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ENERGY EFFICIENCY TECHNOLOGY IMPACT - APPLIANCES

VOLUME 1

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ABSTRACT

In this project, the effect of appliance efficiency on the overall residential end-use energy consumption and subsequent atmospheric emissions of carbon dioxide in Canada is studied based on simulation studies conducted on the Expanded STAR database using the ENERPASS building simulation program. In addition, the effect of fuel substitution for space and domestic hot water heating on residential end-use energy consumption and atmospheric emissions is also evaluated.

To conduct this study, first the CMHC STAR database was reviewed, modified and expanded to develop the Expanded STAR database. The new database exists in three formats which can be used with different building energy simulation programs and is considered acceptably representative of the Canadian housing stock at the national level, though not so at a regional level. As such, it is a valuable tool to study the impact of almost every energy conservation and electrical demand reduction option on the residential end-use energy consumption in Canada.

The findings of this study clearly indicate that improving appliance efficiency reduces the overall end-use energy consumption in the residential sector as well as the associated carbon dioxide emissions. However, the magnitude of the savings as a result of improving only appliance efficiencies is quite small, in the 1-2 percent range. Significantly larger savings, in the order of 5-10 percent, can be obtained by improving house envelopes and heating/cooling systems in addition to improving appliance efficiencies.

The effect of fuel substitution on residential energy consumption and carbon dioxide emissions was also studied, and the results indicate that depending on the fuel substitution scenario adopted, there can be a significant potential to reduce residential end-use energy consumption and carbon dioxide emissions. The Expanded STAR database and the methodology developed here can be used to easily predict the effects of fuel substitution scenarios.

Key Words: residential energy consumption, household appliances, residential energy efficiency, carbon dioxide emissions, residential energy end-use database, fuel substitution, modelling of residential energy consumption.

EXECUTIVE SUMMARY

This project studies the effect of appliance efficiency on the overall residential end-use[1] energy consumption in Canada, based on simulation studies conducted on the Expanded STAR database using the ENERPASS building simulation program. Included in this work was an evaluation of improved appliance efficiency effects on atmospheric CO_2 emissions as well as heating fuel substitution effects on energy consumption and atmospheric emissions.

The study included many tasks. Files for 239 houses in the Hot-2000 data base were converted to augment the newly corrected CMHC STAR-Housing data base which was then converted into both an ENERPASS and a Hot-2000 database for a total of 937 houses. These two programs were then compared to see whether Hot-2000, being a simpler bin-type energy simulation program than the ENERPASS program, would be suitable for this evaluation.

A survey questionnaire and data collection protocol were developed to determine residential appliance end-use energy consumption, usage and load profiles in Canada.

The validity of the Expanded STAR database was assessed by comparing the distribution of houses, fuel consumption and type of fuels used in the database with Canadian statistics. The average annual end-use energy consumption per household, estimated from the baseline simulation done on the entire Expanded STAR database, was also compared to the Canada-2 housing stock model. Based on these assessments, it was found that the Expanded Star database is acceptably accurate at the national level although less accurate on a regional basis.

Appliances were assigned to house files according to the saturation data obtained from Canadian and American statistics. Due to a lack of Canadian appliance usage data (i.e. load curves), data from American sources was used to simulate usage characteristics. This approach was found to be acceptable based on a sensitivity analysis of the American data. Results indicated that total residential end-use energy consumption is not very sensitive to variations in load curve shape unless highly unrealistic load curves are used.

Based on the research performed, the following trends are apparent. An improvement in appliance efficiency corresponds to an increase in space heating energy requirements as well as a decrease in DHW heating and appliance fuel consumption. This space heating energy increase is due to the reduced heat gain from appliances. The reduction in DHW heating energy is attributed to the reduced HW consumption for dish, clothes, and general washing, as well as reduced heat losses from the DHW distribution system. Overall, improving the energy efficiency of appliances

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1. In this report, the values cited for energy consumption and savings are for "end-use" energy rather than "source" energy. This distinction is especially important in interpreting the results for electrical energy consumption and savings. "End-use" electricity consumption and savings values are to be interpreted as electricity consumption and savings at the end-user level; as such, the efficiencies of electricity generation and transmission are not reflected in these values.

reduces the total residential end use energy consumption. Although cooling season analysis was beyond the scope of this project, a decrease in total energy consumption is expected to be greater for houses with air-conditioning since the cooling system will not have to work as hard to remove the appliance heat gain.

The savings associated with the improvement of appliance efficiencies only is less than 1% for 10% market penetration of high efficiency appliances, and less than 1.5% for 20% penetration. When energy saving measures, such as building envelope and mechanical system improvements, are adopted along with high efficiency appliances overall savings can be as high as 4.2% of the total for 10% market penetration of energy saving measures. The magnitude of savings increases linearly with market penetration level. Although the energy savings of higher efficiency appliances is low, the potential peak load reductions may be more significant; however, this analysis was beyond the scope of this project. It is very important that detailed cost-benefit analyses are carried out before making decisions regarding which appliance efficiency improvement measures to promote or legislate.

CO_2 emission reductions were calculated for all of Canada using the national values for contributions from various electrical sources (hydro, nuclear, thermal, etc.). Since relative values for these sources vary significantly with each province, the reductions calculated are indicative of what is possible at the national level, as opposed to a provincial or regional level. CO_2 emission reduction is found to be very close in magnitude to energy consumption savings. The potential to reduce the CO_2 emissions by improving only the appliance efficiencies is less than 1%, depending on the level of efficiency improvements for a 10% penetration of improved appliances in the residential market. Emission reduction increases linearly with market penetration level. This potential increases to as much as 4.2% for a market penetration level of 10%, and to 8.4% for a market penetration level of 20% when other whole house energy saving measures are incorporated with appliance efficiency improvements. These reductions are substantial and present objectives worth pursuing especially in the light of Canada's commitment to meet CO_2 reduction targets as stated in the 1988 Toronto Protocol. The intrinsic benefit of CO_2 emission reduction is an important factor to consider when conducting cost-benefit analyses for energy efficiency measures.

An evaluation of two fuel substitution scenarios found that significant reductions in both total energy consumption and CO_2 emissions in Canada can be achieved by substituting certain fuels for others. However, it should be noted that these findings are only applicable to the two scenarios evaluated, and general conclusions cannot be drawn from these results.

SOMMAIRE

Ce projet traite des répercussions que l'efficacité des appareils ménagers produit sur la consommation résidentielle globale d'énergie utile[1] au Canada selon les études de simulation effectuées au moyen de la base de données augmentée STAR et du programme de simulation immobilière ENERPASS. On y évalue les effets que les appareils ménagers à haute efficacité exercent sur les émissions de CO_2 dans l'atmosphère, ainsi que ceux de la substitution de combustibles sur la consommation d'énergie et sur les émissions atmosphériques.

L'étude a exigé de nombreuses tâches. Les dossiers de 239 maisons dans la base de données HOT-2000 ont été convertis et intégrés à la base de données de la SCHL nouvellement corrigée STAR-Housing; pour un total de 937 maisons, on a ensuite converti toute cette information en une base de données ENERPASS et en une base de données HOT-2000. On a ensuite comparé les résultats de ces deux progiciels pour voir si le programme HOT-2000, bien qu'il soit un outil de simulation d'énergie plus rudimentaire que le programme ENERPASS, convenait à cette évaluation.

On a élaboré un questionnaire d'enquête et un protocole de cueillette de données afin de déterminer les profils de consommation, d'usage et de charge pour l'énergie utile qu'utilisent les appareils ménagers au Canada.

On a évalué la validité de la base de données augmentée STAR par une comparaison de ses résultats pour la distribution des maisons, la consommation de combustible et les types de combustibles avec les statistiques canadiennes. On a estimé la consommation annuelle moyenne d'énergie utile par ménage au moyen d'une simulation élémentaire effectuée pour l'ensemble de la base de données augmentée STAR et on a comparé les résultats à ceux du modèle de parc de logements Canada-2. Grâce à ces évaluations, on a constaté que les résultats de la base de données augmentée STAR étaient convenablement exacts au niveau national quoique moins précis sur une base régionale.

Les appareils ménagers ont été attribués aux dossiers des maisons selon les données de pénétration du marché tirées de statistiques canadiennes et américaines. À cause d'une lacune dans les données sur l'usage des appareils ménagers au Canada (c.-à-d. les courbes de charge), on a utilisé les données des sources américaines pour simuler les caractéristiques d'utilisation. Une analyse de sensibilité des données américaines a révélé que cette démarche était acceptable. Les résultats ont indiqué que la consommation résidentielle totale d'énergie utile n'était pas très sensible aux variations dans la pente de la courbe de charge, à moins qu'on utilise une courbe de charge très peu réaliste.

Sur la base de la recherche effectuée, on a dégagé les tendances suivantes. À une amélioration de l'efficacité des appareils ménagers, correspond un accroissement des besoins d'énergie pour chauffer les lieux ainsi qu'une réduction de la consommation de combustible utilisé par les appareils ménagers et par le chauffe-eau sanitaire. Cette augmentation dans l'énergie consacrée au

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1 Dans ce rapport, les valeurs s'appliquent à la consommation et à l'épargne d'énergie *utile+ plutôt que *produite+. Cette distinction est particulièrement importante pour l'interprétation des résultats de la consommation et de l'épargne d'énergie électrique. Les valeurs de la consommation et de l'épargne d'énergie électrique *utile+ s'appliquent au niveau de l'utilisateur final; elles excluent donc les facteurs d'efficacité au niveau de la production et de la transmission.

chauffage des lieux résulte de la réduction de la chaleur émise par les appareils ménagers. La réduction de l'énergie consommée par le chauffe-eau sanitaire est attribuable à la diminution de la consommation d'eau chaude pour le lavage de la vaisselle, la lessive et le nettoyage général, ainsi qu'à une réduction dans les pertes de chaleur dans le système de distribution de l'eau chaude sanitaire. Globalement, l'amélioration de l'efficacité énergétique des appareils ménagers réduit la consommation résidentielle totale d'énergie utile. Quoique la saison visée par l'étude ait exclu l'analyse de la climatisation de l'air, on pourrait s'attendre à ce que la diminution de la consommation totale d'énergie soit plus prononcée pour les maisons dotées d'un climatiseur car le système de climatisation n'a pas à travailler autant pour éliminer le surplus de chaleur produit par les appareils ménagers.

Les épargnes associées à la seule amélioration de l'efficacité des appareils ménagers sont inférieures à 1 p. cent pour une pénétration de 10 p. cent du marché des appareils ménagers à efficacité élevée et inférieures à 1,5 p. cent pour une pénétration de 20 p. cent. Lorsqu'on adopte des mesures d'épargne d'énergie, notamment des améliorations dans les systèmes mécaniques et dans l'enveloppe des bâtiments, et qu'on installe des appareils ménagers à haute efficacité, les épargnes totales peuvent s'élever à 4,2 p. cent du total pour une pénétration de 10 p. cent de ce marché. L'importance des épargnes augmente de façon linéaire avec le niveau de pénétration du marché. Quoique les appareils ménagers à haute efficacité ne produisent que de faibles épargnes d'énergie, les réductions potentielles de la charge maximale peuvent être plus importantes; cependant, cette analyse dépassait la portée du projet. Il est très important que l'on effectue des analyses détaillées coûts-avantages avant de prendre des décisions concernant l'amélioration de l'efficacité des appareils ménagers par des mesures de promotion ou par législation.

