unlikely that sales have reached 10,000 units per year. In Canada, the government-industry "ēKOCOMFORT" effort is designed to hasten deployment of integrated appliances. The ēKOCOMFORT specification does not require condensing equipment, includes oil-fired units, and requires efficient fan motors for air distribution. The ēKOCOMFORT initiative currently works with five manufacturers (Gucciardo 2003). The Canadian Standards Association is developing rating methods and standards (Gluchkow 2003). Test systems are in 18 homes ranging from 1200-4000 sq. ft, in Ontario and Nova Scotia. About half of the homes have undergone tests for one season.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The first ēKOCOMFORT units are still in field test; so purchase costs and energy savings are not available. Costs of CompleteHeat systems vary with size and by dealer. In a mature market, from bottom-up analysis of component prices we estimate the incremental cost of these systems as about $550 more than the cost of separate base-model water heater and furnace. Counterbalancing the cost of the condensing water heater, hot water coil, and circulator motor is the cost reduction by deleting the gas burning apparatus, heat exchanger, and draft inducer motor in the furnace.

KEY ASSUMPTIONS USED IN ANALYSIS

Integrated units are rated by Combined Annual Efficiency (CAE, ASHRAE Standard 124). We assume that performance is equivalent to separate appliances with an EF of 0.90 in water heating, and 0.93 AFUE in heating (to account for losses in the additional heat exchanger and pump). Our electricity savings estimates are based largely on ACEEE decrements to GE estimates of ECM savings (Sachs and Smith, 2003)

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

Wide deployment requires helping decision-makers understand implications of "CAE" (Combined Appliance Efficiency) for comparisons to conventional choices, and assuring that code officials are comfortable that potable hot water coils in furnaces do not introduce health hazards. Utility incentive programs for gas appliances need ways to accommodate integrated appliances, to encourage adoption of units with appropriate performance. New construction applications are likely to be more common than replacements on burnout, since simultaneous failures of the water heating and space conditioning systems are infrequent.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

DRIVES AND MOTORS

CANADIAN SUMMARY

Several T&I submissions pertained to **drives and motors** including low-power air handling and water pumps. Below is a summary of Canadian implications of these projects.

Current Canadian Status of Technologies

Canadian R&D activity includes work on low-power motors and drives for air handling and water pumping. This includes development of enhanced high-pressure low-flow fluid pump motors and work on energy efficient hybrid ventilation systems for residential buildings. Work is also under way on improving the energy performance of heat recovery ventilator (HRV) fans and fan motors, which has remained unchanged for years.

Canadian Opportunities & Challenges

The stagnant design in HRV motors is prompting redesign, but partnering with U.S. motor and fan manufacturers will be required. Although some Canadian HRV manufacturers exist, they usually source their fans and motors from the U.S. The improved low-power fan motors will significantly enhance opportunities for powering air handling systems with backup, emergency, or renewable power and will allow manufacturers to differentiate a new product. These improvements will also facilitate implementation of incremental regulatory requirements for improved fan motors. The increased use of radiant floor systems in Canada for heating and cooling (whether or not in concert with renewables) is also increasing the demand for low-power water pumps.

D1 ADVANCED APPLIANCE MOTORS

DESCRIPTION OF TECHNOLOGY

Appliances are manufactured in very large volume, with stringent cost, reliability, and efficiency targets. In general, their motors are specialized, low-cost, designs rather than general purpose "frame" motors. Most are fractional hp induction motors dedicated to producing rotary torques to turn washer or dryer drums, to pump water, or to drive fans. On the other hand, advanced technologies, particularly electronically commutated DC permanent magnet (DCPM, often called ECM or ECPM) and switched reluctance (SR) motors offer potential cost, performance, and/or feature set improvements. Both classes rely on electronics to provide precisely timed voltages to the coils, and use rotation position sensors for timing.

CURRENT STATUS OF MEASURE

Both DCPM and SR motors are in commercial service in efficiency-regulated appliances today. The most conspicuous application of DCPM motors (for two decades) is to drive HVAC circulation fans, where they differentiate quieter and more efficient premium products (See also Measure D-3). Increasingly, DCPM motors are being used for condenser fans, inducer fans, and other applications. Switched Reluctance motors are used for several hundred thousand premium clothes washers per year. One primary driver is their combination of high torque at low speed and very high speed range, which has allowed eliminating the conventional transmission, saving money and decreasing weight. Switched reluctance motors require high precision but have few parts and ordinary materials. They also need advanced design techniques and software. This combination suggests lower costs for high-volume motors. For washing machines in particular, the cost to manufacture a switched-reluctance motor machine may be less than current practice (at maturity), since the SR approach allows simplification of the mechanical drive train (Lloyd and Sood, undated).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Thorne and others (2000) estimate savings potential in clothes washers as up to 50% from improved technology and less water use per cycle. From published efficiency data (Sood and others, undated), we now calculate 60% motor power savings in washing machines with variable loads (e.g., wash *v.* spin; light *v.* full load). Fixed-load appliance savings will be much lower, on the order of 15%.

KEY ASSUMPTIONS USED IN ANALYSIS

Our analysis uses washing machines as representative appliances, with 0.27 kWh/cycle and 392 cycles/year (TSD) . Washing machine savings in kWh/yr will be higher than for appliances that draw less current, and as a fraction will be higher than for appliances that have multiple electricity uses (such as water heating by dishwashers). We use DOE MEF conditions (0.27 kWh/cycle, 392 cycles/yr), and assume 3:1 ratio of time in wash to spin; savings would be larger if the wash:spin ratio is higher. Washing machine savings alone are only about 0.06% of 2020 buildings energy use, but highly cost effective ($0.002/kWh). This suggests that SR has the potential for application in other regulated appliances, including variable speed furnace inducers, air conditioner condenser fans, and dishwashers.

Canada-specific assumptions: This measure applies only to circulating pumps, which range from 20 to 35% of the auxiliary motor end-use. Penetration by 2020 is assumed to reach 99% of the residential existing and new stock and 80% of the commercial existing and new stock. Consultant estimate based on Canadian commercial end-use analysis studies that show that the energy use by circulating pumps is smaller than the fan energy consumption. Typical pump energy use ranges from 1 to 1.5 kWh/ft^2.yr out of a typical 5 kWh/ft^2.yr for the HVAC equipment end-use (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The principal barriers are relatively slow model turnover, and the intense first cost pressures on most manufacturers today. Because these motors are commercialized now, universal application should be considered for baseline in all upcoming appliance standards. Only dishwashers and furnaces seem to be relatively near-term candidates. The improved efficiency of these motors also supports higher thresholds for market transformation programs for products such as dishwashers and washing machines in which the cost of motor energy is significant, since the cost of saved energy is extremely attractive.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

D2 ADVANCED UNITARY HVAC COMPRESSORS

DESCRIPTION OF TECHNOLOGY

In the US, almost all residential and light commercial central air conditioners and heat pumps use single-speed reciprocating or scroll hermetic compressors. Compressor peak load efficiencies have improved by 50% since the mid-1960s, with signs of less improvement recently (DOE, 2001). In larger commercial packaged units, the norm has been to use two compressors of different sizes, to give three operation stages. Modulating compressors are more common in Asia for "mini-split" systems in which a single compressor supports multiple, independently-controlled evaporators. Modulating compressors give designers many alternatives for designing products that match varying sensible and latent loads well, particularly when coupled with modulating air handlers (treated in D-3, Advanced HVAC fan motors). Recently, U.S. attention has turned to multi-stage and modulating compressors to improve part-load performance of systems, the subject of this write-up.

CURRENT STATUS OF MEASURE

Bristol introduced the "TS" reciprocating compressor several years ago. It reduces capacity to 40% by idling one of its two pistons, yielding roughly 50% reduction in system capacity. Copeland has introduced the two-stage "UltraTech" compressor for US-style residential split systems. It reduces capacity to 67% by using alternate bypass ports to introduce refrigerant. Several manufacturers now offer two-speed residential air conditioners with very high SEER levels; not all indicate the compressor source. With the current SEER rating method, products can be designed that use the first stage of the compressor for almost all of the test cycle, giving very high SEER values. This design approach does not improve high temperature performance, typically measured with EER. Thus, we expect modulating technology to dominate the market for SEER>14, unless stringent EER requirements are applied, as this approach seems more compact and less expensive than alternative approaches to raise SEER.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Using the appropriate mark-ups, the data in the air conditioner Technical Support Document, or TSD (DOE, 2001) suggest that the retail price of the compressor for a SEER 13 air conditioner itself would be $77 more than for a SEER 10 unit. We use this value for the incremental cost. The 2-stage could reasonably be more costly; we estimate $150 retail for a commodity unit with only the 2-stage compressor added (based on "hints" from a manufacturer about OEM costs).

KEY ASSUMPTIONS USED IN ANALYSIS

We assume a SEER 12/EER 10 Baseline, and SEER 16.5/EER 12 new measure. We use the ENERGY STAR calculator for energy savings (Climate Zone 5), but correct for the relatively high saturation of BPM motors (measure D-3) in very high SEER equipment, decrementing savings by 200 kWh/yr (Sachs and Smith, 2003).. Peak reduction estimates are based on EER 12 *v*. EER 10 baseline, decremented by 0.138 kW summer peak from BPM motor (D-3, this study). This implicitly assumes that the modulating compressor runs in Stage 2 (high) at 95ºF. We

assume possible penetration of SEER 14 and above equipment as 35% of the market, which is almost twice the incentives-supported fraction of SEER 13 units today in New Jersey. This yields a cost of saved energy (CSE) of $0.040.
Canada-specific assumptions: This measure applies to small commercial buildings with residential type small tonnage equipment, which ranges in applicability from a low of 7% to 99% in the religious segment, which is dominated by small tonnage packaged equipment. Penetration by 2020 is assumed to reach 55% of the existing and new stock residential stock and 65% of the commercial existing and new stock. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles that provide a distribution of A/C equipment by type (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Modulating compressors are a branch point for market transformation programs. One path enables "SuperSEER" equipment that does not have EERs significantly above 12. These are likely to be cost-effective on energy savings in hot areas without demand-based residential tariffs, but they will not help capacity-constrained utilities as much as alternative design strategies that boost EER as well as SEER. Equipment for such programs is likely to require advanced compressors, larger heat exchangers, optimized controls, and careful attention to all parasitics (such as the condenser fan).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

D3 ADVANCED HVAC FAN MOTORS

DESCRIPTION OF TECHNOLOGY

Smaller HVAC systems typically use A/C fractional horsepower motors that directly drive the centrifugal fan, which is attached to the extended motor shaft. The market for conventional, baseline, residential split systems and furnaces is completely dominated by multi-tap permanent split capacitor (PSC) induction motors, which combine reasonable efficiency with the ability to select different speeds for heating, air-conditioning, and ventilating, or to match the external static pressure of a particular duct systems. PSC motor efficiencies tend to run from about 35% (low speed) to 65% (high speed). In contrast, premium products (furnaces with AFUE greater than 91; air conditioners with SEER 14 or above) often use electronically-commutated DC permanent magnet motors. These are continuously modulated and 10% (full load) to 100% more efficient (light load, as in ventilation/circulation) than PSC motors. Some units can be "tuned" to supply specified air flow or delivery, regardless of duct conditions.

CURRENT STATUS OF MEASURE

The DCPM is commercially available, with several hundred thousand units/year sold for HVAC applications. In general, these are "bundled" in premium models that combine high efficiency with other features, such as quiet starts and separate controls for temperature and humidity. DCPM are also becoming available for commercial terminal units and powered VAV boxes.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

ACEEE estimates average national savings for residential air handlers as 700 kWh/yr, 500 in heating and 200 in air-conditioning (Sachs and Smith, 2003). One manufacturer estimates average savings twice as large (GE, 2001), but this estimate seems to ignore incremental gas needed in heating season to replace electricity no longer dissipated as heat. ACEEE estimates that the incremental OEM cost of the DCPM motor will be $35 (1/2 hp), or $80 consumer price (using DOE TSD assumptions on price multipliers; Sachs and Smith, 2003).

KEY ASSUMPTIONS USED IN ANALYSIS

Savings measures presented here are based on field measurements of HVAC fan energy consumption and external static pressures, such as Proctor and Parker, 2000, and Pigg, 2003; and laboratory evaluations of advanced systems (Walker et al, 2003). Estimates based on the ARI – DOE method of test are lower, because the external static pressures assumed in the rating method are less than half the average values seen in the field. Economic assumptions on motor costs are based on mature product in a competitive market, and are justified by the observation that alternative technologies (multi-pole switched reluctance, optically commutated induction, etc) may approach or equal the efficiency of the DCPM motor at lower cost (particularly switched reluctance).

Canada-specific assumptions: This measure applies to circulating furnace fans, which are assumed to represent 15 to 20% of the electricity use in single and detached and 10% in apartments and mobile homes. Penetration by 2020 is assumed to reach 65% of the existing and new stock single detached and attached housing and 60% of apartments and mobile homes new and existing stock. Consultant estimate based on Canadian residential end-use analysis studies that show residential fans having a consumption of 800 to 2500 kWh/year (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

There are at least two major barriers to market transformation: (1) Current test methods for standards do not properly reveal air handler energy use. (2) Manufacturers use DCPM motors as part of premium products, differentiated by soft start/stop, system static pressure matching, and effective humidity control; they do not want air handler efficiency to be become a commodity in the market. Market transformation should be based on performance rather than prescriptive standards. Performance-based standards for air handlers require modest additional research on non-condensing furnaces, furnaces with large air handlers for southern climates, and heat pump air handlers. This work should commence immediately. Market transformation programs coupled with condensing furnace programs in northern climates are recommended today, and have been initiated in Oregon, Massachusetts, and Wisconsin (Sachs and Smith, 2003). As quickly as possible, Methods of Test for standards should be revised to incorporate more realistic external static pressures, which will encourage use of more efficient fans.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

D4 HIGH-EFFICIENCY POOL AND DOMESTIC WATER PUMP SYSTEMS

DESCRIPTION OF TECHNOLOGY

Residential pools, spas, and water wells typically utilize pumps ranging in size from 1 to 3 hp. A vast majority of the installed pumps are standard efficiency single-speed pumps. The efficiency and energy use of all three types of pumps can be improved by properly matching pumps to system flow and pressure head requirements. Anecdotal evidence suggests that many of these pumps are frequently oversized based on a "bigger is better" mentality. Coupling oversized pumps with undersized pumping results in inefficient pump operation. Part of the problem can be attributed to how pumps are labeled using "horsepower" and "service factor". Service factor is a measure of how much a pump motor can be under-sized without overloading the motor. For example, a 1 hp pump with a service factor of 2.0 draws about the same power as a two-horsepower pump with a service factor of 1.0. The reasons for marketing high service factor pumps are unclear, but the practice creates confusion and contributes to inappropriate pump sizing.

CURRENT STATUS OF MEASURE

Available national energy use estimates (cited below) suggest that well pumping and pool pumping are roughly of the same magnitude. Spa pumping, is difficult to disaggregate from total spa consumption since it is rarely submetered and some spa pump energy contributes to heating of the spa. Estimated market share and energy use is presented for each of the three categories.

Pool pumps: 5.5 million nationwide, 792 kWh/unit, 4.4 TWh (EIA 1997)
Spa pumps: 2.7 million nationwide, 600 kWh/unit (estimated), 1.6 TWh
Well pumps: 14.3 million nationwide, 315 kWh/unit, 4.5 TWh (LBNL 1998)

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The combined energy *use* is on the order of 10 TWh, or 100 Tbtu. (Since total use is less than our threshold for *savings*, this measure is a low priority) of total residential and commercial building energy use. The pool and spa pump market is increasing at a much faster rate than well pumping, and with its higher "per unit" usage is better suited for targeting. Estimated potential savings for pool and spa filter pumps is difficult since energy savings are dependent upon the pump system curve relating total system head to pump flow rate for a given pump. The goal of any efficient pumping program is to deliver the required amount of flow needed to maintain water quality at the most efficient point on the system curve. Two-speed pumping is an approach that allows for filtration to occur at low-speed over a longer period of time, while having high-speed pump operation available for use with pool cleaning hardware. More efficient pumps are also on the market, some of which use electronically commutated motors (ECM's).

KEY ASSUMPTIONS USED IN ANALYSIS

The incremental cost for a 2 hp two-speed pump with controls is estimated at $580. Energy savings of 58% are projected based on typical applications (DEG 2003). As the market share of two-speed pumps increase, prices should fall especially for the controls which are not currently readily available. The incremental cost of controls should approach zero, but the motor cost will remain about $200.

Canada-specific assumptions: This measure applies only to single detached housing and assumed to be applicable to only 5% of the stock. Penetration by 2020 is assumed to reach 50% of the existing and new stock single detached stock (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The principal barriers are lack of industry support, understanding of the benefits (education), and an installation infrastructure. Prototype demonstrations of various efficient pump options are needed to develop a database of projects throughout the United States. Utility rebates are another approach to educating homeowners and contractors. Initial utility targeting should focus on warmer climates where the pool season is longer generating higher savings. By priming the pump in these areas, hopefully incremental costs will fall improving economics in other parts of the country.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

HEATING, VENTILATING, AND AIR CONDITIONING (HVAC)

CANADIAN SUMMARY

Several T&I submissions pertained to **heating, ventilating, and air conditioning** including those covering drives and motors, integrated HVAC systems, heat recovery, environmental control systems, air conditioning, air quality, moisture management, and natural heating, ventilating, and cooling. Below is a summary of Canadian implications of these projects. The HVAC category covers a broad range of technologies and, consequently, there is some overlap here with observations in the other T&P categories.

Current Canadian Status of Technologies

Drives & Motors

Canadian R&D activity includes work on low-power motors and drives for air handling, including development of enhanced high-pressure low-flow fluid pump motors and work on energy efficient hybrid ventilation systems for residential buildings.

Integrated Systems

Canada's leading fuel cell industry is ready and expressing interest in developing building integration techniques and knowledge. Receptors currently exist in Canadian industry for combined heat and power generation (CHP or 'cogeneration'), whether based on fuel cells or other energy forms. An example is the strong interest of HVAC companies and international semiconductor photocell manufacturers in participating in R&D in Canada. Domestic collaboration includes Natural Resources Canada (NRCan) helping Canada's leading fuel cell cogeneration manufacturer (FCT Ltd) exploit the benefits of simulation in designing their system and helping them assess potential markets. Part of this collaboration included NRCan developing a SOFC-cogeneration modelling tool for FCT in 2001. NRCan is adding new capabilities to the model in 2004 to allow FCT to explore space-cooling options for its systems. Related Canadian research is being done at Dalhousie University and University of Victoria.

Canadian government and industry have also been very successful and gained much experience from launching the ēKOCOMFORT™ line of integrated HVAC systems. Industry associations and manufacturers continue to develop the next generation of these integrated systems including some renewable energy technologies in the mix, such as solar thermal water and/or air, and photovoltaics (PV) to optimise the performance of all system functions. This will lay the groundwork for future inclusion of power generation and thermally driven cooling. Other related integrated systems being developed include multi-fuel and biofuel furnaces and stoves; concentrated solar heat and power systems (Menova of Ontario); and the next generation of energy efficient, environmentally friendly, and durable wall, roof, and foundation systems that integrate solar thermal air and/or water and sometimes photovoltaics.

High-efficiency gas-fired lighting and heating systems are also being explored, where the appliance resides centrally in the building and provides both heat and light from combustion, similar to less efficient fireplaces.

Heat Recovery

The SolarWall-HR heat recovery product was developed and continues to be enhanced by Conserval Engineering of Ontario; the product preheats fresh intake air with solar energy *and* recovered exhaust heat, the latter being an enhancement from their initial SolarWall product. Design criteria are also being defined for extended storage (days, weeks, or even months) of solar thermal energy so the heat can be used to better supplement or satisfy both domestic hot water and space heating loads in Canadian climates year-round.

Another initiative involving heat recovery technologies is Natural Resources Canada's (NRCan) Refrigeration Action Program for Buildings (RAPB), which was launched in 2003 and aims to identify, promote, and demonstrate the next generation of energy efficiency gains possible in Canadian ice rinks, curling rinks, and supermarkets. Examples of identified heat recovery improvement opportunities in Canada's 2500 ice rinks include: recovered refrigeration plant heat; variable condensing temperature according to outside temperature and space heating demand; refrigeration condensing system that utilise a secondary coolant, which serves as heat supply for the network of heat pumps that provide space heat; and fully integrated systems such as the CIMCO Eco-Chiller or Ice Kube, which make maximum use of waste heat, minimise refrigerant use and losses, and use high efficiency components.

Environmental Control Systems

Self-learning algorithms developed for personal environmental control (PEC) and perimeter control systems are being extended to both manual input and automatic control situations, allowing occupants enhanced control and comfort of work and living spaces.

Air Conditioning, Air Quality, & Moisture Management

Housing design technologies and guidelines are also being refined to incorporate architectural and technology features such as solar-assisted liquid desiccant cooling, evaporative cooling, and natural ventilation to achieve optimal balance between space heating and cooling. Canadian R&D is also focusing on preventing excess interior dryness in extreme cold regions and reducing the humidity of fresh outside air in humid regions of the country.

New and improved sensor materials, fabrication technologies, and prototype devices and test fixtures are being developed for intelligent indoor air quality control. Three Canadian companies and three universities have already shown interest in pursuing these air quality control technologies.

Natural Heating, Ventilating, and Cooling

Canadian R&D and commercialisation experience in the window industry is ensuring significant Canadian and international receptors for further advance in fenestration systems (window and door design and placement). Current activity includes development and testing of thermal and optical performance evaluation methods for skylights, entry doors, and glazed facades. There is already sufficient demand for Canadian window systems from the U.S., the U.K., and other countries in Europe. Queens and Ryerson universities are working on thermal models of external blinds and Laval University is researching occupant use of shading and window openings.

Canadian Opportunities & Challenges

Drives & Motors

The stagnant design in HRV motors is prompting redesign, but partnering with U.S. motor and fan manufacturers will be required. The improved low-power fan motors will significantly enhance opportunities for powering air handler systems with backup, emergency, or renewable power and will allow manufacturers to differentiate a new product from others. These improvements will also facilitate implementation of incremental regulatory requirements for improved fan motors. The increased use of radiant floor systems in Canada for heating and cooling (whether or not in concert with renewables) is also increasing the demand for low-power water pumps; some of these hydronic systems are also complemented by forced air.

Integrated Systems

Micro-CHP systems are seen by most HVAC manufacturers as a key technology opportunity for the future. Micro-CHP opens up possibilities for efficient, silent, and stand-alone combined heat and power production. For instance, considerable savings would result from self-powered appliances developed for remote communities (e.g. northern Canada), where electricity costs are high. Additional Canadian R&D would position Canada for international business opportunities and would put Canada in a leading position in this technology arena. Canadian collaboration with international players will help inform energy policy and assist energy utilities and regulators in determining how to address residential cogeneration in the evolving field of distributed power generation.

Opportunities also exist regarding the modelling of fuel cells and other cogeneration technologies, where today's cogen models either ignore the performance of the building or are integrated into expert building simulation environments that are unsuitable for the majority of building simulation practitioners in Canada. Since NRCan's HOT2000 software has achieved broad acceptance among Canadian researchers, architects, and residential energy consultants, advanced fuel cell modelling is expected to garner the same acceptance from this user group. Based on this foreseen opportunity, cogeneration models developed by NRCan and its IEA Annex 42 partners will be integrated into publicly available whole-building simulation programs, such as NRCan's ESP-r/HOT3000 simulator and its HOT2000 v10 graphical user interface.

With increasing recognition of Canada's solar resource, solar thermal supplementary systems and integrated solar thermal systems are gaining more market acceptance in Canada; this will be complementary for some HVAC technologies and a threat to others. Integrated HVAC systems may need to comply with a new "P.10" home mechanicals standard, which is currently being developed by the Canadian Standards Association (CSA) to: 1) align minimum efficiency requirements for products that use different technologies to serve the same function and 2) eliminate poorly performing products from the marketplace. Initially, HVAC systems with integrated renewables are expected to be most economical in northern communities in Canada where electricity prices are high and there is a heavy reliance on fossil fuel. Over time, these products are expected to be sold largely to urban building owners. Much opportunity exists for collaborating with HVAC manufacturers, particularly those experienced in renewables and who participated in the ēKOCOMFORT™ initiative's first generation of products.

Heat Recovery

Current collaboration is expected to continue with engineering firms, facility operators, industry associations, and equipment suppliers involved with ice rink, curling rink, and supermarket refrigeration and heat recovery systems. Major renovations have been identified in the next ten years in ice rinks, curling rinks, and supermarkets, so consultants and facility operators will be receptive to innovative, energy efficient designs for implementation during these renovations.

Environmental Control Systems

Canadian PEC and perimeter control innovations are increasing the thermal and lighting customisation and controlled-technology choices for individual workspaces and other areas of buildings, including the balance between natural (solar) and artificial (powered) heating/cooling and lighting. Canadian government and industry is also working toward open standards for PEC, rather than single-source proprietary technology from PEC manufacturers, which has not been successful in the past.

Air Conditioning, Air Quality, & Moisture Management

There is an opportunity to position mechanical cooling equipment as *optional* if alternate design and low power solutions can meet most consumer needs during Canadian summers, at least in some parts of the country where air conditioning is currently used. Knowledge gained from other countries will be adapted to Canadian climates and building types, while the resulting experience in low technology cooling solutions will be applicable for export to developing countries. Opportunities relating to air quality include design, installation, and commissioning guidelines and improved energy efficiency and ventilation effectiveness of heat and energy ventilation recovery appliances.

Natural Heating, Ventilating, and Cooling

Advanced understanding, testing, modeling, and design of fenestration systems will increase Canada's impact on passive solar heating and daylighting technologies and practices.

H1 NEXT GENERATION COMMERCIAL ROOF-TOP A/C

DESCRIPTION OF TECHNOLOGY

Commercial packaged roof-top air-conditioners (often combined with gas furnaces) are commodity products. They use about 0.74 quads of energy, 54% of all energy used to cool commercial buildings, and cool about half of commercial space (Westphalen and Koszalinski, 2001). The minimum legal federal efficiency rating for 10 ton units is EER 8.9. This measures steady-state operation of the refrigeration cycle and associated fans (condenser and circulating). It does not include the energy required for the same equipment to supply conditioned air to satisfy ASHRAE 62.1 ventilation requirements (dehumidification and cooling), and it excludes the regionally-varying potential benefits of economizers and heat recovery. Several groups are developing or have produced advanced units with higher EERs, better controls, and integrated economizers. The conventional rating method does not recognize the field improvements in efficiency and operations attributable to these features.

CURRENT STATUS OF MEASURE

FEMP sponsored a federal procurement for advanced units with minimum life cycle costs (FEMP Unitary Air Conditioner Procurement). The winning products included mid-efficiency entries by Lennox International, with capacities from 90,000 to 120,000 Btuh; and EERs and ILPVs of 11.0/11.8 to 11.3/12.0, and high-efficiency units from Global Energy Group, with capacities of 88,000 and 115,000 Btuh, and EERs/IPLVs of 13.5/13.9 and 13.4/14.0, respectively. Our analysis begins with the Global Energy unit, because of its advanced specifications. The 10 ton (120,000 Btuh) unit includes powered exhaust and an optional economizer with differential controller.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Our baseline model is an ASHRAE 90.1-1999 ten-ton roof-top unit, with EER of 10.3. According to LBNL (2003), the cost of this unit is $4855, but this seems to be for a 7.5 ton unit. The GEG 115,000 Btu unit proxy for advanced units has a federal price only $800 higher (Frankenfield 2003).

KEY ASSUMPTIONS USED IN ANALYSIS

We have assigned an incremental cost, counting shipping and installation, of $1500.
We assume that the ratings are good estimators of energy efficiency. We assume that the economizer will save an additional 20% per cent of electricity use for the most efficient unit, and the base unit does not have a working economizer. No compensation is made for additional electricity use for continuous ventilation; the advanced unit has 2-speed compressor and fan, so it will run more nearly continually. Assume FEMP default, 1500 full load hours/yr.
Canada-specific assumptions: This measure applies to commercial segments that use rooftop packaged heat cool units and it ranges from 2% in the recreation segment to 65% in retail buildings. Penetration by 2020 is assumed to reach 90%. Consultant estimate based on Canadian

commercial end-use analysis studies and commercial building profiles that provide a distribution of HVAC equipment by type (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Current incentive programs at CEE and ENERGY STAR do not recognize efficiency tiers beyond EER/IPLV 11.0/11.4 (CEE) and 10.0/10.4 (ENERGY STAR) in this size range. Higher performance Tiers and extra incentives for reliable economizers are needed to encourage additional cost-effective products to enter the market. In addition, the Lennox GEG and other relatively efficient units should be used as a performance benchmark for standards processes.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H2 CROMER CYCLE AIR CONDITIONER

DESCRIPTION OF TECHNOLOGY

Air Conditioners both cool the air (sensible heat reduction) and remove moisture (latent heat). With vapor compression systems, adequate moisture removal in humid climates requires reducing the evaporator coil temperature, which increases cooling energy and supplies air at temperatures too cold for comfort, thus requiring reheat. Over the past two decades, latent loads have increased relative to sensible heat loads, as building envelopes and systems (lighting) have improved (TIAX, not citable yet), but unitary equipment has not changed the sensible heat ratio (Amrane and Hourahan, 2003). Increasing efficiency and latent heat removal is difficult with conventional equipment, which generally decreases air flow (to cool the coil) to increase condensing. As an alternative to electric reheat, desiccants (drying agents that can scavenge moisture from a humid air stream and then give up the moisture to dryer air) can be employed for moisture removal. The proprietary Cromer cycle packaged air conditioner combines desiccant and refrigerant cycle components to provide augmented latent heat capability for humid climates. In Cromer cycle commercial equipment, building return air is warmed by a secondary condenser coil. It then passes through a rotating desiccant wheel, where it picks up moisture. This increases moisture removal by the evaporator coil. The cold, saturated air passes through the desiccant wheel, surrendering moisture, before being distributed to the space.

CURRENT STATUS OF MEASURE

DOE is supporting development by Trane and Solar Engineering Company. The goals include reaching a Sensible Heat Ratio of 0.5 to 0.4 (*v.* 0.25 – 0.3 for conventional equipment) and 12% energy savings relative to heat pipes (60% relative to overcooling and reheat) in humid climates; work continues on prototypes. Lab results show goals met (Sand, 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

DOE's goals include a retail price increment of $200 for residential size equipment. This includes the desiccant wheel, its drive, a secondary refrigerant heat exchanger with controls, and system redesign. Airxchange believes this to be achievable (Wellford 2003). Although Trane suggests that the unit will cost twice as much as comparable commercial equipment without part-load humidity control (Hallford 2003). We use a mature market incremental cost of 50% of the baseline equipment cost, based on incremental content.

KEY ASSUMPTIONS USED IN ANALYSIS

We treat residential (H2a) and commercial (H2b) equipment separately. For baseline residential units, we use a SEER 12/EER 10 unit; for commercial units we use ASHRAE 90.1-1999 (EER 9.7, 20 ton). For residential units, we used DOE's $200 incremental cost goal. For 20 ton commercial packaged units, we have adjusted prices from the LBNL (2003) life cycle cost analysis for a 15 ton unit, multiplying by the 20/15 size ratio. We assume 12% peak and energy savings for both commercial and residential applications. Because laboratory testing and simulations continue and no field tests have been carried out, all savings and performance numbers are estimates.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

RECOMMENDED NEXT STEPS

We anticipate four major barriers: First cost, education on the benefits for designers, owners, and contractors; continuing confusion about ventilation requirements for unitary equipment, and field experience to show reliability as well as savings. Building on existing performance rating methods for air-to-air heat exchangers (ARI 1060), ARI has prepared Guideline V for calculating the efficiency of a unitary air conditioner or heat pump equipped with an air-to-air heat recovery device. ASHRAE is developing a Method of Test for combined desiccant/vapor compression systems (Sand, 2003). Trane plans to introduce field test units in 2004, and may offer a commercial product in 2005 (Hallstrom, 2003). Early field evaluations of these units will help show the value of the equipment and the Combined Efficiency metric. Additional simulations, calibrated by these field demonstrations, will help delineate the climate conditions in which Cromer cycle equipment should be preferred. These steps, over the next 2 - 3 years, are required before program offerings can be considered. In addition, either more sophisticated savings calculations will be required, or better documentation and higher savings (beyond 12%) will be needed for the products to succeed with the projected commercial equipment incremental cost.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H3 HEAT PIPES FOR CENTRAL AIR CONDITIONING DEHUMIDIFICATION

DESCRIPTION OF TECHNOLOGY

Heat pipes are passive components used to improve dehumidification by commercial forced-air HVAC systems. They consist of refrigerant-filled tubes that transfer heat by evaporating the refrigerant at the hot end and condensing refrigerant at the cold end. Heat pipes are installed with one end upstream of the evaporator coil to pre-cool supply air and one downstream to re-heat supply air. This allows the system's cooling coil to operate at a lower temperature, increasing the system latent cooling capability. Heat rejected by the downstream coil reheats the supply air, eliminating the need for a dedicated reheat coil. Heat pipes can increase latent cooling by 25-50%, depending upon the application. Conversely, since the reheat function increases the supply air temperature relative to a conventional system, a heat pipe will typically reduce sensible capacity. In some applications, individual heat pipe circuits can be controlled with solenoid valves to provide improved latent cooling control. Primary applications are limited to hot and humid climates and where high levels of outdoor air or low indoor humidity are needed. Supermarkets, hospitals, and laboratories are often good heat pipe applications. Most of the units are being installed in new construction.

CURRENT STATUS OF MEASURE

Heat pipes has been available for over 30 years. Incorporating heat pipes also increases the air-side pressure drop through the duct system, and consequently increases fan energy consumption. With fan energy representing 32% of annual cooling and ventilation energy use (DOE 2003), the added pressure drop may result in the fan penalty exceeding cooling savings in some applications with high part load use, unless bypasses are installed. Heat pipes are also being increasingly used as energy recovery devices on make-up air systems. By reducing the outdoor air load on cooling systems, heat pipe energy recovery devices can contribute to cooling system downsizing, reducing incremental costs. With ASHRAE Standard 62 promoting increased levels of outdoor air, both the energy and humidity-control benefit of heat pipes will increase.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Potential heat pipe energy savings arise from better latent control, reheat savings, and higher supply water temperatures for central chilled water systems. Monitored energy savings of 10-15% have been documented in a high outdoor air application (EPA 1997), although typical savings are likely lower. Installed heat pipe costs are on the order of 65¢ per cfm (Meyers 2003).

KEY ASSUMPTIONS USED IN ANALYSIS

We have estimated cooling savings at 7% for typical applications. The heat pipe for a typical 50-ton packaged unit would cost approximately $13,000 without accounting for cooling equipment downsizing.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

Principal barriers include lack of knowledge of heat pipe benefits and economics, including understanding preferred applications. Improved education for designers would help architects and design engineers understand applications. Further efforts in promoting heat pipe technology should focus on assessing the implications of increased outdoor air requirements on mechanical system sizing and annual operating costs. In addition, alternative humidity control options (such as desiccant systems) and energy recovery systems should be evaluated to determine applicability for each of these technologies.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H4 FREE-STANDING EFFICIENT DEHUMIDIFIERS TO AUGMENT RESIDENTIAL CAC

DESCRIPTION OF PRACTICE

In humid climates, using a free-standing dehumidifier can augment the latent heat removal capacity of the central air conditioner. Humidity control in much of the U.S. is a major concern as typical central air conditioning units are unable to adequately dehumidify indoor air. This is increasingly true in newer, tighter houses with lower cooling loads and therefore less air conditioner (i.e. dehumidification) operation (Lstiburek 2002). Oversized air conditioning systems compound the problem by shortening the length of the operating cycle during which latent cooling can occur. Dehumidifiers improve indoor humidity levels not only during days when the central cooling system operates, but also during cooler, humid weather when dehumidification is still needed.