On a calculé les réductions des émissions de CO_2 pour l'ensemble du Canada au moyen des valeurs nationales de l'électricité produite par les diverses sources (hydrauliques, nucléaires, thermiques, etc.). Comme les valeurs relatives pour ces sources varient énormément selon la province, les réductions calculées indiquent ce qu'il est possible de réaliser à l'échelle nationale plutôt qu'à l'échelle provinciale ou régionale. On a constaté que la réduction d'émissions de CO_2 est d'une magnitude très semblable aux épargnes dans la consommation d'énergie. La possibilité de réduire les émissions de CO_2 par la seule amélioration de l'efficacité des appareils ménagers est inférieure à 1 p. cent, selon le niveau d'amélioration de l'efficacité, pour une pénétration de 10 p. cent du marché des appareils ménagers améliorés. La réduction d'émissions augmente de façon linéaire avec le niveau de pénétration du marché. Conjugué à d'autres mesures d'épargne d'énergie pour l'ensemble de la maison, ce potentiel augmente jusqu'à 4,2 p. cent pour un niveau de 10 p. cent de pénétration du marché et à 8,4 p. cent pour une pénétration de 20 p. cent. Ces réductions sont substantielles, et les objectifs actuels valent la peine d'être poursuivis, particulièrement à la lumière de l'engagement du Canada à satisfaire les cibles de réduction de CO_2 établies dans le cadre du protocole de Toronto en 1988. Les avantages intrinsèques d'une réduction dans les émissions de CO_2 constituent un important facteur pour déterminer quand mener des analyses coûts-avantages pour les mesures d'efficacité énergétique.

Une évaluation de deux scénarios de substitution de combustibles a permis de constater la possibilité de réaliser des réductions importantes dans la consommation totale d'énergie et dans les émissions de CO_2 au Canada grâce à la substitution de certains combustibles par d'autres. Cependant, il faudrait remarquer que ces constatations ne s'appliquent qu'aux deux scénarios évalués et ne permettent pas tirer de conclusions générales de ces résultats.

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1. INTRODUCTION

Energy use by appliances in homes represents a significant portion of the national end-use energy consumption. As such, improving the energy utilization efficiency of household appliances is often seen to represent a significant opportunity to improve the efficiency and reduce impact on the environment. In the past several decades, energy efficiency of several types of appliances sold in Canada showed substantial gains. For example from 1978 to 1983, the efficiency increase was 43 percent for freezers, 27 percent for dishwashers and clothes washers, and 17 percent for refrigerators [1]. This increase in efficiency is expected to continue with regulations and adoption of incentive mechanisms such as energy taxation, energy efficiency grants and subsidies, both in Canada and United States[2].

Energy consumption and efficiency of household appliances have complex effects on the overall energy consumption of houses. This complexity is due to the interaction of a large number of parameters including the time of the year (heating or cooling season); type of heating/cooling system and type of fuel used; efficiencies of the heating/cooling system, house envelope and appliances; time schedules of appliance usage, occupancy and thermostat setting; and type of ventilation system. Because of the interrelated effects of all of these parameters, evaluating the effect of appliance efficiency on overall energy consumption of houses requires detailed computer modelling studies using building energy simulation models that are capable of simulating the effect of these parameters with sensitivity and accuracy.

In this project, the effect of appliance efficiency on the overall residential end-use[3] energy consumption in Canada is studied based on simulation studies conducted on the Expanded STAR database using the ENERPASS building simulation program - Version 3 [2]. Expanded STAR database consists of 937 houses. 698 of these are from the CMHC STAR-HOUSING data base [3] and 239 are from the Hot-2000 data base which includes house files from Ontario Hydro and Merchant studies [4].

In addition to this, the following work was also conducted in this project:

- The effect of appliance efficiency on atmospheric emissions of CO_2 was evaluated.
- The effect of fuel substitution for space and domestic hot water heating on residential end-use energy consumption and atmospheric emissions in Canada was evaluated.
- The CMHC STAR-Housing data base was reviewed and systemic errors were corrected.
- 239 house files in the Hot-2000 data base were converted to STAR format, expanding the number of house files in STAR format to 937.

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2. Canada imports about 20 percent of its refrigerators and clothes washers from the U.S., thus some of the effect of the U.S. legislation is expected to spill over into Canada through competition.

- 937 house files in the Expanded STAR database were converted into ENERPASS input file format. Thus, there now exists an ENERPASS input file database for 937 houses.
- The Hot-2000 files for the 937 house files in the Expanded STAR database were reviewed and some mistakes were corrected. Thus, a Hot-2000 input file database for 937 houses is now available.
- Hot-2000 program [5] was used to study the effect of appliance efficiency on the overall residential end-use energy consumption in Canada to find out whether Hot-2000, being a simpler bin-type energy simulation program, would be suitable for this evaluation. The results of this analysis are documented in appendix 15.
- A survey questionnaire and data collection protocol were developed that can be used in surveys and data collection projects for determining residential appliance energy consumption, usage and load profiles in Canada.

A large part of the work done in this project was reported in a series of Interim Reports submitted to CMHC [6;7;8;11]. In an effort to reduce the size of this Final Report, the contents of these previous reports are not presented. Rather, summaries of the previous work done are presented in Section 2 below, and the Interim Reports are included in volume 2 for reference.

In Sections 3-10 of this report, the methodologies that are used to carry out this research project, as well as the findings, conclusions, and recommendations for future work are presented in detail.

2. SUMMARY OF PREVIOUS WORK REPORTED

2.1 Development of a Consistent Classification of Appliances

Household electrical energy consumption is typically studied in two categories: a) energy consumption for familiar end uses, and b) energy consumption for miscellaneous (other or residual) end use. Assignment of the different electrical energy uses to these two categories is not standardized, with different research groups using different assignments. Familiar end uses generally include space heating, air conditioning, water heating, refrigeration, cooking, clothes drying, dish washing, lighting, television, and furnace fans. Miscellaneous end use includes all other end uses such as bathroom and rangehood fans, audio system, humidifier, microwave, vacuum cleaner, well pump, etc.

Since a standard classification of appliances that can be used in energy studies does not exist, and the energy consumption of appliances in the "miscellaneous" category can be significant, a classification of appliances was proposed in Interim Report No.1 [6]. For this purpose, an exhaustive literature review was conducted, and the classification was based on the results of studies reported in the literature, available Statistics Canada data, and engineering calculations and estimates. This classification is used in the simulation studies conducted as well as in the development of proposed survey protocols.

The classification developed in this study considers the following appliances as "major appliances". All other appliances are considered "minor appliances":

1. Water heaters,
2. Cold food storage equipment (freezers, refrigerator/freezers, refrigerators),
3. Primary cooking equipment (ranges, ovens, cooktops),
4. Clothes dryers,
5. Clothes washers (they additionally impact on energy consumption through hot water usage)
6. Room and central-air conditioners (since combined saturation is close to 30%)
7. TV's,
8. Furnace and attic fans.
9. Spa/hot tub, and sauna
10. Waterbed heaters,
11. Grow lights,
12. Aquarium/terrariums,
13. Swimming pool heaters and pump.

(Note: Appliances no. 9-13 are included since they have a high impact on the house energy consumption if present.)

2.2 Development of a Survey Protocol

When this project was initiated, it was anticipated that new surveys were to be conducted by CMHC and NRCan. A survey questionnaire and data collection protocol were therefore developed that can be used in surveys and data collection projects for determining residential appliance energy consumption, usage and load profiles in Canada. These were presented in Interim Report No. 1 [6], and later a revised and shortened questionnaire and protocol were submitted to CMHC [9]. However, these new surveys could not be conducted and; therefore, new data was not available.

2.3 Review of CMHC STAR-HOUSING and Hot-2000 Data Bases

The CMHC STAR-HOUSING (STAR) and Hot-2000 data bases were received from SAR Engineering in the form of EXCEL spreadsheets. SAR Engineering had previously conducted a thorough review of the STAR database and had found that a large number of house files in the database were incomplete. Thus, these houses were removed from STAR database, leaving 698 house files in the database. The total number of house files in the Hot-2000 data base is 239. Upon further review of both data bases in this project, several systemic mistakes were found [8;10], and they were corrected as described in Interim Report No.3 [8].

2.4 Conversion of Hot-2000 Files into STAR Files

The 239 Hot-2000 house files received in EXCEL spreadsheet format were converted to STAR database format using a computer program that was developed in this project. The procedure used in the conversion was presented in Interim Report No. 3 [8]. Thus, the STAR data base is now expanded by the addition of 239 house files. The total number of house files in the "Expanded STAR" data base is now 937 (698 in original STAR data base plus 239 from Hot-2000 data base).

2.5 Conversion of STAR Files into ENERPASS Input Files

All 937 files in the Expanded STAR database were converted into ENERPASS input data files using a program that was developed in this project. The procedure used in the conversion was presented in Interim Report No. 2 [7]. All of the house files were matched with appropriate weather data files [11]. Thus, an ENERPASS input file database now exists for 937 houses which can be used for any wide scale simulation study.

2.6 Appliance Saturation and Energy Consumption

Data on appliance saturation and energy consumption were compiled from various sources including Association of Home Appliance Manufacturers, California Energy Commission, US Department of Energy, OECD, Natural Resources Canada (formerly Energy Mines and Resources Canada), Statistics Canada, and technical journals. Based on a thorough review and analysis of the published data which was presented in Interim Reports No.1 [6] and No.4 [11], appliances were categorized into eight classes as follows:

Class A: Consumption > 200 kWh/yr and Saturation > 40%
Class B: Consumption > 200 kWh/yr and Saturation < 40%
Class C: Consumption < 200 kWh/yr and Saturation > 40%
Class D: Consumption < 200 kWh/yr and Saturation < 40%
Class ABK: Consumption data not reported and Saturation > 40%
Class CDK: Consumption data not reported and Saturation < 40%
Class KAB: Consumption > 200 kWh/yr and Saturation data not reported
Class KCD: Consumption < 200 kWh/yr and Saturation data not reported

It was concluded in Interim Report No.4 that appliances with a classification Letter of A, B, C, and D were to be included in the simulations. Appliances other than these were not included in the simulations owing to the lack of data and the insignificance of the overall impact of the energy consumption of these appliances on the national residential energy consumption.

The distribution of the appliances among the houses in the data base were done randomly based on the saturation level. The average saturation level for each appliance was given in Tables 15 and 16/2 of Interim Report No.1. For those appliances for which Statistics Canada saturation data exist, the Statistics Canada data were used[3]; for other appliances, the average value in Table 15 of Interim Report No.1 were used. The following procedure was used to distribute the appliances among the houses in the data base:

The average or, if it exists, Statistics Canada saturation level of each appliance was obtained from Table 15 of Interim Report No.1. Then, this percentage of houses in the data base were randomly selected and assigned that appliance. This procedure was applied to assign every appliance. Thus, at the end of this procedure, each house in the data base was assigned a random set of appliances, and the occurrence of the appliances in the data base is the same as its saturation. For example, the 'clothes dryer' (Appl. No. 17) saturation from Statistics Canada is 74%. Thus, 74% of the houses in the data base were randomly selected, and these were assigned an electric clothes dryer. Then, the next appliance, 'freezer' (Appl. No. 7) was checked. The Statistic Canada saturation for freezer is 57.9%. Thus, 57.9% of the houses in the data base were randomly selected, and these were assigned a freezer. This procedure was repeated for each appliance in the list.

The distribution of appliances among the houses was done on a national level rather than provincial. This is owing to the fact that the saturation data given by Statistics Canada (which is broken down according to province) does not cover all of the appliances that are included in the simulations in this project. Thus, rather than assigning some appliances at provincial level, and others at national level, all appliances were distributed at national level.

In addition, a literature search was conducted to identify the potential for energy efficiency improvements for different appliances. Based on this, three levels of appliance efficiency improvement were identified to be used in the simulations. The published data and the potential improvements are presented in detail in Interim Report No.4, and the associated energy savings are summarized in Section 3.1 below.

2.7 End-use Load Shape Data

An exhaustive literature search was conducted, and end-use load shape data were compiled from various sources. It was found that the most useful load shape data were those published by Lawrence Berkeley Laboratory, Bonneville Power Authority, Electric Power Research Institute and Ontario Hydro. A thorough review and analysis of these and other reported data was presented in Interim Report No. 4 [11]. Based on this review and analysis, the end-use load curves that are to be used in the simulations were selected. Since these load curves were not developed from Canadian data, and since the differences between seasons, and weekdays/weekends were not found to be substantial, it was concluded that use of only one load curve for each appliance (rather than using different load curves for different seasons, and

3. The Statistics Canada data were given in Column H of Table 15 in Interim Report No. 1

weekdays/weekends) would be sufficient. For those end uses for which no load curves are published (such as lights, TV, minor appliances), "reasonable" load curves were developed. The load curves that are used in the simulations are presented in Table 1. A sensitivity analysis was conducted to evaluate the effect of variations in load curves on appliance energy consumption. This study is detailed in Appendix 12.

2.8 Electrical Demand (Maximum Load) of Appliances

The electrical demand (maximum electrical load) for each appliance included in the simulations was calculated using the annual energy consumption data and the appliance load curve.

2.9 Modification to ENERPASS Program

The ENERPASS simulations for different scenarios were conducted on all of the 937 houses for which input files were generated. To accommodate these simulations, a batch version of the program, that is capable of running simulations in batch form, was developed by Enermodal Engineering according to Thermal Engineering specifications [12].

Table 1. Baseline appliance load curves (% of daily load in each hour)

Hour	Refrig-erator	Freezer	Cooking	Dish-washer	Clothes-washer	Clothes-dryer	DHW	Lighting	TV	Miscell.
1	3.94	3.97	0.23	1.04	0.45	0.45	1.81	1.23	1.42	1.39
2	3.71	3.88	0.17	0.50	0.23	0.27	1.54	1.23	0.71	1.39
3	3.58	3.89	0.15	0.26	0.19	0.15	1.17	1.23	0.71	1.39
4	3.63	3.89	0.32	0.26	0.17	0.11	1.04	1.23	0.71	1.39
5	3.50	3.72	0.80	0.26	0.19	0.19	1.04	2.63	0.71	1.39
6	3.60	3.67	2.25	0.78	0.61	0.97	1.95	4.94	0.71	1.39
7	3.78	3.70	3.54	1.82	1.46	2.64	4.17	7.41	3.57	1.39
8	3.87	3.80	4.34	3.39	4.49	4.22	7.02	4.94	0.71	1.39
9	3.94	4.04	4.64	6.17	6.55	6.26	7.54	2.63	1.42	6.94
10	4.02	4.10	4.31	6.79	7.74	7.72	7.13	0.62	1.42	6.94
11	4.00	4.25	4.25	5.75	8.37	8.30	6.50	0.62	1.42	6.94
12	4.16	4.37	5.27	4.71	8.28	8.05	5.71	0.62	2.84	6.94
13	4.21	4.47	4.58	4.17	7.75	7.14	4.92	0.62	2.84	6.94
14	4.21	4.61	3.69	4.43	6.59	6.27	4.42	0.62	2.84	6.94
15	4.31	4.68	4.03	3.65	5.76	5.82	3.50	0.62	2.84	6.94
16	4.50	4.75	5.93	3.65	5.76	5.82	3.50	0.62	2.84	6.94
17	4.60	4.66	11.10	3.65	5.76	5.82	3.50	0.62	7.14	6.94
18	4.78	4.52	16.53	4.95	6.35	5.73	4.79	8.64	7.14	6.94
19	4.84	4.41	11.34	9.17	5.51	5.48	5.58	12.34	11.43	6.94
20	4.78	4.26	6.04	11.46	4.96	5.37	5.71	12.34	11.43	1.39
21	4.73	4.23	3.48	9.27	4.57	5.36	5.46	12.34	11.43	1.39
22	4.72	4.08	1.79	6.51	3.89	4.28	5.06	12.34	11.43	1.39
23	4.43	4.07	0.83	4.17	2.54	2.52	4.08	4.94	7.14	1.39
24	4.16	3.97	0.37	3.13	0.96	1.12	2.83	2.63	3.57	1.39
Sum	100.00	99.99	99.98	99.91	99.99	100.00	100.95	100.01	99.86	99.96

3.0 DESCRIPTION OF SIMULATION STUDIES CONDUCTED

Using the ENERPASS building energy simulation program and the Expanded STAR database, simulations were conducted to estimate the total household energy consumption with different scenarios for appliance efficiency, furnace efficiency, higher insulation level, and heat recovery ventilator options. Due to the wide range of domestic hot water usage values in the expanded STAR Database, it was decided that a fixed value of 212 litres/day for DHW usage would be assigned to each house as a baseline value in the simulations [11]. Since there is no data on the type and energy consumption of appliances in the Expanded STAR database, a list of appliances according to the available saturation values are randomly assigned to each house as described in Interim Report No.4 [11].

3.1 Appliance Efficiency Levels Used in Simulations

The simulations were performed utilizing three incremental levels of appliance energy efficiency, as developed and documented in Interim Report No.4 [11]. The improvements associated with each level are as follows:

Energy efficiency improvement - level 1:

A. Refrigerators:
1990 standard for top mount automatic defrost refrigerator: 893 kWh/yr,

B. Freezers:
1990 standard for average of upright and chest, manual defrost freezer: 568 kWh/yr,

C. Cooking:
Reduce energy consumption by 5% from base line,

D. Dishwasher:
Improve dishwasher motor to 1994 standard: 232 kWh/yr,

E. Clothes washers:
Automatic clothes washer controls which senses type of fabric, dirtiness and other factors and adjusts wash parameters accordingly, indirect savings in DHW energy consumption,

F. Clothes Dryer:
Clothes dryer energy consumption at the level of that required by the National Appliance Energy Conservation Act (NAECA) of U.S. for 1993: 834 kWh/yr,

G. Hot Water Heating
Use annual energy consumption of 3090 kWh/yr (reflects a total UES of 1139 kWh/yr corresponding to Items G. 1, 4, 6 in Section 5 of Interim Report No. 4),

H. TV Sets:
1990 standard for average colour TV: 164 kWh/yr,

I. Lights:
Convert from general service (75 W) incandescent lamps to general service halogen lamp with IR coating (55 W) for higher efficiency. Assume 50% of all lights are replaced, savings in load will be: [(400 W) x (0.5) / 75 W] (75 - 55) W = 53 W,

Convert from general service (90 W) incandescent lamps to compact fluorescent floor and table lamps (25 W) for higher efficiency. Assume 50% of all lights are replaced, savings in load will be: [(400 W) x (0.5) / 75 W] (90 - 25) W = 173 W

J. Air-Conditioners:
Improve central air-conditioner efficiency by 5% over baseline,

K. All Other Appliances:
Since this category includes all other appliances, it is not practical or necessary to deal with each appliance individually. Therefore, increase global efficiency by 5% over baseline,

L. Heating System Efficiency:
Increase heating season efficiency by 5% over baseline if possible (i.e. not to exceed 100% - Heat pumps were not included in this work).

Energy efficiency improvement - level 2:

A. Refrigerators:
Refrigerator energy consumption at the level of that required by the National Appliance Energy Conservation Act (NAECA) of U.S. for 1993: 704 kWh/yr,

B. Freezers:
Improved freezer to 1993 DOE standard: 468 kWh/yr,

C. Cooking:
Reduce energy consumption by 10% from baseline,

D. Dishwasher:
Same as in Level 1.

E. Clothes washers:
Bubble action washing machine with scrubbing bubbles and advanced computer design, indirect savings in DHW energy consumption: 185 kWh/yr (included in G. below).

F. Clothes Dryer:
Microwave clothes dryer using microwave rather than electric resistance heat: 617 kWh/yr,

G. Hot Water Heating
Use annual energy consumption of 2082 kWh/yr (reflects a total UES of 2147 kWh/yr corresponding to Items G. 2, 4, 5, 6, 7 in Section 5 of Interim Report No. 4)[11]

H. TV Sets:
Low powered colour TV: 135 kWh/yr,

I. Lights:
Convert from general service (75 W) incandescent lamps to Hafnium Carbide single crystal filament lamps (38 W) for higher efficiency [17]. Assume 50% of all lights are replaced, savings in load will be: [(400 W) x (0.5) / 75 W] (75 - 38) W = 99 W

Convert from general service (90 W) incandescent lamps to screw-in fluorescent (23 W) for higher efficiency [17]. Assume 50% of all lights are replaced, savings in load will be: [(400 W) x (0.5) / 90 W] (90 - 23) W = 179 W

J. Air-Conditioners:
- Improve central air-conditioner efficiency by 25% over baseline.

K. All Other Appliances:
Increase global efficiency by 10% over baseline,

L. Heating System Efficiency:
Increase heating season efficiency by 10% over baseline if possible (i.e. not to exceed 100%).

Energy efficiency improvement - level 3:

A. Refrigerators:
Golden Carrot Refrigerator: 422 kWh/yr,

B. Freezers:
Advanced freezer with improved compressor and insulation: 284 kWh/yr,

C. Cooking:
Reduce energy consumption by 15% from baseline,

D. Dishwasher:
Same as in Level 2,

E. Clothes washers:

Horizontal axis clothes washer with high efficiency motor, 26 kWh/yr,

F. Clothes Dryer:

High speed spin clothes washer/electric dryer (high spin speed removes more water, leaving less water to be removed by dryer): 521 kWh/yr,

G. Hot Water Heating

Use annual energy consumption of 1855 kWh/yr (reflects a total UES of 2374 kWh/yr corresponding to Items G. 3, 4, 5, 6, 7 in Section 5 of Interim Report No.4),

H. TV Sets:

Same as in Level 2,

I. Lights:

Convert from general service (75 W) incandescent lamps to general service coated filament incandescent (24 W) for higher efficiency. Assume 50% of all lights are replaced, savings in load will be: [(400 W) x (0.5) / 75 W] (75 - 24) W = 136 W

Convert from general service (90 W) incandescent lamps to screw-in fluorescent (23 W) for higher efficiency. Assume 50% of all lights are replaced, savings in load will be: [(400 W) x (0.5) / 90 W] (90 - 23) W = 179 W

J. Air-Conditioners:

- Improve central air-conditioner efficiency by 33% over baseline.

K. All Other Appliances:

Increase global efficiency by 15% over baseline,

L. Heating System Efficiency:

Increase heating season efficiency by 15% over baseline if possible (i.e. not to exceed 100%).

3.2 Simulations Conducted

The energy efficiency retrofit scenarios that were simulated are described below.

3.2.1 Baseline Simulations:

Baseline simulations are conducted to establish a baseline energy consumption level to which all other scenarios can be compared. For the baseline simulations, the following input data are used:

- House thermal characteristics (such as RSI values, infiltration, etc.) from Expanded STAR database,

- Baseline energy consumption data, and the load curves for appliances as given in Section 4 of Interim Report No.1 [6] and Table 1 above,

- Heating system efficiency data of the houses given in the STAR HOUSING and Hot-2000 databases. The average of heating system efficiencies in Expanded STAR are given in Table 2.

3.2.2 Series 1 Simulations:

The objective in this series of simulations is to investigate the combined effect of improved appliance and lighting efficiency as well as improved boiler/furnace efficiency on the total residential energy consumption. Thus, house thermal characteristics (such as RSI values, infiltration, etc.) from Expanded STAR database are used unchanged, whereas three different scenarios on appliance efficiency levels, along with three levels of furnace efficiency improvements (as described in Section 3.1 above) are used in the simulations.

Table 2. Average heating system efficiencies in Expanded STAR data base.[4]

Fuel	No. of Systems in Expanded STAR	Average Efficiency (%)
Oil	229	70.3
Natural Gas	406	68.8
Electric	296	99.9
Propane	4	77
Wood	2	45

The following simulations are conducted:

Series 1.A: Level 1 Appliance, Lighting and Furnace/Boiler Efficiency
Series 1.B: Level 2 Appliance, Lighting and Furnace/Boiler Efficiency
Series 1.C: Level 3 Appliance, Lighting and Furnace/Boiler Efficiency

4. See Section 4.6 below for a discussion on the "average efficiency" values.

3.2.3 Series 2 Simulations:

The objective in this series of simulations is to investigate the effect of improved appliance and lighting efficiency on the total residential energy consumption. Thus, in these simulation runs, the furnace and/boiler efficiency values as well as house thermal characteristics are kept at the same value as indicated in the house data files, and only the appliance efficiency levels are changed.