Inadequate dehumidification not only leads to uncomfortable indoor conditions, but also to higher cooling energy use when homeowners lower the thermostat setpoint to achieve improved comfort. Dehumidifiers allow occupants to raise the cooling setpoint due to improved moisture control, and offer non-energy benefits by reducing indoor relative humidity below the 60-70% levels at which dust mites and mold grow. Increasingly, indoor mold concerns are becoming a primary driving force in the purchase of dehumidifiers. Free-standing dehumidifiers are compact packaged refrigeration systems which move indoor air first across low-temperature evaporator coils (removing excess moisture from the air) and then across the condenser coil, delivering dryer, warmer air to the space. Capacities of these units range from single-room units (typically used in basements) to units designed to handle entire houses.

The EnergyStar program currently lists dehumidifiers meeting minimum efficiency requirements. Some of the more efficient models have efficiencies as high as 2.75 liters/kWh, approximately two to three times higher than the baseline models commonly found in basements. Although these advanced units cost more than the baseline units, they are quieter, offer more sophisticated humidistat controls, and are designed to look like a piece of furniture. According to a key manufacturer, sales are highly dependent on summer weather conditions in the humid parts of the country (McConnell 2003).

CURRENT STATUS OF MEASURE

According to the September 2003 issue of Appliance magazine, approximately 16% of U.S. households have a dehumidifier, although only a small fraction of these achieve a high operating efficiency, defined in terms of liters of moisture removal per kWh consumed. Not a priority.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

If we assume the base dehumidifier costs $250 and that the incremental cost of an ENERGY STAR unit is 15% ($38), then the CSE is $0.04/kWh. We are assuming only 5% savings due to the measure.

KEY ASSUMPTIONS USED IN ANALYSIS

The assumption that the units will save 5% is considered reasonable, as a measure of savings from raising the thermostat since comfort is achieved by lowering humidity.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

The principal barrier is that systems are not designed or optimized for separate dehumidifiers as latent heat removal devices. Typically, the air conditioner is specified by the builder or contractor, while the dehumidifier is considered a free-standing appliance chosen by the consumer. Studies on the field performance of free-stranding dehumidifiers these units were not found, probably since these systems have only recently received notice as a potentially significant residential energy-consuming device. Field monitoring is needed to provide quantitative data on how consumers use the devices, how much energy they consume, and what impact they have on indoor humidity and cooling setpoints. In addition, efforts to promote more efficient units should be expanded. In the meantime, this is not an emerging technology, so it is not a priority.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H5 HOT-DRY CLIMATE DESIGNS

DESCRIPTION OF TECHNOLOGY

Residential cooling system design is largely dictated by the performance characteristics of available vapor compression equipment. HVAC manufacturers design and package refrigeration components to meet average outdoor and indoor conditions. This results in equipment designs that achieve sensible heat ratios (SHR) of about 0.75 to 0.80, resulting in latent cooling fractions ranging from 0.20 to 0.25. Unlike in humid climates where latent cooling is essential to indoor comfort, in hot-dry climates latent cooling does not contribute to improved comfort. Ideally hot-dry climate vapor compression equipment would have SHRs above 0.90 or 0.95 to achieve maximum efficiency. Two approaches can meet this goal. One is through a redesign of refrigeration components to achieve optimal performance at the high outdoor temperatures and low indoor relative humidities common to California and the Southwestern U.S.

CURRENT STATUS OF MEASURE

Proctor Engineering has investigated the energy and demand savings potential of an improved hot-dry climate design (PEG 1994). They are continuing to research technological improvements that will hopefully lead to new optimized system designs. A second, short-term, approach is optimize the selection of available indoor and outdoor components to achieve better performance. Mahone (2004) has shown that EER is more tightly correlated with energy use than SEER in hot, dry climates, since so much of the energy consumption occurs when outdoor temperatures are above 90ºF.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

By increasing the supply airflow at the indoor unit, the sensible cooling capacity of a vapor compression system increases. For example, increasing the design air flow for a 3.5 ton unit 350 cfm/ton to 450 cfm/ton increases the cooling capacity from 32.9 kBtu/hour to 36.7 kBtu/hour, an increase of ~12%. This translates into an increase in EER from 7.77 to 8.24, in sensible capacity, an increase in overall efficiency of 6%. This increase in efficiency and sensible capacity can be achieved by matching a 3.5 ton condensing unit with a 4 ton indoor unit (DX coil and air handler). In many situations, the added sensible capacity allows the outdoor unit to be downsized by a half a ton. One major Northern California HVAC contractor is actively pursuing this strategy in virtually all of the new homes they are working on (DEG 2002). The added cost for indoor components is often countered by cost savings for the condensing unit. The one performance disadvantage of this approach is higher fan energy consumption.

KEY ASSUMPTIONS USED IN ANALYSIS

For this analysis we are assuming 6% energy savings at zero incremental cost. Major national HVAC manufacturers show little interest in regional equipment and will only develop and package systems which achieve improved performance in hot-dry climates only if they see a continuing growth in the trend of matching smaller condensing unit with larger indoor components.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

The principal barrier to market introduction of hot-climate air conditioners is that the current rating method, focused on SEER, does not allow manufacturers to establish (with EER, for example) the benefits of regionally-optimized equipment designs. In the short-term, the practice of "mis-matching" indoor and outdoor components appears to be the best approach to improve on the sensible cooling capacity and overall efficiency of vapor compression equipment in hot-dry climates. Monitoring of these systems relative to standard designs would be useful in quantifying savings and benefits. Longer term R&D efforts are needed to lead to an improved system design which provides optimized performance in hot-dry climates. The California Energy Commission PIER program is funding development of an optimized hot-dry climate residential air-conditioner.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H6 ULTRAVIOLET GERMICIDAL IRRADIATION (UVGI) FOR HVAC SYSTEMS

DESCRIPTION OF TECHNOLOGY

Microbes are vulnerable to light at wavelengths at or near 2537 Angstroms (254 nm) due to the resonance of this wavelength with molecular structures. Visible light has wavelengths of about 400 to 700 nm (nanometers). Ultraviolet (UV) light has wavelengths of 100 to 400 nm. The UV spectrum is further divided into A, B, C, and vacuum bands. The C band is called the germicidal bandwidth and lies between 200 and 280 nm approximately. Microbes present in HVAC systems are destroyed by UVC and include bacteria, viruses, yeast, mold, and various spores. When applied to the exit face of a cooling coil, UVC has a cleaning effect and can reduce pressure drop as well as improve air quality.

CURRENT STATUS OF MEASURE

UVGI has been applied in hospitals and prisons since the early 1900s to sterilize the air supply. Application in other more conventional HVAC systems is more recent. In-duct systems now have 27% of the market. The General Services Administration (GSA) issues standards for public buildings and includes a requirement for UVC downstream of all cooling coils and drain pans (GSA 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The energy saving benefit of cleaner cooling coils has only recently been recognized and is still considered to be developing. Typical claims for energy efficiency are a 30% reduction in fan energy and a two-year payback (FPTech 2003). Another typical report comes from Iolani School in Honolulu, a 35,000 ft2 office and classroom building. It consists of six AHUs totaling 45,000 cfm, and used 20 UV lamps total. The lamps last 1.5 years, with a replacement cost of approximately $1,300/year. The installation eliminated mold growth and odor, there were fewer complaints of respiratory problems, and the facility manager is very satisfied. Maintenance savings are estimated at $8,000 per year (Kolderup 2003).

KEY ASSUMPTIONS USED IN ANALYSIS

Because this measure did not demonstrate energy savings, we did no further work on it.
Canada-specific assumptions: This measure is restricted to the portion of "auxiliary motors" that represents fan energy and ranges from 65% TO 80%. Penetration by 2020 is assumed to reach 55%. Consultant estimate based on Canadian commercial end-use analysis studies that show that the energy use by circulating pumps is smaller than the fan energy consumption. Typical fan energy use ranges from 3 to 4 kWh/ft^2.yr out of a typical 5 kWh/ft^2.yr for the HVAC equipment end-use (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

EPRI will study UVGI as part of its 2004 program, element P17.005 Demonstrations and Case Studies of Applications of UVGI for Chiller Coils in Commercial Buildings. Results of these investigations may be available to EPRI members. A report is scheduled for March 2005 (EPRI 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H7 ROBUST AC AND HP

DESCRIPTION OF TECHNOLOGY

Residential air conditioners and heat pumps generally do not achieve the efficiency in the field implied by their SEER ratings (Neal 1998). Shortfalls arise from deficiencies in the national rating method, and from poor installation and maintenance. These factors include low charge (combined with low proportion with thermostatic expansion valves (TXVs)), incorrect air flow, leaky ducts, and oversizing. "Robust" units could largely compensate for charge losses and low air flow (25% cumulative) A new specification to achieve the equipment-related goals is within reach of existing designs. The "robust" air conditioner would be characterized by the highest SEER levels readily attained without modulating compressors (SEER 14), very good high-temperature performance (EER 12), an adaptive refrigerant metering device (TXV or better), and a fan assembly that adapts to the static pressure of the house's duct system. It would include a thermostat equipped with alarm functions, such as "check filter" and "call for service." (Sachs, 2003.)

CURRENT STATUS OF MEASURE

The robust air conditioner concept has been circulated among market transformation groups and selected manufacturers. No insurmountable obstacles or barriers have been suggested. Proposals in review now (by PIER and others) would lead to prototype development and field tests. After that, any of several market transformation mechanisms could be used to pull robust units into the market. For example, it might be attractive to some production builders, as a "hassle-avoidance" measure, or for federal procurement for military base housing and similar applications.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

From Neal (1998), the field-adjusted SEER for is 25% lower than the rated value, bringing SEER 12 down to SEERFA (field-adjusted) 11.1. By correcting these problems, the Robust unit at SEER 14 delivers SEERFA=13.9, for a saving of 19% through better air conditioning performance. This includes compensation for the 60% market penetration of TXVs among current SEER 13 and 14 units.

KEY ASSUMPTIONS USED IN ANALYSIS

Our baseline is the ET project minimum specification: SEER 12, EER 10, and HSPF 8.5 for heat pumps. We boost TXV or equivalent penetration to 100%, to assure good performance under faulty charge or air flow conditions. However, we reduce Neal's calculated value because 60% of SEER 13 and 14 units already have TXVs (TSD 2001). Fan energy savings are based on Sachs and Smith (2003). HSPF potential savings relative to the ENERGY STAR baseline are taken as the same ratio used for air conditioning. We find national net average energy savings of 710 kWh/yr (heating and cooling together), and a peak demand reduction of 450 watts relative to the existing stock. Incremental cost is estimated (bottom-up) as $270 over the baseline SEER 12 unit by adding the cost of components.

Canada-specific assumptions: This measure is restricted to the portion of residential space heating that is electric and heat pump. Penetration by 2020 is restricted to new construction only or 50% of the entire stock. The estimate of portion of residential space heating that is electric and heat pump was derived from Canada's Energy Use Data Handbook (NRCan 2004).

RECOMMENDED NEXT STEPS

The principal barrier is the lack of a specification that manufacturers can meet and use for marketing. We recommend that PIER and other program developers explore the following steps: (1) reaching consensus among program operators and manufacturers on a feature set, (2) Developing and demonstrating prototype equipment, and (3) launching market transformation activities, including working with manufacturers to encourage production. For example, this could become a next-generation ENERGY STAR program. As a carrot for manufacturers, a Robust air conditioner program could require that all components (condenser, evaporator, furnace (if included), air handler (fan), and controls) be provided and guaranteed by a single source, to avoid finger-pointing in case of trouble.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H8 SMALL PACKAGED ADVANCED ABSORPTION CHILLERS (~5 TON)/HYBRID ABSORPTION & MECHANICAL CHILLER

DESCRIPTION OF TECHNOLOGY

Residential absorption heat pumps use an ammonia-water absorption cycle to provide heating and cooling. The heat pumps circulate ammonia and water through the system. Ammonia (the refrigerant) is sequentially absorbed, boiled out, condensed, and reabsorbed in water (the absorbent) to produce the heat pump action (Sauer & Howell 1983).

CURRENT STATUS OF MEASURE

Although cooling-only absorption units have existed for several decades, absorption heat pumps are still in the research stage. The Department of Energy has been funding Rocky Research and Ambian Climate Technologies to produce an absorption heat pump using the Generator Absorber heat eXchanger (GAX) technology. This technology uses the heat that is released when the ammonia is reabsorbed into the water. By using this heat, the efficiency of the unit is increased significantly. Ambian Climate Technologies is a consortium of utility investors, including Mississippi Energies, Inc., Southern California Gas, Southwest Gas, Texas Gas Pipeline and others including the Gas Technology Institute.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The new Chiller/ Heat Pump technology developed by Rocky Research and Ambian uses GAX technology but also has a number of other innovations. These include: a method for achieving high-efficiency vapor separation, ability to control variable refrigerant flow rates, the utilization of a low-emission, variable-capacity combustion process, and a new novel solution pump. The technology is currently in the development stage, soon to have prototypes in field tests (Anderson 2003).

These recent developments have resulted in a very efficient unit with a cooling COP (Coefficient of Performance) of 0.7 at 95° F and a heating COP of 1.4 at a 47° F. However, since the technology allows for variable capacity, the efficiency seen during normal use should typically be higher, while cycling losses are significantly reduced. The 5-ton unit is expected to have a production cost target of $3,000 with a goal of entering the market in 2005 (Anderson 2003). It is anticipated that other capacities will become available as the product is commercialized.

KEY ASSUMPTIONS USED IN ANALYSIS

The most favorable applications for an absorption heat pump is in displacing conventional air conditioning systems in new construction applications. Retrofitting, although possible, is more difficult and costly, since it would be necessary to replace the refrigerant lines and the coil with a hydronic loop. Although the GAX technology is at a source energy performance disadvantage when compared to new 12 SEER cooling systems, the lower relative cost for gas (vs. electricity) results in homeowner cost savings, which will be amplified if time-of-day or demand rates are

applied for residential tariffs. Maintenance requirements for the system are not yet clearly known, but the goal is to have requirements comparable to conventional HVAC equipment.
Canada-specific assumptions: This measure is restricted to the portion of residential space heating that is electric and heat pump. Penetration by 2020 is restricted to new construction only or 50% of the entire stock. The estimate of portion of residential space heating that is electric and heat pump was derived from Canada's Energy Use Data Handbook (NRCan 2004).

RECOMMENDED NEXT STEPS

The GAX technology faces significant barriers since maintenance and field performance of the unit has not been well quantified. Once the technology is proven in the field, the gas industry can effectively market the technology. Additional ongoing research areas include incorporating a water heating option to reclaim cooling mode waste heat. Added cooling mode energy benefits will help in offsetting the fairly low cooling efficiency.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H9 ADVANCED COLD-CLIMATE HEAT PUMP/FROST-LESS HEAT PUMP

DESCRIPTION OF TECHNOLOGY

Residential heat pumps lose capacity and efficiency when outdoor temperatures fall below the mid-30's^{0}F. Fundamental thermodynamic effects combine with refrigeration systems and controls that often are not optimized for cold weather operation. Since building loads increase as temperatures fall, a standard air-source heat pump must be rely on inefficient resistance heat to meet the capacity shortfall.

CURRENT STATUS OF MEASURE

Two R&D efforts are currently underway to improve the cold climate performance of air source heat pumps. The EnerKon Corporation, in partnership with Nyle Special Products, is starting initial production runs of a "cold climate heat pump" which features two compressors (a two-stage compressor and a second booster compressor), intelligent controls, and a plate heat exchanger to improve low temperature performance. Preliminary test data indicates a fairly flat heating capacity. Preliminary test data indicates an HSPF of about 9.6 (EnerKon, 2003), a 17°F heating COP of 2.7, and a 0°F heating COP of 2.3. Projected rated cooling efficiency is targeted at 16 SEER. In addition, Additional research is occurring at Oak Ridge National Laboratory is working to improve air source heat pump defrost performance. The current solution is to reverse the refrigerant flow through the heat pump allowing condenser heat to defrost the outdoor coil. This has numerous drawbacks including the need for indoor resistance heat. ORNL supplies a small amount of heat to the refrigerant accumulator, to retard the formation of frost on the outdoor coil. However, this practice will only be effective at a temperature range of 41 to 32°F. Lab testing has shown that the small amount of heat that is added to the accumulator reduces the need for defrost cycling by a factor of 5. ORNL is currently working on commercializing the design with American Best.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The EnerKon heat pump is currently in the initial production mode, and thus a near term option for improved cold climate heat pump performance. Forty prototype units were tested in 2002/2003 by utilities in the Northeast and Midwest. Results were favorable and expected sales in 2004 are estimated at 2000 units (Constantino 2003). List prices range from $4,300 for a 3.5 ton unit to $5,600 for a 5 ton unit. Prices should decline with production economies and competition, but will remain hundreds of dollars/unit higher than for simpler units with a single fixed-capacity compressor.

KEY ASSUMPTIONS USED IN ANALYSIS

The chief barrier is believed to be the poor reputation of air source heat pumps, particularly in cold climates. Even with accurate rating methods, consumers are likely to be wary of performance claims. High and volatile prices for alternatives (such as propane) will encourage

adoption. Projected savings of 30% are assumed relative to a standard 6.8 HSPF unit, based on the HSPF ratios. Actual savings may be higher since the EnerKon unit will likely eliminate most of the resistance heat consumed during low temperature and defrost operation. The principal obstacle is the ability of the firm to establish solid distributor and dealer relationships and a strong reputation based on customer satisfaction.
Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

Detailed monitoring of the EnerKon unit and conventional heat pumps would provide valuable data for evaluating performance. If promised performance levels are achieved, the EnerKon unit will demonstrate performance comparable to geothermal heat pumps at a much lower installed cost. With favorable results, winter-peaking utilities should evaluate incentives based on the expected demand reduction.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H10 GEOTHERMAL HEAT PUMPS (GSHP)

DESCRIPTION OF TECHNOLOGY

Ground coupled heat pump systems (also called GeoExchange) consist of a hydronic loop for exchanging thermal energy between soil or groundwater and one or more heat pumps providing space heating, cooling, and/or water heating to the conditioned space. In most applications the hydronic loop is a closed loop transferring heat with tubing located in the ground. Ground loops are typically vertical boreholes (~200-300 foot depth per ton of capacity) with U-tubes providing a flow path through the grouted borehole. Alternatives use groundwater which is returned to the same aquifer. By coupling the outdoor heat exchanger with the moderating influence of the earth, ground coupled systems are able to achieve higher operating efficiencies than typical air-source heat pump equipment. Several key advantages of ground coupled technology derive from the single-package design, which eliminates the outdoor heat exchanger. Due to the short refrigeration path within the indoor unit, the refrigerant charge is lower and can be accurately measured at the factory. The lack of outdoor components increases expected equipment life.

CURRENT STATUS OF MEASURE

Ground coupled technology was aggressively promoted by DOE and EPA in residential and commercial applications through funding of the Geothermal Heat Pump Consortium (GHPC), headquartered in Washington DC. GHPC is implementing the National Earth Comfort Program with the goal of completing 400,000 ground coupled installations nationally by 2007. Significant market penetration has been achieved in regions where severe climates and low electric rates (such as the South and Midwest), or the absence of competitively priced heating fuel(s), favor ground coupled systems.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

In a study of 9 commercial systems, the average GSHP system used 14.4 kWh/ft^2-year, vs. 22.7 for the alternatives considered for those buildings. Peak demand was also significantly lower: 4.7 W/ft^2 instead of 7.2 for the conventional systems modeled. For these buildings, the average return on investment was 19%, or a simple payback of 5.9 years (ASHRAE 1998). In some markets (e.g., schools in some regions), ground coupled first costs may cost less than competing systems. They generally are competitive with 4-pipe chilled water systems, less expensive than chiller-VAV systems, but more expensive than simple roof-top equipment.

Annual residential energy cost savings vary with rates, climate, loads, conventional system type, and other factors, but tend to fall within the range of 20% to 60%, with the higher end of the savings range based on houses heated with resistance heat. In regions of the country where there is a lack of infrastructure, the ground loop installation cost can represent a substantial incremental cost premium over competing systems. Generally accepted ground coupled added value features include enhanced comfort, quieter operation, lower maintenance, and extended equipment life due to more favorable operating conditions.

KEY ASSUMPTIONS USED IN ANALYSIS

For a commercial installation larger than 100 tons, we assume competitive costs. In most regions, residential installations will be much more expensive.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

Where there is a reasonable infrastructure of informed designers, drillers, and mechanical contractors, GSHPs are competitive for commercial installations: more expensive than roof-tops, but less so than many chiller systems. In contrast, the primary barrier to increasing the penetration rate of residential ground coupled technologies is the high installed system cost. Commercialization efforts should focus on reducing the installed cost in the production builder environment. One option is through financing programs or direct utility incentives.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H11 LEAKPROOF DUCT FITTINGS

DESCRIPTION OF TECHNOLOGY

The majority of duct leakage in residential and small commercial HVAC systems is due to improperly sealed connections between ductwork and fittings. Even when duct connections are initially well-sealed, leakage may increase over time (Walker et al. 1998). Although the use of mastics and mechanical fasteners is becoming more widespread, a low cost, leakproof system will help to transform the market. The benefit of any duct remediation technology is greatest in climates with high cooling loads and attic ducts. Available round-section spiral sheet metal systems from Lindab and others are targeted to commercial applications in the US. They are used for residences in Sweden, but cost about twice as much as conventional residential systems in the US (Spartz 2004).

CURRENT STATUS OF MEASURE

In California, the installation of tight duct systems has increased significantly over the past three years as the Title-24 code has provided a credit for "tight" duct systems leaking less than 6% of system airflow. One approach to reducing duct leakage is the use of mastic, mechanical fasteners, and UL-181 approved duct tapes. An alternative approach is through the use of long-lasting leak proof duct connections that can be reliably field installed with a minimum of skill. Proctor Engineering Group has developed the Snap Duct system of fittings with support from DOE's Small Technology Transfer program. The system consists of mechanically fastened fittings (couplings, boots, plenums, wyes) for flex and hard ducts that snap together to create a long-lasting seal. Testing of the fittings show that about 90% of the leakage within the duct system is eliminated (Proctor 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Various field studies indicate that mitigating residential duct leakage may reduce HVAC energy use by roughly 20% (Proctor 1992; Hammurlund 1992). The California Title-24 energy code assumes typical new residential duct systems leak 22% of HVAC system airflow (CEC 1999). Typical new construction costs for manual duct sealing are about $250 per house (CEC 2000). The Snap Duct technology is still in the prototype stage, but indications are that the system will be less expensive than current manual duct sealing techniques. Although the fitting cost will be more than standard fittings, labor savings is expected to more than offset the incremental cost. Duct pressurization testing is still necessary to insure proper installation.

KEY ASSUMPTIONS USED IN ANALYSIS

Based on laboratory testing data, we are assuming a 90% reduction in typical duct leakage. The Snap Duct system is principally a product for the new construction market. Estimated costs are assumed to be $100 for a typical house.

Canada-specific assumptions: This measure is restricted to the portion of residential space heating that uses warm air furnaces. Penetration by 2020 is restricted to new construction only or

50% of the entire stock. The estimate of portion of residential space heating that uses furnaces was derived from Canada's Energy Use Data Handbook (NRCan 2004). H19 is only applicable to office space, labs and health facilities. The applicability ranges from 10% in health to 50% in offices (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The proposed Snap Duct technology has not yet been commercialized. Proctor Engineering is working with a Midwestern regional manufacturer of duct fittings to produce the Snap Duct system. Some retooling is necessary to produce the improved fittings and the goal is to start production in the next six months. Two builders (one in Nevada and one in Chicago) have indicated interest in field-testing of the Snap Duct system. Successful field-test results coupled with lower costs than conventional sealing methods would likely lead to rapid growth of the Snap Duct system.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H12 AEROSEAL OR OTHER SPRAY-IN/COMPREHENSIVE RESIDENTIAL HVAC DUCT SEALING

DESCRIPTION OF TECHNOLOGY

Approximately 20% (Proctor 1992; Hammurlund 1992) of energy use in ducted residential space conditioning systems is associated with duct losses with about half due to conduction and half due to leakage (Jump et al. 1996). Sealing ducts not only reduces annual heating and cooling energy use, but also significantly reduces air conditioning peak demand for systems with attic ducts. Although new homes can achieve leakage levels on the order of 5-10% (of HVAC airflow) through the use of improved materials and diagnostic testing, fixing existing home duct leakage is often problematic and expensive as ducts are often in hard or impossible to access locations such as small attics, crawl spaces and duct chases. Manual duct sealing has been performed for many years, but it is messy, labor-intensive, and not always effective at eliminating a majority of the leakage.

CURRENT STATUS OF MEASURE

An aerosol duct sealing technology developed at Lawrence Berkeley National Laboratory can seal holes in ducts up to ¼″ in diameter from the inside by spraying atomized latex aerosol into a sealed duct system. By pressurizing the duct system while spraying the atomized aerosol, the material collects around small leaks in ductwork and seals them in a process similar to that used by canned flat tire sealers. A computer monitors and controls the atomization and duct pressurization process that typically lasts 40-90 minutes.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

A number of large-scale utility demonstration projects have documented the performance of the Aeroseal technology. The Sacramento Municipal Utility District (SMUD) (Kallett et al. 2000) found an average 81% reduction in leakage for a sample of 121 houses that underwent the Aeroseal process. A 1996 Florida study of 47 houses found an average 80% reduction in leakage (Modera et al. 1996). The average cost per house for the Sacramento study was slightly over $1,000, although other remediation work occurred at many of the sites. A better mature market cost estimate for Aeroseal remediation is in the range of $500 to $900 per site (Bourne et al. 1999).

In 2001 Aeroseal was acquired by the Carrier Corporation, which greatly increases the visibility and marketing of the technology. Currently there are close to 80 Aeroseal franchises nationwide, performing about 3,000 sealing jobs during 2002. The hottest markets for Aeroseal are Sacramento, Phoenix, southern California, and parts of Washington state and Illinois. Aeroseal is projecting 10,000 jobs per year by 2007. Some utilities are continuing rebate programs to partially offset some of the cost of performing Aeroseal remediation. In the Sacramento area, where about 100 jobs a month were completed in 2000 (Kallett et al 2000), SMUD is currently offering a $300 rebate to residential customers.

KEY ASSUMPTIONS USED IN ANALYSIS

We focused on houses that use more energy than average, specifically 25% more than the US average for A/C and Heating, limiting the feasible applications to 32% (roughly the top 50% of single family residences by consumption). We assumed existing houses, the primary target, with older HVAC equipment (AFUE 70; SEER 9), and that Aeroseal would eliminate 81% of the estimated 23% air leakage from the duct system.

Canada-specific assumptions: This measure is restricted to the portion of residential space heating that uses warm air furnaces. Penetration by 2020 is restricted to new construction only or 50% of the entire stock. The estimate of portion of residential space heating that uses furnaces was derived from Canada's Energy Use Data Handbook (NRCan 2004). H19 is only applicable to office space, labs and health facilities. The applicability ranges from 10% in health to 50% in offices (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

No technical barriers exist to further commercialization of aerosol duct sealing, but the service is expensive relative to consumer expectations. The major barriers relate to educating consumers about duct leakage. A cable TV promotion effort currently underway will help spread the word. Utilities and state energy offices can serve as a valuable resource in educating consumers about the benefits of duct leakage remediation. Incentives to partially offset the incremental cost would also help in promoting the technology. As field experience is gained, it should become feasible to target house types with the greatest potential for savings (*e.g.,* flex duct in attics), and to develop lower cost approaches to these types.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H13 MICROCHANNEL HEAT EXCHANGERS

DESCRIPTION OF TECHNOLOGY

Microchannel heat exchangers transfer heat through multiple flat fluid-filled tubes containing small channels while air travels perpendicular to the fluid flow. Compared to current fin-tube heat exchangers, the air passing over the heat exchanger has a longer dwell time increasing both the efficiency and the rate of heat transfer. This increased in heat exchanger effectiveness allows the microchannel heat exchanger to be smaller and yet have the same performance as a regular heat exchanger, or to get improved performance in the same volume as a conventional heat exchanger. The smaller size of the exchanger reduces the refrigerant pressure drop, improving overall compressor performance. Microchannel technology is very common for automotive air conditioning applications due to its small size, which indicates the technology has overcome the critical manufacturing hurdles.

CURRENT STATUS OF MEASURE

Modine Manufacturing is currently producing Parallel Flow (PF) heat exchangers for various applications within the automotive industry. Efforts to integrate PF heat exchangers in the HVAC field are still in the R&D stage. Issues to be resolved include evaporator design related to refrigerant flow and the ability of the evaporator coil to effectively shed condensate. The coil moisture retention problem is exacerbated by the small air passages in the PF design that allows condensate to cling to the evaporator coil. Several approaches to shedding water from the evaporator have been investigated. The simplest involves angling the heat exchanger so condensate is more easily shed. Research at Purdue University found that angling the heat exchanger resulted in improved heat pump efficiency, however it actually reduced the ability of the heat exchanger to shed water (personal communication with D. Groll 2003). More research needs to be done to fully solve technical problems before the technology can be integrated with HVAC equipment. Lennox purchased a key component manufacturing company in the microchannel field and it is not clear how that will affect technology development (Stephens 2004).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Costs for these heat exchangers are still high with little available data from the manufacturer on anticipated costs for production heat exchangers. Energy savings greatly depend on the size of the heat exchanger, the application, and how other refrigerant components are optimized (cost and performance). In general, these heat exchangers are approximately 15% more effective than conventional fin and tube heat exchangers (Groll 2003).

KEY ASSUMPTIONS USED IN ANALYSIS

Limited advancements in microchannel technology in the HVAC field make performance and cost projections tenuous. For this study, we are assuming a 15% heat exchanger efficiency improvement translates to a 5% energy savings potential. Incremental costs are estimated at $100, but are highly dependent upon cost and performance optimizations.

Canada-specific assumptions: This measure is restricted to the portion of residential space heating that is electric and heat pump. Penetration by 2020 is restricted to new construction only or 50% of the entire stock. The estimate of portion of residential space heating that is electric and heat pump was derived from Canada's Energy Use Data Handbook (NRCan 2004).

RECOMMENDED NEXT STEPS

Whether microchannel technology enters the building HVAC arena is not clear at this time. A few technical problems exist, but they do not appear to be significant. Once these problems are addressed through additional research, microchannel heat exchangers could be introduced to HVAC manufacturers. In the interim, market transformation efforts are premature at best. There also are doubts about MT strategies that focus prescriptively on technologies instead of performance.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H14 SOLID STATE REFRIGERATION (COOL CHIPS ™) FOR HEAT PUMP APPLICATIONS

DESCRIPTION OF TECHNOLOGY

Most conventional air conditioners and heat pumps rely on refrigerant-based, mechanical vapor compression cycles to provide space conditioning. Thermoelectric (TE) devices, such as Peltier Junctions, directly convert electricity to cooling. TE devices have long been used for special applications such as keeping medicine cold, or cooling electronic components. Because of the low efficiency of these components, they have never been adopted on a large scale.

CURRENT STATUS OF MEASURE

A recent breakthrough in the field of TE heat pumps greatly increased their efficiency. Where traditional TE's are composed two electrodes bonded together, the Cool Chip™ product is constructed with a vacuum gap of 30 to 100 Angstroms between the electrodes. This gap is small enough to allow thermotunneling, or the passing of electrons across a very small space, which means the electric current can pass from one electrode to the other without the heat from the hot side conducting back to the cold side. This technology has the potential of achieving efficiencies up to 11 times that of current Peltier Junctions, and opening up a large field of heating and cooling applications. The current estimate is a 55% Carnot efficiency for the Cool Chip, relative to a 5% Carnot efficient for a standard Peltier junction and a 45% Carnot efficiency for vapor compression cycles (Magdych 2003). There are several potential configurations of HVAC systems using Cool Chips™ including distributed systems and central systems using hydronic coils.

This technology is in the final phases of development. It is estimated that prototypes will be available for third party testing during 2004 (Magdych 2003). Once the technology is fully developed in its raw form, it can be adopted to specific applications. If progress continues at the current pace, we can expect to see prototype TE HVAC systems in 2006 or 2007.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The manufacturer claims that OEM costs will be around $0.10 per Watt (Magdych 2003). Under this assumption, a 3-ton unit would require over $1,000 of the Cool Chip product, and a 5-ton unit over $1,750. For perspective, a high-efficiency compressor for a 3-ton central air conditioner would cost the OEM about $167.25 (TSD 2001). Depending on the configuration of the system, the compressor loop would be replaced with central or distributed hydronic loops and controls.

KEY ASSUMPTIONS USED IN ANALYSIS

Optimistically, this measure may incur no incremental cost in a mature market due to the replacement of the vapor compression loop, but for this study we are estimating a $2,000 incremental cost for a 3-ton system. A major assumption used for this analysis is that the theoretical energy savings targets will be reached once the development is complete. We assumed that the same efficiency increase would be seen for heating as for cooling. We assumed a 18% increase in Carnot efficiency for both heating and cooling operation, relative to the Carnot efficiency of 45% for the base case air source (mechanical) heat pump.

Canada-specific assumptions: This measure is restricted to the portion of residential space heating that is electric and heat pump. Penetration by 2020 is restricted to new construction only or 50% of the entire stock. The estimate of portion of residential space heating that is electric and heat pump was derived from Canada’s Energy Use Data Handbook (NRCan 2004).

RECOMMENDED NEXT STEPS

TE technology will first be used in automotive and aerospace applications. Adapting it to building HVAC configurations will require significant research and adaptation in order to take advantage of TE's unique benefits. Once the technology has been integrated into prototype HVAC equipment and field testing has been completed, the savings and cost estimates should be updated. At that time it would be reasonable to pursue market transformation efforts based on monitored system performance and overall economics.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H15 PRACTICES FOR DESIGN FOR LOW PARASITICS

INTRODUCTION

This practice complements PR2 (Ultra Low Energy Commercial Building Designs (50% > codes) and PR3, Integrated Commercial Building Design LEED Level (30% > Code), by focusing on the improvements in the air and fluid handling systems as technical measures for achieving the benefits of integrated design. In buildings with chilled water systems, energy distribution from the mechanical areas may require as much energy a the chiller itself (Westphalen and Koszalinski 1999, figure 5-17; Higgins and others, 2003). Although few in number, the buildings with these systems are large, and may account for 20-25% of California's commercial cooling capacity, for example (Higgins and others 2003). Improvements of at least 25% are feasible, from roughly 1.7 kWh/sq.ft.-yr to 1.3 kWh/sq.ft.-yr.

CURRENT STATUS

Whole building simulation required by LEED (2003) and in some cases for compliance with ASHRAE 90.1-1999 encourages designers to look carefully at parasitics, for both demand reduction and energy savings. The forthcoming ASHRAE Guides being developed by Special Project 102 may move the practice even further into the mainstream (These are best described as quasi-prescriptive guidance for mechanical designers, and aim for performance 30%, 50%, and 75% better than ASHRAE 90.1. The first, for office buildings smaller than 20,000 sq.ft., is to be issued in 2004, with accompanying training programs).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

In 5 monitored buildings, Higgins and others (2003) found that fan energy represents 20% to 50% of the total HVAC electrical energy use, or 10% to 30% of the total building electrical energy use, and can be more than the chiller. They claim potential fan energy savings of 50% or more, or total building energy savings of 12%. Better approaches will increase design costs (at first) but reduce equipment and duct size and cost; we project no cost net increase.

KEY ASSUMPTIONS

Following Westphalen and Koszalinski 1999, we assume that the base case operated as simulated, without field degradation. Actual savings are thus likely to be larger if more efficient systems are also better installed and maintained (See PR4, Retrocommissioning). We adopt the Westphalen analysis, including its regional and equipment distribution assumptions. Because the total number of LEED-certified buildings is still very small, we infer very low market penetration of sound design practices.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

BARRIERS AND RECOMMENDED NEXT STEPS

The principal barriers are institutional: present limitations in training, fee basis, and risk-reward trade-offs within mechanical design firms do not support efforts to go beyond minimum requirements and present experience. Good system design requires more training, and may take more time. Revising fee structures so designers are not paid a fraction of the value of the mechanical contract is probably required to align incentives with sound practices. We also recommend continued support of LEED, ASHRAE, and other MT efforts to highlight the savings potential of exemplary *system* designs.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H16 HIGH EFFICIENCY GAS-FIRED ROOFTOP UNITS

DESCRIPTION OF TECHNOLOGY

The majority of current commercial gas fired rooftop air conditioning units are single-speed non-condensing units with combustion efficiencies in the range of 78%-82%. Newer high efficiency units using condensing heat exchangers or pulse combustion can boost this efficiency to 89%-97%. Another method of increasing energy efficiency is modulating the burner and combustion air flows. This modulating approach provides greater control over temperature and eliminates much of the cycling losses, resulting in higher seasonal efficiencies.

CURRENT STATUS OF MEASURE

There are currently several manufacturers producing high efficiency units, with modulating units being more common. Condensing furnaces are not commonly specified: The commercial market tends to focus on first cost, and manufacturers are concerned about freezing conditions affecting weatherized unit flues. Of the major national manufacturers, only Lennox produces pulse combustion heaters (on a custom basis). Trane and other major manufacturers produce modulating units. Lennox in a joint venture with CME produces custom multi-zone units. A two-stage modulating gas heater controls the heating, with heat also recovered with multiple economizer units.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

A typical 20-ton Trane GasPak unit typically costs about $12,000, while a 30-ton Trane Intellipak unit with the modulating gas burner would cost $35,000, resulting in a cost premium of about $500/ton (Crumley 2003). Lennox multi-zone units cost $35,000 - $40,000 and are only built on a custom basis (Brotnov 2003). Most of the applications are for retrofitting aging multi-zone units. Only 300-400 units are sold per year, with many of these units installed on schools. To date, most units are not used for new installations due to the custom nature of the units. The potential for cost reduction appears significant if production volumes increase.

KEY ASSUMPTIONS USED IN ANALYSIS

An incremental cost of $1000 per unit was assumed since typical condensing furnace upgrade costs include a step up in the manufacturer's product line. Preferred applications include high heating load buildings located in cold U.S. climates.
Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

Commercial package unit condensing furnaces are rarely installed, with less than 5% of Intellipak units sold with the modulating gas option (Crumley 2003). With such a small market the incremental cost is fairly high. However the high "per unit" savings potential indicates that the market share should grow if first costs are lower. Utility incentives or a golden carrot program with manufacturers may be the best way to promote the technology. Education of architects and design engineers in cold climates would also be beneficial in conveying the economics of specifying condensing furnace technology.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H17 SOLAR PRE-HEATED VENTILATION AIR SYSTEMS (SOLARWALL™)

DESCRIPTION OF TECHNOLOGY

A transpired solar collector is a vertical unglazed collector consisting of a perforated metal absorber that can be mounted to the exterior surface of a building. Air is heated by a thin stagnant air-film on the surface of the absorber and then drawn into the building ventilation system through 1/32" diameter holes spaced 1 cm apart. On a sunny day the collector can raise the incoming air temperature by 30 - 50°F with an operating efficiency of up to 75%. The collector both pre-heats incoming ventilation air and eliminates heat loss through the portion of the building shell covered by the collector. During cooling season ventilation air is drawn directly from outside through a bypass damper and heated air in the collector is rejected through vents at the top of the collector plenum.

CURRENT STATUS OF MEASURE

Conserval Engineering currently manufactures a transpired solar collector called SolarWall, which has been used on many building types including warehouses, industrial buildings, and multifamily high-rises. They also have a large international market using the collectors for crop drying. In warehouses and industrial buildings, the collectors provide a separate outside air supply through diffusers such as a bag duct. For multifamily buildings the collectors provide tempered outside air to pressurize hallways. Although not emphasized, the collectors can also be used in residential situations where outside ventilation air is required. The heated air can be delivered directly into a space or can supply a heat recovery ventilator or furnace.
The metal absorber is manufactured in either steel or aluminum with a dark colored coating, typically a polyvinyl fluoride such as Kynar, used for standing seam metal roofs. There were initial concerns of corrosion in the steel absorber. However, after six years of exposure there has been no sign of corrosion, perhaps due to the drying effect of the air as it is drawn through the holes (Hanson 1998). Although the dark color of the collectors can be acceptable as replacement for industrial and warehouse wall cladding, the integration of a large area of dark metal into a commercial facade can be problematic.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

SolarWall panels cost \$3 per ft^2 for steel and \$4 per ft^2 for aluminum. With fans, ducts, and controls the installed cost is on the order of \$12 per ft^2 (Hollick 2003). The incremental cost can be lower if the collectors are installed in lieu of an expensive cladding. In retrofit situations the collector can protect aging cladding such as brick or stucco. Each square foot of collector can deliver 1-7 cfm of preheated air depending on the air temperature rise desired. Annual savings are estimated by the manufacturer at 2 to 4 therms per ft^2 (Hollick 2003), but will vary with climate.

KEY ASSUMPTIONS USED IN ANALYSIS

The key assumption used in this analysis was an average annual savings estimate of 3 therms/ft^2. It was also assumed that many more industrial buildings (warehouses, manufacturing facilities), than commercial buildings could use the thermal solar cladding due to the absence of windows and less of concern for aesthetic appearance.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

Although SolarWall offers significant savings potential in cold climates there are significant aesthetic issues and complications involved with integrating SolarWall with the HVAC control system (Shipley 2003). Mechanical designers need to be educated on how best to optimize control of the SolarWall with the existing mechanical system. Improved design assistance and additional monitored demonstration projects are needed to develop a better understanding of system performance.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H18 VENTILATION CONTROLLED BY IAQ INDICATORS

DESCRIPTION OF TECHNOLOGY

Since 1916, CO_2 level controls have been recommended to ensure sufficient ventilation in buildings, but it wasn't until the late 1990's that an accurate, reliable, and affordable CO_2 sensor was developed for integration with zoned commercial HVAC systems. By 2000, some manufacturers controller product lines were 100% compatible with demand-controlled ventilation (DCV). Using CO_2 to trigger ventilation in areas of commercial buildings where significant occupancy fluctuations occur, can result in significant fan energy and ventilation load savings over standard "cfm/occupant" (or per ft^2) sizing rules. The standard method involves estimating the number of occupants, usually the maximum, and constantly supplying an amount of ventilation air sufficient for maximum occupation, regardless of the actual occupation at any given time. DCV only operates when CO_2 levels indicate ventilation is needed, adapting to the occupancy of critical areas, such as conference rooms, board rooms, cafeterias and other spaces with changing occupancy. ASHRAE 62-2000 allows this method of ventilation control.

CURRENT STATUS OF MEASURE

Major manufacturers of commercial HVAC control systems supply CO_2 controls as an option to their standard product line. There has recently been an upsurge in adoption of this technology partly due to the increased interest in indoor air quality and a resulting increase in fan energy use. Once design engineers are educated on the potential benefits of this technology, market penetration should increase rapidly.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

A DCV system can save 100% of the energy used for ventilation of a underused space anytime that space is not being used, and will always be saving energy anytime the space has less than the design occupancy present. One manufacturer estimated that converting critical spaces to DCV could save 20-30% (personal communication with J. Shaw 2003) of the overall ventilation air energy use. The cost for adding this functionality is approximately $575 per zone (CEC 2002).

KEY ASSUMPTIONS USED IN ANALYSIS

A 50,000 ft^2, two-story office building with 6 control points was assumed for the analysis. A 20% ventilation energy savings was assumed at a cost of $575 per control point.
Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

The key barrier to increased use of CO_2 controls is perceived complexity and concern about reliability among designers, architects, and building owners. The technology has proven to be increasingly robust and increased visibility and case studies will further support the technology. Recommended next steps include introducing the technology to design engineers and to local building jurisdictions. Monitoring studies documenting savings could be used to develop case studies on the performance of CO_2 control.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H19 DISPLACEMENT UNDERFLOOR VENTILATION WITH LOW STATIC PRESSURE

DESCRIPTION OF TECHNOLOGY

Displacement ventilation is a process by which air (usually 100% outdoor air) is introduced under the floor, or at floor level, at a low velocity and at a temperature just slightly lower than the desired room temperature. Occupants, office equipment and external cooling loads then warm the air. The buoyancy of the warmed air causes it to rise, where it is removed through a ceiling mounted exhaust grill. The warm air carries the CO_2 and other contaminants away from the occupants and is replaced by the freshly supplied cool air. There are many benefits to this type of system, including IAQ improvement (with 100% outside air) and energy savings from reduced fan energy and higher supply air temperature. This technology has been in use for decades in Europe, especially Scandinavia, but is still not widely seen in the U.S. or Canada.

CURRENT STATUS OF MEASURE

Displacement ventilation is often assumed to be synonymous with underfloor ventilation, which has been gaining popularity due to its zoning flexibility. However, most U.S. underfloor systems still use induction rather than displacement ventilation. Several projects have been constructed both in the Northeast and the Southwest as early as 1995 and have been considered a great success. Currently there are several manufacturers promoting displacement ventilation in the U.S., and the design practice is gaining increased interest based on expected energy savings. PIER is funding a project on design guidelines for TDV in California schools with Architectural Energy Corporation (AEC) and the Halton Company (Stubee, 2004).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Energy savings from displacement ventilation vary greatly and are highly dependant on climate, building type, occupancy characteristics, and system design. The performance of displacement ventilation was compared to conventional VAV systems using DOE-2 for four California locations, with projected savings found to vary from 29% to 57% (Bourassa et al. 2002). Other studies found the energy savings to be between 10% and 30% (Hensen and Hamelinck 1995) and 20% - 35% (Loftness and others, 2002). Available cost comparisons indicate equal or lower first cost for displacement ventilation system relative to conventional system designs (Loftness and others, 2002). Additional cost and performance data are needed to better understand the performance and economics of these systems.

KEY ASSUMPTIONS USED IN ANALYSIS

The building used in the Bourassa et al (2002) modeling study was very generic and did not take into consideration isolating designs appropriate for displacement ventilation, nor were any locations outside of California studied. A classroom was chosen since the first of these systems in the US went into classrooms. Based on the prior modeling studies, a conservative savings estimate of 20% was assumed for our analysis. Zero incremental cost was assumed for the displacement ventilation system, based on available data.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

The principal barriers are lack of information, and inertia. For example, owners may not understand the marketing advantages of easy reconfiguration. Education is needed to familiarize architects and design professionals with the benefits and design constraints of displacement ventilation. At least in California, current performance-based energy codes do not provide incentive to design underfloor systems because the code compliance methods do not properly account for the energy savings of these systems (Stubee, 2004). ASHRAE is expected to release of a design guide for Displacement Ventilation in 2004, which will assist mechanical designers (Bauman 2003). Additional monitoring of installations and development of case studies would help document the cost and performance of the technology. Utilities can assist in supporting demonstration projects and providing incentives.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

H20 ADVANCED CONDENSING BOILERS (COMBINED W/ W4)

INTRODUCTION AND DESCRIPTION OF MEASURE

Commercial gas boilers (larger than 300,000 Btuh) are used in larger buildings. Applications include perimeter radiative heating, reheat for air-conditioning humidity control, and general space heating with forced air or hydronic systems. The maximum steady-state efficiency of conventional gas boilers is about 83%, to allow enough heat to escape to support gravity venting and to avoid local condensation that would cause corrosion problems. In contrast, condensing boilers are built of corrosion-resistant materials and designed to utilize energy from condensing water vapor in the exhaust gases. This requires a heat sink (returning water) less than 140ºF, and preferably <120ºF. In turn, this requires controls (and often an operating sequence) designed for low-temperature operation whenever possible. Most condensing boilers of 500,000 Btuh capacity and above have modulating outputs. Some residential boilers are used as "lead" boilers in smaller commercial boiler trains that may have up to 10 units (one or two condensing boilers, the rest non-condensing for winter conditions. In multi-boiler applications, outdoor temperature reset is used to reduce capacity and distribution loop temperature in mild weather, so the unit has as much latent heat recovery capacity as possible. As outdoor temperatures fall, supply temperatures must rise to meet heat losses; when the boiler no longer condenses the system will dispatch a non-condensing boiler or let the condensing boiler lapse into non-condensing mode. The technology does not include oil-fired equipment.

CURRENT STATUS OF THE MEASURE

At least six brands (33 models) of commercial-scale condensing boilers were available in 2001 (CEE 2001), in sizes ranging from 300,000 to 3.3 million Btuh. CEE (2001) estimated that commercial and residential condensing boilers were about 2% of their respective markets, at 750 +/- 250 and 7000 +/- 700 units, respectively. The total stock of gas-supplied commercial buildings larger than 5000 sq.ft. and equipped with boilers is only about 132,000 units, or 3% of the total stock of commercial buildings, 6% of the gas-supplied commercial buildings (from data in CBECS).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

AVAILABLE INFORMATION ON MEASURE SAVINGS AND COSTS

Commercial-scale condensing boilers may cost up to three times as much as baseline non-condensing models (CEE 2001). On the other hand, as components of systems the incremental cost is lower; 19% and 23% in two case studies (CEE 2001). High performance requires using effective controls.

KEY ASSUMPTIONS USED IN THE ANALYSIS

We assume the same life expectancy as for steel water tube boilers (ASHRAE 2003). Costs and savings based on high school retrofit case study in CEE 2001. We assume that the median installation has 2.5 boilers, so that 40% could be selected as "lead" condensing boilers.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

The principal barrier is the small number of larger buildings that use boilers for heat. This limits the market, and assures high prices from low volume. Another barrier is that many older systems use steam, and lack distribution capacity for hot water conversion. The secondary barriers are lack of awareness and the skills required to design the system to optimize performance. CEE 2001 concluded that programs for market transformation are most likely to succeed in the Northeast and Midwest (cold climates, common hydronic systems), and that schools and federal facilities that look at life cycle economics are the most likely market segments. Additional technical and marketing information, and training for system designers are likely to increase technology uptake rate.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

LIGHTING

CANADIAN SUMMARY

Several T&I submissions pertained to the category of **lighting** include advanced fenestration systems (window and door design and placement), personal environmental controls, perimeter zone controls, responsive buildings, and the lighting drivers resulting from integrated structural or HVAC systems with photovoltaics. Below is a summary of Canadian implications of these projects.

Current Canadian Status of Technologies

Various Canadian projects are under way to integrate photovoltaics into wall panel systems, roofing systems, and HVAC systems. The low or zero net power requirement with PV systems is helping to drive the demand for low power lighting, such as light emitting diodes (LEDs), that can draw solely on these systems or backup/emergency systems.

Canadian R&D and commercialisation experience in the window industry is also ensuring significant Canadian and international receptors for further advance in fenestration systems (window and door design and placement). There is already sufficient demand for Canadian window systems from the U.S., the U.K., and other countries in Europe. Successful Canadian lighting performance simulation procedures and software developed by Natural Resources Canada (NRCan) and the National Research Council (NRC) include Lightswitch Wizard, SKYVISION for skylights, and DAYSIM for daylighting. Canadian performance simulation procedures and software are currently adopted in many countries and by ISO.

High-efficiency gas-fired lighting and heating systems are also being explored, where the appliance resides centrally in the building and provides both heat and light from combustion, similar to less efficient fireplaces.

Canadian Opportunities & Challenges

Several Canadian homebuilders and technical firms have expressing interest in zero energy homes, which use a combination of energy efficient technologies and solar heating and lighting. Current development and testing of thermal and optical performance evaluation methods for skylights, entry doors, and glazed facades will help enhance Canada's impact on passive solar heating and daylighting technologies and practices. Canadian advances in personal environmental control (PEC) and perimeter control procedures and algorithms will contribute to lighting technology choices and uptake, as well as the balance between natural (solar) and artificial (powered) lighting.

L1 HIGH EFFICACY SUPER T8 LIGHTING

DESCRIPTION OF TECHNOLOGY

T8 electronic ballasts and lamps were introduced in the early 1980s with the promise of significantly reducing lighting energy use in commercial and institutional buildings. Since that time, manufacturers have continuously improved T8 performance, particularly with regard to reliability and features. At the same time, the product cost has decreased. However, system efficacy has remained at 85 to 88 Lumens/Watt for a typical system consisting of F32T8 lamps with instant start ballasts (NLPIP, 2000). The recent emergence of high efficacy Super T8 lighting systems marks real improvement when compared with generic T8s and particularly with the T12 lighting systems that were estimated to account for 75% of the U.S. commercial fluorescent lighting energy use as late as 2000 (DOE 2002).

CURRENT STATUS OF MEASURE

In 2002, both GE Lighting and Osram Sylvania introduced Super T8 lighting systems with a claimed system efficacy of about 100 Lumens/Watt; Phillips now has systems too. Ballasts are available in both 120V and 277V, and will soon be available in 347V for the Canadian market. Additional advantages over standard T8 systems include higher lamp lumen maintenance and, if long-life products are selected, an extended lamp life of up to 30,000 hours vs. the standard 20,000 hours. Savings are achieved through delamping, using low ballast-factor ballasts, or through installation of fewer fixtures. Otherwise the high efficacy systems will use the same amount of energy as the conventional T8 systems, while producing a higher lighting level. Super T8s were introduced after the 1998 ET study, but have already reached market penetration well beyond 2% (Sardinsky and Benya 2003), so they are no longer emerging technologies. Thus, the super T8 is not included in our statistics. This summary is kept because many are unaware of the products and their potential.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Super T8 systems (lamp and ballast) can show up to 81% improvements in efficacy (lumens/watt) relative to T12s; 31% relative to generic T8s (Sardinsky and Benya 2003). However, the wide range of applications discussed above means that actual energy savings are generally more modest, in the range of 15% - 20% relative to standard T8 systems (Thorne and Nadel 2002), implying roughly 27% - 36% relative to older T-12s. US incremental costs are in the range for $1/bulb, and $1 to $5 for the best ballasts (Sardinsky and Benya 2003), but as much as $10 per two-lamp fixture in another study (Southern California Edison 2004).

KEY ASSUMPTIONS USED IN ANALYSIS

We consider the Super T8 for both new construction and retrofit applications assuming a 2-lamp fixture with an operation of 3400 hrs/year (DOE, 2002). For new construction, the Super T8 fixture is assessed against a 2-lamp F32T8 fixture with an instant start ballast with an incremental material cost of $5/fixture and a 20-year life. For a retrofit, the Super T8 fixture is assessed against a T12 fixture and a full cost of $36/fixture (for ballasts and lamps, but not the fixture itself) including labor and material.

Canada-specific assumptions: This measure applies only to fluorescent lighting, which ranges from 10% in churches and arenas to 90% in schools. Penetration by 2020 is assumed to reach 99%. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles that provide a distribution of lighting in buildings by type (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The main barriers to the adoption of Super T8 fluorescent lighting system are lack of awareness by end-users, confusion over similar-sounding options, and incremental cost over standard T8 fluorescent lighting. Awareness of the benefits of Super T-8 systems relative to generics is much lower, however. Collaborative promotion and awareness generation by government, utilities and trade allies is necessary to make the Super T8 lighting fixture the preferred choice in the market. In particular, awareness is needed of the need to use low BF ballasts or otherwise adjust the for higher-light output. End-user and trade ally education efforts, as well as limited financial incentives, may be needed for a few years until the market takes off.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L3 HALOGEN INFRARED REFLECTING A-LINE LAMPS

DESCRIPTION OF TECHNOLOGY

Halogen Infrared Reflecting (HIR) lamps look like conventional incandescents but contain a tungsten halogen filament with a multi-layer film coating on the inside of the halogen capsule. The coating reflects infrared energy back onto the lamp filament, which makes the lamp burn hotter, and in turn, increases lamp efficacy. HIR lamps have been available for reflector lamps since the early 1990s and are now sold in sufficient quantities to no longer be considered an emerging technology in reflector-lamp applications. This analysis focuses on general service, screw-in, globular, HIR replacements for conventional A-lamp incandescent bulbs, which are appropriate in low to medium-use residential applications (higher-use applications should generally use CFLs).

CURRENT STATUS OF MEASURE

In the late 1990s, the Environmental Protection Agency (EPA) and the Department of Defense (DOD) made informal offers to major manufacturers, such as General Electric, Osram Sylvania, and Philips, to manufacture the technology. However, the manufacturers showed little interest (Rubinstein 2003). The government agencies sent out a Request for Technical Proposal (RFTP) to manufacturers, but did not receive any serious bids. A European procurement initiative also did not result in any serious offers to develop the product. Osram Sylvania did eventually develop an HIR A-lamp, but has had difficulty selling the product. The lamps are priced at $6-7 each, significantly more than a typical incandescent, which sells for $1 or less. Sylvania has unsuccessfully marketed the product based on energy savings for direct replacement of high wattage lamps (Bockley 2003). General Electric has also developed HIR A-lamps, but it is uncertain if the company will proceed in commercializing the product in the near future. The large incremental cost (~$5.50/lamp) relative to incandescent lamps is a major concern for the company (Shepard 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

This analysis assumes that the HIR A-lamps would be applicable in 100 percent of current low-use residential applications (i.e., less than 3 hours per day). Low-use applications represent 35% of residential lighting energy use (Vorsatz 1997). In computing savings, Sylvania compared the energy use of HIR 60-watt A-lamps to the energy use of standard 75- watt incandescents. HIR 60-watt A-lamps can provide 20-25 lumens per watt, higher than most 75-watt incandescents. Energy savings at 3 hr/day amount to 16 kWh/year when compared to a 75-watt incandescent.

KEY ASSUMPTIONS USED IN ANALYSIS

General service HIR A-lamps were expected to be used in cases where CFLs would not be cost-effective due to low operating hours. However, as CFLs become smaller and cheaper, they are becoming real alternatives to standard incandescent lamps, even for low-use applications. For the about the same price, one can buy a CFL that has twice the lumens/watt and a longer life than a HIR A-lamp. HIR A-lamps face great challenges as prices for CFLs decline (Rubinstein 2003).

For HIR A-lamps to compete HIR lamp costs will have to come down substantially, but manufacturers do not consider this likely.
Canada-specific assumptions: This measure is assumed to apply to only 35% of the lighting in households. The other lighting is either decorative, fluorescent or directional track lighting that cannot be replaced. Penetration by 2020 is assumed to reach 99%. Consultant estimate based on Canadian residential end-use analysis studies (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

At this time, manufacturers have little interest in pursuing this technology. As CFLs become more competitive with incandescent lamps, the business case for developing the technology is not very strong. We do not have any recommended next steps for this technology at this time.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L4 COST EFFECTIVE LOAD SHED BALLAST

DESCRIPTION OF TECHNOLOGY

This report focuses on devices that respond to utility peak demand reduction efforts, approximately 100 hours per year. Around 80% of dimming ballasts are instant-start, providing electrode-heating voltage during starting or operation (Bierman 2003, NLPIP 1999). The California Energy Commission's PIER Lighting Program (PIER) is currently developing an instant-start ballast that would receive a signal from a controller to dim light fixtures during peak demand periods. The controller device would communicate with an outside source, such as a utility or customer energy management system, and then send the signal to the ballast to dim the lights.

CURRENT STATUS OF MEASURE

Several models of dimming ballasts are currently available. A laboratory prototype of a demand-limiting controller was to be completed in Fall 2003, according to the Lighting Research Center (LRC), the manager for the PIER project (Bierman 2003). LRC has had discussions with OSRAM/Sylvania to manufacture a limited number of load shed ballasts for further tests and field demonstrations. However, the manufacturer has not committed to commercialize the product. LRC is also actively seeking a manufacturer for the control device that would work with the ballast and is now discussing the possibility with a New York State manufacturer. To facilitate manufacturers acceptance of the technology, the New York State Energy Research and Development Authority (NYSERDA) has awarded a grant to develop the controller. NYSERDA is also providing funding for a demonstration project that will show how the dimming system works. LRC's goal is to have the ballast and controller system commercialized no later than 2008.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

An economic study performed by LRC estimates that the incremental cost of the load shed ballast and its accompanying controller is about $9 per lighting fixture relative to the cost of an instant start, non-dimming ballast (LRC 2003). Each controller can send PLC (power line carrier) signals to ballasts located in a 10,000 square foot area. For new construction, no additional installation costs would be needed since the load shed ballast would simply replace the regular ballast found in the lighting fixture. LRC estimates a simple payback to the customer of 2.57 years for new construction. However, payback years will depend on local utility rate structure and the customer's use of dimming. As a pure peak-shaving measure, it would save virtually no energy, leading to a CSE of $0.43/kWh. We recommend that the peak shaving feature be combined with other aspects of dimming control (e.g., daylighting) to share its costs across both energy and demand.

KEY ASSUMPTIONS USED IN ANALYSIS

In this analysis, we assumed that the technology would be applied to assembly, classrooms, dining and office areas. Feasible applications are 80% of these spaces in the commercial sector. The LRC study assumed that the lamps would be dimmed by about 30 percent for 100 hours per year during peak demand periods in the summer time (LRC 2003). When using a standard 2-lamp T8 fluorescent fixture with electronic ballast, LRC estimates a 20-watt demand reduction during peak. We implicitly assume that the devices operate in parallel with customer controls such as daylighting, with utility-required dimming having priority.

Canada-specific assumptions: This measure only applies to schools and office, which can take advantage of fluorescent dimming. Only perimeter lighting near windows can take advantage of dimming systems. Penetration by 2020 is assumed to reach 99% (DOE 2002, Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Further commitment from manufacturers is needed to commercialize the product. A NYSERDA-funded demonstration project will show building owners and lighting designers more Workshops and seminars directed to decision makers would also help. Both utilities and customers can benefit from the technology through reduced cost for peak electricity. Analysis by LRC (2003) suggests that the new-construction version is cost-effective through demand reduction for California utilities. From this we infer that incentives would be very effective in transforming the market.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L5 ADVANCED/INTEGRATED DAYLIGHTING CONTROLS (ADCS)

DESCRIPTION OF TECHNOLOGY

In most office spaces, lighting has traditionally been designed to provide equal amount of light for all occupant spaces. However, lighting may not be needed in all spaces; part-time occupancy and daylight may eliminate lighting needs. Individual workers needs and expectations also vary. New lighting control products allow individuals more flexibility in setting light levels for their spaces. Most allow workers to change lighting levels using their computers or remote control devices. Four models of advanced daylighting controls (ADCs) are currently available in North America: the Ergolight by Ledalite, which uses PC screens; the PerSONNA by Lutron, which works with a handheld device; LightBug by StarField Controls, which uses a direct-wired desktop dimmer; and the IRC 1000 by the Watt Stopper which can be operated with a handheld remote control (Krepchin and Stein 2000). The Lighting Research Center (LRC) has also developed a prototype of a self-commissioning photosensor and control device, and is now seeking a partner to commercialize the product (IESNA 2003). WattStopper is developing a self-commissioning photosensor through a PIER project (Stubee, 2004).

CURRENT STATUS OF MEASURE

ADCs have been installed in large offices around the country. LRC has installed the self-commissioning photosensor and control device in private offices in Connecticut and plans to monitor the sites for six months. LRC also monitored Ergolights in New York (D. Aumann, to E. Stubee 2004). In a study done in offices at the National Center for Atmospheric Research (NCAR), most workers preferred the model used with desktop computers, such as Ledalite's Ergolight (Krepchin and Stein 2003). Ledalite has seen increases in the number of units sold in the last few years. The company now has more than 10,000 Ergolights in various locations. The World Resources Institute installed Ergolight in 140 individual workstations in Washington, D.C. with positive results (Krepchin and Stein 2000). BC Hydro also installed 195 Ergolight systems at one of their facilities. The British Columbia utility company is now seeing monthly savings of 65- 80% (EDC 2002). At its facility in Tewskbury, Massachusetts, Raytheon Company replaced 697 fixtures (combination of 2-lamp & 4-lamp T12s) with 503 Ergolights and has seen similar savings. Raytheon has since added more units and now has about 3,000 of the fixtures. Ledalite has also received an order to install 2000 Ergolight units at the California Transportation Department's new building (Scott 2003). Ledalite will be releasing a new version of the Ergolight in the near future.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

ADCs' cost $125 to $400 per unit, depending on available features. Fully integrated systems with occupancy sensors, such as Ergolight, cost around $400 or $2-3/sq.ft. As the volume of sales increase, these prices will likely come down. Standard T8 lamps cost around $1.75/sq.ft. to install. For this analysis, we estimated that the incremental cost for the user is about 50¢/sq.ft. over a standard T8 fixture. Compared to using standard T8 lamps, we compute energy savings of 46%.

KEY ASSUMPTIONS USED IN ANALYSIS

ADCs have been used in office workstations, private offices, conference rooms, classrooms, and hospitals. Together, these commercial spaces account for approximately 26% of lighting energy consumed in this sector (DOE 2002). For this analysis, we estimate that feasible application are two-thirds of this total.

Canada-specific assumptions: This measure only applies to schools and office, which can take advantage of fluorescent dimming. Only perimeter lighting near windows can take advantage of dimming systems. Penetration by 2020 is assumed to reach 99% (DOE 2002, Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Principal barriers include difficulty of predicting energy savings (Krepchin & Stein 2000), and relatively high costs. Even with large energy savings, simple payback period could be up to 14 years, an unacceptable time frame for most organizations (Krepchin & Stein 2000). Increased productivity and other non-energy benefits are the more likely motivation for businesses that are considering ADCs. Measuring productivity improvements would, if feasible, improve the value proposition. We recommend that such studies be attempted. If the results are favorable, employers, building owners, lighting designers and other building professionals would need to trained and educated about these benefits. Some good case studies need to be developed and presented to these groups.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L6 HID REFLECTOR LAMP/CERAMIC METAL HALIDE

DESCRIPTION OF TECHNOLOGY

Advances in metal halide (MH) lamp technology have led to the production of ceramic metal halide (CMH) lamps which use ceramic rather than quartz arc tubes typical of most MH lamps. Ceramic arc tubes can tolerate a higher temperature than quartz, resulting in improved color rendering and color temperature and the warm tones desired in retail and other color-sensitive applications. Furthermore, CMH lamps can provide the concentrated beams required for accent lighting both in retail and other architectural applications. CMH lamps represent an attractive alternative to the halogen PAR lamps commonly used in these applications because they have a much longer life and use just half of the energy.

CURRENT STATUS OF MEASURE

All major lamp manufacturers currently offer CMH lamps in the 39 to 400W range. CMH lamps are most common in wattages of 39 to 150W. A 39W CMH lamp produces 2200-2400 lumens, a higher output than both the 100W halogen-infrared (HIR) PAR lamps (2070 lumens) and the 100W halogen PAR lamps (1400 lumens) typically used in retail and other commercial applications. Unlike halogen sources, CMH lamps require a ballast to operate.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

CMH lamp systems use less than half the energy of HIR PAR lamps to produce a similar light output. In addition to energy savings, CMHs last three to four times as long as halogen-IR PAR lamps (9,000 to 12,000 hours versus 3,000 hours) and can reduce the number of fixtures required to illuminate a space. In a typical retail application, replacement of each 100W halogen-IR PAR lamp with a 39W ceramic metal halide (lamp plus ballast uses 44W) saves roughly 225 kWh per year. For retrofits, current costs are approximately $175 per fixture including lamp, fixture, and ballast costs. However, in many cases – particularly where halogen PAR lamps have not been upgraded to halogen-IR – fewer than one-to-one fixture replacements are required, reducing the overall retrofit project costs. For new construction and remodeling projects, the current incremental cost relative to halogen-IR lamps is approximately $140 (Thorne and Nadel 2003).

KEY ASSUMPTIONS USED IN ANALYSIS

For this analysis, we estimate energy savings for replacement of a 100W halogen-IR lamp with a 39W CMH lamp system. According to DOE (2002), operating hours for lighting in retail applications total roughly 4,000 hours per year and approximately 32% of retail lighting energy is consumed by incandescent light sources. Additional savings opportunities exist in other color-sensitive environments such as museums. We assume future incremental costs of one-half the current costs as the technology matures and adoption increases.
Canada-specific assumptions: This measure is only applicable to 10% of retail lighting, which is assumed to represent spot PAR lamps. Penetration by 2020 is assumed to reach 99%. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles that provide a distribution of lighting in buildings by type (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The major barriers to greater adoption of CMH lamp technology are high first costs, limited experience with the technology resulting in uncertainty over lamp performance, and unawareness of the technology among end-users, lighting suppliers, and contractors that specify lighting in many retail applications. We recommend greater documentation of in-field performance through demonstrations and development of case studies. Additional educational materials to illustrate the benefits of the technology in specific applications would also be of use—this has proven a successful strategy for other new lighting technologies. Finally, targeted incentives to help lower first costs could increase adoption, build the market and result in overall price declines.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L7 MOTION SENSOR NIGHTLIGHT

DESCRIPTION OF TECHNOLOGY

One of the largest energy end uses in hotels is bathroom lighting, largely due to guests leaving the bathroom light on as a nightlight. Watt Stopper has developed a hotel bathroom night light that takes advantage of new high intensity LEDs and motion sensors to efficiently provide a night light for hotel guests. The nightlight is an integrated unit that fits into a standard wall switch plate. A high intensity LED lights the bathroom until motion is detected. At this point the lights in the bathroom are turned on providing illumination. The nightlight has an adjustable time delay allowing the light to stay on from 15 minutes to 2 hours.

CURRENT STATUS OF MEASURE

This product is currently in production and in use in a limited number of hotels. However, since the unit is considerably more expensive than a regular light switch ($38 compared to $6) it has met some resistance. Lawrence Berkeley National Laboratory (LBNL) monitored numerous hotel rooms and determined that the bathroom light was a significant source of energy consumption (LBNL 1999). The LBNL study led to the installation and monitoring of WattStopper units in a Sacramento hotel under a program promoted by the Sacramento Municipal Utility District's (SMUD) (Bisbee 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

A monitored 400 room hotel project in Sacramento, California demonstrated 166 kWh annual savings per room (Bisbee 2003). Total installation and labor costs were estimated at $50 per room. In addition to a favorable payback, it was the researchers found that maintenance costs were reduced due to the longer lamp lifetimes.