The following simulations are conducted:

Series 2.A: Level 1 Appliance and Lighting Efficiency
Series 2.B: Level 2 Appliance and Lighting Efficiency
Series 2.C: Level 3 Appliance and Lighting Efficiency

3.2.4 Series 3 Simulations:

In these simulation runs, the objective is to investigate the combined effect of:

(i) improved building envelope,
(ii) improved appliance/lighting efficiencies, and
(iii) improved furnace/boiler efficiencies

on the residential energy consumption. Thus, the RSI values for walls, roof, and windows are increased from their actual values to "medium insulation level" (see Table 3) in all houses that have insulation levels lower than the "medium insulation level". It is assumed that when a home owner improves the insulation level, air-tightness level is also improved as a result of direct (such as caulking, weather-stripping, etc.) and indirect (reduced leakage through joints, window-wall interfaces, etc.) improvements. Consequently, in these simulations the infiltration rate (Equivalent Leakage Area, ELA) is reduced by 15% reflecting the improvements in building envelope. The list of the houses that are assigned for "medium insulation level" is shown in Appendix 1.

Series 3.A: Level 1 Appliance, Lighting and Furnace/Boiler Efficiency
Series 3.B: Level 2 Appliance, Lighting and Furnace/Boiler Efficiency
Series 3.C: Level 3 Appliance, Lighting and Furnace/Boiler Efficiency

Table 3. Description of "Medium" and "High" insulation levels [13]

	Medium	High
Roof RSI	4.39	6.49
Wall RSI	2.52	3.8
Window RSI	0.31	0.48
Note: Wall RSI increase in exposed walls only.		

3.2.5 Series 4 Simulations:

These simulation runs are similar to Series 3 simulations described above, except in these simulation runs, the RSI values for walls, roof, and windows are increased from their actual values to "high insulation level" (see in Table 3) - rather than "medium insulation level" - in all houses that have insulation levels lower than the "high insulation level". It is similarly assumed that when a home owner improves the insulation level, air-tightness level is also improved as a result of direct (such as caulking, weather-stripping, etc.) and indirect (reduced leakage through joints, window-wall interfaces, etc.) improvements. Consequently, in these simulations the infiltration rate (Equivalent Leakage Area, ELA) is reduced by 30% reflecting the improvements in building envelope. The list of houses that are assigned for "high insulation level" is shown in Appendix 2.

Series 4.A: Level 1 Appliance, Lighting and Furnace/Boiler Efficiency
Series 4.B: Level 2 Appliance, Lighting and Furnace/Boiler Efficiency
Series 4.C: Level 3 Appliance, Lighting and Furnace/Boiler Efficiency

3.2.6 Series 5 Simulation:

To study the effect of retrofitting heat recovery ventilators on energy consumption, heat recovery ventilator (HRV) option is assigned in this simulation run to every house which has a mechanical ventilation system but no HRV.[5] The list of houses that have mechanical ventilation systems, and those that have HRV's are given in Appendix 8. Thus, those houses which do not have a HRV are assigned a HRV in this simulation run.

Since the performance of the HRV is assumed to be independent of the appliance efficiency, only the baseline level of appliance, lighting and furnace/boiler efficiency is used in the simulation (in fact, HRV performance is affected by fan motor efficiency; however, fan motor efficiency is not studied explicitly in this project). Thus, the following simulation is conducted:

Series 5: Baseline Level Appliance, Lighting and Furnace/Boiler Efficiency

3.2.7 Series 6 Simulations:

To study the effect of temperature setback on energy consumption, a temperature setback of 3° C is assigned to all houses that do not have temperature setback. The temperature setback schedule is from midnight to 8 o'clock in the morning (0:00 to 8:00). The list of houses which were assigned temperature setback is given in Appendix 9.

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5. The term "mechanical ventilation system" is used explicitly to refer to ducted ventilation systems serving all or most areas of a house; as such, bathroom fans are not included. These mechanical ventilation systems and HRV's are assumed to operate continuously.

The following simulations are conducted:

Series 6.A: Baseline Level Appliance, Lighting and Furnace/Boiler Efficiency
Series 6.B: Level 1 Appliance, Lighting and Furnace/Boiler Efficiency
Series 6.C: Level 2 Appliance, Lighting and Furnace/Boiler Efficiency
Series 6.D: Level 3 Appliance, Lighting and Furnace/Boiler Efficiency

3.2.8 Series 7 Simulations:

These simulations are conducted to study the combined effect of:

(i) improved insulation to "medium insulation level",
(ii) retrofitting with HRV,
(iii) night temperature setback (3°C between 00:00 hours to 08:00 hours), and
(iv) three levels of appliance, lighting and furnace/boiler efficiency

on residential energy consumption.

Thus, the RSI values for walls, roof, and windows are increased from their actual values to "medium insulation level" (see Table 3) in all houses that have insulation levels lower than the "medium insulation level", the infiltration rate (Equivalent Leakage Area, ELA) is reduced by 15% reflecting the improvement in air tightness (see Section 3.2.4), heat recovery ventilator (HRV) option is assigned to every house which has a mechanical ventilation system but no HRV, and a temperature setback of 3°C from 00:00 to 08:00 hours is assigned to all houses that do not have temperature setback. The following simulations are conducted:

Series 7.A: Level 1 Appliance, Lighting and Furnace/Boiler Efficiency
Series 7.B: Level 2 Appliance, Lighting and Furnace/Boiler Efficiency
Series 7.C: Level 3 Appliance, Lighting and Furnace/Boiler Efficiency

3.2.9 Series 8 Simulations:

These simulations are conducted to study the combined effect of:

(i) improved insulation to "high insulation level",
(ii) retrofitting with HRV,
(iii) night temperature setback (3°C between 00:00 hours to 08:00 hours), and
(iv) three levels of appliance, lighting and furnace /boiler efficiency.

Thus, the RSI values for walls, roof, and windows are increased from their actual values to "high insulation level" (see Table 3) in all houses that have insulation levels lower than the "high insulation level", the infiltration rate (Equivalent Leakage Area, ELA) is reduced by 30% reflecting the improvement in air tightness (see Section 3.2.5), heat recovery ventilator (HRV) option is assigned to every house which has a mechanical ventilation system but no HRV, and a temperature setback of 3°C from 00:00 to 08:00 hours is assigned to all houses that do not have temperature setback. The following simulations are conducted:

Series 8.A: Level 1 Appliance, Lighting and Furnace/Boiler Efficiency
Series 8.B: Level 2 Appliance, Lighting and Furnace/Boiler Efficiency
Series 8.C: Level 3 Appliance, Lighting and Furnace/Boiler Efficiency

3.2.10 Series 9 Simulations:

These simulations are conducted to study the effect of variations in load curves on energy consumption. The objective is to understand whether use of highly accurate load curves are necessary to obtain meaningful results in simulation studies such as this one. The simulations conducted, and the results obtained are given in Appendix 12.

3.2.11 Series 10 Simulations:

To study the impact of the presence appliances on energy consumption, a simulation run is conducted with all appliances removed from all houses in the Expanded STAR database of 937 houses.

4.0 COMPARISON OF EXPANDED STAR DATABASE WITH OTHERS

The Expanded STAR Database was compared to StatsCan data [14], Can-2 [15], and Can2/1989 [16] data in order to assess the degree to which it is representative of the Canadian housing stock.

4.1 Provincial Distribution of Housing Stock

The distribution of the Canadian housing stock amongst the provinces from various databases is given in Table 4. A more detailed comparison of the Expanded STAR database and Statistics Canada Data is given in Table 5.

As it can be seen from Tables 4 and 5, the distribution of the Canadian housing stock in the Expanded STAR database is relatively close to the Statistics Canada data; however, it should be noted that:

- the housing stock in Newfoundland, Manitoba, Saskatchewan and British Columbia are over-represented,
- the housing stock in P.E.I., Nova Scotia, New Brunswick, Quebec, Ontario and Alberta are under-represented (there are no houses from P.E.I. in Expanded STAR).

Thus, in future data collection efforts, the under-represented provinces should receive priority in order to make the Expanded STAR database more representative of the provincial distribution of the Canadian housing stock. The additional number of houses needed in the expanded STAR database to achieve a 0.015 percent or more representation in each province is given in Table 6.

Table 4. Comparison of distribution of housing stock in various data bases (percent)

	Nfld.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.	Total
1 Expanded STAR	7.36	0.00	0.85	1.81	19.53	32.02	8.11	7.90	7.26	15.15	100.00
2 CAN-2	2.20	0.50	3.60	3.00	23.70	35.30	4.70	4.90	9.70	12.30	99.90
3 CAN-2/1989	2.20	0.50	3.60	2.90	23.20	36.10	4.50	4.60	9.80	12.70	100.10
4 Statistics Canada	2.23	0.54	3.74	3.08	20.03	37.74	4.40	4.37	10.56	13.34	100.03

Table 5. Comparison of distribution of housing stock: Expanded STAR and Statistics Canada data

Stats. Can. Data (1992) No. of Single Dwellings			Expanded STAR	
	Thousands	Percent	No. of houses	Percent
Canada	6846	100.00	937	100.00
Nfld.	153	2.23	69	7.36
P.E.I.	37	0.54	0	0.00
N.S.	256	3.74	8	0.85
N.B.	211	3.08	17	1.81
Que.	1371	20.03	183	19.53
Ont.	2584	37.74	300	32.02
Man.	301	4.40	76	8.11
Sask.	299	4.37	74	7.90
Alta.	723	10.56	68	7.26
B.C.	913	13.34	142	15.15

Table 6. Expanded STAR sample size relative to number of single dwellings in Canada and Additional Number of Houses Required for 0.015% Representation

	Exp. STAR Sample Size (%)	For 0.015%	
		Sample size needed	Additional No. needed
Canada	0.01369	1027	201
Nfld.	0.04510	23	-46
P.E.I.	0.00000	6	6
N.S.	0.00313	38	30
N.B.	0.00806	32	15
Que.	0.01335	206	23
Ont.	0.01161	388	88
Man.	0.02525	45	-31
Sask.	0.02475	45	-29
Alta.	0.00941	108	40
B.C.	0.01555	137	-5

4.2 Space Heating Fuel Type

The distribution of houses according to the principal space heating fuel in Expanded STAR and in the Canadian housing stock given by Statistics Canada for single dwellings [6] is compared in Table 7. The "% Difference" column shows the difference between Expanded STAR and Statistic Canada data, with positive values indicating larger values in Expanded STAR, and negative values indicating the opposite.

It can be seen from Table 7 that in Expanded STAR:

- oil heating is generally over-represented in all provinces except in N.S. and P.E.I.,
- more houses with natural gas heating are needed in Ontario and B.C.,
- more houses with wood and propane heating are needed in all provinces,
- more houses with electricity heating are needed in Quebec, Ontario, Manitoba and Saskatchewan,
- the distribution of houses according to the principal space heating fuel in Expanded STAR is closer to Statistics Canada data when all of Canada is considered rather than individual provinces.

6. "Single dwellings" include single detached, single attached (double, row or terrace) and mobile homes.