KEY ASSUMPTIONS USED IN ANALYSIS

A monitored 400 room hotel project in Sacramento, California demonstrated 166 kWh annual savings per room (Bisbee 2003). Total installation and labor costs were estimated at $50 per room. In addition to a favorable payback, it was the researchers found that maintenance costs were reduced due to the longer lamp lifetimes.

Canada-specific assumptions: This measure is only applicable to bathroom lighting in hotels. Hotels represent 50% of the segment consumption and bathroom lighting accounts for 2% of total lighting. Penetration by 2020 is assumed to reach 99%. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The principal barriers are: Lack of understanding of the magnitude of bathroom lighting energy use, and high first cost compared to standard light switch. We recommend that prior to education, further study be done on lighting usage in hotels to verify usage statistics gained by

LBNL. We recommended that information be prepared in a case study format and disseminated to the hotel/motel industry. Utility incentives and state building standards would also help to increase penetration of this technology.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L8 UNIVERSAL LIGHT DIMMING CONTROL DEVICE

DESCRIPTION OF TECHNOLOGY

MaxLite, a lighting products manufacturer, recently developed DimALL, a device that can dim fluorescent, incandescent or halogen lamps without the installation of a special ballast. The device has a microprocessor that is attached to a lighting circuit. The microprocessor regulates the circuit's operation and voltage to maintain the lamp's dimming operations. The actual dimming capability depends on the quality and variety of lamps supported by the circuit (ET Currents 2003). The best dimming capability (down to 10% of full output) is attained when the circuit is connected to high-quality lamps with similar characteristics. Dimming power is reduced when the circuit supports a mix of incandescent and fluorescents fixtures. DimALL will be available in 200-watt and 1,000-watt circuit capacity. The manufacturer claims that the product can be installed without the need for special wiring.

CURRENT STATUS OF MEASURE

MaxLite is currently refining the technology and expects to release the product in Fall 2004 (Kang 2003). The manufacturer is working on increasing the dimming capacity for CFLs (currently to 45% of full output) and broadening the list of CFL models for which the technology can work. MaxLite is also developing an infrared remote control to use with the device. MaxLite hopes that commercial consumers would be able to use the product to dim linear fluorescents, such as T8 and T10 lamps, used in conference rooms, and hotel dining rooms, where lighting control needs are high. For residential purposes, the manufacturer feels that, with the product, consumers would be willing to switch to CFLs from incandescents for lighting needs in their living rooms and dining areas. DimALL does not need a dimming CFL lamp, or special ballast, and can be used with a standard wall-dimmer switch (Kang 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

A DimALL device capable of supporting 1,000 watts, ideal for commercial use, will cost $200 each, according to manufacturer estimates (Kang 2003). Dimmable ballasts, currently selling at around $20 incremental, would be more cost effective for commercial use. A lower 200-watt device that would be used in residential homes would cost $40-50. We estimate that installation cost would be around $25 each. The manufacturer plans to give a 5-year warranty for the product.

KEY ASSUMPTIONS USED IN ANALYSIS

For this analysis, we assumed that the universal dimming capability from the technology would facilitate the conversion from incandescents to CFLs for certain residential spaces, such as dining and living room spaces. Together, these spaces account for 36% of lighting energy consumed in this sector (DOE 2002). Feasible applications are estimated at 50% of these spaces in the residential sector. Additional savings could also be realized from the light dimming itself. According to the manufacturer, dimming fluorescent lamps on average by 50% with DimALL could result in additional energy savings of 30% (Kang 2003). For commercial spaces, the technology is currently not competitive with dimmable ballasts, which cost around $20.

Canada-specific assumptions: This measure's applicability in residential housing is assumed to be 5% based on one fixture in 20 can be dimmed. Penetration by 2020 is assumed to reach 99% (DOE 2002, Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The technology would be attractive for consumers who are already considering CFL replacements for their incandescent lamps. DimALL could serve as an additional incentive to purchase CFLs for certain residential uses. Utilities could offer additional financial incentives to their customers who purchase the device with CFLs.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L9 ADVANCED HIGH INTENSITY DISCHARGE (AHID) LIGHT SOURCES

DESCRIPTION OF TECHNOLOGY

Conventional high intensity discharge (HID) light sources are commonly used in outdoor applications such as street lighting, parking garages, and other places where high levels of light are needed over large areas. They are also popular in indoor, high-ceiling applications such as warehouses, gymnasiums, arenas and even banks. HID lamps use an electrical arc column across tungsten electrodes to produce light. Typically, the arc column uses 90% of the electric power, with the remaining 10% dissipated as electrode losses. About 57% of the electric power that penetrates the arc column escapes as heat, and 33% is utilized to produce visible light (EPRI 2002) – roughly three times the efficiency of incandescents. Advanced HID lamps (AHID), currently under research, would shift some energy (infrared) from the arc to near UV or visible emission, improving efficiency. The research goal is to raise lumens per watt up to 40% above the current rate.

CURRENT STATUS OF MEASURE

The Electric Power Research Institute (EPRI), Los Alamos National Laboratory (LANL), the National Institute of Standards & Technology, the University of Wisconsin, General Electric and Phillips Lighting are currently engaged in a research program to develop AHID light sources. The ALITE II program has made good progress in developing the technology, but needs additional funding to conduct additional experiments (EPRI 2002). The program is scheduled to be completed at the end of 2005. If the research goes well, the lamp companies will then develop a product and begin commercialization, which will take 2- 3 years (Gough 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Most HIDs used today in existing buildings are white, probe-start, metal halide lamps that are between 100-400 watts (Gough 2003). The 400-watt lamps are commonly used in indoor, high-ceiling commercial or industrial buildings (Advanced Buildings Technologies & Practices 2003). These lamps have efficacies of about 70 mean lumens per watt and use magnetic ballasts (NLPIP 2003). The lamps currently cost an average of $60 and ballasts range from $70 – 130. AHID lamps would increase average efficacy rating about 40%, with an incremental cost of 20-30% on the lamp. To get the 40% energy savings, the lamps would likely need to run on electronic ballasts, which currently cost twice as much as magnetic ballasts (Gough 2003.)

KEY ASSUMPTIONS USED IN ANALYSIS

AHIDs are estimated to have similar rated life hours as regular metal halide HID lamps (about 15000 hours). Conventional HID (metal halide) lamps currently consume about 9% of commercial lighting electricity, excluding outdoor applications (DOE 2002). For this analysis, we assumed that feasible applications for AHID would be 70% of current lighting energy consumed by HIDs. AHID lamps would provide about 40% energy savings. This is perhaps 10-15% savings relative to pulse start MH with electronic ballasts.

Canada-specific assumptions: This measure's applicability ranges from 5% in schools (gymnasium) to 70% in warehouses. Penetration by 2020 ranges from 50 to 65% based on rate of replacement. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The ALITE program, which is developing AHID lamps, continues to work with lamp companies and national laboratories to come up with a prototype. However, additional funding seems to be the barrier to completing the necessary research. The program is currently seeking additional funding from utilities, the Department of Energy (DOE) and the National Science Foundation (NSF) for further research (Gough 2003). Once a prototype has been developed and commercialization has begun, incentive programs can help promote the technology to consumers. If the research goals are achieved, AHID lamps would provide the same amount of light with 40% less in electricity and have total life hours similar to regular lamps. The substantial incremental cost of 30% would be a good investment at 4¢/kWh cost of saved energy.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L10 HYBRID SOLAR LIGHTING

DESCRIPTION OF TECHNOLOGY

Hybrid Solar Lighting (HSL) combines roof-top sunlight collectors, light pipes (optical fibers) and special luminaries that augment fluorescent lighting with sunlight. An HSL system has a solar dish collector that tracks the sun and focuses it into large optical fibers that deliver most of the light to "hybrid" luminaires. The fixtures are connected to lighting controls that automatically reduce the amount of electric light used depending on the amount of available sunlight coming in. Commercially-available recessed fluorescent luminaries can be retrofitted to include solar illuminant dispersing devices.

CURRENT STATUS OF MEASURE

HSL is currently being tested at Oak Ridge National Laboratory (ORNL) in Tennessee. Ohio University also has a partial system installed in one of its buildings. In Fall 2003, the HSL system will also be tested in an office complex in Alabama and in a classroom in Mississippi. The Sacramento Municipal Utility District (SMUD) has decided to try out the HSL for one of its lobby areas as well. Wal-Mart, one of the program's partners, is considering installing a system in one of its "Neighborhood Markets" which are smaller stores with lower ceiling heights (Tarricone 2003.) Some prototypes have shown a greenish cast to the light from the hybrid collector (Brodrick 2004).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The target price for an HSL system is $4,700, which includes the retrofitting of up to 16 fluorescent luminaries. ORNL estimates that a 1.5-meter dish collector can deliver roughly 100,000 lumens to 12-16 light fixtures covering 1000 sq.ft. on the top floor of a building (Muhs 2003a). Payback time would be moderate (about 4 years) for the sunbelt areas, since electricity savings are over 50%. However, for areas in the Northeast or the Midwest, payback time would be twice as long (Muhs 2003b).

KEY ASSUMPTIONS USED IN ANALYSIS

The technology would be feasible in low-rise (up to two floors) commercial buildings, located in the southern and western United States. Together, low-rise floor space in these regions comprise about 56% of all low-rise commercial floor space in the United States (BoC 1999). HSL can also be used on the upper two floors of multi-story buildings, but the losses in available low-cost light fibers are too great for applications more than two floors below the light collector. Additionally, HSL systems work best in spaces with low-ceilings (up to 11 feet), such as spaces in schools or small government buildings (Muhs 2003b). Considering these factors, we estimate the feasible applications to be 60% of low-rise, commercial floor space in the southern and western United States.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

Current activities are directed at refining the technology. Research is being done to reduce the number of moving parts on the collector, improve the fiber optics, and improve luminaire retrofits. The Illuminating Engineering Society of North America (IESNA) has not recommended a specific type of retrofitted luminaire at this time (Muhs 2003b). The technology has good potential in the sunbelt states, but the longer payback period for the Midwest and Northeast markets, may make market penetration more difficult in these regions. In addition to issues of the number of sunny days, additional maintenance costs due to snow accumulation on the collector and its moving parts, would also play a factor. Further research is needed regarding these issues.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L11 LED LIGHTING

DESCRIPTION OF TECHNOLOGY

Light Emitting Diodes (LEDs) are solid-state devices that convert electricity to light, potentially with very high efficiency and long life. They are generally monochromatic, so early applications have been for (red) exit signs and for traffic signals. Recently, lighting manufacturers have been able to produce "cool" white LED lighting indirectly, using ultraviolet LEDs to excite phosphors that emit a white-appearing light.

CURRENT STATUS OF MEASURE

Red and green LED traffic signals are now mainstream. White LED products are entering niche markets including retail displays, building exterior illumination, task lighting, elevators, kitchens (under- cabinet), and backlighting for liquid crystal displays. LumiLeds has released a warm white, incandescent-equivalent LED lamp with average light output of 22 lumens and 50,000 hr. life at 70% of initial brightness (LumiLeds 2003). For comparison, a typical 60-watt incandescent bulb has an output of around 800 lumens, and lasts about 1000 hr. GE has announced white LED lighting products with an efficacy of 30 Lumens/Watt and 50,000 hour life (Talbot, 2003). For comparison, current CFLs generally exceed 70 lumen/watt (IESNA 2000), with life expectancy of several thousand hours. Technical Consumer Products, Inc, a lighting manufacturer, recently released an $89, five watt LED desk lamp (TCP 2003). When compared to a typical 60-watt incandescent lamp, the LED desk lamp offers over 90% in energy savings (David 2003). In California, the PIER Lighting program expects to have LED fixture prototypes ready in Fall 2003 that could be used for residential porches, commercial entry ways, and other exterior illumination needs (Porter 2003). PIER is also working on low profile fixtures, for elevators, kitchen cabinets and similar applications. The products are expected to reach marketable stage towards the end of 2004. Much current research is focused on improving the efficacy and light quality of white LEDs.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Currently, white LEDs are estimated to cost about 20¢/lumen (Ton et al 2003, Craford 2002). But this number could continue to go down if the design of LED systems components also improves (Ton et al 2003). There are also other technical challenges related to semiconductors used in LEDs (Simmons 2003). Currently, thermal management is a key issue that needs to be resolved for LED systems. Although they do not radiate as much as heat as other lighting sources, LEDs still need an appropriate heat sink so that light output and life span do not decrease.

KEY ASSUMPTIONS USED IN ANALYSIS

For this analysis, we assumed that white LED lighting could be used in both residential and commercial applications. For residential use, white LED lighting could replace incandescents (and halogens) used in kitchens (such as under-cabinet shelf), task lighting, porches, backyards, and other applications requiring less than two hours of use per day. Most rooms (except kitchen, utility, dining, living, utility, and outdoor have lighting used 2.0 hours or less (US Lighting Market Characterization 2002, Table 5.9). For commercial use, white LED lighting could be used for various exterior illumination, retail merchandise & display, and signage. These applications comprise roughly 21% of commercial lighting energy, in part because the daily duty time is long. In the long-term, additional applications will become feasible, but over the next five years (the timeframe of this report), white LEDs will likely be limited to these niches.)

Canada-specific assumptions: This measure's applicability in commercial construction is based on the percentage of lighting that is assumed to be architectural incandescent that can take advantage of LED. The applicability ranges from 2 to 15%. Penetration by 2020 is assumed to reach 99%. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles that provide a distribution of lighting in buildings by type (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

LED Lighting has made major advances toward broader applications. However, further improvements are needed for LEDs to compete with other lighting sources. At 20¢/lumen, LED lighting currently costs at least five times more than compact fluorescents. Average efficiency of LED lighting is around 25 lumens/watt, which is higher than incandescents and halogens but still much lower than fluorescent lighting. Because LEDs emit light directionally, their light output is also difficult to accurately compare in the photometric system (lumens/watt) used in traditional lighting sources. DOE maintains an active research program in this area, at http://www.netl.doe.gov/ssl/ (Broderick 2004). Current incentive programs for LED lighting only focus on exit signs and traffic signals. As more LED products are introduced into the market, commercial and residential lighting programs include educational activities as well as financial incentives.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L13 HIGH QUALITY RESIDENTIAL CFL PORTABLE FIXTURES

DESCRIPTION OF TECHNOLOGY

Residential portable fixtures include table lamps, desk lamps, floor lamps (torchieres), and other plug-in fixtures typically found in living rooms, home offices and family rooms. Together they consume roughly 20% of total annual household lighting energy (Calwell et al.1999). Although energy efficient compact fluorescents (CFLs) are available for use with these fixtures, most users still prefer lower cost incandescent lamps. However, many manufacturers have now developed residential portable fixtures designed specifically for pin-based CFLs. When used, these CFL-dedicated fixtures guarantee energy savings, since they are incompatible with incandescents.

CURRENT STATUS OF MEASURE

Depending on the region of the country, CFL residential portable fixtures can be purchased in furniture stores, lighting specialty stores, home improvement stores, hardware stores, department stores and national discount stores (RER 2000) but availability is limited in home improvement stores and large discount stores. Additionally, a recent study in California showed that many retailers are not very knowledgeable about fluorescent lighting fixtures (Heschong Mahone 1999). Also, replacement bulbs are not widely stocked or readily available. Currently, several initiatives are underway to encourage lighting manufacturers and designers to create better portable CFL fixtures. The Consortium for Energy Efficiency (CEE), the American Lighting Association (ALA) and the U.S. Department of Energy (DOE) have partnered to sponsor *Lighting for Tomorrow*, a national competition for lighting fixture designs. The sponsors have selected several portable CFL fixtures as finalists and honorable mentions based on paper designs. Some of the portable fixtures are estimated to cost less than $100 retail. Manufacturers and lighting designers who made the final round are due to submit their prototypes in January 2004. The California Energy Commission (CEC) also recently started the ENERGY STAR Residential Fixture Advancement Project, which reimburses manufacturers for 50 percent of their cost to design higher-end table or floor lamps. Program managers estimate that products will be out in the market by mid-2004.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Energy savings from portable CFL fixtures could be more than 70% over traditional incandescent fixtures. A 27-watt CFL fixture is equivalent to a typical 100-watt incandescent table lamp (ENERGYGuide 2003). However, the incremental retail cost of the fixture is high, almost $40 (including replacement bulbs). For cost as well as aesthetic reasons, consumers have been slow in accepting CFL table lamps. CFL floor lamps are growing in popularity, however, as a replacement for halogen torchieres, which have been shown to be unsafe (Calwell et al. 1999).

KEY ASSUMPTIONS USED IN ANALYSIS

For this analysis, we estimate a feasible applications to be 50% of the portable fixture market. Incremental cost is assumed at $22 (decremented from $30 in Nadel and others 1998) plus $16 for two replacement bulbs over the life of the fixture.

Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

CFL portable fixtures can provide large energy savings potential to consumers. However, consumers complained about poor quality and design in the past (Heschong Mahone 1999, RER 2000). Further outreach programs need to take place to educate both retailers and consumers, on the value (both energy and non-energy related) of the fixtures. A special effort must be made to reach large home improvement and discount stores where most consumers go for their lighting needs. Some utilities give discounts directly to their customers for ENERGY STAR products (without having to apply for rebates). ENERGY STAR ncentive programs should also be made available through retailers. Programs can work to improve stocking of replacement bulbs, locally and /or on internet.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L14 ONE-LAMP LINEAR FLUORESCENT FIXTURES WITH HIGH PERFORMANCE LAMPS

DESCRIPTION OF TECHNOLOGY

One-lamp fixtures for fluorescent lamps can reduce lighting electricity consumption for most commercial buildings, especially for those with small or oddly dimensioned offices, spaces with some daylighting, and offices where computer-oriented tasks predominate. In many commercial buildings, general lighting levels are set around 50 foot-candles, typically more light than needed to perform tasks using desktop computers. The Illuminating Engineering Society of North America (IESNA) has recommended that decreasing ambient lighting levels to about 30 foot-candles would reduce excess lighting and improve worker comfort and productivity (IESNA 2000). One way that high energy savings and 30 foot-candles can be attained is by using one-lamp fixtures with super T8 lamps and high-output electronic ballasts (ballast factors of 1.18 to 1.26). Using one-lamp indirect T5 fixtures is also an option.

CURRENT STATUS OF MEASURE

Despite the IESNA recommendation and the potential energy savings for one-lamp lighting design, installing one-lamp fixtures is still not common. Some major utilities do recognize the energy savings potential and currently offer financial incentives for one-lamp lighting system designs. National Grid currently offers $10 per fixture and an additional $5 for using Super T8 lamps on new construction projects. However, the number of proposals for 1-lamp fixture designs has generally been low (less than 5% of total number of proposals in the last year) (Hagspeil 2003). The utility has received proposals to replace many two-lamp fixtures in school classrooms, but has not seen many for offices. Xcel, Pacific Gas & Electric (PG&E), and Portland General Electric (for existing buildings) are also offering financial incentives for lighting designs that reduce energy consumption, for which one-lamp fixtures would qualify. (Xcel 2003, Savings by Design 2003, Portland General Electric 2003)

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Energy savings can add up to 204 kWh/yr per unit or 72% by using two one-lamp fixtures with super T8 lamps instead of two two-lamp fixtures with standard T8 lamps. When replacing a T12 system, savings will be greater. T8 and T12 fluorescent lamps comprise more than 50% of total lighting energy use in commercial buildings (DOE 2002). We estimate that the feasible application for this technology is 50% of T8 and T12 use in the commercial sector.

KEY ASSUMPTIONS USED IN ANALYSIS

High-efficiency one-lamp fixtures cost about the same as two-lamp fixtures, about $100 (from several lighting distributors). Super T8 lamps cost approximately $1-2 more than standard T8 lamps (Thorne & Nadel 2003, BPA 2003). But, two one-lamp fixtures could share one high-power electronic ballast, which costs about $50. For some detail tasks, task lighting may be necessary. For new construction and major remodeling, there are no incremental costs to the

consumer. However, for retrofit projects, the installation of one-lamp systems would require the additional costs of rewiring electrical sources and retiling ceilings.
Canada-specific assumptions: This measure applies to office schools and hotels. Technology applies only to fluorescent lighting, which ranges from 85 to 90% of total. Penetration by 2020 is assumed to range from 60 to 65%. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

One-lamp lighting systems can provide large energy savings for the consumer. However, many lighting designers are still reluctant to step away from conventional systems. Lighting designers and contractors in the commercial sector need to be given guidance regarding using this design in office spaces. Program managers should develop easily accessible materials outlining energy and non-energy benefits. Other tools that help designers are guidelines (spacing, etc.), generic submittal sheets, and easy-to-assimilate training materials. This information may be targeted to building owners and managers as well. Decision-makers also need to be aware of financial incentives that many utilities offer for one-lamp fixture designs. Utility programs should more explicitly promote one-lamp fixture designs and generally phase out incentives for three-lamp and four-lamp fixtures, except in high-bay applications.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L15 SCOTOPIC LIGHTING

DESCRIPTION OF TECHNOLOGY

Conventional design practice ignores color temperature and spectral balance, and only considers the light output and efficacy for most commercial applications. Research over the past decade has established substantial subtlety in how eyes respond to different parts of the spectrum, opening new opportunities for efficiency. In particular, "scotopic" lighting, which stimulates the eyes' photoreceptors called rods, makes pupils contract, increasing visual acuity. Although it may have lower measured efficacy than "photopic" illumination (which activates photoreceptors called cones), well-chosen scotopic lighting can provide greater efficiency, diminished glare (at computer screens), and greater user comfort. In test situations, scotopically-enhanced lighting appears slightly bluer, but also brighter to occupants even when light levels were reduced. Lawrence Berkeley Laboratory (LBL) has determined that fluorescent and HID lamps with high correlated color temperature (CCT≥ 5000 kelvin), give the clearest vision. When compared with lamps with lower CCTs and same wattage, these deliver greater visual effectiveness per watt used. The visual acuity does not diminish when lights are reduced or dimmed somewhat, thus providing the opportunity for energy savings.

CURRENT STATUS OF MEASURE

Well-grounded research has been published for over a decade, but the findings have not yet affected the IESNA *Lighting Handbook* or practice in the field (Berman, 2003).
The DOE continues to provide some funding for research on scotopic lighting. Pacific Gas & Electric (PG&E) has adopted the practice in some of their facilities and will soon release the results of its study (Rubinstein 2003). A smaller study is being done at the Bay Area Air Quality District in California (Jewett 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

In the mid-1990s, Intel Corporation retrofitted its facilities in Hillsboro, Oregon, replacing 34W T12 lamps with a CCT of 3500K with 32-W T8 lamps with a CCT of 5000K. Lighting levels went down from 65 foot-candles to 45 foot-candles without adverse effects on the occupants. Average watts used per luminaire went from 144 W to 62 W, resulting in 57% energy savings (Berman 2003). Somewhat lower energy savings could result from the replacement of T8 lamps with low CCTs instead of T12s. Fluorescent lamps with high CCTs cost approximately the same as their counterparts with lower CCTs.

KEY ASSUMPTIONS USED IN ANALYSIS

The practice would be feasible in commercial applications where T8 & T12 lamps are used. Together, these lamps account for about 50% of lighting electricity consumed in the commercial sector. For this analysis, we assumed a base case of 2- 32W T8 lamps with CCT of 3500k, commonly used in commercial applications, compared with 2- 32W T8 lamps with CCT of 6500k. According to a study by LBL, T8 lamps with CCT of 6500k can operate at 64% of the power density of T8 lamps with 3500k CCT and produce the same amount of scotopic lumens

(Berman 2003). A DOE-funded study suggests 20% savings (Brodrick 2004). The practice would be most useful in office environments where the work focus is mainly on the computer. Eye strain and computer glare can be reduced by adjusting ambient light.
Canada-specific assumptions: This measure applies only to fluorescent lighting, which ranges from 10% in churches and arenas to 90% in schools. Penetration by 2020 is assumed to reach 100%. Penetration by 2020 is assumed to reach 99%. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

This practice needs evaluation and recognition by the Illuminating Engineering Society to gain acceptance among mainstream lighting designers. Standards for labeling lamps with their spectral balance (Scotopic/Photopic [S/P] Value) need to be developed. Manufacturers need to make information on the spectral balance (S/P value) of lighting sources available to designers and engineers. Lighting engineers need to receive further education on incorporating the CCT and S/P ratio into their work. In parallel, more demonstrations with documentation could bolster the case for the technology. DOE has funded a project in this area, being carried out by the firm "After Image+space." The 2004 report is to deal with recommended next steps, and they find savings of about 20%, with occupants noting no difference in the lighting system (Brodrick 2004).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

L16 RECESSED AIR-TIGHT CFL CANS

DESCRIPTION OF TECHNOLOGY

Increasingly recessed downlights have become the lighting fixture of choice for residential construction. Because only a very small part of the fixture is visible, the fixtures can be made inexpensively without sacrificing aesthetics. It is estimated that 21.7 million were manufactured in 2001 alone with approximately 350 million currently installed (PNL 2002). However, there are two energy related problems associated with recessed downlights. First, they rely on low efficacy incandescent lamps, and second they add envelope leakage and potentially an insulation void to the area they are located. In sixty new California homes, Davis Energy Group found an average of 12 recessed lights per house, leaking 104 cfm_{50}, or 6% of total measured house leakage (DEG 2002).

CURRENT STATUS OF MEASURE

To improve on current practice, manufacturers are now beginning to produce air-tight recessed downlight fixtures that use Compact Fluorescent Lamps (CFLs). One problem discovered during extensive testing completed at Pacific Northwestern National Laboratories relates to problems with heat build up in the remote ballast. Since the ballast is in the attic and surrounded by insulation, the heat being generated by the ballast is not adequately removed and thus the ballast overheats. Research completed by LBNL under the California Energy Commission's PIER program developed an advanced CFL downlight. LBNL, in a partnership with NRDC, the CEC, the Sacramento Municipal Utility District, and Lithonia Lighting has installed these units in about fifty new homes in the Sacramento area.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Replacing a 75 Watt incandescent bulb with a 28 Watt CFL will reduce lighting energy use by 63%. The configuration of the advanced CFL downlight is such that two cans share a single electronic ballast. With higher light output, six CFL downlights can replace eight standard downlights at an equivalent installed cost (Siminovitch 2004).

KEY ASSUMPTIONS USED IN ANALYSIS

It is assumed that the 28 Watt CFL will replace a standard recessed can with a 75 Watt bulb. Assuming 2.1 hours of use a day (DEG 1997), the 75 Watt bulb will consume 57 kWh/year and a 28 Watt CFL will consume 21 kWh/year, a 63% reduction. The configuration of the advanced CFL downlight is such that two cans share a single electronic ballast. With higher light output, six CFL downlights can replace eight standard downlights at an equivalent installed cost, for additional energy savings (Siminovitch 2004).
Canada-specific assumptions: This measure assumes tat only 20% of residential lighting can use the technology. Penetration by 2020 is assumed to reach 70%. Consultant estimate based on Canadian residential end-use analysis studies (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Successful results from the SMUD field trial and favorable builder reviews indicate a high potential for this product. Utility incentives and marketing support would help in promoting this product. Energy codes promoting fluorescent lighting would also promote use of efficient lighting. With the current high demand for recessed can lighting in new homes, an improved low-cost product offers high potential for success.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

POWER

CANADIAN SUMMARY

Several T&I submissions pertained to the category of **power** including fuel cell and cogeneration technologies. Below is a summary of Canadian implications of these projects.

Current Canadian Status of Technologies

Canada's leading fuel cell industry is ready and expressing interest in developing building integration techniques and knowledge. Receptors currently exist in Canadian industry for combined heat and power generation (CHP or 'cogeneration'), whether based on fuel cells or other energy forms. An example is the strong interest of HVAC companies and international semiconductor photocell manufacturers in participating in R&D in Canada. Domestic collaboration includes Natural Resources Canada (NRCan) helping Canada's leading fuel cell cogeneration manufacturer (FCT Ltd) exploit the benefits of simulation in designing their system and helping them assess potential markets. Part of this collaboration included NRCan developing a SOFC-cogeneration modelling tool for FCT in 2001; NRCan is adding new capabilities to the model in 2004 to allow FCT to explore space-cooling options for its systems. Related Canadian research is being done at Dalhousie University and University of Victoria.

Canadian Opportunities & Challenges

Micro-CHP systems are seen by most HVAC manufacturers as the technology for the future. CHP opens up possibilities for efficient, silent, and stand-alone combined heat and power production, where considerable savings would result from self-powered appliances developed for remote communities (e.g. northern Canada), where electricity costs are high. Additional Canadian R&D would position Canada for international business opportunities and would put Canada in a leading position in this technology arena. Canadian collaboration with international players will help inform energy policy and assist energy utilities and regulators in determining how to address residential cogeneration in the evolving field of distributed power generation. Opportunities also exist regarding the modelling of fuel cells and other cogeneration technologies, where today's cogen models either ignore the performance of the building or are integrated into expert building simulation environments that are unsuitable for the majority of building simulation practitioners in Canada. Since NRCan's HOT2000 software has achieved broad acceptance among Canadian researchers, architects, and residential energy consultants, advanced fuel cell modelling is expected to garner the same acceptance from this user group. Based on this foreseen opportunity, cogeneration models developed by NRCan and its Annex 42 partners will be integrated into publicly available whole-building simulation programs, such as NRCan's ESP-r/HOT3000 simulator and its HOT2000 v10 graphical user interface. In addition to usual technology transfer plans, workshops will be held in conjunction with IEA/ECBCS Annex 42 experts meetings to encourage collaboration, info exchange between industry, policy, utility, and program stakeholders.

O1 NETWORKED COMPUTER POWER MANAGEMENT

DESCRIPTION OF TECHNOLOGY

Computer networks consume a considerable and increasing amount of energy. Approximately 74 TWh of power is used by office equipment and networks (LBNL 2002). A large fraction of this energy is consumed while the user is not present, even though ENERGY STAR desk-top computers with "sleep" capabilities have been available for years. In corporate, institutional, and government offices, the network software may not support use of low-power states when the computer is un-used for long periods of time. Conceptually and pragmatically, the problem has at least two dimensions, notably the monitor and the central processor unit (CPU). The potential power savings are about 30 to 50 Watts for CRT monitors, and about half that for LCD screens. The Pentium 4 processors in current CPUs draw about 55 Watts while working, and 2 Watts while in sleep mode.

CURRENT STATUS OF MEASURE

Control of networked CRT and LCD monitors is no longer considered an emerging technology, with tools incorporated in network management packages from vendors such as Computer Associates, CSC, and others. Many large organizations have implemented the feature on their own, and in addition, ENERGY STAR distributes monitor software (EZ Save) for free. Korn estimates that at least 30% of large networks have monitor controls now (Korn 2003). The current "frontier" is CPU power management. Commercial products are available from Verdiem (Surveyor) 1e (NightWatchman) and others, but their market penetration is considered low (Korn 2003). Surveyor software is readily available at this time and has been extensively tested in a number of different environments (Tatham 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The cost of installation is dependent upon the size of the network, but is approximately $15 per computer (personal communication with Tatham 2003). Incremental savings for CPU management (beyond monitor management) are estimated at 100-400 kWh/year (Verdiem 2003) and 200 kWh/year (personal communication with P. Degans 2003).

KEY ASSUMPTIONS USED IN ANALYSIS

Annual energy use per CPU and screen is estimated at 496 kWh/year (LBL 2002). Based on available data, we estimate annual savings of 200 kWh per computer at a cost of $15.
Canada-specific assumptions: This measure is restricted to plug loads in office buildings, which represent 50% of the auxiliary equipment energy use. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Both technical and human interface problems remain. The former is exemplified by "wake-on-LAN" features to allow software updates, security patches, and other network activities overnight; network administrators do not yet have confidence in these features, so rising concerns about system security, viruses, and worms lead IT staffs to disable features (Schroeder 2003). Users occasionally have trouble understanding the difference between “sleep” and “off,” and attempt to reboot their work stations in the mornings. They also fear that the new software might include “spyware.” The next recommended step is further dissemination of information to network administrators and end-users. It is recommended that the “wake on LAN” be implemented at test sites to verify its performance and acceptance.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

P1A RESIDENTIAL MICRO-CHP USING FUEL CELLS

DESCRIPTION OF MEASURE

This profile examines residential combined heat and power (CHP) applications using fuel cells in to deliver both electricity and heat. . Fuel cells produce electricity through electrochemical reactions, similar to a battery but different in that the fuel cell is continuously supplied with fuel and oxygen. The fuel cell technologies currently under development are distinguished by the electrolyte they use and their operating temperature. The different types of fuel cells include proton exchange membrane (PEM) fuel cells, solid oxide fuel cells (SOFC), direct methanol fuel cells (DMFC), molten carbonate fuel cells (MCFC), phosphoric acid fuel cells (PAFC), and alkaline fuel cells (AFC). PEM cells are currently the most advanced in this size class, though they are a low temperature technology so the quality of the heat is lower than for technologies such as MCFC and SOFC that could drive thermally activated cooling technologies. Natural gas is the most likely fuel for these systems in the near-term (Shipley 2004). Fuel cells promise efficient, clean and quiet electricity generation. To achieve maximum efficiency, a significant portion of fuel cell waste heat must be captured and put to use to displace thermal loads in the house (e.g., space heating) or through thermally activated technologies such as desiccant or absorption cooling.

CURRENT STATUS OF MEASURE

Several North American fuel cell developers and manufacturers have targeted the residential sector, including Avista Labs, Ballard, H Power, Plug Power (now merged with H Power) and others. Most expect to have commercial products available in 2005 or 2006.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Actual electric conversion efficiencies of PEM fuel cells being achieved in tests are about 25%. Installed costs in CHP mode today are over $6,000/kW. Once fully developed however, PEM fuel cells operated on natural gas are expected to be about 30% efficient for power generation with an additional 38% of the fuel input recoverable as heat for an overall system efficiency of 68%. Installed CHP system costs using PEM fuel cells are projected to be about $5,500/kW.

KEY ASSUMPTIONS USED IN ANALYSIS

The analysis assumes an average 2,000 sq.ft. house with an annual electricity consumption of 12,338 kWh/year and total space heating and DHW consumption of 89 MMBtu/year. In the analysis a 2 kW PEM fuel cell with heat recovery is used, and meets the majority of the electric, space heating and DHW loads, with the balance made up with purchased energy. Since the details and availability of net metering are uncertain, the systems are not sized to produce power for resale. Thermally activated cooling technologies were included only implicitly. If resale of power were an attractive option, the systems should be resized to achieve maximum economic benefit based on the specifics of the tariff. The analysis assumes an installed system cost of $11,000 for the fuel cell plus a maintenance and overhaul costs of 1.5cents/kWh. Manufacturers'

goal is for a stack life of 40,000 hours with an estimated stack replacement cost equivalent to 60% of the original cost.
Canada-specific assumptions: This measure applies to 100% of the residential sector. Penetration by 2020 is assumed to reach 1% (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

To support market uptake of residential CHP, and stationary fuel cells, in general, governments and utilities need to deal with barriers pertaining to interconnection and integration with the distribution system. One critical issue is the structure of net-metering and time-based rates to connect the CHP systems to the grid. Standardized building and electrical codes are also necessary to make permitting easier and to boost end-user acceptance. Another critical step is continued aggressive R&D to reduce the cost and improve performance of the fuel cell technologies and address building integration issues. Development of small scale thermally activated cooling technologies would expand the potential into cooling-dominated regions and afford greater electric demand reduction by shifting cooling load from the electric grid to the CHP system.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

P1B RESIDENTIAL MICRO-COGENERATION USING STIRLING ENGINES

DESCRIPTION OF TECHNOLOGY

Distributed power refers to small-scale generation connected to the electricity grid and to generation on the customer side of the meter. It promises low cost, reliable and efficient power and heat. Stirling Engines are promising distributed power technologies for residential micro-cogeneration. The Stirling engine is a heat engine driven by thermal expansion and contraction of a working gas, usually hydrogen. Stirling engines use an external heat source, which simplifies design, minimizes noise and vibration, and allows multi-fuel use. These features make the Stirling engine a promising alternative to the internal combustion engine. The Stirling engine concept originated in the 1800s, however they were unsuccessful until recently due to the high precision manufacturing processes required. Two types of Stirling engines show potential for residential cogeneration, kinematic Stirling, and free-piston Stirling. The free-piston Stirling does away with mechanical linkages, resulting in fewer moving parts, no need for a lubricant, low maintenance costs and a longer life. Kinematic Stirling engines are typically larger than their free-piston counterparts. Electric capacities for kinematic Stirling units are between 5-500 kW, while the capacity for free-piston units are between 0.01-25 kW.

CURRENT STATUS OF MEASURE

Internationally, several developers and manufacturers have targeted the residential sector for Stirling engine applications, supported in part by government and utility programs. Commercialization expected in the 2003-2006 period. The emphasis to date has been on engine capacities designed to meet all or a portion of the typical electricity and heating loads required of grid-connected single detached homes. Some European companies involved in Stirling engine research include Gasunie, Gastec, Zantingh, EnergieNed and ENECO Energie. WhisperGen is a New Zealand company promoting a natural gas 850 W kinematic Stirling unit. In the U.S. two firms, Stirling Thermal Motors (STM) and Stirling Technology Co. (STC), are developing Stirling technology on site generators in sizes upwards of 1 kW. STC offers 5 sizes from 100W to 3kW. Sunpower has developed a prototype biomass-fired 1 kW free-piston Stirling engine, and expects to have a commercial model ready by 2006.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The Stirling engines are between 15%-30% efficient in converting heat energy to electricity, with many reporting a range of 25% to 30%. The goal is to increase the performance to the mid-30% range (Krepchin, 2002). Early prototypes for the kinematic Stirling cost $10,000/kW, but are expected to reach a mature price of approximately $1,000/kW by 2006. Free-piston Stirling engines are currently more expensive (Sunpower’s 1 kW prototype cost $35,000), however the mature market price is expected to be between $500-$1,000 per kW. Stirling engines are expected to run 50,000 hours between overhauls, and free-piston Stirling engines may last up to 100,000 hours (Krepchin, 2002).

KEY ASSUMPTIONS USED IN ANALYSIS

This analysis assumes 25% electricity conversion efficiency, and a 40% waste heat recovery efficiency for space heating and DHW. The analysis assumes an average 1,800 sq.ft. house with an annual electricity consumption of 12,338 kWh/year and total space heating and DHW consumption of 89 MMBtu/year. This analysis also assumes a mature cost of $1,000/kW plus overhaul and maintenance costs of 3 cents/kWh.

Canada-specific assumptions: This measure applies to 100% of the residential sector. Penetration by 2020 is assumed to reach 1% (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Both technical and institutional issues need to be addressed for Stirling engines to be accepted in the residential market. Governments and utilities need to collaborate in dealing barriers pertaining to connection and integration with the distribution system. Standardized building codes, permit procedures and electrical interconnection standards are necessary to boost end-user acceptance. Technically, there is a need for continued support to help developers work to lower first costs through a combination of design refinements and material substitution.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

P2 A&B COMMERCIAL MICRO-CHP USING FUEL CELLS AND MICROTURBINES

DESCRIPTION OF MEASURE

Commercial combined heat and power (CHP) refers to the use of reciprocating engines, microturbines, Stirling engines, and fuel cells to produce both electricity and thermal power at or near the building site. Recent advances in small-scale power generation technologies have begun to make CHP a reality, with the potential to both reduce building energy costs and increase power reliability and quality. One key is better thermal technologies for cooling with waste heat, such as absorption refrigeration and desiccant cooling. Reciprocating engine approaches lead today, because of their efficiency, reliability, and low installed cost. Fuel cells and microturbines may compete with low emissions, higher thermal temperatures (in some cases) and quiet operation. Fuel cell technologies include proton exchange membrane (PEM), solid oxide (SOFC), direct methanol (DMFC), molten carbonate (MCFC), phosphoric acid (PAFC), and alkaline (AFC). Fuel cell technologies are scalable allowing for the installation of multiple units to meet an application requirement. While PEM fuel cells are currently the most advanced, SOFC and MCFC are of particular interest for building CHP systems because their higher temperature allows for use of thermally activated technologies (Shipley 2004). Microturbines (generally < 250 kW capacity) using technologies derived from aircraft engines have been developed by several companies. In the near term, microturbines promise lower cost, higher thermal energy temperatures, and better load following capability (Hedman 2002 and Capstone 2003).

CURRENT STATUS OF MEASURE

A number of companies are currently involved in commercial-scale fuel cell development. They include Nuvera, Ballard, Plug Power and Siemens Power Generation. The development efforts are being supported by a variety of government technology and innovation initiatives. Most of the companies expect to have products available between 2005 and 2006. There are currently five major manufacturers of microturbine generators. Capstone (30 kW and 60 kW electric capacity), Ingersoll-Rand (70 kW and 250 kW, and 2 MW), Bowman Power (U.K, 80 kW). Elliott and Turbec (the latter a joint venture between Volvo and ABB in Sweden) produce 100 kW units. All of the manufacturers offer combined heat and power options. Natural gas is the most common fuel, but many of the units can burn other fuels.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Once fully developed, SOFC are expected to be between 40-50% efficient and cost between $1,000-$1,500/kW. Alkaline fuel cells are expected to be 50-60% efficient, and prices should drop to $350-$1000/kW in mass production (E-Source, 2002). Most fuel cells assemblies for commercial use are being designed for natural gas with capacities in the 150-250 kW range. Projections from the U.S. Department of Energy's Annual Energy Outlook for 2002 predict that the cost of all types of fuel cells will remain above $4,000/kW in the next few years, only trickling down to $1400/kW by 2020, though manufacturers are clearly more optimistic about the timing (EIA 2001, Shipley 2004). Microturbine efficiency has been improving while the cost has been falling as the technology matures. We project that the electric efficiency of a microturbine in CHP configuration will increase to 25% while 40% of the input energy can be recovered as usable thermal energy for an overall operating system efficiency of 65%. The electric efficiency of CHP system turbines is lower than power-only turbines because of the need to raise the exhaust temperature for better thermal performance. The installed cost of microturbine CHP systems is projected to about $1750/kW (Hedman 2002).

KEY ASSUMPTIONS USED IN ANALYSIS

We model a 100,000 commercial office building with energy intensity of 13.4 kWh/sq.ft. for electricity and 28.6 kBtu/ sq.ft. of gas for DHW and space heating. A portion of these energy requirements are met using a building CHP system using either a fuel cell or microturbine. Since the details and availability of any power resale tariff is uncertain, the systems are sized to produce no excess power. Thermally activated cooling technologies were also not explicitly considered. If resale of power were attractive, the systems should be resized to achieve maximum economic benefit based on the specifics of the tariff. The fuel cell system uses 200kW of SOFC with an electricity conversion efficiency of 40% and further 35% of the input energy recovered for space heating or DHW, bringing the overall efficiency to 75%. The installed cost of the fuel cell CHP system is assumed to be $3,500/kW. A maintenance cost of 1.5 cents/kWh and a stack life of 40,000 hours are assumed. The microturbine system uses 200kW of turbines with an electricity conversion efficiency of 25%, and 40% of the input energy recovered for space heating or thermally-activated cooling, bringing the overall efficiency to 65%. The installed cost of the microturbine CHP system is assumed to be $1750/kW. A maintenance cost of 2 cents/kWh and a 40,000 hours between rebuilds are assumed (Hedman 2002).
Canada-specific assumptions: This measure applies to 100% of the commercial sector. Penetration by 2020 is assumed to reach 5% (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Both the fuel cell and microturbine technologies need further development to reduce cost, improve reliability and enhance operating performance. Additional research is needed to understand how best to integrate CHP systems into buildings to achieve maximum benefit. This includes the use of thermally activated cooling technologies that offer the promise of greater efficiency and load reduction benefits from displacing vapor-compression cooling. In addition, a better understanding of how distributed energy (DE) systems interact with the electric system is needed to support utility policies. On the policy front a number of challenges exist with getting interconnection and tariff issues related to DE systems, including interconnection standards, real time electricity pricing, and tariff structures that allow the sell-back of electricity at certain times.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

PRACTICES

CANADIAN SUMMARY

Several T&I submissions pertained to the category of **building practices** including building design guidelines and diagnostics tools. Below is a summary of Canadian implications of these projects.

Current Canadian Status of Technologies

Building Design

Software is being developed domestically to model different air leakage control strategies, with the goal of having it used during in the integrated design process of buildings. Particular focus is being paid to air leakage in multi-use residential buildings (MURBs) and air and water tightness of building joint details. Green roofs are also being investigated further for their insulative qualities, among other benefits; implementation and maintenance guidelines are being developed specific to Canadian climates.

Successful Canadian lighting performance simulation procedures and software developed by Natural Resources Canada (NRCan) and the National Research Council (NRC) include Lightswitch Wizard, SKYVISION for skylights, and DAYSIM for daylighting. Canadian performance simulation procedures and software are currently adopted in many countries and by ISO. A design guide being assembled will help practitioners to apply daylighting technologies during the integrated building design process.

Design, installation, and commissioning guidelines are being developed to achieve more effective air conditioning systems. Intentional networks of designers, builders, and constructions teams are also being established so the incremental costs can be minimised and addressed when implementing energy efficient technologies and so industry 'alternative' approaches can be tested and verified.

A number of Canadian initiatives are also under way to strive for zero energy houses and neighbourhoods, such as the "Eko[5]" program. These initiatives will use a structured framework to evaluate and rank low environmental impact housing solutions and provide builders and developers the tools to compare alternative solutions. The solutions will provide linkages between energy, waste, water, and social parameters, taking into account lifecycle energy use and environmental impacts. Another holistic design approach is the EverGreen initiative, which will provide best practices and tools to consider all energy-consuming appliances and systems when designing retrofits or renovations for homes. EverGreen will build on Natural Resources Canada's successful EnerGuide for Houses program.

Building Diagnostics

Software is being developed domestically to diagnose air and water leakage. Another active diagnostics initiative is to increase the awareness and capability of building operators in correctly operating increasingly more complex building monitoring and control systems. An example of this is a set of tools and procedures to improve the operation of supermarket refrigeration systems - the project partners being MicroThermo, a major supermarket controls manufacturer, and Loblaws, Canada's largest supermarket chain.

Canadian Opportunities & Challenges

Building Design

Canadian efforts also include air and water tightness of joint details, with opportunities to provide new joint assembly types and new solutions for existing problem buildings. Optimum value engineering and integrated design methods will serve to minimise the incremental cost of building houses to the R2000 level; it is hoped similar methods will be adopted in Canada's commercial building sector as well.

Current development and testing of thermal and optical performance evaluation methods for skylights, entry doors, and glazed facades will help enhance Canada's impact on passive solar heating and daylighting technologies and practices. Canadian advances in personal environmental control (PEC) and perimeter control procedures and algorithms will contribute to lighting technology choices and uptake, as well as the balance between natural (solar) and artificial (powered) lighting.

Building Diagnostics

Canadian diagnostics innovations may lead to new cross-referencing methodologies for non-destructively evaluating performance faults in new and existing assemblies.

PR1 AUTOMATED BUILDING DIAGNOSTICS SOFTWARE (ABDS)

DESCRIPTION OF TECHNOLOGY

Building Automation Systems (BAS) were introduced in the mid 1980s to optimize the operation of HVAC equipment through computerized monitoring and control of HVAC equipment in large commercial buildings. The technology has continuously evolved from the first systems that performed monitoring and simple control via bulky mini-computer based workstations to the latest distributed networks with powerful graphic workstations, wireless web-based components and expanded self-tuning control algorithms. Despite the level of evolution, the performance of BAS, also referred to as Facility Management Systems (FMS) has been disappointing, falling short of the overall potential to improve comfort while reducing energy use (Krepchin 2001, Turner 2003). Most of the problems stem from the difficulties in operating the BAS once they have been installed and commissioned. Building owners and operators often do not have the necessary dedicated personnel who can solve BAS/FMS problems. There is a tendency to solve building comfort and operational problems through simple "triage" by disabling BAS/FMS control loops or disabling equipment schedules. The next generation of BAS/FMS software, Automated Building Diagnostic Software (ABDS), promises to solve these common problems through the use of more advanced self-tuning control algorithms and automatic data analysis to identify problems and suggest solutions using built-in "expert systems". ABDS is designed to automatically perform building commissioning on an ongoing basis, but without the time, disruption and cost of a commissioning project. The capacity to provide continuous optimization through control, correction and monitoring results in a greater certainty of meeting the performance potential.

CURRENT STATUS OF MEASURE

The ABDS systems are capable of optimizing the performance of both large commercial centralized systems and packaged HVAC equipment used in smaller buildings. ABDS is still in its infancy with the development of the systems being led by private and public research institutions and companies. Currently, there are four ABDS products that are either commercially available or under development. The most versatile and commercially available ABDS tool is the Performance and Continuous Recommissioning Analysis Tool (PACRAT) from Facility Dynamics Engineering. This tool is designed for large commercial buildings. The Whole Building Diagnostician (WBD), being developed through collaboration among the Pacific Northwest National Laboratories (PNNL), the California Energy Commission and the U.S. Department of Energy (USDOE), is a tool designed to provide diagnostics of air handling equipment. The Diagnostic Agent for Building Operators (DABO) system is being developed by the Energy Diversification Research Laboratory (CEDRL) of the Canadian Centre for Mineral and Energy Technology (CANMET's). DABO's primary capabilities are to perform diagnosis of air handling units and VAV boxes through continuous monitoring of data and use of artificial intelligence models. A commercially available version is expected to be licensed to DELTA Controls and available in the fall of 2004. The ACRx Handtool, developed by Field Diagnostic Services Inc. and licensed in 2001 by Honeywell is designed for diagnosis of compressors in packaged equipment and is used primarily in batch mode for troubleshooting during scheduled maintenance intervals (Krepchin 2001).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The results from ABDS demonstrations to date indicate that energy savings are similar to what can be achieved through recommissioning with typical savings ranging from 5% to 20%. The demonstration costs for implementation and interface of an ABDS for a 250-point BAS can be up to $50,000. For a 100,000 ft^2 building this translates into a cost of $0.50/$ft^2$. The one-time cost of an ACRx Handtool plus software and sensors is approximately $2,500. There are additional charges during the inspection of equipment to access historical data which cost another $500. Most of the costs for using an ACRx Handtool are for the technician's time during the inspection plus the required maintenance/repair costs (Krepchin, 2001).

KEY ASSUMPTIONS USED IN ANALYSIS

For a new construction application, savings of 10% of the total whole building energy use intensity (EUI) are assumed in this analysis. This is equivalent to 2.8 ekWh/ft^2.yr (electricity and heat) for an average commercial building with a whole building EUI of 28 ekWh/ft^2yr. Assuming some cost reduction for an eventual maturing of the technology, costs are assumed to be in the range of $0.20 to $0.50/$ft^2$.

Canada-specific assumptions: This measure is restricted to large commercial buildings only with an applicability that ranges from 15% of hotels to 65% of offices. Penetration by 2020 ranges from 50% in large retail to 99% in health care (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The ABDS technology promises to achieve a greater certainty of achieving energy savings and comfort improvement in the commercial building market. However, the successful market penetration of the technology depends on the active support and participation of the major BAS/FMS industry players. The consensus by experts is that 50% or more of the current installed base of BAS/FMS systems do not operate as they are supposed to (Turner, 2003). Since most of these systems are being maintained by the original control vendors, the necessary steps to troubleshoot and fix these systems will have to be undertaken by the same vendors. Owners would be unreceptive to the idea of a new software package from a new vendor that is separate from their existing BAS/FMS software. The preferred solution would be one seamless product that represents an upgrade to the existing BAS/FMS front end. It's expected that alliances will need to be formed in order to develop fully integrated products that merge ABDS and the BAS/FMS control software. It's also anticipated that the major control companies will consider in house development of ABDS for their next generation systems in order to address the large base of BAS/FMS systems that do not function properly. In 2001, Johnson Controls was the only reported controls company to be actively working on development of ABDS and was in the process of transitioning from a research phase to product development. However, in 2001 Honeywell licensed the ACRx Handtool from Field Diagnostic Services Inc. Program operators should encourage demonstrations of the new features, to document savings.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

PR2 ULTRA LOW ENERGY COMMERCIAL BUILDING DESIGNS (50% > CODES)

DESCRIPTION OF PRACTICE

The integrated design process (IDP) to produce highly energy efficient and comfortable commercial and institutional buildings has become visible in North America. The IDP Design Assistance Professional (DAP) contributes knowledge of energy efficient technologies and applications using a variety of analytical tools. Several programs have shown high performance construction using IDP, including Pacific Gas and Electric (PG&E) Advanced Customer Technology Test (ACT²), Bonneville Power Administration (BPA) Energy Edge and Canada's C-2000 program. They showed 25% - 50% energy use reductions relative to the current code, at relatively low costs. A common element is the use of a displacement ventilation (DV) system with radiant cooling (McDonell 2003).

CURRENT STATUS OF MEASURE

Current initiatives designed to demonstrate the performance of ultra-low energy buildings include the Zero Energy Buildings in the U.S. , Europe's Zero Energy Developments (ZED), and the International Energy Agency (IEA) Annex 35 Hybrid Ventilation demonstration projects. In London, the new 450,000 ft^2, 40 story UK headquarters of Swiss Re is expected to set new standards for high rise office building construction. It uses a hybrid ventilation system with displacement ventilation that operates when weather conditions do not allow sufficient air exchange. The Swiss Re building designers used computational fluid dynamic (CFD) models to examine the natural ventilation air flow patterns. The CFD modeling showed that the building could rely on natural ventilation 40% of the time and automatically seal itself and go on either heating or cooling mode when weather conditions could not meet the comfort needs (Kitson 2003). Other energy efficiency features of the building include electrochromic glazing and 100% daylighting via light wells. The 8,000 ft^2 Zion National Park Visitor Centre in Utah is another leading edge high performance building with hybrid ventilation.. With the help of a photovoltaic design, the purchased energy use is 64% below that of a conventional design (Criscione 2002).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Energy savings of 50% to 70% over conventional construction can be achieved with the ultra-low energy designs, at zero or low incremental costs. Design optimization tends to reduce HVAC equipment sizes, resulting in lower equipment costs that help to offset the incremental design costs. Most of the IEA Annex 35 Hybrid Ventilation projects, for example, have demonstrated neutral costs. The Bang & Olufsen headquarters in Denmark, has a hybrid ventilation design that resulted in an overall construction cost equal to that of a current practice, while the cost of HVAC equipment was 50% less than typical HVAC costs (Hendriksen 2002). Several buildings demonstrated in Canada's C-2000 program have also exhibited similar results (NRCan Buildings Group 2002)

KEY ASSUMPTIONS USED IN ANALYSIS

This analysis is based on a commercial building with a whole building EUI of 28 kWh/ft^2yr (13 kWh/ft^2yr of electricity and 29 kBtu/ ft^2yr of natural gas) and assumes potential energy savings of 65% over current practice. This generates an energy saving of 18.2 $kWh/ft^2.yr$ (equal hydro and heat reduction) and a peak demand reduction of 1.2 W/ft^2, which would not necessarily coincide with the utility peak. We assume an incremental cost of $\$1/ft^2$.

Canada-specific assumptions: This measure is restricted to commercial buildings. Penetration by 2020 ranges from 10% to 20% of new construction (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The key barriers preventing wider adoption of these design techniques are lack of awareness by owners and developers, and lack of familiarity with tools and techniques by designers. Efforts to accelerate the market take-up focus on three key areas: First, familiarize the design community with how to design displacement ventilation systems (McDonell 2003). Second, educate the design community in the use of CFD software. The cost of the software learning curve represents a significant barrier. Third, multiple modeling platforms are required to model non-standard HVAC systems such as photovoltaics or transpired solar collectors (SolarWalls). Beyond the design community itself, there is the need to convey to the target market that the ultra-low energy design offers considerable non-energy benefits, including better health, comfort and productivity of occupants and tenants. Technology demonstrations and case studies in North America would help; the European experience, while inspiring, often seems remote to building owners in the U.S. and Canada.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

PR3 INTEGRATED COMMERCIAL BUILDING DESIGN LEED LEVEL (30% > CODE)

DESCRIPTION OF TECHNOLOGY

Clients and designers increasingly seek ways to differentiate projects with "green" attributes and efficiency. One of the most important response to have emerged is the energy performance requirement embodied in the Leadership in Energy and Environmental Design (LEED) Green Building Rating System™, which offers a pathway to accelerate market penetration of highly energy efficient buildings in North America. LEED includes points for high energy efficiency by design. Several programs and demonstrations show that LEED accredited buildings readily achieve performance levels 30% beyond current code.

CURRENT STATUS OF MEASURE

LEED is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. In the U.S. and Canada, the Green Building Council, representing all segments of the building industry, has the lead role in developing LEED as a national standard for "green construction". The LEED rating includes evaluation of site selection, water efficiency, energy performance and atmospheric pollution, materials and resources, indoor environmental quality, and innovation in the design process. Municipalities and states with design guidelines include the Portland Green Building Initiative Guidelines and the State of Pennsylvania Guidelines for High Performance Buildings (Krepchin 2000). Following publication of the New Buildings Institute (NBI) "e-benchmark," ASHRAE committed to producing guidance documents for highly efficient buildings, too.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Energy savings vary significantly. CBIP, BC Hydro and Enbridge Consumers Gas have minimum targets of 25% better than Canada's Model National Energy Code for Buildings (MNECB). On average CBIP buildings have shown a modeled performance that is approximately 30% to 35% better than an MNECB reference building (NRCan 2003). Initiatives by Southern California Edison (SCE) Savings by Design program, National Grid US (formerly (New England Electric System) Design 2000 Plus and others show that 30% savings are readily achievable. Of course, costs vary with performance targets. The most cost-effective Energy Edge buildings (from a 1990s program operated in the Pacific Rim NW) had an incremental cost (adjusted to 1998 dollars) of $3/ft² (Suozzo and Nadel 1998). Buildings built under the Design 2000 Plus from National Grid were reported to have average incremental costs of $1.30/ft². BC Hydro's Design Assistance Program has seen, on average, no incremental cost over the base case design (BC Hydro). Canada's C-2000 program showed average costs of approximately 2% more than the base case design.

KEY ASSUMPTIONS USED IN ANALYSIS

We have assumed a 30% energy savings above ASHRAE 90.1 – 2001. This reduction is equivalent to 8.4 kWh/ft²yr for an average commercial building with a whole building EUI of 28 kWh/ft².yr (13 kWh/ft²yr of electricity and 29 kBtu/ ft²yr of natural gas). We also estimate a 0.7 W/ft² reduction in peak demand based on a 0.5 W/ft² reduction in lighting and a 0.2 demand in cooling plant and auxiliaries. We have used incremental costs of $1/ft² in our analysis, and we have assumed that the technology applies to 75% of new construction.

Canada-specific assumptions: This measure is restricted to commercial buildings. Penetration by 2020 ranges from 30% to 50% of new construction (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

A useful next step to help the design community adopt IDP for new construction is to redesign the fee structures to give bonuses for more efficient designs instead of the equipment cost (Hubbard and Eley 1996). Easy-to-use design tools will help, and can be the basis for training programs. Dissemination of successful design results will give confidence to adopt IDP and recommend it to clients. Utilities could use incentive programs to provide additional impetus to the market, but must coordinate their programs with existing initiatives sponsored by governments and other green building organizations. In the long term, building codes will need to be revised to reflect a new base level for energy efficiency.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

PR4 RETROCOMMISSIONING

DESCRIPTION OF TECHNOLOGY

On start-up, many new commercial buildings do not perform as designed. Additionally, commercial building performance tends to degrade over time, unless there are active programs and knowledgeable personnel to operate and maintain equipment and controls. When buildings operate poorly, operators face rising equipment repair costs, rising utility bills, deteriorating indoor air quality, and tenant dissatisfaction. *Retrocommissioning* (RCx) involves a systematic step-by-step process of identifying and correcting problems and ensuring system functionality (Haasl and Sharp 1999). RCx focuses on steps for optimizing the building through O&M tune-up activities and diagnostic testing, though capital improvements may also be recommended. The best candidates for retrocommissioning are those buildings over 100,000 sq. ft, with newer HVAC systems, and a functioning building control system. By conducting RCx, building managers can diagnose problems in mechanical systems, controls, and lighting, and improve the overall performance of the building. Improving the functionality of individual mechanical and electrical components, as well as their combined performance as a system, reduces energy consumption, operating costs and occupant discomfort.

CURRENT STATUS OF MEASURE

RCx is not a widespread practice, though awareness about its benefits is starting to grow. A small number of utilities and other organizations have developed programs to promote RCx. Programs offer provider and building manager training, technical and financial assistance, and demonstration projects. For example, through its FlexTech and Technical Assistance Programs, the New York State Energy Research & Development Authority (NYSERDA), offers technical assistance and no-cost scoping studies by trained RCx providers. NYSERDA intends to demonstrate the benefits of RCx through several case studies. Nstar, Xcel, and PGE also have programs (Thorne and Nadel 2003) There are also efforts to strengthen the commissioning industry. The Northwest Energy Efficiency Alliance initiated the Building Commissioning Association (BCA), which hosts conferences to promote the understanding of commissioning and provides training to professionals involved in the field. Other professional organizations such as The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Association of Energy Engineers (AEE) have also incorporated retrocommissioning into their activities.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

In 1996, a study conducted of 44 retrocommissioned buildings found that energy savings in range from 5% to 15% or more (median of 19%) and energy cost savings range from 2% to 49% (Gregerson 1997). The buildings varied in size and type. RCx investment ranged from 3¢ to 43¢ per square foot (average of 19¢), with simple payback of two to four years. About half of the projects were conducted by staff and students at Texas A& M University. RCx conducted by professional providers would likely incur higher costs.

KEY ASSUMPTIONS USED IN ANALYSIS

For this analysis, we include the floor space of non-warehouse commercial buildings over 100,000 sq.ft., plus ½ the 50,000 to 100,000 sq.ft. stock. These are the best candidates for RCx. We also assume an average cost of 25¢/sq.ft., and ongoing costs of 5¢/sq.ft.-year, maintain savings. RCx would most feasible in large buildings that have HVAC systems less than 20 years old, and with a functioning control system. These buildings account for about 5% of the number of commercial buildings in the U.S., but about 32% of the commercial building floor area.(2003 Buildings Energy Databook, Table 2.2.5)

Canada-specific assumptions: This measure is restricted to large buildings only with an applicability that ranges from 15% of hotels to 65% of offices. Penetration by 2020 ranges from 50% in large retail to 100% in health care (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Despite many demonstrated benefits, RCx faces some important barriers. Most important is simple lack of awareness of the benefits. A number of misperceptions, such as large costs and long-term paybacks, also persist. Therefore, educating building owners and operators on the energy and non-energy benefits and providing training to RCx providers are early critical steps. Assisting owners in conducting site studies and offering financial incentives have also proven to be effective in encouraging buildings owners. There is also need for further training of engineers on how to do RCx well & cost-effectively.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

PR5 ZERO (NET) ENERGY HOUSES, INCLUDING HOUSES WITH 50% + ENERGY SAVINGS

DESCRIPTION OF TECHNOLOGY

The goal of Zero (Net) Energy House programs is commercial acceptance of houses that are so efficient that modest investments in on-site renewable energy (photovoltaics and solar thermal, primarily) lead them to use less purchased energy annually than they can sell back as surplus. This includes and builds on integrated design processes (IDP), a fully integrated approach to construction and equipment to maximize savings while minimizing costs. Canada's Residential 2000 (R-2000) program and Advanced House project, Pacific Gas &Electric's ACT², the Davis and Stanford Ranch houses and others demonstrated that energy savings of 50% to 60%, relative to current construction practice (Eley Associates, 1996). To date, the market penetration of such homes has been low. However, the Zero Energy House (ZEH), a conceptual advance, combines the IDP with annual energy self-sufficiency through on-site renewable energy.

CURRENT STATUS OF MEASURE

The U.S. DOE ZEH initiative aims to increase the market penetration of new homes that perform at least 50% more efficiently than those built to current minimum efficiency standards, while also increasing the number of new homes that can meet their own energy needs. DOE has funded "home building" teams consisting of energy efficiency experts and homebuilders to construct four demonstration houses across the U.S. To date, two ZEH homes have been constructed, in Livermore, California and in Tucson, Arizona. Through its "Build America" initiative, DOE has also collaborated with the Tennessee Valley Authority (TVA) to build demonstration "Affordable Zero Energy Test Houses" for Habitat for Humanity; two such homes have been built so far.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The ZEH demonstration homes built to date have aggressively reduced overall energy use. The 1998 Florida Solar Energy Center (FSEC) demonstration project achieved 82% electricity savings over standard construction. Performance results from two of the ZEH demonstrations shows that relative to code construction, overall energy savings were 51%, with electricity savings ranging from 60% to 82% and fossil fuel savings of 46% (Dakin, 2003). The measures in the zero energy package included light colored exterior walls, tight construction and ducts, more insulation and the elimination of insulation defects, fluorescent lighting, and highly efficient appliances. The customer level peak demand reduction for both the FSEC and Livermore ZEH houses was estimated to be 2.4 kW The incremental cost of constructing the ZEH homes has ranged from $ 21,000 to $ 38,000 with approximately half of the cost attributed to the PV system (Dakin 2003).

KEY ASSUMPTIONS USED IN ANALYSIS

We have assumed an overall 65% reduction in whole house energy use (85% electricity and 60% space heating and DHW). We have assumed a 2.5 kW peak demand at the customer level,

equivalent to an average photovoltaic collector. We expect the incremental cost of a market-mature ZEH, to decline significantly, particularly since the PV component is such a large portion of the incremental cost (EIA, 2003). We envision an overall reduction of 30% to 50% relative to the costs of the early demonstration projects. The analysis is based on an assumed average current incremental cost of \$16/ft² and an assumed mature incremental cost of \$9/ft².
Canada-specific assumptions: This measure is restricted to residential buildings. Penetration by 2020 ranges from 1% to 6% of new construction (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The NREL ZEH program goal is a construction rate of 100,000 ZEH affordable houses by 2020. While the technology is still maturing, the principles are well understood, and true ZEH houses will probably be built within the next 12 to 24 months. The real challenges are those of communication and promotion in order to familiarize builders and home buyers with the design philosophy. The second challenge is to make ZEH cost effective. Current demonstration projects have significant incremental costs, which need to come down. Since a large portion of the cost is in the photovoltaic collectors, a reduction in the manufacturing cost of photovoltaic systems will make a significant contribution towards the reduction of the incremental costs. In the interim, efforts to promote homes with 50% + energy savings, but without the distributed generation should be encouraged.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

PR6 EASIER TO USE AND MORE EFFECTIVE SIZING METHODS FOR RESIDENTIAL HVAC

DESCRIPTION OF TECHNOLOGY

Empirically, furnaces, boilers, and central air conditioners are generally oversized enough to reduce performance. For air conditioners, oversizing causes short-cycling, which reduces efficiency and latent heat capability. For non-condensing furnaces and boilers, short cycling increases off-cycle losses. Oversizing is the norm. For example, James et al (1997) found that ½ of 400 houses had central air conditioning systems oversized by 20% to 60%, compared to "ACCA Manual J," the most widely used actual load calculation approach. Manual J has been implemented in computer versions by several groups. For retrofits, Manual J requires measurements of window, wall, foundation, and other relevant elements, and estimates of insulation levels and similar parameters for each. This is generally time-consuming, so there is need for trustworthy practices that will save time and convert the information to a form that helps contractors sell equipment and services better.

CURRENT STATUS OF MEASURE

Market transformation programs in New Jersey, California, and Florida require contractors to complete and submit ACCA Manual J. load calculations for incentives, with flexibility on what implementations are used for the analysis. The cost of these computations is presumably borne by the consumer. Available programs take about an hour for all inputs and calculations; less for an operator very experienced with a particular house type. No PDA or simplified programs have been found other than for room air conditioners.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

ACCA Manual J yields sizes that are generous by 15% (James et al 1997). In that study, oversizing led to 13% greater air conditioning peak demand (0.3 kW), 4% greater cooling energy use, and 5% greater heating energy (primarily due to short-cycling). These losses could be essentially eliminated with proper sizing. Easier to use methods probably would include graphic interfaces, pre-loaded "templates" for most common house types (including defaults for insulation levels) weather data for specific metropolitan areas, and fast ways to estimate wall and floor areas accurately enough. For example, photometric system software integrated into a PDA could size windows and walls and determine house area from exterior photographs (Sachs, 2003). Sensitivity analyses and related research are required to help contractors understand how much precision is required for each measured or estimated parameter. Counting amortization of software and time required for a proper analysis, we estimate cost at $75, and potential savings of $40 relative to standard sizing techniques.

KEY ASSUMPTIONS USED IN ANALYSIS

Canada-specific assumptions: This measure is restricted to residential buildings. Penetration by 2020 is assumed to reach 50 to 55% (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The key barriers to proper sizing are (a) contractor resistance to changing methods that they believe minimize callbacks, (b) time required to do proper analyses relative to perceived value to customers, and (c) difficulty of doing proper analyses, particularly since some parameters are under owner control (e.g., use of window shading). Funding is required to develop simplified methods, carry out pilot studies, and do the training and related activities required to integrate them into conventional practice.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

PR7 BULLS-EYE COMMISSIONING

DESCRIPTION OF TECHNOLOGY

"Bulls-Eye Commissioning" is a technique to spot the most cost-effective areas to address in retrocommissioning (RCx) (Practice PR4) by analysis of 15 minute interval billing data. Its premise is that most benefits (80%) can be found with relatively little effort (20% of full RCx), if the right data are analyzed. In this case, the basic tool is graphic display of daily to annual time series of electricity consumption (kW) per 15 minute intervals, data available at low cost with automated meter reading (AMR) meters.

CURRENT STATUS OF MEASURE

Bulls-Eye Commissioning was introduced recently, and is currently in use by one municipal utility, Eugene (OR) Water and Electric Board (EWEB). Bulls-Eye Commissioning is specifically designed to find and fix the most severe problems as quickly and inexpensively as possible, rather than carry out comprehensive analyses. It uses the 80:20 label as an indicator of its approach.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

In the only published study, Price and Hart (2002) suggest that the Bulls-Eye diagnostic methods added 15% to energy savings in one non-commissioned building whose savings after retrofit were "disappointing." When interval data are analyzed by knowledgeable staff, Bulls-eye Commissioning is likely to efficiently find control problems including inappropriate equipment schedules. We estimate that the cost is likely to be about $1950 (AMR purchase and installation, software, and a day of professional time for analysis.)