Table 7. Percentage distribution of Households by Principal Heating Fuel: comparison of Expanded STAR data with Statistics Canada Data (Statistics Canada data for single dwellings only)

	OIL			NATURAL GAS			PROPANE			ELECTRICITY			WOOD		
	Exp. STAR	Stats. Can.	% Difference	Exp. STAR	Stats. Can.	% Difference	Exp. STAR	Stats. Can.	% Difference	Exp. STAR	Stats. Can.	% Difference	Exp. STAR	Stats. Can.	% Difference
Can.	24.4	17.1	42.9	43.3	48.6	-10.9	0.4	1.0	-56.7	31.6	27.6	14.6	0.2	5.7	-96.3
Nfld.	50.7	35.3	43.7	0.0	0.0	0.0	0.0	0.0	0.0	47.8	41.2	16.1	1.4	23.5	-93.8
P.E.I.	0.0	81.1	-100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.2	-100.0
N.S.	0.0	60.2	-100.0	0.0	0.0	0.0	0.0	1.6	-100.0	100.0	22.3	349.1	0.0	14.5	-100.0
N.B.	52.9	28.4	86.2	0.0	0.0	0.0	0.0	0.0	0.0	47.1	54.0	-12.9	0.0	17.1	-100.0
Que.	37.2	20.8	78.8	3.8	3.7	2.8	0.0	0.0	0.0	58.5	67.7	-13.6	0.5	7.7	-92.9
Ont.	21.3	16.4	30.3	44.7	61.7	-27.6	0.0	0.9	-100.0	34.0	17.7	92.2	0.0	3.2	-100.0
Man.	5.3	5.0	5.6	78.9	61.5	28.4	0.0	0.0	0.0	15.8	27.9	- 43.4	0.0	4.0	-100.0
Sask.	13.5	9.0	49.6	85.1	81.9	3.9	1.4	1.7	-19.2	0.0	5.0	-100.0	0.0	0.0	0.0
Alta.	4.4	1.7	165.8	92.6	93.9	-1.3	1.5	2.5	-40.9	1.5	0.0	0.0	0.0	0.0	0.0
B.C.	25.4	11.9	112.4	55.6	62.5	-11.0	1.4	0.0	0.0	17.6	17.6	-0.2	0.0	6.7	-100.0

4.3 Fuel Usage in Residences

The comparison of fuel usage from baseline simulations on Expanded STAR and from Statistics Canada and Natural Resources Canada data is given in Table 8 for each province and all of Canada. The data for Natural Gas, Oil, Propane and Electricity are from Statistics Canada. Since Statistics Canada does not publish any statistics for wood consumption, the figures for wood consumption used in the table are from Natural Resources Canada estimates. Similar conclusions to those in Section 4.2 above can be drawn from Table 8.

4.4 Annual Average Energy Consumption per Household

The average energy consumption in the CANADA-2 housing stock model is 151 GJ/year [3]. The average energy consumption for all houses in the Expanded STAR database estimated from the baseline simulations is 152 GJ/year which is only 0.66% higher than the CANADA-2 estimate.

4.5 DHW and Appliance Energy Consumption

As explained in Interim Report No.4, heating energy requirement for domestic hot water (DHW) heating is assumed to be 4490 kWh/yr in the baseline simulations done on the Expanded STAR database [11].[7] The average of DHW heating energy consumption for all houses in the STAR database (698 houses) is 4279 kWh/yr. Thus, the difference between the value used in the simulations and the value in the STAR database is 4.9%.

The average baseline appliance electricity consumption (excluding DHW and lighting) in Expanded STAR is 6903 kWh/yr. In the STAR database (698 houses) the appliance energy consumption is 6556 kWh/yr. Thus, the difference between the value used in the simulations and the value in the STAR database is 5.3%.

4.6 Average Heating System Efficiency Values

The average heating system efficiencies in Expanded STAR data base were given in Table 2. The average efficiency for natural gas heating systems in Expanded STAR is somewhat lower than expected (at 68.8%, it is actually lower than the average efficiency of oil heating systems, which is 70.3%). This may be due to the data collected from older natural gas furnaces or data from natural gas conversions done on originally oil fired furnaces.

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7. "Heating energy requirement" refers to the amount of energy that has to be actually supplied to the water. Thus, to obtain the equivalent fuel consumption, this value has to be divided by the fuel conversion efficiency and the fuel heating value.

Table 8. Percentage distribution of Fuel Usage: Comparison of Expanded STAR data with Statistics Canada Data (Source: Statistics Canada, Quarterly Report on Energy Supply-Demand in Canada, 1992-IV, Cat. 57-003, June 1993 and NRCan 1992 Estimates for Wood (from Efficiency and Alternative Energy Branch)

	OIL			NATURAL GAS			PROPANE			ELECTRICITY			WOOD		
	Exp. STAR	Stats. Can.	% Difference	Exp. STAR	Stats. Can.	% Difference	Exp. STAR	Stats. Can.	% Difference	Exp. STAR	Stats. Can.	% Difference	Exp. STAR	Stats. Can.	% Difference
Can.	16.92	10.82	56.38	37.37	43.36	-13.81	0.20	1.12	-81.85	45.33	36.98	22.60	0.18	7.58	-97.69
Nfld.	41.81	30.15	38.66	0.00	0.00	N/A	0.00	0.88	-100.00	56.97	44.89	26.90	1.22	24.08	-94.92
P.E.I.	0.00	62.27	-100.00	0.00	0.00	N/A	0.00	3.26	-100.00	0.00	13.07	-100.00	0.00	21.41	-100.00
N.S.	0.00	47.12	-100.00	0.00	0.00	N/A	0.00	2.04	-100.00	100.00	30.80	224.68	0.00	17.72	-100.00
N.B.	45.23	30.98	46.00	0.00	0.00	N/A	0.00	2.18	-100.00	54.77	47.18	16.07	0.00	19.65	-100.00
Que.	30.85	18.00	71.39	3.37	8.38	-59.83	0.00	0.64	-100.00	65.22	61.07	6.79	0.57	11.91	-95.25
Ont.	14.39	6.34	126.87	37.93	57.13	-33.61	0.00	0.97	-100.00	47.68	30.98	53.91	0.00	4.58	-100.00
Man.	4.39	3.19	37.66	61.06	53.03	15.13	0.00	0.60	-100.00	34.55	37.53	-7.92	0.00	5.65	-100.00
Sask.	9.83	3.78	160.11	65.78	73.44	-10.42	0.74	1.51	-50.84	23.64	18.34	28.88	0.00	2.52	-100.00
Alta.	4.29	0.33	1211.48	69.43	80.92	-14.20	0.82	1.53	-46.26	25.46	14.31	77.86	0.00	2.40	-100.00
B.C.	12.46	4.67	166.64	46.57	48.85	-4.68	0.41	1.34	-69.04	40.56	37.80	7.32	0.00	7.32	-100.00

5. RESULTS OF ENERPASS SIMULATIONS ON EXPANDED STAR

5.1 General Comments

All series of simulations described in Section 3.2 were conducted using the batch version of the ENERPASS hourly energy simulation program. In each series of simulations, all of the 937 house files were used. The printout subroutine of the ENERPASS program was modified to reduce the amount of output. However, due to the large number of houses, the output from one batch run is about 2.5 MB, and it is clearly not feasible to include all results in this report. Instead, a sample output file is presented in Table A11-1, Appendix 11 and the input and output files are included in the computer data storage tapes described in Appendix 10. In summary, the following files are available:

1. ENERPASS input data files for each batch run,
2. ENERPASS output files for each batch run saved in EXCEL spreadsheet format (A sample printout from one of the output files is given in Appendix 11.),
3. Summary of ENERPASS output files for each series of simulations (Two summary EXCEL spreadsheet files containing the provincial totals of each fuel used for space heating, DHW heating and appliance electricity consumption are included. One of these summary files contain the results of Baseline and Series 1-8 simulations and the other Series 9-10 simulations. A sample printout from one of the summary output files is given in Table A11-2, Appendix 11.)

5.2 Comments on Result Analysis

The result analysis presented in the following sections of this report focuses on the totals for each primary space heating fuel for all of Canada. No analysis of the results are conducted at provincial level because the distribution of housing stock, fuel usage and fuel consumption in Expanded STAR is more representative of the Canadian housing stock at national level.

The interrelationships due to use of different fuels for space heating and DHW heating are not analyzed as it is not possible within the scope of this study to carry out all of the different levels of analyses that can be done using the results of simulations conducted. This is because of the sheer quantity of the results and the large number of cases that can be evaluated. The size of the analysis domain can be appreciated from Figure 1 where the number of possible analyses that can be carried out are shown.

The detailed simulation results described in Section 5.1 above can therefore be considered as a tool to carry out the various analyses that may be found necessary. Similarly, for additional analyses for which simulation runs have not already be carried out, the ENERPASS input files can be modified, and ENERPASS batch runs can be conducted with ease.

5.3 Analysis of Results

In the following sections, the results of simulations are analyzed for each series of simulations separately. In the analysis of each series, the results are presented in tabular (Tables 10-18) and in graphical form (Figures 2-10) for each different space heating fuel. The equivalent energy consumption (in GJ) and relative fuel consumption with respect to baseline for each fuel for space heating, DHW heating and appliances are given in these Tables and Figures. Since in some houses the space heating fuel and DHW heating fuel are not the same, the DHW fuel consumption given for a fuel may not be from the same houses in the group. Thus, the results presented in the tables are to be interpreted as follows (see Table 9 for reference):

1. Each table has two parts. The first part, which is the left hand side half of the table gives the equivalent energy consumption for each fuel for all of the houses in Expanded STAR in GJ. In Table 9, the portion of a table for electricity and natural gas is given.
2. The second part of the table, which is the right hand side half, gives the relative energy consumption with respect to the baseline, i.e. the baseline energy consumption is assigned a value of 100, and the relative fuel consumption for other scenarios (i.e. Series 1.A, 1.B and 1.C in Table 9) are calculated based on 100.
3. Equivalent energy consumption (GJ) and relative energy consumption (base 100) values for each fuel are given separately. Thus, each table has five sections: Electricity, Natural Gas, Oil, Propane and Wood.
4. In Columns 1 and 6 the simulation scenario names are given.
5. In Columns 2 and 7, the equivalent and relative energy consumption values for space heating are given for each fuel for all houses in Expanded STAR for space heating.
6. In Columns 3 and 8, the equivalent and relative energy consumption values are given for each fuel for all houses in Expanded STAR for DHW heating. Since in some houses different fuels are used for space heating and DHW heating, the houses included in 'Space Heat' and 'DHW' columns may be different.
7. In Columns 4 and 9, the actual and relative electricity consumption by appliances are given for each fuel used for space heating.
8. In Columns 5 and 10, the total equivalent fuel consumption and relative fuel consumption values are given for each fuel. These values are the totals for space heating, DHW heating and appliances.
9. At the bottom of each table, the average house fuel consumption is given for all scenarios. These values are calculated by dividing the total energy consumption for all houses and dividing the total by the number of houses in Expanded STAR.

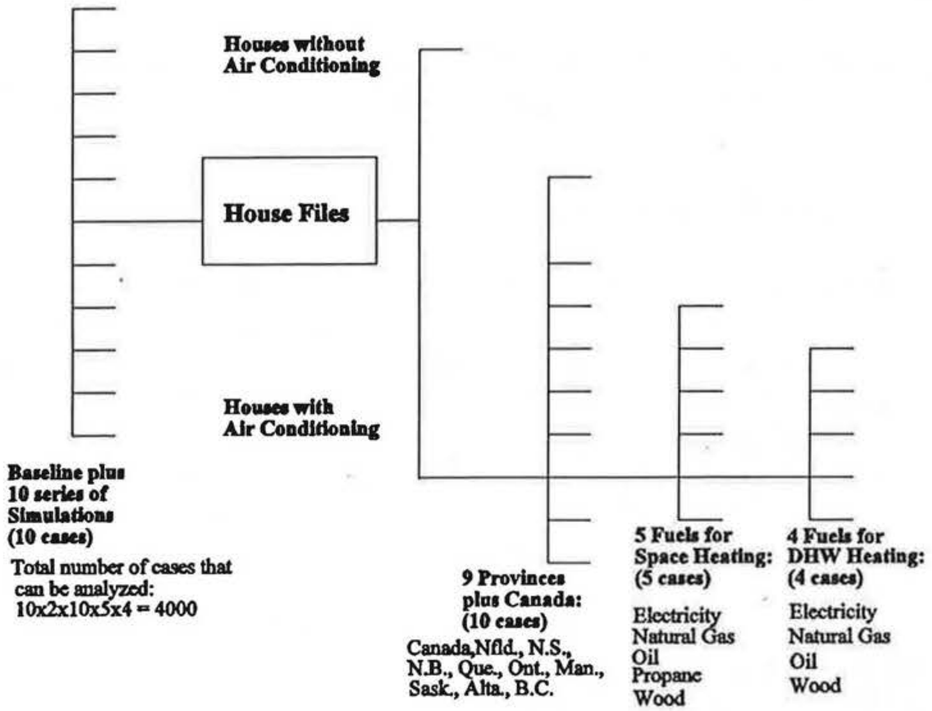


Figure 1. Depiction of possible cases that can be analyzed

Table 9. Sample Results Table - Partial - Canada

COLUMNS

1	2	3	4	5	6	7	8	9	10
All Values in GJ					Relative Values				
Electricity					Electricity				
	Space Heat	DHW	Appliance	TOTAL		Space Heat	DHW	Appliance	TOTAL
BASELINE	16878	8368	12539	37785	BSLN	100	100	100	100
Series 1.A	19572	6461	7800	33833	1.A	116	77	62	90
Series 1.B	20277	4761	6466	31504	1.B	120	57	52	83
Series 1.C	20992	4382	5266	30640	1.C	124	52	42	81
Natural Gas					Natural Gas				
	Space Heat	DHW	Appliance	TOTAL		Space Heat	DHW	Appliance	TOTAL
BASELINE	42182	10894	16967	70043	BSLN	100	100	100	100
Series 1.A	44435	8400	10559	63394	1.A	105	77	62	91
Series 1.B	42817	6181	8749	57748	1.B	102	57	52	82
Series 1.C	41413	5685	7126	54224	1.C	98	52	42	77