KEY ASSUMPTIONS USED IN ANALYSIS

We assume that Bulls-Eye effort is done as a form of (retro)commissioning, so that problems will be fixed by mechanical contractor, and the owner (or program operator) is only exposed to Bulls-Eye Commissioning costs. For other retrocommissioning, repair costs are included. The feasible stock is taken as non-warehouse commercial buildings between 5000 and 50,000 sq.ft. Larger buildings generally need more comprehensive retrocommissioning. We assume a shorter life than for retrocommissioning, because bulls-eye does not include a training component.
Canada-specific assumptions: This measure is restricted to small commercial that uses packaged DX cooling equipment. Penetration by 2020 is restricted to new construction only or 50% of the entire stock. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles that provide a distribution of A/C equipment by type (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

One barrier noted by Price and Reid is that customers often do not accept that their costly computer controlled HVAC systems are not working optimally. In addition, Bulls-Eye Commissioning, although relatively inexpensive, still has a perceived first cost barrier for the smallest commercial buildings, as the cost of instrumentation and analysis will be about $1400. We recommend additional field demonstrations in other regions for verification.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

REFRIGERATION

CANADIAN SUMMARY

Several T&I submissions pertained to the category of **refrigeration** including HVAC efficiency gains in ice rinks, curling rinks, and supermarkets. Below is a summary of Canadian implications of these projects. This summary is based strictly on project funding submissions and does not contain primary research by Marbek.

Current Canadian Status of Technologies

Natural Resources Canada's (NRCan) Refrigeration Action Program for Buildings (RAPB) was launched in 2003 and aims to identify, promote, and demonstrate the next generation of energy efficiency gains possible in Canadian ice rinks, curling rinks, and supermarkets. Examples of identified improvements in Canada's 2500 ice rinks include:
1) Recovered refrigeration plant heat
2) Variable condensing temperature according to outside temperature and space heating demand
3) Refrigeration condensing system that utilise a secondary coolant, which serves as heat supply for the network of heat pumps that provide space heat
4) Fully integrated systems such as CIMCO Eco-Chiller or Ice Kube (make maximum use of waste heat, minimise refrigerant use and losses, and use high efficiency components)
5) Digital controls with more sophisticated control algorithms to replace conventional low cost refrigeration thermostats; and
6) Efficient small tonnage screw compressors which now offer higher coefficients of performance compared to reciprocating compressors

Canadian companies working with CETC-Varennes are also developing software for web-based control of space cooling using ice storage systems.

Canadian Opportunities & Challenges

Current collaboration is expected to continue with engineering firms, facility operators, industry associations, and equipment suppliers. Major renovations have been identified in the next ten years in ice rinks, curling rinks, and supermarkets, so consultants and facility operators will be receptive to innovative, energy efficient designs for implementation during these renovations.

R1 SOLID STATE REFRIGERATION (COOL CHIPS™)

DESCRIPTION OF TECHNOLOGY

Cool Chips™ are thin, efficient, and small thermoelectric cooling devices. Thermoelectric cooling uses an electric current to move high-energy electrons (and their associated heat) across a junction between two semi-conductors. Conventional thermoelectric cooling efficiencies are limited to about 10%. *Cool Chips* use nanotechnology manufacturing to replace the electron transfer junction with a 2 to 10 nanometer gap. This gap enables the electrons to move in one direction only through electron tunneling, thereby preventing heat migration back to the heat source. The result is a cooling coefficient of performance (COP) that is twice that of conventional mechanical cooling systems. *Cool Chips* also offer reduced operation and maintenance costs (no moving parts), improved environmental performance (no refrigerants and less material), quieter operation, and lower space requirements (as an example, a one square inch Cool Chip panel could satisfy the requirements of an average refrigerator, [Criscione 2002].)

CURRENT STATUS OF MEASURE

The *Cool Chips* technology is being developed by Cool Chips plc. Lab-scale production of Cool Chips prototypes is currently underway. The Cool Chips goal is greater efficiency than conventional compressors, with simpler processes that yield competitive products. In December 2002 Cool Chips announced a research agreement with SRI International for prototype characterization and fabrication. This research will help develop a manufacturing process for production devices. (Cool Chips 2003) Boeing's Phantom Works conducted an independent evaluation, and determined that the operating principles of the technology are sound and that the measured physical data comply with the theory (Boeing 2001).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

There is no prototype demonstration experience from which to obtain measure cost estimates and, consequently, performance assumptions are based on observations emerging from lab scale work. Laboratory results show efficiencies of 50-55% of the theoretical maximum Carnot efficiency, but the developers project that this will ultimately rise to 70% to 80%, approximately 50% better than conventional refrigeration devices now in use (Cool Chips 2003). The company claims that product costs would be lower compared to conventional compressor technology used in residential refrigerators, saving $20-30 per refrigerator (Cool Chips 2003).

KEY ASSUMPTIONS USED IN ANALYSIS

We conservatively assumed savings of 40% relative to conventional refrigerators and air conditioners. We have assumed zero incremental costs. It is too early in the product development cycle for refrigerator manufacturers to speculate on the likely success and production cost of products made with Cool Chips. If the product performs as predicted by the developer, it would ultimately replace mechanical refrigeration throughout the residential market.
Canada-specific assumptions: This measure is restricted to the portion of auxiliary equipment that represents refrigeration, which ranges from 5 to 65% in hotel and restaurants. Penetration by

2020 is assumed to reach 60%. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

This is a high-risk technology with significant potential if it succeeds. Government's role at this stage is likely limited to providing funds for basic research. The technology is likely to be developed initially for niche applications, such as aerospace. At that point, governments will become the major customers for the technology.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

R2 MODULATING COMPRESSORS FOR PACKAGED REFRIGERATION

DESCRIPTION OF TECHNOLOGY

Packaged refrigeration equipment is estimated to account for more than half of the electricity used by refrigeration systems in the commercial sector. Reach-in/display cases consume approximately half of the energy use in packaged refrigeration equipment. The rest is consumed by vending machines, ice-makers and other equipment. (Easton 1993). Efficient commercial refrigerators and freezers that achieve savings of 25% to +40% (falling under the CEE Tier 1 and Tier 2 categories) are currently available in the North American market. In the U.S. the ENERGY STAR labeled commercial refrigerators and freezers are the same as CEE Tier 1 equipment. These savings are achieved with improved single-speed compressors and improved insulation, gaskets and controls. Additional energy can be saved by using modulating compressors and scroll compressors.

CURRENT STATUS OF MEASURE

Hermetic reciprocating compressors are the most common type of compressor in commercial packaged refrigeration. Energy use of these compressors can be reduced through compressor speed modulation, which can be attained with an electronically commutated motor (DCPM). The BCPM motors, more commonly referred to as variable speed motors, provide capacity control to more accurately match the refrigeration load (TIAX 2002), and may reduce noise levels, too. Unfortunately, these compressors are not common in North America: Electrolux offers a full range in Europe, but only one model for the U.S. market (Electrolux 2003). Scroll compressors also offer superior performance, reliability, and longevity. New models also have capacity control and so are well suited to capacity modulation with ECMs. Fully modulating scroll compressors, more commonly referred to as variable speed scroll compressors, are available in sizes above 2 HP (Copeland 2003b).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Replacement of hermetic reciprocating compressors with variable speed hermetic compressors would reduce energy use ranging 15% to 40%. For example, the Electrolux Americold model shows an EER that is 30% greater than the value of a comparable fixed speed compressor used in a typical two-door commercial reach-in refrigerator. Energy savings of 25% to 50% can be achieved with variable speed scroll compressors based on utility measured savings for larger 3 HP condensing units. The estimated cost premium of a variable speed compressor ranges from $100 to $150 for a typical 48 cu.ft. two-door, reach-in commercial refrigerator (TIAX 2002).

KEY ASSUMPTIONS USED IN ANALYSIS

In this analysis, variable speed compressors are conservatively estimated to save 20% of energy relative t conventional hermetic reciprocating compressor technology. The application comprises the variable speed compressor, ECM and controls. This would save 640 kWh/year for a typical

48 cu.ft. two-door reach-in commercial refrigerator with an annual consumption of 3,200 kWh/year. The baseline cost of the compressor is assumed to be approximately $500; the incremental cost to include modulation is approximately $150 (or 30%). is not included in the measure.

Canada-specific assumptions: This measure is restricted to the portion of auxiliary equipment that represents refrigeration, which ranges from 5 to 65% in hotel and restaurants. Penetration by 2020 is assumed to reach 60%. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Cost appears to be the main barrier to the manufacture of variable speed scroll compressors in the fractional HP sizes suitable for the commercial packaged refrigeration market. Technical development and demonstration is required to prove performance. In turn, this will support the necessary educational efforts targeted to manufacturers, to consider better compressors and capacity modulation, and consumers, on the benefits of these compressors to stimulate demand for high performance equipment. (TIAX 2002)

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

R3 EFFICIENT FAN MOTOR OPTIONS FOR COMMERCIAL REFRIGERATION

DESCRIPTION OF TECHNOLOGY

Packaged refrigeration equipment is estimated to account for more than half of the electricity used by refrigeration systems in the commercial sector. In the U.S. the ENERGY STAR labeled commercial refrigerators and freezers are generally at least 25% more efficient than some products in the market. However, the existing stock of packaged refrigeration equipment is considered very inefficient due to the focus by most purchasers on first cost and the lack of effort from manufacturers to differentiate equipment on the basis of energy efficiency (Nadel 2002). Fan and fan motors used in the condensers and evaporators account for 20% of the annual energy use and operate at overall efficiencies as low as 7% to 15%. These low efficiencies are due to both inefficient fans and low cost shaded pole (SP) motors with low efficiencies (TIAX 2002). New axial fan designs enable improved fan performance and advanced electric motors such as brushless DC or electronically commutated motors (ECM) offer motor performance solutions.

CURRENT STATUS OF MEASURE

Better evaporator and condenser fan-motor combinations are available in the North American marketplace, but their use has been mostly in premium residential refrigerator products. The emergence of these technologies in commercial refrigeration is being affected by voluntary efficiency programs in the U.S. and Canada. The specifications from all these agencies establish acceptable levels of energy consumption. Higher efficiency fan-motor combinations are a part of the manufacturers' strategy for meeting these efficiency levels. The Canadian Standards Association (CSA) issued Energy Performance Standards both for Food Service Refrigerators and Freezers and for Automatic Ice-Makers and Ice Storage Bins in 1998. As of 2000, over 80% of available models of ice-makers met the ice-maker performance standard. In 2001, the U.S. EPA circulated a draft ENERGY STAR specification for reach-in refrigerators and freezers. The Consortium for Energy Efficiency's Tier 2 efficiency specifications for reach-in refrigerators and freezers, and for ice-makers will drive better fan motors.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

It appears that the majority of currently installed evaporator and condenser fan-motor sets can be replaced with advanced units that can achieve energy savings as high as 70% of the fan-motor energy. The input fan power of an evaporator and condenser in a typical 48 cu. ft. two-door reach-in commercial refrigerator can be reduced from 70W (35W per component) to 20W (10W per component) with use of the energy efficient fans and motors (TIAX 2002). Incremental costs range from a low of approximately $20 for a better fan with a brushless DC motor to $50 for an ECM motor. The total incremental cost for a commercial fridge would be in the range of $40 to $100. (Nadel 2002; TIAX 2002).

KEY ASSUMPTIONS USED IN ANALYSIS

In this analysis savings of 70% are assumed with replacement of evaporator and condensers fan that draw a total of 35W each with ECM equipped evaporator and condenser fan motors that draw 10 Watts each. This is equivalent to electricity savings of 448 kWh for a typical 48 cu.ft. two-door, reach-in commercial refrigerator with an annual consumption of 3,200 kWh/year.

Canada-specific assumptions: This measure is restricted to the portion of auxiliary equipment that represents refrigeration, which ranges from 5 to 65% in hotel and restaurants. Penetration by 2020 is assumed to reach 60%. Consultant estimate based on Canadian commercial end-use analysis studies and commercial building profiles (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Educational material for equipment purchasers on the benefits and economics of energy efficient commercial refrigeration equipment is highly desirable (Nadel 2002). In turn, this will help purchasers start to demand efficiency and prompt manufacturers to use the more efficient components. The two-tier efficiency standards will also drive the market towards these efficiency fan-motor combinations. The minimum standards should be reset periodically to continue to move the bottom end of the market. The upper tier of products, those rated high efficiency, should ideally be identified using a recognized brand such as ENERGY STAR. Since the current market share for ENERGY STAR commercial refrigerators is around 50% (Smith et al 2003), the USEPA should consider revising the ENERGY STAR specification, perhaps to the CEE Tier 2 level. Unfortunately, the total energy consumption of this equipment is small (2841 GWh in 2020), so it is a low priority.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

BUILDING ENVELOPE (SHELL)

CANADIAN SUMMARY

Several T&I submissions pertained to the category of **building envelopes** including insulation, air and moisture leakage, integrated wall panels, and alternative building materials. Below is a summary of Canadian implications of these projects. This summary is based strictly on project funding submissions and does not contain primary research by Marbek.

Current Canadian Status of Technologies

Insulation
Canada is working on the next generation of energy efficient, environmentally friendly, and durable wall, roof, and foundation systems, including incremental improvement of minimum insulation levels in the model energy code for houses. Also active is the testing of vacuum insulation systems and incorporation of the systems into building products. These envelope products are being optimised for the range of indoor and outdoor conditions in extreme climates. Green roofs are also being investigated further for their insulative qualities, among other benefits. Most of Canada's green roof designs were being imported or adapted from warmer climate countries in Europe where cold climate performance data is scarce or non-existent; green roofs are therefore being tested domestically for durability and thermal performance in Canadian climates. A few Canadian manufacturers are currently supplying green roofs and Quebec's Energy Board has launched the Green Roof Financial Incentive Program to promote them as an energy efficiency measure.

Air & Moisture Leakage
Canadian initiatives are under way to update the model national energy code for buildings (MNECB) to specify maximum air leakage for new buildings based on testing, construction methodology, and materials selection. Software is being developed domestically to model different air leakage control strategies, with a goal to be used during in the integrated design process of buildings. Particular focus is being paid to air leakage in multi-use residential buildings (MURBs) and air and water tightness of joint details.

Integrated Renewable Energy Technologies
Today, Canadian industry associations and manufacturers are moving toward integrating solar thermal water and air and photovoltaics (PV) with the building envelope to optimise the performance of both system functions. Examples of envelope components integrating renewables are solar shingles, solar roofing systems, PV curtain walls, and energy generating panel walls. Many of these technologies can be integrated into any building design without having visual impact on the architecture and some, like photovoltaics, can be less expensive than conventional facade materials. The Seabird Island First Nation Sustainable Community Project was completed in 2003 by CMHC as a demonstration of integrating renewables.

Fenestration (Doors & Windows)
Canadian R&D and commercialisation experience in the window industry is ensuring significant Canadian and international receptors for further advance in fenestration systems (window and door design and placement). Current activity includes development and testing of thermal and

optical performance evaluation methods for skylights, entry doors, and glazed facades. There is already sufficient demand for Canadian window systems from the U.S., the U.K., and other countries in Europe.

Alternative Materials
There is current Canadian work on optimised blends and mixture proportions for concrete alternatives, ultimately seeking industrial by-products and other ingredients as replacements for Portland cement in "green building" concrete construction, where the final product must be both durable and environmentally friendly.

Canadian Opportunities & Challenges

Insulation
Higher-insulated envelope systems will take a while to penetrate the Canadian stock because the 'stick building' sector is large and well established in Canada; envelope enhancements will therefore largely apply to the existing network of alternative framing and structural system companies, which use steel stud, composite wood, insulated concrete forms, etc. Any such Canadian innovations or research data in envelope components or green roofs have the potential for export to other cold climate regions like the northern U.S.

Air & Moisture Leakage
Canadian efforts also include air and water tightness of joint details, with opportunities to provide new joint assembly types, new solutions for existing problem buildings, and new cross-referencing methodologies for non-destructively evaluating performance faults in new and existing assemblies.

Integrated Renewable Energy Technologies
With increasing recognition of Canada's solar resource, integrated solar thermal systems are gaining more market acceptance in Canada; this will be complementary for some envelope component technologies and a threat to others. Integrated envelope systems may need to comply with a new "P.10" home mechanicals standard, which is currently being developed by the Canadian Standards Association (CSA) to: 1) align minimum efficiency requirements for products that use different technologies to serve the same function and 2) eliminate poorly performing products from the marketplace.

Fenestration (Doors & Windows)
Advanced understanding, testing, modeling, and design of fenestration systems will increase Canada's impact on passive solar heating and daylighting technologies and practices.

Alternative Materials
One of the challenges of developing alternative concrete construction materials is the availability of quick, efficient, and reliable performance-based test methods for the material blends.

S1 HIGH INSULATION TECHNOLOGY (HIT) WINDOWS (U<0.25)

DESCRIPTION OF TECHNOLOGY

In most homes, windows are the weak link in terms of energy efficiency and comfort (NRCan OEE 2002) and can account for as much as 25% of the heat loss of homes built to current code. Over the past 10 to 15 years or so, new windows has improved significantly, by adopting low emissivity glazing, inert gas fills, insulating spacers and better design of window frames. Indeed, the small incremental cost of low-e coatings and gas fill have made double pane, low-e gas filled windows commonplace both for new construction and the replacement market, with Canadian Energy Ratings (ERs) ranging from -11 to +15. (NRCan 1994). (ER accounts for solar gain and infiltration losses, as well as the transmission losses. Canada's R-2000 standard requires minimum ER in Toronto of -13, NRCan OEE 2002). To qualify for ENERGY STAR in the U.S, a window must have a U-value no higher than 0.35 Btu/hr-ft^2-°F (that is, an R-value no lower than 2.86 hr-ft^2-°F/Btu). High Insulation Technology (HIT) windows, also known as "superwindows" are now available in the market offering energy and comfort performance improvements that exceed these requirements.

CURRENT STATUS OF MEASURE

HIT windows embody incremental design and performance improvements beyond today's energy-efficient windows. For example, using low-e films suspended between 2 panes of glass to create two or more spaces (interpane air space) can achieve performance superior to triple pane windows. These multi-air space windows have the same weight as a double pane window. Alternative HIT window strategies include vacuum windows, and aerogels. Due to their high cost, HIT windows are currently best for heating dominated climates above 5500 HDD. HIT window sales currently amount to less than 1% of the North American market. Nevertheless, there are a significant number of HIT products available with a thermal performance greater than R-4 (Arasteh, 2003). The National Fenestration Rating Council (NFRC) May 2003 Certified Products Directory lists approximately 360 manufacturers that offer roughly 3800 window products rated at greater than R-4 and some 80 products beyond R-6. The HIT window products include fixed and operable windows with wood, fiberglass, plastic and vinyl frames (no aluminum windows). They are available in two to four pane units as well as a few double pane units with interpane air spaces. In general, HIT windows rated at R-4 and beyond can replace double pane, low-e, aluminum thermally broken frame (R-2) windows for both new construction and replacement applications.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

While energy savings vary by climate, there are performance results from demonstrations and studies in many areas of North America. A 2000 study by Lawrence Berkley National Laboratories (LBNL) and the NFRC showed modeled seasonal heating energy savings of 14% to 16% and fuel cost savings of $50 to $100/year for a typical 2000 ft² house located in a northern state (Arasteh 2003). Costs of HIT windows are dropping continuously thanks to increased demand and improved technology (Reilly 2001).

KEY ASSUMPTIONS USED IN ANALYSIS

The analysis is based on a typical new 2000 ft² cold climate house with 300 ft² of window area located in Chicago, IL with an annual space heating energy use of 84,400 MJ/year (80 MMBtu/year). Space heating energy savings of 15% are assumed resulting in savings of 12,700 MJ/year (12 MMBtu/year). A cost increment of 20% or $3.0/ft² of window is estimated, based on a mature market. Current cost differential is approximately $5/ ft² (Thwaites 2003) but this can be expected to narrow with time.

Canada-specific assumptions: This measure applies to 100% of the residential stock. Penetration by 2020 is assumed to reach 35% (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

Energy benefits alone may not convince homeowners and builders to upgrade to HIT windows. Currently, the combination of high incremental first cost and poor awareness of the benefits mean that the cost of the windows will not be fully reflected in the potential sale price of the home. Collaboration with window manufacturers to reduce the incremental cost of HIT windows as was done in the mid 1990s between Viking and BPA would help increase the HIT windows market share. There is also a need for improved promotion of HIT windows by utilities, to encourage their use to help reduce peak cooling loads. Designers and builders should be targeted with promotional campaigns that will raise their awareness of the benefits of the new window designs.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

S2 ACTIVE WINDOW INSULATION (AUTOMATED VENETIAN BLINDS)

DESCRIPTION OF TECHNOLOGY

The use of an active window insulation (automated venetian blind) system as a daylighting strategy offers potential savings in both lighting and cooling-related energy use. As part of a "smart" integrated window/lighting/cooling system, automated blinds can provide dynamic control of daylight exposure vis-à-vis lighting/cooling requirements and current operating conditions.

CURRENT STATUS OF MEASURE

Automated venetian blinds are currently in a pre-market status, being produced in very limited quantities with field tests underway (LaFrance 2003; Lee 2003).

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Testing by Lawrence Berkeley National Labs of an automated venetian blind system in a southeast-facing private office in Oakland, CA (over the course of a year) identified a daily lighting energy use reduction of 1-22%, daily cooling load reduction of 13-28%, and peak cooling loads reduction of 13-28%. Incremental cost at the Oakland test bed site was determined to be approximately \$7-8/ft^2-glass (or \$3-4/ft^2-floor), including balance of system (power source, motor, drive electronics, microprocessor, software, photodetectors, dimmable ballasts, remote control, wiring, installation, commissioning, and maintenance). Simple payback of the integrated system was estimated at 10 years at \$0.09/kWh (Lee et al. 1998).

KEY ASSUMPTIONS USED IN ANALYSIS

DOE-2 building energy simulations have predicted annual energy savings from an integrated venetian blind/lighting system in a Los Angeles commercial building at 16-26 percent, and annual peak demand reductions at 17-24 percent (with any exposure except north) over a baseline advanced spectrally-selective window system (Lee and Selkowitz 1998).

Results of the DOE-2 energy simulations have been used in the analysis for commercial buildings, with residential benefits assumed at half the level of commercial benefits. Incremental cost estimates of \$7.50/ft^2-glass have been assumed, based on the LBL analysis. The residential building assumed in this analysis has 2,000 sq.ft. of floor space and 300 sq.ft. of window; commercial building is assumed at 25,000 sq.ft. of floor space and 2,000 sq.ft. of window.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

RECOMMENDED NEXT STEPS

Cost is still a predominant issue with active window insulation, and additional sales would likely improve economies of scale. Additional research may bring further cost reductions, although research is currently focused on alternative technologies, such as electrochromic glazings, that achieve similar function without obstructing views.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

S3 ELECTROCHROMIC GLAZING (ACTIVE GLAZING)

DESCRIPTION OF TECHNOLOGY

Electrochromic glazing permits dynamic changes of a window's thermal, solar, and visible transmittances by applying small amounts of electric current to an electrochromic film affixed to the glass. Designs can incorporate manual or automatic actuation through devices such as rheostats, thermostats, photocells, etc. Several electrochromic technologies are under study; including a design using electrically conductive layers of film that exchange ions when a voltage (or negative voltage) is applied. (Lee and DiBartolomeo 2000).

CURRENT STATUS OF MEASURE

Electrochromic glazing is a research, development, and demonstration area today.
Electrochromics are currently being produced in pilot-scale quantities, and undergoing limited field tests. Commercially, they may first be seen in residential sector skylights, where smaller glazing size and defects are of less concern. Later, promising markets include commercial buildings, where both cooling costs and peak shaving opportunities are high, especially where both cooling and heating benefits can be achieved.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Electrochromic glazing offers savings through cooling, lighting, and peak load reduction. Electrochromic glazing has the potential to reduce peak cooling loads 10% (Scruton 2004) to 20-30 percent (Lee et al. 2000) in perimeter zones of commercial buildings. At more than $100/sq.ft., electrochromic glazing is currently cost-prohibitive, although extensive research continues in this area. With an incremental cost target of $\$25/ft^2$ by 2007, which may be optimistic, according to Scruton (2004), and $\$5/ft^2$ by 2020, electrochromics continue to receive a few million dollars per year in research support, as seen in the recent DOE grants awarded to Sage Electrochromics and Rockwell (DOE 2003; LaFrance 2003).

KEY ASSUMPTIONS USED IN ANALYSIS

Recent presentations show electrochromic glazings yielding cooling energy savings up to 28 percent, and heating energy savings up to 31 percent (Sage 2003). Because these numbers represent best-case performance, we assume half of those savings in commercial buildings and heating residential buildings; cooling in residential buildings is assumed to be one-quarter of the best-case savings specified above.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

RECOMMENDED NEXT STEPS

Price is the major barrier; little else will matter until costs fall to a tenth of less of their present levels. It should be noted that reductions achieved through electrochromic glazings are accompanied by a significant reduction in visible transmittance. Thus, cooling load reductions provided by the glazings are likely to be offset by some degree of lighting use increase. Further research is necessary to improve material performance and reduce costs. Until electrochromic glazings can become more competitive in the marketplace, they are likely to remain a niche product.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

S4 ATTIC FOIL THERMAL ENVELOPE (RESIDENTIAL)

DESCRIPTION OF TECHNOLOGY

Typical residential construction separates the upper weather barrier from the upper thermal barrier: a pitched roof protects from rain and snow, while an insulated ceiling is supposed to isolate the attic thermally from the living area, controlling both exfiltration and conductive/radiative heat transfer. Unfortunately, in the world of real buildings, the situation is more complex. Radiant barriers such as reinforced aluminum foil can mitigate the transfer of heat from the very hot roof to the cooler insulation top side, thus decreasing the flow of heat to the occupied space during the cooling season. By definition, radiant barrier materials must have high reflectivity (usually 0.9, or 90%, or more) and low emissivity (usually 0.1 or less), and must face an open air space to perform properly (DOE, 1991).

CURRENT STATUS OF MEASURE

Radiant barriers are commercially available, but with low market penetration. For example, in Florida, where benefits would be nearly maximum and where the product has been promoted and tested for years, current market share is about 1.8%. (Parker and others, 2001). From this we infer that the national and even regional shares are substantially less than 2%.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

From DOE (1991) we take the unit cost of radiant barriers as ½ the unit cost of R-19 insulation, or 30¢/sq.ft.. Both Medina (2000) and DOE (1991) note that savings are inverse to the level of attic insulation in place, ranging from 42% of ceiling heat transfer with R-11 insulation, down to 25% with R-30 insulation. DOE (1991) notes that ceiling heat flow is only 15% - 25% of total heat gain, so the range of gains is only 4% to 10% in the total cooling bill.

KEY ASSUMPTIONS USED IN ANALYSIS

We assume 9% cooling energy savings and 16% unit reduction in peak demand (3.6 kWh/day and 0.42 kW, respectively, per Parker and others (2001), and applicability in humid regions, that is, 25% of houses. We assume national shipment-weighted average central air conditioners (SEER 11.1, EER 9). We assume a 20 year life for downward-facing foil radiant barriers installed under attic roofs; there seems little evidence of degradation over time of the downward-facing surface from dust, etc, so the remaining dangers would be mechanical damage (Yarbrough, 2003).
Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

Roofers are not enthusiastic, since radiant barriers marginally raise roof temperatures (ca. 3ºF) and could thereby shorten roof assembly life. The product has suffered also from "hyping" by vendors claiming savings of 30% or more. Radiant barriers mounted on attic floors instead of being hung from rafters or attached to sheathing may lose some effectiveness as dust accumulates and reduces reflectance/increases emissivity. From examination of the tables in

DOE (1991), the best applications will be hot climate retrofits where additional attic insulation would be even harder to install, and where the attic is adequately ventilated. No large-scale steps are recommended nationally, regional/state promotion may be appropriate in hot climates, particularly with capacity constraints (measure appears to reduce peak demand more than energy use.)

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

S5 RESIDENTIAL COOL COLOR ROOFING

DESCRIPTION OF TECHNOLOGY

Light color roofing material has been used widely in cooling-dominated climates to reduce the summer contribution of solar-driven roof gains. Typically these lighter colored roofing materials are used on commercial or industrial buildings with flat roofs not visible from the ground. These reflective surfaces haven't found popularity in the residential sector due primarily to aesthetic issues associated with having a shiny white roof surface. New "cool" color technology research has developed products that reflect heat regardless of color. These products came from military research in the early 1980's where the goal was to find pigments that would confuse infrared sensors. The cool colors achieve high infrared reflectance (~65%) by adding metallic elements to get a product with a traditional appearance that has an improvement in Total Solar Reflectance (TSR) of 150 to 500%.

CURRENT STATUS OF MEASURE

Although cool colors have only had limited success in the residential market (less than 1% market share) significant research is being completed at national laboratories and major roofing manufacturers. Much work is being done to incorporate the technology into darker roofing materials since they promise the greatest benefit. The status of these technologies varies from development to commercialized. Metal roof manufacturers currently offer cool roofs using these pigments, and work with the color manufacturers to incorporate the new, more efficient products when they become available. The Cool Metal Roofing Coalition is a consortium of manufactures that has been encouraging the use of cool colors in the building industry (CMRC 2003). Clay tile cool roofs are in the prototype phase, and the asphalt shingles and cedar shakes are also under development. Oak Ridge National Laboratory (ORNL) is currently working with the California Energy Commission and the Sacramento Municipal Utility District (SMUD) on a demonstration program for two products. Four houses will be built in Sacramento, California, two with metal roofs and two with tile roofs. Each pair of houses will consist of one base case and one cool roof.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

The current ENERGY STAR Cool Roof simulation model available online at the ORNL website estimates 60% roof cooling load reduction using cool color roofing (ORNL 2003). Savings will vary depending on the product, the climate, house insulation characteristics, and amount of cooling energy use. Reduction in cooling peak demand and improved duct efficiencies (for attic ducted systems) are also significant in cooling dominated climates. Depending on the product, the climate, and the house insulation characteristics, the savings and paybacks can vary widely (Indeed, there will be no cost differential for some categories (Scruton 2004)). Peak demand benefits and improved duct efficiencies are also significant in cooling dominated climates where attic ducts are common.

KEY ASSUMPTIONS USED IN ANALYSIS

With residential roofs contributing approximately 11% to annual residential cooling energy consumption (DOE 2002), savings of 6.6% are projected based on the estimated 60% roof

cooling load savings. Estimated cost is assumed to be 10¢ per ft^2 of roof area. Estimated life for asphalt roofing is 20 years and 40 years for metal and tile roofs.
Canada-specific assumptions: No Canada-specific assumptions were made for this measure.

RECOMMENDED NEXT STEPS

The most important issue identified by manufacturers and ORNL is education of the public and builders as to the potential savings these products offer. Upon completion of the Sacramento study, data will be available for development of a case study. Additional regional studies would further document Cool Roof performance. Cost-benefit evaluations could then be completed with results disseminated to builders, architects, and policy makers. Utility incentives and building codes which recognize the benefit of cool colors would be appropriate.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

S8 HIGH QUALITY ENVELOPE INSULATION

DESCRIPTION OF TECHNOLOGY

Current industry standard construction practice focuses on rapid installation of wall insulation with little attention to detail. Although standard width wall cavities with no obstructions (such as wiring, piping, electrical outlets, etc.) are often adequately insulated, many non-standard cavities are poorly insulated. Insulation is crammed into these narrow cavities, batts are compressed, and voids are common in areas where added labor is necessary for proper installation. Field measurements performed at ten California production homes (DEG 2002) led to the adoption of California Title 24 energy standards which degrade typical cavity insulation R-value to 69% of nominal, while providing a credit for third-party verified "quality" insulation installation. Two alternatives exist for improving the installed performance of wall insulation. The first requires improved training and compensation for insulation contractors to provide them the knowledge and the time to properly insulate a home. The second is use of spray-applied insulation which if installed properly results in a void-free wall cavity.

CURRENT STATUS OF MEASURE

A number of fiberglass insulation contractors offer a "Premium" service to install zero defect wall insulation. Much of this attention has been driven by construction quality programs such as MASCO's Environments for Living (EFL) program. Spray-applied cellulose is a competing product providing performance equal to or exceeding "zero defect" batts. To date, it has not achieved significant penetration in the production home market. As more and more builders enter quality construction programs they quickly realize the benefits of proper insulation installation and will hopefully adopt it as standard practice in all their homes.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

For a typical sized home, the added cost for proper batt insulation is about $250 (Stover 2001) and for spray-applied cellulose is about $300-$400 (Lea 2003). DOE's Energy Databook estimates that on a national basis, 15% of heating loads and 8% of cooling loads are due to energy transfers through walls. Savings will vary with climate and indoor thermostat setpoints.

KEY ASSUMPTIONS USED IN ANALYSIS

Wall assembly U-values were calculated for a nominal 2x4 wall (16 inches on center) with standard R-13 batt insulation and zero defect installation. The overall wall average R-value improved from 8.2 to 9.7, after accounting for framing factor effects. An incremental cost of $250 was assumed.
Canada-specific assumptions: This measure applies to 100% of the residential stock. Penetration by 2020 is assumed to reach 99% (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The construction industry is slow to adopt new construction practices that don't directly translate into increased marketability or reduction in cost. With the advent of quality construction programs such as EFL, builders are starting to realize the benefits of a wide range of measures including improved wall insulation. Improved indoor comfort translates into happier homeowners resulting in a positive impact on a builder's bottom line. Energy codes and utility incentives should recognize (and credit) improved wall insulation practices to help promote its acceptance.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

S9 ENGINEERED WALL FRAMING

DESCRIPTION OF TECHNOLOGY

Engineered Wall Framing (EWF) is a subset of Optimum Value Engineering (OVE), which was first introduced through a HUD project named "Operation BREAKTHROUGH" in 1977. Rising lumber costs at that time motivated a study of ways to reduce costs by more efficiently using resources and reducing jobsite waste. Typical residential construction practices do not focus on framing either in the design phase (e.g. laying out roof trusses over wall studs) or in the field where framers add considerably more wood than is needed for structural integrity. These traditional construction practices produce excessive scrap and many redundant structural members, resulting in a much higher percentage of wood in the wall cavity than needed. The thermal performance of the wall is degraded since R-1 per inch wood replaces R-3 (or more) insulation in the wall cavity. EWF practices promote improved thermal performance and reduced wood use by implementing the following techniques:

- 24" on center wall framing
- Align wall framing with trusses and use a single top plate
- Design headers for loading conditions and use insulated headers
- Align door/window openings with stud spacing where possible
- Eliminate unnecessary framing at intersections and corners.

The EWF construction practice requires up-front engineering to determine if the wider stud and floor joist spacing is sufficient for the specific design and location. Also, the framing crew must be trained in the alternative window and door framing techniques that reduce redundant support members while providing sufficient support.

CURRENT STATUS OF MEASURE

Most of the Building America Teams are currently using some form of OVE as part of their stick-built projects and have had good success. The Natural Resources Defense Council (NRDC 1998) and the National Association of Home Builders Research Center (NAHB 1997) have both published manuals detailing construction techniques. There is currently a joint effort underway between NAHB and HUD known as the Program for Research and Optimum Value Engineering (PROVE). This program is in its seventh year of operation, and is dedicated to research and education of OVE techniques. As their program progresses and the education campaign proceeds, we can expect to see more of these optimized building practices in the future.

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

ENERGY SAVINGS AND COSTS

Spray cellulose and premium batt insulation can improve the cavity R-value by about 30%. In analyzing the cases, the improved insulation walls were modeled with an R-13 cavity R-value, and the base case assumed a cavity R-value of 9, consistent with the 2005 CEC Standards. The R-values were calculated for a 8' by 20' wall with the two framing factors, and the corresponding energy uses calculated using these R-values.