5.3.1 Results of Series 1 Simulations

In these series of simulations the effect of improvements in appliance and heating system efficiencies are evaluated, and the results are given in Table 10 and Figure 2. Based on these results the following trends are apparent:

1. In houses where the primary space heating fuel is electricity:

   a) Space heating energy requirement increases significantly as appliance efficiency improves. There are two reasons for this: (i) as appliance efficiency increases, heat gain from appliances decreases, thus space heating requirement increases, (ii) since the efficiency of space heating with electricity cannot increase (already 100%), there is no reduction in space heating energy requirement.

   b) The electricity consumption for DHW heating and appliances decreases significantly as appliance efficiency increases. The reason for the reduction in DHW heating energy is the reduced DHW consumption for dish washing, clothes washing and general washing, as well as reduced heat losses from the system.

   c) The reduction in appliance energy consumption is greater than the increase in electricity consumption for space heating, indicating that it is not beneficial to "heat" a house with appliances. There are several reasons for this:
      - A large part of the energy wasted in inefficient heating and use of DHW (such as in a clothes washer) is lost down the drain without any heat gain to the house,
      - A large part of the energy wasted in clothes dryers is exhausted directly to outdoors,
      - The heat gain from inefficient appliances is not always "useful" heat gain. When little or no heating is necessary during the warmer periods of shoulder seasons, the heat gain is wasted since it does not offset the heating requirement from the furnace or boiler. On the other hand, during the cooling season, the heat gain is a nuisance in non-air-conditioned houses and a source of additional energy waste in air-conditioned houses since the air-conditioner has to work harder to extract this additional heat gain.

   d) The total energy consumption for space and DHW heating and appliances decrease by close to 20%.

   e) A review of the detailed output files indicate that in houses with air-conditioning the decrease in total energy consumption with increased appliance efficiency is even greater since the air-conditioning system has to work less to remove the appliance heat gain during the cooling season.

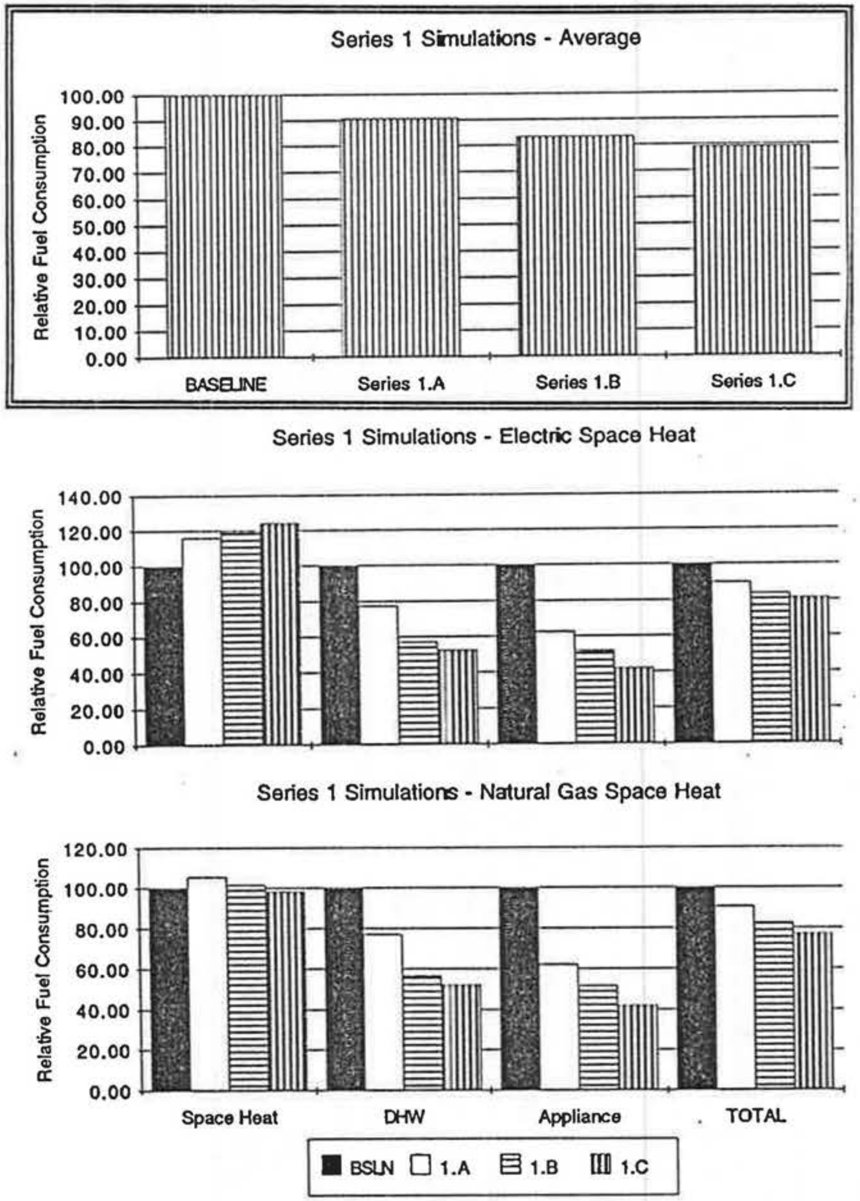
2. In houses where the primary heating fuel is other than electricity:

   a) Space heating energy requirements increase in Series 1.A simulation because the increase in heating system efficiency cannot make up for the loss of heat gain from improved appliances. However, in Series 1.B and 1.C simulations, space heating energy decreases slightly to the level of baseline consumption as the improvement in heating system efficiency can make up for the reduced heat gain from appliances.

Table 10. Series 1 Simulation Results

All Values in GJ				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
Baseline	16878	8368	12539	37785
Series1.A	19572	6461	7800	33833
Series 1.B	20277	4761	6466	31504
Series 1.C	20992	4382	5266	30640
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
Baseline	42182	10894	16967	70043
Series1.A	44435	8400	10559	63394
Series 1.B	42817	6181	8749	57748
Series 1.C	41413	5685	7126	54224
Oil				
	Space Heat	DHW	Appliance	TOTAL
Baseline	21997	2029	9381	33407
Series1.A	23385	1566	5740	30691
Series 1.B	22606	1154	4743	28503
Series 1.C	21929	1062	3832	26822
Wood				
	Space Heat	DHW	Appliance	TOTAL
Baseline	220	29	81	330
Series1.A	232	22	51	305
Series 1.B	219	16	43	278
Series 1.C	209	15	35	258
Propane				
	Space Heat	DHW	Appliance	TOTAL
Baseline	288	0	166	453
Series1.A	314	0	102	416
Series 1.B	307	0	85	391
Series 1.C	301	0	68	369
Total				
	Space Heat	DHW	Appliance	TOTAL
Baseline	81565	21319	39135	142019
Series1.A	87938	16449	24253	128639
Series 1.B	86226	12113	20085	118425
Series 1.C	84844	11143	16326	112312
	Ave. House			
Baseline	152			
Series1.A	137			
Series 1.B	126			
Series 1.C	120			

Relative Values				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	116	77	62	90
1.B	120	57	52	83
1.C	124	52	42	81
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	105	77	62	91
1.B	102	57	52	82
1.C	98	52	42	77
Oil				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	106	77	61	92
1.B	103	57	51	85
1.C	100	52	41	80
Wood				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	105	77	63	92
1.B	99	57	53	84
1.C	95	52	43	78
Propane				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	N/A	100	100
1.A	109	N/A	61	92
1.B	107	N/A	51	86
1.C	105	N/A	41	81
Total				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	108	77	62	91
1.B	106	57	51	83
1.C	104	52	42	79
	Average			
BSLN	100			
1.A	91			
1.B	83			
1.C	79			



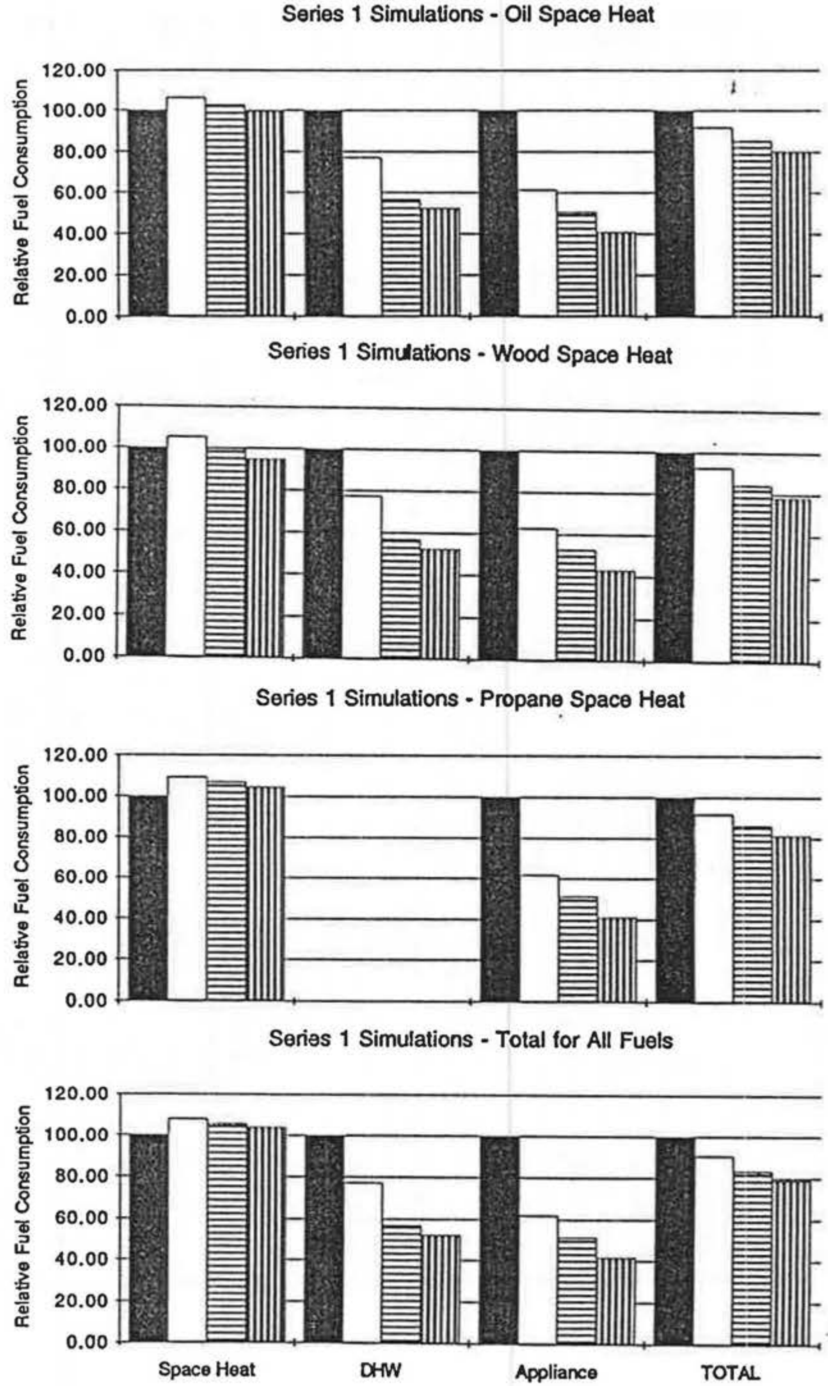


Figure 2. Series 1 simulation results

b) Since no houses in Expanded STAR have propane DHW heating, the reduction in total energy consumption for houses with propane space heating is smaller compared to those with other fossil fuels. Also, it should be noted that propane consumption increases since propane is used only for space heating.