KEY ASSUMPTIONS USED IN ANALYSIS

Projected savings are based on framing factor calculations of walls with 26.1% framing factor and optimal 12% framing factor. Annual savings were calculated based on the improved wall thermal performance and nationwide estimates of walls on residential heating and cooling energy consumption of 15% and 8% respectively.
Canada-specific assumptions: This measure applies to 100% of the residential stock. Penetration by 2020 is assumed to reach 99% (Marbek 2002 and DSE 2003).

RECOMMENDED NEXT STEPS

The principal barrier is probably the low visibility of improvement to consumers. Promotion efforts by Green Building groups and other environmental organizations will help promote the resource benefits of technology. Codes can assist in helping builders achieve energy credits associated with EWF. As the industry is transformed, the cost of training will be eliminated and the economic incentive for the builder will increase. Effort is needed in

For Canadian specifics, see the Canadian Summary at the beginning of this technology section.

REFERENCES

[AWHC] American Water Heater Company. 2003. Polaris High-Efficiency Residential Gas Water Heater. Product Brochure No. L-PG-10.0a.

[AWHC] American Water Heater Company. 2003. Polaris High-Efficiency Commercial Gas Water Heater. Product Brochure No. L-PG-10.0a.

[BoC] U.S. Census Bureau. 1999. "Census Region and Division, Floorspace, 1999." http://www.eia.doe.gov/emeu/cbecs/pdf/b5.pdf. Washington, D.C.: U.S. Bureau of the Census. Accessed August 2003.

[BoC] U.S. Census Bureau. 1999. "Census Region and Division, Floorspace, 1999." http://www.eia.doe.gov/emeu/cbecs/pdf/b5.pdf. Washington, D.C.: U.S. Bureau of the Census. Accessed August 2003.

[BPA] Bonneville Power Administration. 2003. "High Performance T8 Fluorescent Lighting Systems. " http://www.bpa.gov/energy/n/projects/conserve_augmentation/eso/high_per_fluor_faq.pdf. Portland, Oreg.: Bonneville Power Administration. Accessed August 2003.

[Census] U.S. Census Bureau. 1999. Natural Gas Consumption and Conditional Energy Intensity by Building Size, 1999. Available at http://www.eia.doe.gov/emeu/cbecs/tables/consumption.html. Washington, D.C.: U.S. Bureau of Census. Accessed October 2003.

[Copeland] Copeland Corporation. "Product Solutions Digital Scroll". 2003.

[Copeland] Copeland Corporation. "Product Solutions Scroll Compressors". 2003.

[Copeland] Copeland Corporation. "Take the Lead Discover a New Horizon". 2003.

[DOE] U.S. Department of Energy), 2002. Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps, Including Regulatory Impact Analysis. Department of Energy, Washington, DC http://www.eere.energy.gov/buildings/appliance_standards/residential/pdfs/title_page.pdf

[DOE] U.S. Department of Energy), 2002. Water Heater Rating Method. 10 CFR Ch. II (1–1–02 Edition) Pt. 430, Subpt. B, App. E

[DOE] U. S. Department of Energy. 2003. "Clothes Washer Technical Support Document." Appendix B. http://www.eere.energy.gov/buildings/appliance_standards/residential/clwash_0900_r.html. Washington, D.C.: U.S. Department of Energy. Accessed October 2003.

[DOE] U.S. Department of Energy), 2003. ENERGY STAR® Labeling Potential for Water Heaters. Available http://www.energystar.gov/ia/partners/gen_res/prod_development/new_specs/downloads/water_heaters/WH_Paper.pdf. Washington: D.C. Accessed October 2003.

[DOE] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. 2002. http://www.eere.energy.gov/buildings/appliance_standards/residential/gs_fluorescent_0100_r.html Washington, D.C.: U.S. Department of Energy. Accessed October 2003.

[DOE] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program. 2002a. *U.S. Lighting Market Characterization, Volume 1: National Lighting Inventory and Energy Consumption Estimate*. September. Prepared by Navigant Consulting. Washington, DC: U.S. Department of Energy.

[DOE] U.S. Department of Energy. 2001. Technical Support Document for Energy Efficiency Standards for Residential Central Air Conditioners. Washington, D.C.: U.S. Department of Energy.

[DOE] U.S. Department of Energy. 2001. "Energy Conservation Program for Consumer Products: Energy Conservation Standards for Water Heaters, Final Rule." Federal Register Vol. 66, No. 11 Wednesday January 17, 2001, 4474 – 4497

[DOE] U.S. Department of Energy. 2002. U.S. Lighting Market Characterization, Volume 1: National Lighting Inventory and Energy Consumption Estimate. Prepared by Navigant Consulting. Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program.

[DOE] U.S. Department of Energy. 2003. "Energy Department Awards $20.4 Million for Projects That Will Save Energy in Homes and Commercial" U.S. DOE Press Release. October 15. Available at http://www.energy.gov/engine/content.do?PUBLIC_ID=14302&BT_CODE=PR_PRESSRELEASES&TT_CODE=PRESSRELEASE

[DOE] U.S. Department of Energy. 2003. In Hot Water…A Newsletter about Heat Pump Water Heaters and efficient domestic water heating. June. Volume 2, Issue 2. Washington, D.C.: U.S. Department of Energy.

[DOE] U.S. Department of Energy. 2003a. High-Intensity Discharge Lamps. DOE Building Technologies Program: High-Intensity Discharge Lamps. July. http://www.eere.energy.gov/buildings/components/lighting/lamps/highintensity.cfm. Accessed July 2003.

[DOE] U.S. Department of Energy. 2003b. "Draft Framework for Determination Analysis of Energy Conservation Standards for High Intensity Discharge Lamps." June 30, 2003. http://www.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/hid_draft_report.pdf Washington, D.C.: U.S. Department of Energy Building Technologies Program Office of Energy Efficiency and Renewable Energy. Accessed July 2003.

[Easton] Easton Consultants, Inc. 1993. Commercial Baseline Refrigeration Study. September. Standford, CT: Easton Consultants, Inc.

[EDC] Environmental Design and Construction. 2002. "Saving Energy with High-Tech Lighting Systems." Available at http://www.edcmag.com/edc/cda/articleinformation/features/bnp__features__item/0,,77293,00+en-uss_01dbc.html Accessed September 2003.

[EIA] Energy Information Agency. 2003. Annual Energy Outlook 2003: Table 3. Energy Prices by Sector and Source

[EIA] Energy Information Agency. 2004. http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_nus_a_d.htm (Mar. 25, 2004).

[EIA] Energy Information Agency. 2004 Table 1d, http://www.eia.doe.gov/cneaf/electricity/esr/esr_tabs.html (Mar. 25, 2004)

[ENERGYGuide] ENERGYGuide. 2002. "ENERGY STAR Lights®" Product catalog. Fall 2002. Wellesley Hills, Mass.: ENERGYGuide.

[ENERGYGuide] ENERGYGuide. 2003. "ENERGY STAR Lights®" Product catalog. Spring 2003. Wellesley Hills, Mass.: ENERGYGuide.

[EPA] U.S. Environment Protection Agency ENERGY STAR Program. 2003. "Lighting the Way to a Brighter Future." Spring/Summer 2003. Available at http://www.lightingfortomorrow.com/pdf/ESNewsltrJune2003.pdf. Washington, D.C.: U.S. Environmental Protection Agency ENERGY STAR Program.

[EPA] U.S. Environment Protection Agency ENERGY STAR Program. 2003. "Lighting the Way to a Brighter Future." Winter 2003. Washington, D.C.: U.S. Environmental Protection Agency ENERGY STAR Program.

[EPA] U.S. Environment Protection Agency ENERGY STAR Program. 2002. "Lighting the Way to a Brighter Future." Fall 2002. Washington, D.C.: U.S. Environmental Protection Agency ENERGY STAR Program.

[EPA] U.S. Environmental Protection Agency ENERGY STAR Program. 2003. "The ENERGY STAR Residential Light Fixture Advancement Project." Invitation to Participate. March 15, 2003. http://energystar.gov/ia/partners/manuf_res/The_Energy_Star_RLF_Ad_Invitation.pdf. Washington, D.C.: U.S. Environment Protection Agency ENERGY STAR Program.

[EPA] U.S. Environmental Protection Agency. 2003. ENERGY STAR Central air conditioner calculator. Available at http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/Calc_CAC.xls Washington, D.C.: U.S. Environmental Protection Agency. Accessed October 2003.

[EPRI] EPRI. 2002. Technology Innovation in Electricity Use: A Cornerstone of Economic Progress. Draft, 12-13-02. Palo Alto, Calif.: EPRI.

[GAMA] Gas Appliance Manufacturers Association. 2003. Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment. April. Available at www.gamanet.org. Arlington, Virg.: Gas Appliance Manufacturers Association. Accessed October 2003.

[GAMA] Gas Appliance Manufacturers Association. undated. Statistical Highlights Ten Year Summary. Available at http://www.gamanet.org/member/statistics/TYS1992-2001.pdf Accessed 25 April 2003. Arlington, Virg.: Gas Appliance Manufacturers Association.

[HMG] Heschong Mahone Group, Inc. 2003. Modular Skylight Well for Suspended Ceilings. Prepared for the New Buildings Institute on behalf of the California Energy Commission's PIER Program. Fair Oaks, Calif.: Heschong Mahone Group, Inc.

[IEA] International Energy Agency. 2002. Principles of Hybrid Ventilation. IEA-ECBCS Annex 35 "Hybrid Ventilation in New and Retrofitted Buildings.

[IESNA] The Illuminating Engineering Society of North America. 2000. The IESNA Lighting Handbook: Reference & Application. Ninth Edition. New York, NY.: The Illuminating Engineering Society of North America.

[Laars] Laars Heating Systems. 2003. http://www.laars.com. Moorpark, Calif.: Laars Heating Systems. Accessed October 2003.

[LBNL] Lawrence Berkeley National Laboratory. Electrochromic Window Tests in U.S. Office Show Promise. Environment Energy Technologies Division News. http://eetd.lbl.gov/newsletter/nl5/electro_window.html Spring 2000

[LRC] Lighting Research Center – National Lighting Product Information Program. 1999. Dimming Electronic Ballasts. Specifier Reports. Volume 7 Number 3. Available at http://www.lrc.rpi.edu/. Accessed August 2003. Troy, NY.: Lighting Research Center.

[LRC] Lighting Research Center. 2003. Draft Technology Transfer Plan for Project 3.2: Energy Efficient Load Shedding Technology. Prepared for the California Energy Commission – PIER Lighting Research Program. Troy, NY.: Lighting Research Center.

[LRC] Lighting Research Center. 2003. Integrated Skylight Luminaire. DELTA Field Test report. Issue 1. Troy, NY: Lighting Research Center.

[MaxLite] MaxLite. 2003. http://www.maxlite.com. Pinebrook, NJ.: MaxLite

[NBI] New Buildings Institute. 2001. Advance Lighting Guidelines. 2001 Edition. White Salmon, Wash.: New Buildings Institute.

[NEPSC] New England Power Service Company. 1987. *Load Research Report*. Westborough, Mass.

[NFRC] National Fenestration Rating Council. "We are changing the way America shops for Windows, Doors and Skylights". 2002. http://www.nfrc.org/. Silver Spring, MD: National Fenestration Rating Council. Accessed October 2003.

[Ngrid] National Grid. "Design 2000 Plus 2003 Energy-Efficient Lighting Systems." http://www.masselectric.com/filelib/pdf/d2wk1-02.pdf. Northborough, Mass.: National Grid. Accessed July 2003.

[NLPIP] National Lighting Product Information Program. 2000. "Electronic Ballasts." Specifier Reports. 8(1). Troy, NY: Rensselaer Polytechnic Institute, Lighting Research Center.

[NLPIP] National Lighting Product Information Program. 2003. Mid-wattage Metal Halide Lamps. Lighting Answers (7:1). January.

[NRCan] Natural Resources Canada. "Standards for Window Energy Performance". 2002.

[NRCan] Natural Resources Canada. 1994. Consumer's Guide to Buying Energy Efficient Windows and Doors. Ottawa, ON: Natural Resources Canada.

[NRCan] Natural Resources Canada. 2003. http://oee.nrcan.gc.ca/neud/dpa/data_e/Parliament/Chapter_5.cfm. Ottawa, ON: Natural Resources Canada Office of Energy Efficiency. Accessed January 2004.

[NRCan] Natural Resources Canada. 2004. "Energy Use Data Handbook, 1990 and 1996 to 2002." http://oee.nrcan.gc.ca/neud/dpa/data_e/Handbook04/TofC.cfm?text=N&printview=N.

[ORNL] Oak Ridge National Laboratory. 2003. "Advanced Refrigerator/Freezer Technology." http://www.ornl.gov/ORNL/BTC/adv-rf-tech.htm. Oak Ridge, Tenn.: Oak Ridge National Laboratory. Accessed October 2003.

[ORNL] Oak Ridge National Laboratory. 2003. Hybrid Solar Lighting Summit. Preliminary notice. Knoxville, Tenn.: Oak Ridge National Laboratory.

[PIER] PIER Lighting Research Program. 2003. Project 3.2 Energy Efficient Load Shedding Technology Goals and Objectives. Available at http://www.archenergy.com/lrp/demandresp_lighting/project_3_2.htm. Accessed August 2003.

[RER] Regional Economic Research, Inc. 2000. Residential Energy-Efficient Lighting Consumer Research. Report #00-051. Prepared for Northwest Energy Efficiency Alliance. http://www.nwalliance.org/resources/reports/00051.pdf. San Diego, Calif.: Regional Economic Research, Inc.

[Savings by Design] Savings by Design. " Savings by Design 2003 Participant Handbook: Policies and Procedures for participation in the statewide Savings by Design Program." http://www.savingsbydesign.com/pdfs/2003SBDParticipantHandbook.pdf. San Francisco, Calif.: Savings by Design. Accessed July 2003.

[Sunpower] Sunpower. 2003. "Linear Compressors for Refrigeration." http://www.sunpower.com/technology/line_comp.html. Athens, OH: Sunpower. Accessed October 2003.

[TCP] Technical Consumer Products, Inc. 2003. GALAXe LED Desk Lamp. Specification sheet. Available at http://www.tcpi.com//pdf/Galaxe%20spec%20sheet.pdf. Aurora, Ohio: Technical Consumer Products, Inc.

Thorne, J. and S. Nadel. 2003. Commercial Lighting Retrofits: A Briefing Report for Program Implementers. ACEEE-A032. Washington, D.C.: American Council for an Energy Efficient Economy.

[TIAX] Technology and Innovation Business Unit LLC. 2002. Application of Best Industry Practices to the Design of Commercial Refrigerators: Development of a High Efficiency Reach-In Refrigerator. Prepared for the U.S.

Department of Energy National Energy Technology Laboratory. June. Cambridge, MA: TIAX LCC (formerly A.D. Little, Inc.)

[Xcel] Xcel Energy. "Xcel Energy New Construction Lighting Rebate Application."

Advanced Buildings Technologies & Practices. 2003. HID Electronic Ballasts & Lamps. http://www.advancebuildings.org/main_t_lighting_hid.htm. Ontario, Can.: Advanced Buildings Technologies & Practices. Accessed July 2003.

Amrane, K. and G. Hourahan, 2003 ??. Title. ASHRAE Transactions.

ANSI/ARI Standard 1060-2001, Rating Air-To-Air Heat Exchangers For Energy Recovery Ventilation Equipment, 2001, Air-Conditioning and Refrigeration Institute, 4100 North Fairfax Drive, Suite 200, Arlington, VA 22203, U.S.A.

Appliance Magazine. 2003a. "LG to Mass Produce 'Green' Fridge" Available at http://www.ammagazine.com. Troy, Mich.: Appliance Manufacturer. Accessed October 2003.

Arasteh, D. 2003. E-mail correspondence to G. Todesco. July. Lawrence Berkeley National Laboratories. Berkeley, CA.

ARI (in preparation) Guideline V-2003: CALCULATING THE EFFICIENCY OF ENERGY RECOVERY VENTILATION AND ITS EFFECT ON EFFICIENCY AND SIZING OF BUILDING HVAC SYSTEMS.

ARI, 2000. Directory of Certified Unitary Equipment Standards 210/240, 270. Air Conditioning and Refrigeration Institute, Arlington, VA.

Arthur D. Little, Inc. 1999. Opportunities for Energy Savings in the Residential and Commercial Sectors with High-Efficiency Electric Motors. USDOE Contract No. DE-AC01-90CE23821, Report Reference 35495-14.

Arthur D. Little, Inc. "Application of Best Industry Practices to the Design of Commercial Refrigerators". 2002. http://www.cee1.org/com/com-ref/doe-rep02.pdf. Cambridge, MASS: Arthur D. Little. Accessed October 2003.

ASHRAE, 1991. Methods of Testing for Rating Combination Space-Heating and Water-Heating Appliances. ANSI/ASHRAE 124-1991. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA.

ASHRAE, 1998. Operating Experiences with Commercial Ground-Source Heat Pump Systems. Special Publication, 66 pp. ASHRAE, Atlanta, GA.

ASHRAE, 2003. Handbook, Applications, Chapter A36, Table 3. ASHRAE, Atlanta, GA.

Aumann, D. 2004. Personal communication to E. Stubee.

Babyak, Richard. 2001. "Linear Launch." http://www.ammagazine.com/CDA/ArticleInformation/features/BNP__Features__Item/0,2606,27010,00.html Troy, Mich.: Appliance Manufacturer. Accessed October 2003.

Bardhi, P. (National Grid). 2003. Personal communication with Marycel Tuazon. July.

Bauman, F. 2003. *Underfloor Air Distribution Design Guide.* ASHRAE, Atlanta GA.

Berman, Sam. 2000. "The Coming Revolution Lighting Practice" Energy User News October 2000. Vol. 25, No. 10. Troy, Mich.: Energy User News.

Bierman, A. (Lighting Research Center). 2003. Personal communication with Marycel Tuazon.

Bockley, E. (Sylvania) 2003. Personal communication with Marycel Tuazon. July.

Boeing.. "Boeing Completes Evaluation of Borealis Cool Chips™ Technology." 2001. http://www.boeing.com/news/releases/2001/q4/nr_011130a.html. Seal Beach, CAL: Boeing. Accessed October 2003.

Boston, MA 02109. http://www.cee1.org/gas/gs-blrs/Boiler_assess.pdf

Brodrick, J. 2004, personal communication.

Brons, J. 2003. Personal communication with Marycel Tuazon. September.

Bulbs.com. 2003. http://www.bulbs.com. Worcester, Mass.: Bulbs.com. Accessed July 2003.

Bullough, J. 2003. "LED Lighting Systems." Volume 7 Issue 3. May 2003. Available at http://www.lrc.rpi.edu/programs/NLPIP/publicationdetails.asp?id=885&type=2. Troy, NY: Lighting Research Center.

Calwell, C., C. Grandha, L. Gordon, and M. Ton. 1999. "Lighting the Way to Energy Savings: How Can We Transform Residential Lighting Markets." Volume 1. Strategies and Recommendations. http://www.cee1.org/resid/rs-lt/rs-lt-pubs/ltwy_vol1.pdf. Washington, D.C.: Natural Resource Defense Council.

Calwell, C., C. Grandha, L. Gordon, and M. Ton. 1999. "Lighting the Way to Energy Savings: How Can We Transform Residential Lighting Markets." Volume 2. Background and Reference.

http://www.cee1.org/resid/rs-lt/rs-lt-pubs/ltwy_vol2.pdf. Washington, D.C.: Natural Resource Defense Council.
Calwell, Chris and Travis Reeder. 2002. *Power Supplies: A Hidden Opportunity for Energy Savings*. May. San Francisco, CA: Natural Resources Defense Council.
CBECS 1999 Detailed Tables, Table B6. Building Size, Number of Buildings, 1999. http://www.eia.doe.gov/emeu/cbecs/set3.html
CBECS 2002. 1999 Commercial Buildings Energy Consumption Survey (CBECS) Detailed Tables. U.S. Department of Energy, Energy Information Agency. http://www.eia.doe.gov/emeu/cbecs/detailed_tables_1999.html
CEE 2001. A Market Assessment for Condensing Boilers in Commercial Heating Applications. CEE, Boston, can be downloaded from http://www.cee1.org/com/gs-blrs/gs-blrs-main.php3
Chen, D. (Reth). 2003. Personal communication with Hugh Dwiggins.
Cool Chips plc. 2003. Cool Chips plc Business Plan. Gibraltar: Cool Chips plc.
Craford, M.G. 2002. Visible LEDs: The Trend toward High Power Emitters and Remaining Challenges for Solid State Lighting. Presented to Ernest Orlando Lawrence Berkeley Laboratory. Available at http://ncem.lbl.gov/team/presentations/Craford/sld001.htm. Accessed August 2003.
Craford, M.G., N. Holanyak, Jr. and F. Kish, Jr. 2001. In Pursuit of the Ultimate Lamp.@ Scientific American. February 2001. 63-67.
Crawford, J. (Sunpower). 2003. Personal communication with Marycel Tuazon. October.
Criscione, P. 2002. "A Change in the Wind for Natural and Hybrid Ventilation" E Source ET Currents. August.
Criscione, Peter. 2002. "A New Reality for Refrigeration?" ET Currents 19: 6-7.
Crowe, Joan. P. (undated, accessed 11/2003) Radiant Barriers: Essentials. http://www.professionalroofing.net/article.aspx?A_ID=290
Dakin, B. 2003. E-mail correspondence to G. Todesco. July. Davis Energy Group Inc. Davis, CA.
David, S. (Technical Consumer Products, Inc.) 2003. Personal communication with Marycel Tuazon. August.
DiLouie, C. 2004. Lighting Controls: Today and Tomorrow. Energy User News, April, pp. 12, 14. Distributed Energy Resources Guide: Stirling Engines
DOE 2004 http://www.energystar.gov/index.cfm?c=new_specs.water_heaters Potential ENERGY STAR Water Heater Criteria
DOE, 1991. Attic Radiant Barrier Fact Sheet. DOE/CE-0335P. http://www.ornl.gov/sci/roofs+walls/radiant/rb_01.html
DOE. 2003. Energy Department Awards $20.4 Million for Projects That Will Save Energy in Homes and Commercial Buildings. Department of Energy press release. October 15.
DOE/EIA. 1997. Nonresidential buildings energy consumption survey: Characteristics of commercial buildings 1995. DOE/EIA-0246(95).
DSE. 2003. Manitoba Hydro DSM Market Potential Study 2003: Final Report. Winnipeg, MB: Demand Side Energy and Marbek Resource Consultants.
E Source, 1996. Technology Atlas Series, Volume III: Space Heating. Boulder, CO: E Source, Inc.
E Source, 2003. DimALL from MaxLite @ ET Currents Number 28. July 2003: 2-3.
E Source. 2002. "Emerging Fuel Cell Technology" E Source. August.
E Source. 1997. Technology Atlas Series Volume II: Cooling. Boulder, CO: E Source , Inc.
ECR International, Watter$aver web page, http://www.enviromaster.com/watter_saver/, accessed 24 July 2003.
EIA. 2003. *2001 Residential Energy Consumption Survey*. Household Energy Consumption and Expenditures Tables. www.eia.doe.gov/emeu/recs/recs2001/detail_tables.html. Accessed 11/7/03.
EIA. 2003. *2001 Residential Energy Consumption Survey*. 2001 Consumption and Expenditures Tables: Electric Air-Conditioning Consumption Tables. Table CE3-1c.
EIA. 2003. *2001 Residential Energy Consumption Survey*. Total Energy Consumption in U.S. Households by Type of Housing Unit, 2001 - Preliminary Data. Table CE1-4c. ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/enduse_consump.pdf
Eley Associates. 1996. ACT² Davis Residential Site Impact Evaluation Report. Draft Report. Prepared for the Research and Development Department, Pacific Gas and Electric Company. San Ramon, California: Eley Associates.
Eley Associates. 1996. ACT² Stanford Ranch Residential Site Impact Evaluation Report. Draft Report. Prepared for the Research and Development Department, Pacific Gas and Electric Company. San Ramon, California: Eley Associates.
ENERGY STAR. "Commercial Solid Door Refrigerators & Freezers." 2003.

eWaterheaters. http://www.ewaterheaters.net. Accessed October 2003.
FEMP Unitary Air Conditioner Procurement. http://www.pnl.gov/uac/
FEMP, 1995. Residential Heat Pump Water Heaters: Energy-Saving Alternative for Home Hot Water. Federal Technology Alert, http://www.eere.energy.gov/femp/prodtech/pdfs/FTA_res_heat_pump.pdf, accessed 24 July 2003
Foster, R. (Consortium for Energy Efficiency). 2003. Personal communication with Marycel Tuazon. July.
Foster, S. (Ecos Consulting). 2003. Personal communication with Marycel Tuazon. August.
Frankenfield, Guy, personal communication, October 30, 2003.
FSEC (Florida Solar Energy Center). EnergyGauge USA: Code Compliance and Home Energy Rating Software. http://energygauge.com/USARes/default.htp
GAMA, 2003. April 2003 Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment. Gas Appliance Manufacturers Association, Arlington, VA. http://www.gamanet.org/consumer/certification/certdir.htm
Gautheir, Julia (Xcel Energy) 2002. Personal communication with Steven Nadel. October.
General Electric. 2003. Halogen Lamps. Product Catalog. http://www.gelighting.com.
Glouchkow, J. 2003. Conversation with Marycel Tuazon. October 2003.
Gough, A. (EPRI). 2003. Personal communication with Marycel Tuazon. July.
Gregerson, J. 1997. Commissioning Existing Buildings. Tech Update TU-97-3. Boulder, Colo.: E Source, Inc.
GRI, 1991. Assessment of Technology for Improving the Efficiency of Residential Gas Water Heaters. Topical Report GRI-91/0298. Gas Research Institute, Chicago, Il.
Gucciardo, April. 2003. Conversation with Marycel Tuazon. October 2003.
Haasl, T. and T. Sharp. 1999. A Practical Guide for Commissioning Existing Buildings. Prepared for the Office of Building Technology, State and Community Programs, U.S. Department of Energy. Oak Ridge, Tenn.: Oak Ridge National Laboratory.
Hagspiel, A. (National Grid). 2003. Personal communication with Marycel Tuazon. July.
Haitz, R., F. Kish, J. Tsao, and J. Nelson. 2000. The Case for a National Research Program on Semiconductor Lighting. White Paper. Available at http://www.sandia.gov/lighting/lightingdocs/hpsnl_long.pdf. Albuquerque, NM.: Sandia National Laboratories. Accessed August 2003.
Hallford, Art, (Trane) Personal communication, 2003. Trane team leader.
Hedman, Bruce (Onsite Energy/Energy Nexus Group). 2002. Gas-Fired Distributed Generation Technology Characterizations. Golden, CO: National Renewable Energy Laboratory.
Heschong Mahone Group. 1999. Lighting Efficiency Technology Report Volume I: California Baseline. Prepared for California Energy Commission. September 1999. http://www.energy.ca.gov/efficiency/lighting/lighting_reports.html. Fair Oaks, Calif.: Heschong Mahone Group
Heschong Mahone Group. 1999. Lighting Efficiency Technology Report Volume III: Market Barriers Report. Prepared for California Energy Commission. September 1999. http://www.energy.ca.gov/efficiency/lighting/lighting_reports.html. Fair Oaks, Calif.: Heschong Mahone Group
Higgins, C. *ed.* Integrated Energy Systems: Productivity & Building Science, Program Final Report. California Energy Commission P500-03-082
Hourahan, Glen, 2003. Personal Communication.
Hoye, M. (ICF Consulting). 2003. Personal communication with Marycel Tuazon. July.
Hubbard , G., Eley, C. 1997. "Green Fees: Getting Paid for Getting It Right – Performance Based Fee Contracts for New Construction" in Proceedings from Solar Forum
Interlight. 2003. http://www.interlight.biz. Hammond, Ind.: Interlight International Lighting Corporation. Accessed July 2003.
Ira Krepchin. 2000. Integrated Building Design: Can Teamwork Lead to High-Performance, Cost-Effective Buildings? E Source Report ER-00-15. Boulder, CO : E Source, Inc.
James, P., J.E. Cummings, J. Sonne, R. Vieira, J. Klongerbo, "The Effect of Residential Equipment Capacity on Energy Use, Demand, and Run-Time," ASHRAE Transactions 1997, Vol 103, Pt. 2., American Society of Heating, Refrigerating, and Air- Conditioning Engineers, Inc., Atlanta, GA.
Jennings, J.D., F. Rubinstein, and D. DiBartolemeo. 2000. Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed. LBNL-43096. http://eande.lbl.gov/btp/450GG/papers/43096.pdf. Berkeley, Cal.: Ernest Orlando Lawrence Berkeley National Laboratory.
Jewett, Don. 2003. Conversation with Marycel Tuazon. October 2003.
Johnson, Russ, 2003. Personal communication with Harvey Sachs. July 25, 2003.

Jump, D., A. Rosillo, J. Flanagan, and J. Cavalli. 2003. "Retro-Commissioning Buildings with Public Goods Funds-Learning Lessons in Oakland." In Proceedings of the 11th National Conference on Building Commissioning. Session 28. Portland, Oreg.: Portland Energy Conservation, Inc.

Jump, D. et al. 1996. Field Measurements of Efficiency and Duct Retrofit Effectiveness in Residential Forced Air Distribution Systems. In Proceedings of the 1996 ACEEE Summer Study on Energy-Efficiency in Buildings, 1.147-1.156. Washington, D.C. American Council for an Energy-Efficient Economy.

Kang, S. (MaxLite). 2003. Personal communication with Marycel Tuazon. August.

Kendall, M. and M. Scholand. 2001. Energy Savings Potential of Solid State Lighting in General Lighting Applications. Final Report. Prepared for U.S. Department of Energy, Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy. Available at http://www.eere.energy.gov/buildings/documents/pdfs/ssl_final_report3.pdf. Arlington, Virg.: Arthur D. Little, Inc.

Kesting, O. (Pacific Gas & Electric). 2003. Personal communication with Marycel Tuazon. July.

Kinney, L. 2002. "Stirling Set to Make a Big Stir" E Source ET Currents. January.

Kitson, M. 2003. Swiss Re Headquarters: Inside & Out.@ Fluent News. 12 (1): S2.

Komonowsky, J. (Pacific Gas & Electric). 2003. Personal communication with Marycel Tuazon. August.

Krepchin, I. 2001. Automated Building Diagnostics: Improving Energy Performance and Occupant Comfort E Source Report ER-01-18. Boulder, CO : E Source, Inc.

Krepchin, I. 2002. "Stirling Technology II: Free-Piston Devices" E Source ET Currents March

Krepchin, I. and J. Stein. 2000. New Dimming Controls: Taking it Personally. Boulder, Col.: E Source, Inc.

LaFrance, M. 2003. DOE. Personal communication.

Lee, E. 2003. LBL. Personal communication.

Lee, E. S. and D. L. DiBartolomeo. 2000. Application Issues for Large-Area Electrochromic Windows in Commercial Buildings. Accepted for publication by Solar Energy Materials and Solar Cells. LBNL-45841.

Lee, E. S. and S. E. Selkowitz. 1998. Integrated Envelope and Lighting Systems for Commercial Buildings: A Retrospective. Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA. American Council for an Energy-Efficient Economy.

Lee, E. S., D. L. DiBartolomeo, and S. E. Selkowitz. Electrochromic Windows for Commercial Buildings: Monitored Results from a Full-Scale Testbed. Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings, August 20-25, 2000, Pacific Grove, CA. American Council for an Energy-Efficient Economy.

Lee, E. S., L. D. DiBartolomeo, E. L. Vine, and S. E. Selkowitz. 1998. Integrated Performance of an Automated Venetian Blind/Electric Lighting System in a Full-Scale Private Office. Proceedings of the ASHRAE/DOE/BTECC Conference, Thermal Performance of the Exterior Envelopes of Buildings VII, Clearwater Beach, Fl., December 7-11, 1998.

Lee, Eleanor (LBL). Personal communication.

LEED 2003. Green Building Rating System For New Construction & Major Renovations (LEED-NC) Version 2.1 (revised). U.S. Green Building Council,

Leslie, R. 2003. Personal communication with Guiliano Todesco. April.

Lighting for Tomorrow. 2003. Finalists. July. Available at http://www.lightingfortomorrow.com/finalist.shtml. Accessed July 2003.

Loftness, V., R. Brahme, M. Mondazzi, E. Vineyard, M. McDonald, 2002. Energy Savings Potential of Flexible and Adaptive HVAC Distribution Systems for Office Buildings. Final Report. ARTI. Available from http://www.arti-21cr.org/

Lstiburek, J 2002. Residential Ventilation and Latent Loads. ASHRAE Journal 44, 18-22.

LumiLeds. 2003. "Lumileds to Ship Warm White, Incandescent-Equivalent LED in August." Press release. Available at http://www.lumileds.com. Accessed August 2003. San Jose, Calif.:

Mahone, D. 2004. Residential HVAC for Hot, Dry Climates, Final Report. N. Horowitz, ed. Natural Resources Defense Council, San Francisco.

Marbek Resource Consultants. 2002. BC Hydro Conservation Potential Review 2002: Final Report. Vancouver, BC: Marbek Resource Consultants.

Martinez, V. (LumiLeds). 2003. Personal communication with Marycel Tuazon. August.

McDonell, G. 2003. Underfloor and Displacement: Why They are No the Same.@ ASHRAE Journal (July): 18-24.

McHugh, J. 2003. Personal communication with Marycel Tuazon. September.

McMaster-Carr. 2003. http://www.mcmaster.com. Atlanta, GA: McMaster-Carr. Accessed July 2003.

Medina, Mario, 2000. Radiant Barriers: Performance Revealed. Home Energy, Sept./Oct. 2000, pp 30 – 33.

Meier, Alan. 2002. Presentation to the California Energy Commission Public Interest Energy Research Workshop on Standby Power. August 26. Berkeley, CA.

Messerschmidt 2003. http://www.messerschmitt.com/en/ftp/INCOS_e.pdf

Minneapolis, Minn.: Xcel Energy. Accessed July 2003.

Muhs, J. 2003a. Hybrid Solar Lighting: Shedding new light on solar energy…bringing sunlight inside. Presented at the American Council for an Energy Efficient Economy, Washington, D.C., May.

Muhs, J. 2003b. (Oak Ridge National Laboratory). Personal communication with Marycel Tuazon. August.

Muhs, J. and D.D. Earl. 2001. Preliminary Results on Luminaire Designs for Hybrid Solar Lighting Systems. @ Proceedings of Forum 2001: Solar Energy: The Power to Choose, Washington D.C., April 21-25. Available at http://www.ornl.gov/hybridlighting/pdfs/AsmeLuminaire.pdf. Accessed August 2003.

Nadel, S. 2002. Packaged Commercial Refrigeration Equipment: A Briefing Report for Program Planners and Implementers. December. Washington, D.C.: American Council for an Energy-Efficient Economy.

Nadel, S., D. Bourne, M. Shepard, L. Rainer, and L. Smith. 1993. *Emerging Technologies to Improve Energy Efficiency in the Residential and Commercial Sectors.* Washington, D.C.: American Council for an Energy-Efficient Economy. Report A931.