3. For all houses in Expanded STAR:

   The average house fuel consumption decreases as appliance and heating system efficiencies increase. A switch to the highest level of efficiency in all houses would result in a reduction of 21% in overall residential energy consumption, all of which is in the form of electricity.

5.3.2 Results of Series 2 Simulations

In these series of simulations the effect of improvements in appliance efficiencies are evaluated with heating system efficiencies kept constant. The results are given in Table 11 and Figure 3. Based on these results the following trends can be identified:

1. In houses where the primary space heating fuel is electricity, the results are identical to those in Series 1 simulations since the heating system efficiency is constant at 100%.

2. In houses where the primary heating fuel is other than electricity:

   a) Space heating energy requirements increase for all fuels since the heat gain from appliances decrease as appliance efficiency increases, and the heating systems have to make up for this heat gain.
   b) While the fuel consumption for space heating increases, the fuel consumption for DHW heating and appliances decrease as appliance efficiency increases. The net result of this is that the total energy consumption for space/DHW heating and appliances decrease for all houses regardless of space heating fuel type.
   c) The ratios of the increase in space heating energy consumption to the reduction in appliance energy consumption show expected trends. For example, if the results from baseline and Series 2.A simulations are compared, the following ratios can be found:

   <u>Electricity:</u>
   Reduction in appliance energy consumption (Series 2.A - Baseline) =
   12539 - 7800 = 4739 GJ
   Increase in heating energy consumption (Series 2.A - Baseline) =
   19572 - 16878 = 2694 GJ
   Ratio of increase in space heating energy consumption to reduction in appliance energy consumption = 2694 / 4739 = 0.57

Table 11. Series 2 simulation Results

All Values in GJ					Relative Values				
Electricity					Electricity				
	Space Heat	DHW	Appliance	TOTAL		Space Heat	DHW	Appliance	TOTAL
Baseline	16878	8368	12539	37785	BSLN	100	100	100	100
Series	19572	6461	7800	33833	1.A	116	77	62	90
Series 2.B	20277	4761	6466	31504	1.B	120	57	52	83
Series 2.C	20992	4382	5266	30640	1.C	124	52	42	81
Natural Gas					Natural Gas				
	Space Heat	DHW	Appliance	TOTAL		Space Heat	DHW	Appliance	TOTAL
Baseline	42182	10894	16967	70043	BSLN	100	100	100	100
Series2.A	47740	8400	10559	66699	1.A	113	77	62	95
Series 2.B	49183	6181	8749	64113	1.B	117	57	52	92
Series 2.C	50637	5685	7126	63447	1.C	120	52	42	91
Oil					Oil				
	Space Heat	DHW	Appliance	TOTAL		Space Heat	DHW	Appliance	TOTAL
Baseline	21997	2029	9381	33407	BSLN	100	100	100	100
Series2.A	25063	1566	5740	32369	1.A	114	77	61	97
Series 2.B	25850	1154	4743	31747	1.B	118	57	51	95
Series 2.C	26647	1062	3832	31540	1.C	121	52	41	94
Wood					Wood				
	Space Heat	DHW	Appliance	TOTAL		Space Heat	DHW	Appliance	TOTAL
Baseline	220	29	81	330	BSLN	100	100	100	100
Series2.A	257	22	51	331	1.A	117	77	63	100
Series 2.B	268	16	43	327	1.B	122	57	53	99
Series 2.C	278	15	35	328	1.C	126	52	43	99
Propane					Propane				
	Space Heat	DHW	Appliance	TOTAL		Space Heat	DHW	Appliance	TOTAL
Baseline	288	0	166	453	BSLN	100	N/A	100	100
Series2.A	335	0	102	437	1.A	116	N/A	61	96
Series 2.B	347	0	85	431	1.B	121	N/A	51	95
Series 2.C	359	0	68	428	1.C	125	N/A	41	94
Total					Total				
	Space Heat	DHW	Appliance	TOTAL		Space Heat	DHW	Appliance	TOTAL
Baseline	81565	21319	39135	142019	BSLN	100	100	100	100
Series2.A	92967	16449	24253	133668	1.A	114	77	62	94
Series 2.B	95924	12113	20085	128122	1.B	118	57	51	90
Series 2.C	98914	11143	16326	126382	1.C	121	52	42	89
	Ave. House					Average			
Baseline	152				BSLN	100			
Series2.A	143				1.A	94			
Series 2.B	137				1.B	90			
Series 2.C	135				1.C	89			

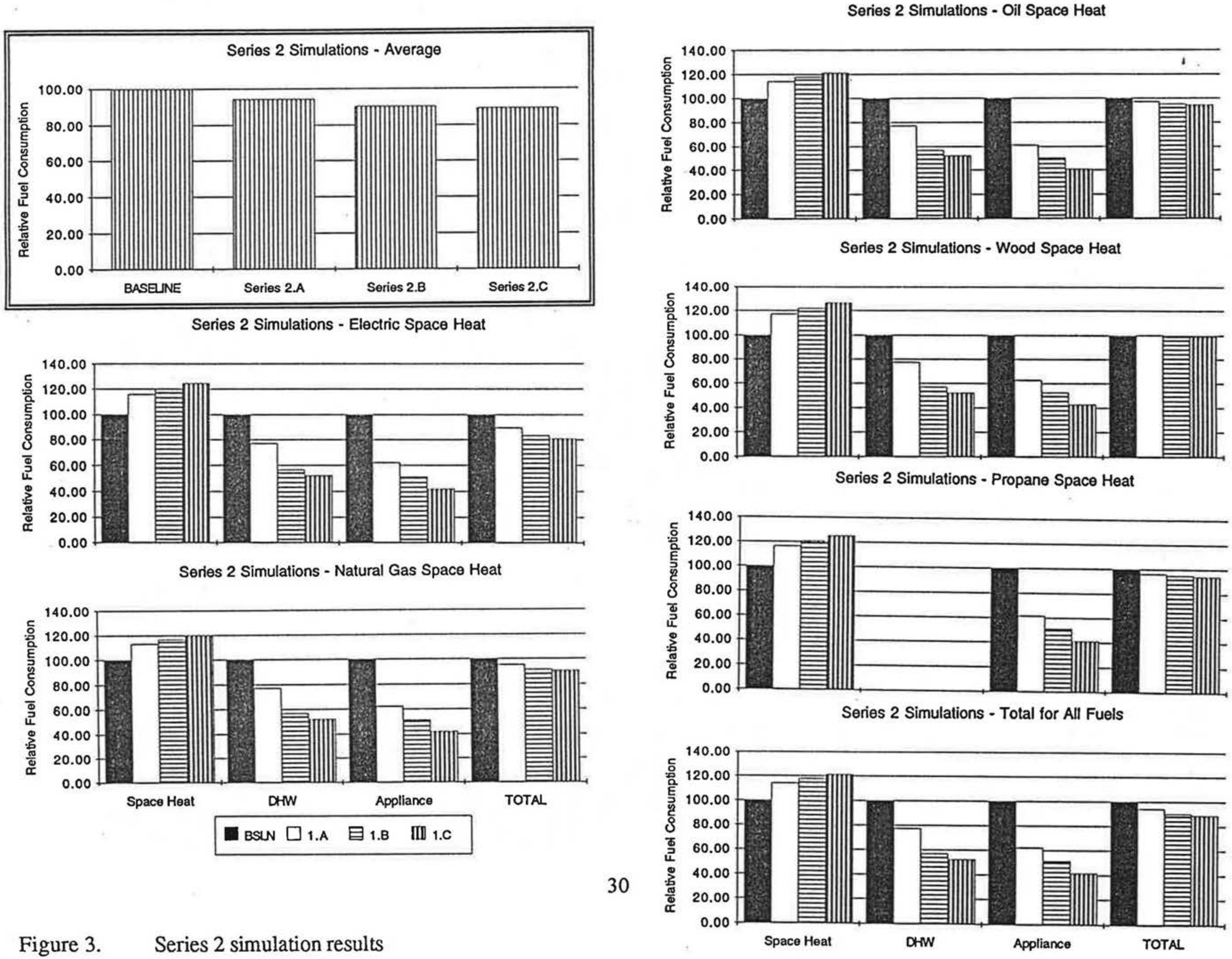


Figure 3. Series 2 simulation results

Using the same methodology, the same ratio can be calculated for other fuels and other scenarios. The ratios for Series 2.A and Baseline results are as follows:

Natural Gas:

Ratio of increase in space heating energy consumption to reduction in appliance energy consumption = 0.87

Oil:

Ratio of increase in space heating energy consumption to reduction in appliance energy consumption = 0.84

Wood:

Ratio of increase in space heating energy consumption to reduction in appliance energy consumption = 1.23

Propane:

Ratio of increase in space heating energy consumption to reduction in appliance energy consumption = 0.73

These ratios clearly show the effect of heating system efficiency on the heating energy requirement and end-use energy savings. In those houses where electricity is used for space heating (which has a conversion efficiency of 99.9%), the increase in space heating energy consumption is equivalent to 57% of the savings in appliance energy consumption. Thus, for each 100 units of electricity saved in appliances, the heating system has to provide 57 units of heat from electricity. Thus, it is clear that heat gain from appliances is not a feasible source of space heating. Similar conclusions can be made for natural gas, oil and propane space heating systems. However, for wood space heating, the conclusion is the opposite. It can be seen that the increase in space heating energy consumption is actually more than the savings in appliance energy consumption. The reason for this is the low (45%) energy conversion efficiency of wood space heating systems. Consequently, for every 100 units of electricity saved in appliances, wood equivalent of 123 units of energy has to be burned in the furnace. However, when the savings in DHW heating energy are also included in the comparisons, it is clear from Table 11 that high efficiency appliances would result in overall end-use energy savings.

d) The total energy consumption for all fuels decreases with the use of more efficient appliances. Thus, by switching to more efficient appliances, electricity consumption is replaced by a smaller amount of other fuel consumption.

3. For all houses in Expanded STAR, the average house fuel consumption decreases as appliance efficiencies increase. A switch to the highest level of efficiency would result in a reduction of 11% in overall residential energy consumption, all of which is in the form of electricity. Clearly, the total reduction in energy consumption is less than that of Series 1 simulations due to the lower efficiencies of heating systems.

5.3.3 Results of Series 3 Simulations

In these series of simulations the effect of improvements in insulation to medium insulation level, and improvements in appliance and boiler/furnace efficiencies are evaluated. The results are given in Table 12 and Figure 4. When these results are compared to the results from Series 1 simulations, it can be seen that the improvements in insulation result in a further 10% reduction in total residential energy consumption.

5.3.4 Results of Series 4 Simulations

In these series of simulations the effect of improvements in insulation in the houses to high insulation level, as well as improvements in appliance efficiencies are evaluated, and the results are given in Table 13 and Figure 5. When these results are compared with the results from Series 1 and Series 3 simulations, it can be seen that the improvements in insulation result in a 20% reduction in total energy consumption compared with Series 1 results, and a 10% reduction compared with Series 3 simulations

5.3.5 Results of Series 5 Simulations

In these series of simulations the effect of installing HRV in all houses that have mechanical ventilation systems is evaluated, and the results are given in Table 14 and Figure 6.[8] Out of the 937 houses in the Expanded STAR, only 69 houses have mechanical ventilation (7% of all houses), and 54 of these did not have HRVs.