Nadel, S., L. Rainer, M. Shepard, M. Suozzo, and J. Thorne. 1998. *Emerging Energy-Saving Technologies and Practices for the Buildings Sector*. Washington, D.C.: American Council for an Energy-Efficient Economy. Report A985.

Nadel, S., R. N. Elliott, M. Shepard, S. Greenberg, G. Katz, and A.T. de Almeida. 2002. Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities. 2nd Edition. Washington, D.C.: American Council for an Energy-Efficient Economy.

Neal, 1998, Field Adjusted SEER [SEERFA]. Residential Buildings: Technologies, Design, and Performance Analysis. Pp. 1.197 – 1.209 in ACEEE Summer Study on Energy Efficiency in Buildings, 1998. ACEEE, Washington, DC.

Neme, C., S. Nadel, and J. Proctor, 1999. Energy Savings Potential from Addressing Residential Air Conditioner and Heat Pump Installation Problems. American Council for an Energy-Efficient Economy, Washington, DC. Report A-992.

NHSaves. 2003. "NHSaves." Product catalog. Spring 2003. Westborough, Mass.: NHSaves.

NRCan 2003PR3 Energy savings vary significantly. CBIP, BC Hydro and Enbridge Consumers Gas have minimum targets of 25% better than Canada's Model National Energy Code for Buildings (MNECB). On average CBIP buildings have shown a modeled performance that is approximately 30% to 35% better than an MNECB reference building. (NRCan 2003)

NRCan OEE. 2002. http://oee.nrcan.gc.ca/equipment/english/page50.cfm?PrintView=N&Text=N Nyle Specialties, http://www.nyletherm.com/waterheating.htm.

Parker, D.S., J. R. Sherwin and M. T. Anello, January 2001. "FPC Residential Monitoring Project: New Technology Development — Radiant Barrier Pilot Project," Contract Report FSEC-CR-1231-01 , Florida Solar Energy Center, Cocoa, Florida http://www.fsec.ucf.edu/bldg/pubs/rbs/index.htm.

Perry, T. 2003. Red Hot.@ ICEEE Spectrum June: 27-29.

Plasski, M. (Applied Proactive Technologies, Inc.). 2003. Personal communication with Marycel Tuazon. July.

Porter, J. (Architectural Energy Corp). 2003. Personal communication with Marycel Tuazon and Harvey Sachs. July.

Porter, J. (Architectural Energy Corp.). 2003. Personal communication with Marycel Tuazon.

Portland General Electric. "Lighting Rebates – Existing Buildings." http://www.portlandgeneral.com/business/energy_efficiency/programs/pdfs/existlight.pdf. Portland, Oreg.: Portland General Electric. Accessed July 2003.

Portland, Oreg.: Ecos Consulting.

Price, W. and R. Hart. 2002. Bulls-Eye Commissioing: Using Interval Data as a Diagnostic Tool. 2002 ACEEE Summer Study on Buildings, p. 3.295

Proctor, John and Danny Parker. 2000. "Hidden Power Drains: Residential Heating and Cooling Fan Power Demand." In Proceedings of the ACEEE 2000 Summer Study on Buildings, 1.225-1.234. Washington, D.C.: American Council for an Energy-Efficient Economy.

Proctor, John, 1998. Performance of a Reduced Peak kW Air Conditioner at High Temperatures and Typical Field Conditions. P. 1.265 – 1.274 in ACEEE Summer Study on Energy Efficiency in Buildings, 1998. ACEEE, Washington, DC

Prolighting.com. 2003. http://www.prolighting.com. Howell, Mich.: Accessed July 2003.

Pureland Supply. 2003. http://www.purelandsupply.com. Bridgeport, NJ: Pureland Supply. Accessed July 2003.

Regents of the University of Minnesota. "Benefits". 2003. http://www.efficientwindows.org/benefits.cfm. Twin Cities, MINN: Efficient Windows Collaborative. Accessed October 2003.

Regents of the University of Minnesota. "Comparison of Window Performance in New Versus Existing Construction". 2003.

Reilly, S. 2001. High Performance Glazing in Commercial Buildings. E Source Report ER-01-16. Boulder, CO : E Source, Inc.

Roland Pitts, NREL. Personal communication.

Roney, R. (Roney Marketing Inc.). 2003. Personal communication to author. 20 October. Roney Marketing represents GE lighting products in Ontario.

Ross, J.P. and Alan Meier. 2000. "Whole-House Measurements of Standby Power Consumption." Second International Conference on Energy Efficiency in Household Appliances. September. Naples, Italy: Association of Italian Energy Economics.

Rubinstein, Francis. (Lawrence Berkeley National Laboratory). 2003. Personal communication with Marycel Tuazon. July.

Rubinstein, Francis. (Lawrence Berkeley National Laboratory). 2003. Conversation with Marycel Tuazon. October.

Sachs, H. and S. Smith, 2003. Saving Energy with Efficient Residential Furnace Air Handlers: A status report and Program Recommendations. ACEEE Report A-033. ACEEE, Washington DC.

Sachs, Harvey M. 2002. Toward Market Transformation: Commercial Heat Pump Water Heaters for the New York Energy $martSM Program. Final Report, Project 6299. American Council for an Energy-Efficient Economy, Washington, DC.

Sachs, Harvey M. 2003. Prospectus for Program Development: The Sales Engineer: Key to Residential HVAC Efficiency. ACEEE, Washington, DC.

Sachs, Harvey M. 2003. Sustained High Performance Central Air Conditioners and Heat Pumps: Delivering Energy Efficiency in Use. PreProspectus, ACEEE, 2003

Sachs, Harvey M. and Sandy Smith. To be Published in 2004. "How much Energy could Residential Furnace Air Handlers Save?" ASHRAE Transactions. Volume 110, Part 1.

Sachs, Harvey M. and Sandy Smith. 2003. Saving Energy with Efficient Residential Furnace Handlers: A Status Report and Program Recommendations. ACEEE-A033. Washington, D.C.: American Council for an Energy-Efficient Economy.

Sage Electrochromics, Inc. 2003. Untitled. Presentation at DOE's Windows R&D Roadmap Implementation Meeting. AAMA Fall 2003 Meeting.

Sand, J. R. (personal communication, 2003). ASHRAE development of Method of Test, status of DOE project.

Sand, J. R., Oct. 6, 2003. Trane Active Cromer Cycle Development and Performance Testing. Fact sheet for DOE management.

Sandia National Laboratories. 2003. http://www.sandia.gov/lighting/index.html. Albuquerque, NM: Sandia National Laboratories. Accessed August 2003.

Sardinsky and Benya 2003. Super T8s: Super Lamps, Super Ballasts. Report ER-03-16, Platt's Research and Consluting, Boulder, CO.

Scruton, C. 2003. Personal communication to E. Stubee.

Shepard, M. (General Electric). 2003. Personal communication with Marycel Tuazon. July.

Shiller, D. (Environmental Protection Agency). 2003. Personal communication with Marycel Tuazon. July.

Simmons, J. (Sandia National Laboratory). 2003. Personal communication with Marycel Tuazon. August.

Sood and others, 1999.

Spartz, Philip 2004 personal communication. Comments on market position of spiral ducts with <1% leakage in the residential market.

Stubee, Eric, 2004. Comments in review of draft document.

Suozzo, M. and S. Nadel. 1998. Selecting Targets for Market Transformation Programs: A National Analysis. Washington, D.C.: American Council for an Energy-Efficient Economy. ACEEE Report A985.

Talbot, D. 2003. LEDS VS. The Lightbulb.@ Technology Review: MIT's Magazine of Innovation 106 (4): 30-36.

Tarricone, P. 2003. The Oak Ridge Boys.@ Lighting Design + Application July 2003. 42-44.

The Home Depot. 2003. http://www.homedepot.com. Atlanta, GA: The Home Depot. Accessed July 2003.

Thorne J., Toru Kubo, and Steven Nadel. 2000. Opportunity Knocks: Capturing Pollution Reductions and Consumer Savings from Updated Appliance Efficiency Standards. ACEEE-A001. Washington, D.C.: American Council for an Energy-Efficient Economy.

Thorne, J. and S. Nadel. 2003. *Commercial Lighting Retrofits: A Briefing Paper for Program Implementers*. March. Washington, DC: American Council for an Energy-Efficient Economy.

Thorne, J. and S. Nadel. 2003. Retrocommissioning: Program Strategies to Capture Energy Savings in Existing Buildings. A035. Washington, D.C.: American Council for an Energy Efficient Economy.

Thorne, Jennifer, 1998. Integrated Space Conditioning and Water Heating Systems: One System is Often Better than Two. ACEEE Report #A982. Washington, D.C.: American Council for an Energy Efficient Economy.

Ton, M., S. Foster, and C. Calwell. 2003. LED Lighting Technologies and Potential for Near-Term Applications. Report #E03-114. Market Research Report. Prepared for Northwest Energy Efficiency Alliance. Available at http://www.nwalliance.org/resources/reports/114ES.pdf.

Tsao, J. Y. ed. 2002. Light Emitting Diodes (LEDs) for General Illumination: An OIDA Technology Roadmap Update 2002. Available at http://lighting.sandia.gov/lightingdocs/OIDA_SSL_Roadmap_Tutorial.pdf. Washington, D.C.: Optocelectronics Industry Development Association.

Turner, W. 2003. “Know Our Systems Better – Or Utilize Higher Technology?” Strategic Planning for Energy and the Environment. Lilburn, Georgia: Vol. 23, No. 1.

Unger, Reuven. 1999. “Development and Testing of a Linear Compressor Sized for the European Market.” http://www.sunpower.com/pdf/Doc0074.pdf Athens, OH: Sunpower. Accessed October 2003.

USDOE. Energy Conservation Program for Consumer Products: Energy Conservation Standards for Water Heaters, Final Rule. Federal Register / Vol. 66, No. 11 / Wednesday January 17, 2001, 4474 – 4497

Vieira, Robin K., Parker, Danny S., Klongerbo, Jon F., Sonne, Jeffrey K., Cummings, Jo Ellen. “How Contractors Really Size Air Conditioning Systems.” http://www.fsec.ucf.edu/Bldg/pubs/ACsize/

Vineyard, Edward A. and James R. Sand. 1997. Experimental and Cost Analyses of a One Kilowatt-Hour/Day Domestic Refrigerator-Freezer. ASHRAE Transactions: Symposia 103, Paper BN-97-7-2, pp 621 – 629.

Vorsatz, D., L. Shown, J. Koomey, M. Moezzi, A. Denver, and B. Atkinson. 1997. Lighting Market Sourcebook for the U.S. LBNL-39102. Berkeley, Calif.: Ernest Orlando Lawrence Berkeley National Laboratory.

Walerczyk, S. (Lighting consultant). 2003. Personal communication with Jennifer Thorne. August 2003.

Westphalen, D. and S. Koszalinski 1999. *Energy Consumption Characteristics of Commercial Building HVAC Systems. Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation.* Arthur D. Little, Inc. Reference No. 33745-00, published for Office of Building Equipment Office of Building Technology State and Community Programs U.S. Department of Energy, Contract No.: DE-AC01-96CE23798

Westphalen, D. and S. Koszalinski, 2001. *Energy Consumption Characteristics of Commercial Building HVAC Systems, Vol. 1: Chillers, Refrigerant Compressors, and Heating Systems*. NTIS PB2001-104340.

Windows and Daylighting. “Residential Performance: Annual Energy Databases & Modeling Assumptions“. 2003. http://windows.lbl.gov/AEP/database.htm. Buildings Technology Department. Environmental Energy Technologies Division. Lawrence Berkley National Laboratory: Windows and Daylighting. Accessed October 2003.

Wolpert, J.S. 1992. Simulation, Monitoring, and the Design Assistance Professional.@ Energy Engineering. 89 (5): 6-21.

Xcel Energy. 2002. “Building Recommissioning.” http://www.xcelenergy.com/ProductsServices/BuildingrecommissioningMN.asp. Minneapolis, Minn.: Xcel Energy.

Yarbrough, David, 2003 (personal communication). Consultant recommended by industry association, RIMA, on life expectancy.

World Wide Web References:

http://cetc-varennes.nrcan.gc.ca/eng/publication/r2000-93e.html DABO

http://greenbuilding.ca/GBIC.htm Green Building Information Centre

http://oee.nrcan.gc.ca/newbuildings/cbip.cfm Natural Resources Canada's Commercial Building Incentive Program

http://www.acrx.com/ ACRx Solutions, ACRx Handtool, Honeywell HVAC Service Assistant

http://www.avistalabs.com/ ReliOn, Inc. (fuel cells)

http://www.ballard.com/ Ballard (fuel cells)

http://www.buildingsgroup.nrcan.gc.ca/projects/adv_houses_e.html NRCan Advanced Houses

http://www.buildingsgroup.nrcan.gc.ca/projects/windows_ep_detail_e.html. Ottawa, ON: Natural Resources Canada. Accessed October 2003.

http://www.buildingsystemsprogram.pnl.gov/ DOE whole building diagnostician

http://www.cee1.org/com/com-ref/com-ref-main.php3 CEE, High-efficiency commercial reach-in, solid-door refrigerators and freezers

http://www.cee1.org/com/com-ref/ice-main.php3 CEE Commercial Ice Makers

http://www.coolchips.com/ Cool Chips PLC

http://www.copeland-corp.com/cp_rf/prod_sol/cp_rf_products_scroll.htm. Copeland Corporation. Modulating (variable speed) scroll compressors. Accessed October 2003.

http://www.copeland-corp.com/cp_rf/prod_sol/cp_rf_products_scroll_dig.htm. Copeland Corporation. Accessed October 2003.

http://www.ecopeland.com/Literature/eCopeland/en_Broch_Cope_Horizontal.pdf. Welkenraedt. BELGIUM: Copeland S.A. Accessed October 2003.

http://www.eere.energy.gov/buildings/zeroenergy/ DOE EERE Zero Energy Homes FSEC

http://www.eere.energy.gov/buildings/zeroenergy/pdfs/zeb_path_29915.pdf

http://www.eere.energy.gov/femp/technologies/eep_ice_makers.cfm DOE EERE *How to Buy an Energy-Efficient Commercial Ice Machine*

http://www.efficientwindows.org/conditions.cfm. Twin Cities, MINN: Efficient Windows Collaborative. Accessed October 2003.

http://www.eia.doe.gov/oiaf/aeo/assumption/tbl12.html Assumptions to the *Annual Energy Outlook*

http://www.ekocomfort.com/ ēKOCOMFORT

http://www.electroluxcompressors.com/ECC/WebObjects/Electrolux.woa/wa/Nav/serieSpecMain?s=ESD ACC Compressors. 2003. “ESD Series”. Pordenone, ITALY. Accessed October 2003.

http://www.enerkoncorp.com/default.asp EnerKon

http://www.energystar.gov/index.cfm?c=commer_refrig.pr_commercial_refrigerators. ENERGY STAR. Accessed October 2003.

http://www.esv.or.at/aktuelles/energyglobe/globe02/bbedzed_e.htm BedZED: the Zero Energy Urban Village

http://www.facilitydynamics.com/pacrat.html Performance And Continuous Re-commissioning Analysis Tool (PACRAT)

http://www.fluent.com/about/news/newsletters/03v12i2/s1.htm Swiss Re Headquarters Inside & Out

http://www.fosterandpartners.com/internetsite/html/Project.asp?JobNo=1004 Swiss Re Headquarters

http://www.fuelcelltoday.com Fuel Cell Today

http://www.medistechnologies.com/ Medis Technologies Fuel Cells

http://www.nbnnews.com/NBN/issues/2004-02-09/Research/ article that describes the Livermore ZEH house

http://www.nuvera.com/ Nuvera Fuel Cells

http://www.pge.com/003_save_energy/003c_edu_train/pec/info_resource/act2_proj.shtml Advanced Customer Technology Test (ACT^2) for Maximum Energy Efficiency

http://www.plugpower.com/ PlugPower (fuel cells)

http://www.stirlingtech.com/ Stirling Technologies Company (Stirling engines)

http://www.stmpower.com/ Stirling Thermal Motors Power (Stirling engines)

http://www.sunpower.com/ Sunpower (Stirling engines)

http://www.usgbc.org/ US Green Building Council http://www.usgbc.org/Docs/LEEDdocs/LEED_RS_v2-1.pdf *Green Building Rating System For New Construction & Major Renovations* (LEED-NC) v. 2.1

http://www.usgbc.org/LEED/LEED_main.asp Leadership in Energy and Environmental Design

http://www.utcfuelcells.com/ UTC Fuel Cells (United Technologies)

http://www.whispergen.com/ WhisperGen (Stirling engines)

http://www.xcelenergy.com/docs/retail/busmrkts/BusinessLightingNewConstructionRebateMN.pdf. *Xcel Energy New Construction Lighting Rebate Application*

APPENDIX A

ACEEE STUDY VERSION-COMPARISON OF CURRENT STUDY WITH PAST STUDY RESULTS

This Appendix presents a comparison of the current and past ACEEE ET study results.

A.1 CHANGES THROUGH TIME

Table A-1 compares the disposition of high and medium ranked T&P measures in the 1998 and 2004 studies. Note that Table A-1 does not include extra attention to "special" measures (new construction and region-specific), since they were not included in the 1998 study, although integrated building design is included in the table. "H," "M" and "L" refer to priority levels. "MT" means "Market transformed," i.e., that the technology or practice has a market share estimated as more than 2% today. "Drop" means that the 1998 measure was not included in this study. This may have occurred because products have been withdrawn from the market, or that our evaluation of the potential savings did not meet our threshold for consideration.

Five measures, marked "MT," were removed because they have become mainstream products in the market (advanced clothes washers and dishwashers, improved CFLs, TP-1 distribution transformers, and commercial "cool roofs." Indirect-direct evaporative coolers were not considered because no appropriate products are on the market today.

In addition, about 28 lower priority measures from 1998 were dropped from this study, largely because their market prospects have not grown as quickly as expected. Note also that in some cases the "mapping" from 1998 to 2004 measures is not exact, as we found it necessary to slightly modify the definition to capture current and expected future practices.

Table A-1
Disposition of High and Medium 1998 Measures in this Study

1998		2004		
#	Priority	Priority	#	Measure
A1	M	H	A1	"Low leak" Home Electronics
A2	M	H	A2	One kWh/day Refrigerator/Freezers
A3	H	MT		High-Efficiency Vertical-Axis Clothes Washers
A4	M	MT		High-Efficiency Dishwashers
A5a	M	M	D2	Improved Efficiency Air Conditioning Compressors
A5b	M	L	R2	WAS: Improved Efficiency Refrigeration Compressors
A6	M	L	D1	WAS: Advanced Clothes Washer and Dishwasher Controls
D5	M	L	D1	WAS: Switched Reluctance Drives
H14	M	drop		Indirect-Direct Evaporative Coolers
H18	M	M	H5	WAS: Evaporative Condenser Air Conditioning
H2	H	M	H12	Aerosol-Based Duct Sealing
H3	M	M	H11	WAS: Commercial Distribution System Air Sealing
H4	H	M	PR4	Commissioning Existing Commercial Buildings
H5	H	drop		Dual Source Heat Pumps
H8	H	M	H11	Improved Ducts and Fittings

1998		2004		
#	**Priority**	**Priority**	**#**	**Measure**
H9	H	L	H13	Improved Heat Exchangers
I1	M	drop		Advanced Metering/Billing Systems
L11	M	M	L14	WAS: One-Lamp Fixtures and Task Lighting
L14	M	M	L13	Compact Fluorescent Floor and Table Lamps
L4	M	L	L8	Improved Fluorescent Dimming Ballasts
L7	H	MT		Reduced-Cost and/or Higher Efficiency CFLs
L8	H	L	L3	Metal Halide Replacements for Incandescents
P1	M	L	P1	Fuel Cells
P2	M	L	P2	Microturbines
P4	M	MT		Dry-Type Distribution Transformers
PR1	H	M?	PR2	Integrated New Home Design
PR2	H	H	PR3	Integrated Commercial Building Design
S2	M	MT		(Comm.) Heat Reflecting Roof Coatings
S3	M	L	S1	High R (>4) Windows
W2	M	drop		Integrated Electric Space Conditioning/Water Heating Systems
W3	H	L	W4	Integrated Gas- and Oil-Fired Space/Water Heating Systems
W4	M	M	W1	Residential Heat Pump Water Heaters

A.2 COMPARISON TO THE 1993 AND 1998 STUDIES

Between 1993 and 1998, the number of measures analyzed dropped by about 25%, but stabilized for this study (Table A-2). Similarly, the 1998 study had only two-thirds as many high and medium priorities as the first. However, the current study is close to the 1998 level. In addition, this study also adds 20 "special" measures for new construction or regional applications. Only three of these measures would save enough energy to qualify on the national scale as high or medium priorities.

Table A-2
Number of Measures by Priority, 1993, 1998, and 2004 Studies

	1993	1998	2004
Total Measures Analyzed	102	73	75
High Priority	21	12	5 – 6
Medium Priority	32	21	20 – 27
High + Medium	53	33	26 – 30[9]
"Special"	N/A	N/A	20

Over the past decade and three Emerging Technologies reports, there is a reduction in the number of high and medium priority technologies identified, from 53 in the first study down to 29 in the present report. In retrospect, one interesting anomaly emerges. One reason for the drop in the number of high and medium priorities from 1993 to 1998 is that the Cost of Saved Energy criteria changed, from \$0.06/kWh to \$0.041/kWh, and from \$4/MMBtu to \$3.16/MMBtu, so the

9 Total is lower than the sum of the two rows above because of overlaps: some measures could be considered either high or medium priority.

screening was tighter. In this study, we also used a conservative assumption that emerging technologies and practices would gradually "ramp up" their market presence, rather than emerging at full potential, which reduced the savings proportionately. In addition, it is clear for the 2004 study that more conservative estimates of total energy savings had an effect on the number of measures considered high priority.

Still, it is instructive to compare the 1998 and 2004 results for High and Medium priority measures (Table A-3).

Table A-3
Disposition of 51 High & Medium 1993 Measures in 1998 and 2004 Studies

Disposition of 51 High & Medium 1993 Measures	1998	2004 (relative to 1993)
Moved into mainstream (> 2%)	8	16
Remained High or Medium Priority	12	7
Moved down to Low Priority	9	2
"special" (new category)		3
No Longer Included	22	24

It is heartening that 16 emerging technologies and practices (30%) have moved into the mainstream, with market shares > 2%, in a decade; these are listed in Table A-4.

Table A-4
Measures from 1993 that Have Become Mainstream Products

100 W equiv. Screw-in Fluorescent
Advanced Dishwasher & Clothes Washer Controls
Low Energy & Water Use Dishwasher
Low Temperature Dishwashing Detergent
Low Power Color Television
Thermal Bridging for Fluorescent Fixtures
High-R Case Doors
Very Low Head Pressure
Supermarket Refrigerator System Integration
Improved Inkjet Printers, etc.
Improved Cold-Fusing Printers, Copiers, etc.
Golden Carrot Refrigerator/Freezer
Horizontal Axis Clothes Washer
High Spin Clothes Washer

On the other hand, a number of measures that were considered quite promising in 1993 are not included in our study, largely because they have been discontinued as products or have not yet entered the market. These are listed in Table A-5.

Table A-5
Twenty-four Measures from 1993 that are Not Included in the Present Study

Outcome	Measure
Mandated by law for 2010	Zeotropic Refrigerants
Not yet achieved market penetration	200-300 kWh/yr Refrigerator
Not yet achieved market penetration	Indirect/Direct Evaporative Cooling
Not yet achieved market penetration	Advanced Reflector Design
Not yet achieved market penetration	Cool Storage Roof
Not yet achieved market penetration	Microwave Clothes Dryer
Not yet achieved market penetration	Coated Filament Lamp
Not yet achieved market penetration	Hafnium Carbide Filaments
Not yet achieved market penetration	Fluorescent Surface Wave Lamp
Not yet achieved market penetration	DC Lighting System
Not yet achieved market penetration	Electrohydrodynamic HX Enhancement
Not yet achieved market penetration	Cool Ceiling Displacement Ventilation
Not yet achieved market penetration	Adsorption Cooling
Not yet achieved market penetration	Combination Refrigerator/Water Heater
Not yet achieved market penetration	Five Phase Motors
Not yet achieved market penetration	Heat Pump Clothes Dryer
Left the market	Bubble-Action Clothes Washer
Left the market	Green Plug Motor Controller
Now low priority	Low-Cost Dimmable Ballast
Now low priority	General Service Halogen IR Lamp
Now low priority	Ozonated Commercial Laundering
Now low priority	Advanced Freezer
Now low priority	Dimmable CFLs
Now low priority	Pilotless Instantaneous DHW
Now low priority	Integrated Fixtures and Controls

Of these, at least two have been withdrawn from the market (bubble-action clothes washers and the Green Plug motor controller), and fifteen have not (yet) entered the market. With the benefit of hindsight, some of these are not surprising. Consider the combination refrigerator/water heater. Since refrigerators have become much more efficient, the value of the few hundred kWh/yr they dissipate as heat now is small compared with heating loads that often will be several thousand kWh/yr, so there is much less impetus for such products. DC lighting systems have another issue, the proverbial chicken-and-egg problem. They would primarily be useful for new construction but that market may be too small to be attractive. In addition, the bar has been raised by the emergence of newer and more efficient systems such as CFLs. Some other technologies have been out-competed by other emerging technologies. This probably explains the slow progress of general service and PAR halogen IR lamps, which are "in the shadow" of the rapid cost reductions and market share gains of compact fluorescents.

The pattern that emerges from review of the 1993 study is interesting. A decade later, more measures either largely failed by our criteria (25) or entered the mainstream marketplace (15) than remain as priorities for future work (11). Technologies are progressing but there are also failures. To some extent, we believe that this also reflects greater optimism by the earlier teams, compared to a more conservative approach by the present group. This is particularly true for estimates of energy savings. In addition, not all R&D efforts will succeed, almost by definition.

The 12 high priority measures in 1998 averaged about 824 TBtu per measure as potential national impact; the six highest priority measures in this study average about 540 TBtu per measure (Table A-6). The total estimated savings from all measures is only three-quarters as large as in 1998. As noted above, in 2004 we used more moderate measure penetration estimates than in 1998, which accounts for much of the difference. We also believe that the analyses were systematically more conservative this time, accounting for most of the remaining difference.

Table A-6
Aggregated Savings of Source Energy, 1998 and 2004

	1998	2004
High Priority Average Savings	824 (12 measures)	520 (6 measures)
Hi, Med, Low,	1239 (71)	852 (66)
Hi, Med, Low, + Special		913 (20)

In considering Table A-6 it is important to note that savings often overlap between measures and that savings across measures are frequently not additive – we show the additive savings only to provide a rough point of comparison between the two studies. In addition, in this study we chose to "ramp up" the market penetration of technologies and practices as they enter the market and increase their penetration, which reduces the calculated savings. Also, given the many assumptions made in the calculations, these estimates should be viewed as approximate and not absolute.

A.3 COMPARISON BY MEASURES IN GROUPS

Table A-7 compares the number of measures studied (regardless of rating) in 2004 and 1998, by measures
group.

Table A-7
Changes in Number of Measures (regardless of rating) Within Groups Between 1998 and 2004 Studies

Measures Group	1998	2004
Appliances	8	2
Motors and Drives	6	4
HVAC	19	23
Lighting	15	167
Power	5	4
Practices	2	7
Refrigeration	1	3
Shell	5	10
Water Heating	7	4
Laundry	3	0

Measures Group	1998	2004
Miscellaneous, other	1	2

HVAC and Lighting are the largest groups in both studies, with relatively small changes in numbers from study to study (although the measures within groups did change). The most striking change from 1998 to 2004 is the great reduction in the number of appliance measures considered, particularly in the context of the declines in the closely related water heating and laundry categories. Some measures are included in both studies (*e.g.,* 1 kWh/day refrigerator, low-leak power supplies). Some, such as more efficient clothes washers, have been dropped because they succeeded in achieving more than 2% market share.

Appliances dropped from eight High and Medium Priority measures to two. Two measures entered the mainstream (High efficiency clothes washers and dish washers.) One moved up from Medium to High priority (Low "Leak" home electronics.) One of the 1998 group, Improved Air Conditioning Compressors, was treated in the "Drives" group this time but remained a Medium Priority. In addition, none of the advanced clothes washing technologies of 1998 remained on the 2004 list: ultrasonic clothes washers, microfiltration wastewater recovery, and ozonated commercial laundering. We did not find evidence of progress in the market for any of these.

Drives saw one category, advanced motors for appliances and HVAC, move from Low to Medium, in part because the current study "lumped" advanced technologies including switched reluctance and copper rotor into a single category of advanced appliance motors (D1.) This has two effects: Conceptually, it indicates that the study is indifferent about which specific motor technologies emerge as efficiency winners. Practically, it aggregates the savings from "motor improvements," so it is more visible as an opportunity in this study.

In *HVAC,* only one of about twenty 1998 measures moved into the mainstream (modulating gas furnaces). Six were dropped completely: cool storage roofs (but not reflective residential "cool roofs"), engine-driven vapor compression air conditioning, indirect-direct evaporative coolers, integrated chillers with heat recovery, dual source heat pumps, and ductless thermal distribution systems. None of these has enlarged its market visibility substantially. Indeed, residential engine-driven air conditioning, dual source heat pumps, and Indirect-direct evaporative coolers are not now commercially available. Ductless distribution ("mini-splits") remains a niche solution for retrofits. Indeed, during this period there has been a slow expansion of capabilities offered in ducted systems, such as better filtration and integration with outdoor air for ventilation, which raises the competitive barriers for ductless systems. Condensing commercial boilers moved from Low to Medium Priority, largely because of the current study's restricted focus on larger boilers for constrained applications. No other technologies moved up, and most of the remaining ones moved down from High or Medium to Medium or Low.

Of the 15 *Lighting/lighting system* measures in 1998, two (improved CFLs and integrated lighting systems) entered the mainstream through Market Transformation. No measures moved from lower to higher priority, but several moved downward. Five lighting measures were dropped in this study (indirect lighting, advanced light distribution systems, sulfur lighting, plastic downlight luminaires, and reduced-cost and/or higher efficiency CFLs). Indirect lighting seems to be part of the common palette of options today, driven by glare concerns in offices. In this study, we focused on a specific lighting distribution system, namely L10, Hybrid Solar Lighting, largely because high intensity sulfur lighting has not been a commercial success, and this was the "engine" that would have supported centralized lighting approaches (Sulfur lighting, while highly efficient, has not been feasible in low wattage fixtures). Our California study finds that dimmable CFLs are economically attractive, with a CSE of approximately $0.01/kWh, and that they have better color rendition at reduced output than incandescents.

Power continued the same pattern: the time horizon of both fuel cells and microturbines was stretched out and their ratings reduced, and the two photovoltaic technologies were deemed unlikely to satisfy our threshold criteria in the near future. We believe that studies that fully incorporate the peak reduction benefits of photovoltaics are likely to find strong reasons to encourage their adoption in some sectors (commercial) and regions.

Practices fared better; with the two from 1998 surviving and being joined by several others in this study, specifically Retrocommissioning (M), and "Bulls-eye" commissioning (L). We consider this to be an example of the generally greater importance of "people factors" as the early technology opportunities have been captured through standards and market transformation programs.

The 1998 study pointed out the potential of advances in *packaged refrigeration* for products such as beverage vendors and ice-makers. Since then the Consortium for Energy Efficiency has established programs with common specifications for solid- and glass-door commercial reach-in refrigerators and freezers, glass door refrigerators, and ice makers (CEE via WWW). ENERGY STAR has a solid-door reach-in refrigerator program, and one for beverage vendors. Thus, these products from the 1998 study have reached and gone beyond our 2% market share criterion and are no longer emerging technologies. Thus, the present study focuses on new opportunities in this sector, including solid state alternatives to vapor compression, modulating compressors, and advanced evaporator fan motors, as ways to further increase efficiency of commercial refrigeration products.

Two *shell* measures were dropped this time: Low-e interior surfaces, and Low-e spectrally selective Retrofit Window Films. We find no evidence that these are important in the market today, or likely to become so. On the other hand, a number of new measures entered the system this time, such as active window insulation (M for commercial, L for residential) and residential "cool roofs." (Commercial "cool roofs" would have been included, but they are already beyond 2% of the market).

Finally, the water heating technologies are pruned in 2004 relative to 1998. Several measures that looked promising, have shown limitations and/or slow market uptake. For example, the passive "GFX" gray-water heat exchanger will rarely be highly cost-effective for retrofits, since it requires about a 4' vertical drop for the heat exchanger. This works for single- and two-story houses that have basements and sub-basement plumbing. However, it is problematic for single-story slab-on-grade and crawl space construction, unless plumbing is deep in the ground. It is unattractive for houses with basements, if the baths are on the first floor and the waste plumbing is near the basement ceiling. Although low-efficiency combination systems that use hot water heaters for domestic hot water and a heating coil for space heating have gained market share for apartments, more efficient devices have not been rapidly adopted in the new construction market. As retrofits, they are not very attractive unless both the furnace and the water heater are near the end of their service lives, in a planned upgrade. This is thought to be a rather limited fraction of the market, and dealers have reported concerns about call-backs. The heat pump water heater market has not grown, but remains poised for growth. In some senses, this is ironic. DOE and others are beginning to pay attention to new approaches to water heating, including solar systems, but there seems little chance of large market penetration within 5 years, given today's market dynamics.

Laundry. To the authors, one largely pleasant surprise in this study has been the results of the changing market for residential clothes washers. In advance of new federal standards in January 2004 and January 2005, horizontal axis and other technologies that are energy- and water-efficient have achieved significant market shares. In most cases, these premium products carry with them the advanced controls highlighted as opportunity A6 in the 1998 study. On the other hand, we find evidence that any of the radically different laundry technologies studied in 1998 have seen widespread adoption (or emergence as commercial products) since that study. These include heat pump clothes dryers, ultrasonic clothes washers, and commercial ozonated laundry and microfiltration to recover waste water and its heat.

Technologies v. *Practices.* The last important change from 1998 to 2004 is our greater awareness of design and operating practices as significant sources of energy savings. The 1998 study recognized two such measures, Integrated New Home Design (PR1), and Integrated Commercial Building Design (PR2). In 2004, we examined seven practices, and six of them entered the analysis (Table A-8).

Table A-8
Practices Evaluated in 2004 Study, Sorted by Priority

Measure	Name	Priority, first round	In 1998?
PR3	IDP 30% > Code	H	no
PR4	Retrocommissioning	M	no
PR2	Ultra Low Energy Designs & Zero Energy Buildings	L	
PR5	Low Energy Use Homes and Zero Energy Houses	L	
PR6	Better, Easier to Use, Residential Sizing Methods	L	no
PR7	Bulls-Eye Building Commissioning		no

One High Priority measure (Advanced automated, building diagnostics) and one Medium Priority measure (Retrocommissioning) identified in this study were not included in the 1998 project.[10] In addition, Super T8 lamps and ballasts were introduced after the 1998 study, but have already emerged as mainstream products with 5% - 10% of the market (Sardinski and Benya, 2003. Although we evaluated them in this study, they are not included in the results because they are no longer emerging.

[10] In addition, a low priority technology was removed, but the categories are not exactly the same, so we treat the 1998 "Integrated Commercial (Residential) Designs as functionally equivalent to the Low Energy Designs and Zero Energy Buildings plus the IDP LEED level (30% > Code) of this study.