The reduction in total energy consumption as a result of installing HRVs is quite small because of the small number of houses that have mechanical ventilation systems. Similarly, there is no reduction in oil, wood and propane consumption because there are no houses with mechanical ventilation systems that use these fuels. As a result, the reduction in energy consumption is less than 2% for all of the houses in Expanded STAR.

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8. The term "mechanical ventilation system" is used explicitly to refer to ducted ventilation systems serving all or most areas of a house; as such, bathroom fans are not included. These mechanical ventilation systems and HRV's are assumed to operate continuously.

Table 12. Series 3 Simulation Results

All Values in GJ				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
Baseline	16878	8368	12539	37785
Series	16934	6458	7802	31194
Series 3.B	17620	4759	6466	28845
Series 3.C	18320	4379	5265	27964
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
Baseline	42182	10894	16967	70043
Series3.A	37884	8396	10563	56843
Series 3.B	36639	6178	8751	51568
Series 3.C	35566	5682	7126	48374
Oil				
	Space Heat	DHW	Appliance	TOTAL
Baseline	21997	2029	9381	33407
Series3.A	18401	1565	5739	25705
Series 3.B	17907	1153	4742	23801
Series 3.C	17483	1061	3830	22373
Wood				
	Space Heat	DHW	Appliance	TOTAL
Baseline	220	29	81	330
Series3.A	210	22	51	283
Series 3.B	199	16	43	258
Series 3.C	190	15	35	240
Propane				
	Space Heat	DHW	Appliance	TOTAL
Baseline	288	0	166	453
Series3.A	250	0	102	351
Series 3.B	245	0	85	330
Series 3.C	242	0	68	310
Total				
	Space Heat	DHW	Appliance	TOTAL
Baseline	81565	21319	39135	142019
Series3.A	73678	16441	24257	114377
Series 3.B	72610	12107	20086	104802
Series 3.C	71801	11137	16324	99261
	Ave. House			
Baseline	152			
Series3.A	122			
Series 3.B	112			
Series 3.C	106			

Relative Values				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	100	77	62	83
1.B	104	57	52	76
1.C	109	52	42	74
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	90	77	62	81
1.B	87	57	52	74
1.C	84	52	42	69
Oil				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	84	77	61	77
1.B	81	57	51	71
1.C	79	52	41	67
Wood				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	95	77	63	86
1.B	90	57	53	78
1.C	86	52	43	73
Propane				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	N/A	100	100
1.A	87	N/A	61	78
1.B	85	N/A	51	73
1.C	84	N/A	41	68
Total				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	90	77	62	81
1.B	89	57	51	74
1.C	88	52	42	70
	Average			
BSLN	100			
1.A	81			
1.B	74			
1.C	70			

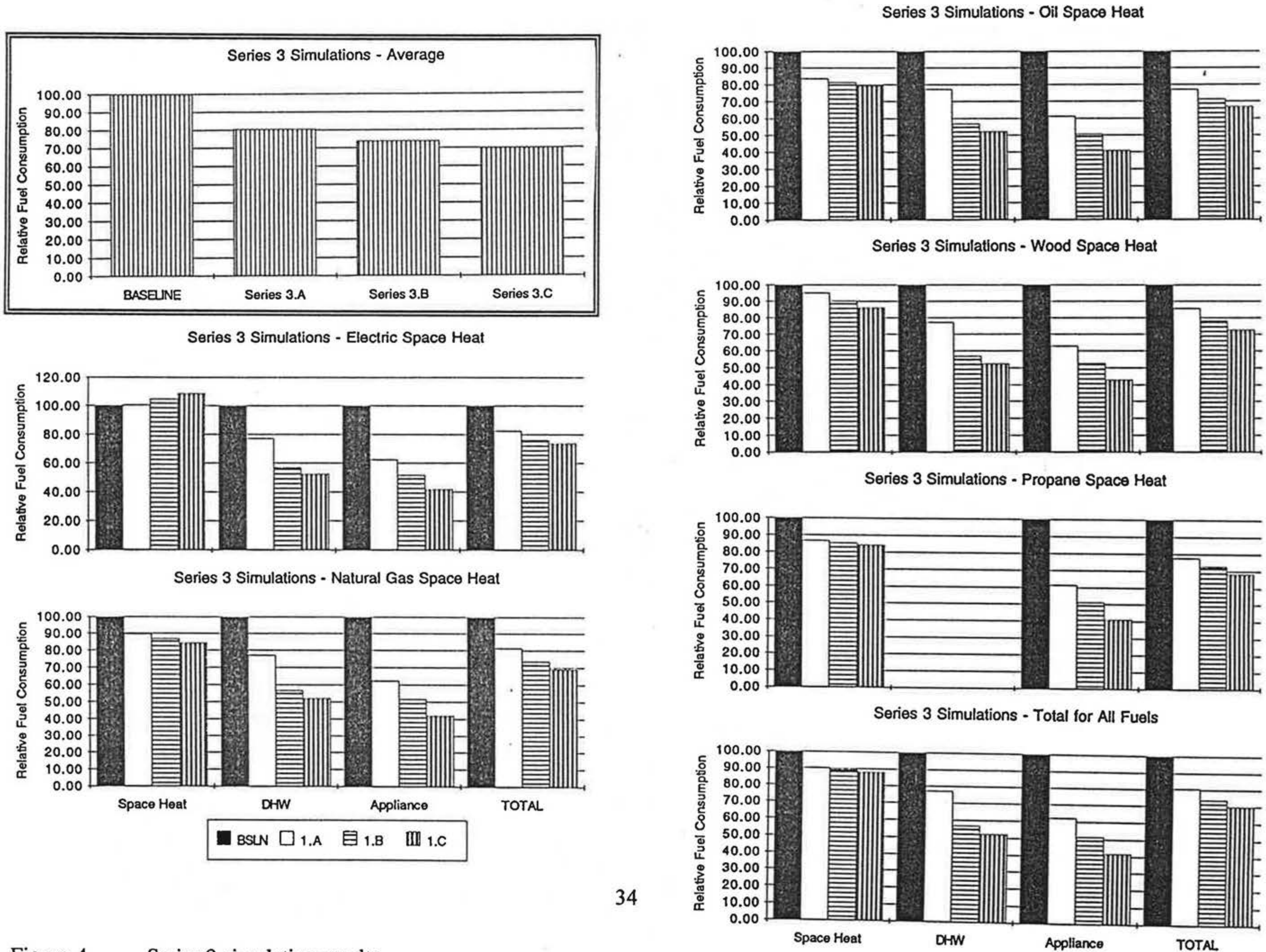
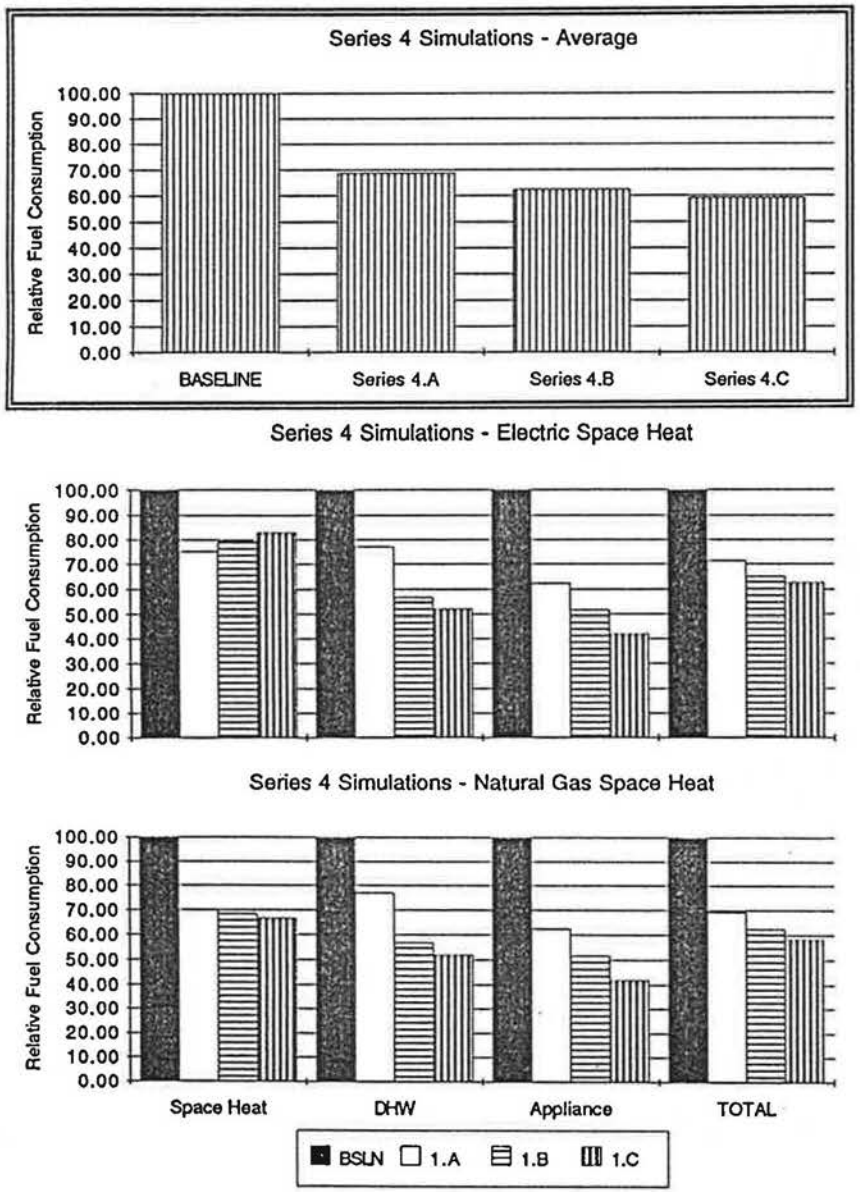


Figure 4. Series 3 simulation results

Table 13. Series 4 Simulation Results

All Values in GJ				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
Baseline	16878	8368	12539	37785
Series4.A	12708	6452	7823	26982
Series 4.B	13350	4753	6480	24584
Series 4.C	14009	4374	5276	23659
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
Baseline	42182	10894	16967	70043
Series4.A	29589	8389	10586	48565
Series 4.B	28810	6172	8766	43747
Series 4.C	28150	5676	7138	40964
Oil				
	Space Heat	DHW	Appliance	TOTAL
Baseline	21997	2029	9381	33407
Series4.A	14247	1564	5746	21558
Series 4.B	13977	1152	4746	19875
Series 4.C	13754	1060	3833	18646
Wood				
	Space Heat	DHW	Appliance	TOTAL
Baseline	220	29	81	330
Series4.A	169	22	51	242
Series 4.B	161	16	43	220
Series 4.C	155	15	35	205
Propane				
	Space Heat	DHW	Appliance	TOTAL
Baseline	288	0	166	453
Series4.A	205	0	102	307
Series 4.B	203	0	85	287
Series 4.C	201	0	68	270
Total				
	Space Heat	DHW	Appliance	TOTAL
Baseline	81565	21319	39135	142019
Series4.A	56919	16426	24308	97653
Series 4.B	56501	12093	20120	88714
Series 4.C	56269	11125	16349	83744
	Ave. House			
Baseline	152			
Series4.A	104			
Series 4.B	95			
Series 4.C	89			

Relative Values				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	75	77	62	71
1.B	79	57	52	65
1.C	83	52	42	63
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	70	77	62	69
1.B	68	57	52	62
1.C	67	52	42	58
Oil				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	65	77	61	65
1.B	64	57	51	59
1.C	63	52	41	56
Wood				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	77	77	63	73
1.B	73	57	53	67
1.C	71	52	43	62
Propane				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	N/A	100	100
1.A	71	N/A	61	68
1.B	70	N/A	51	63
1.C	70	N/A	41	59
Total				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
1.A	70	77	62	69
1.B	69	57	51	62
1.C	69	52	42	59
	Average			
BSLN	100			
1.A	69			
1.B	62			
1.C	59			



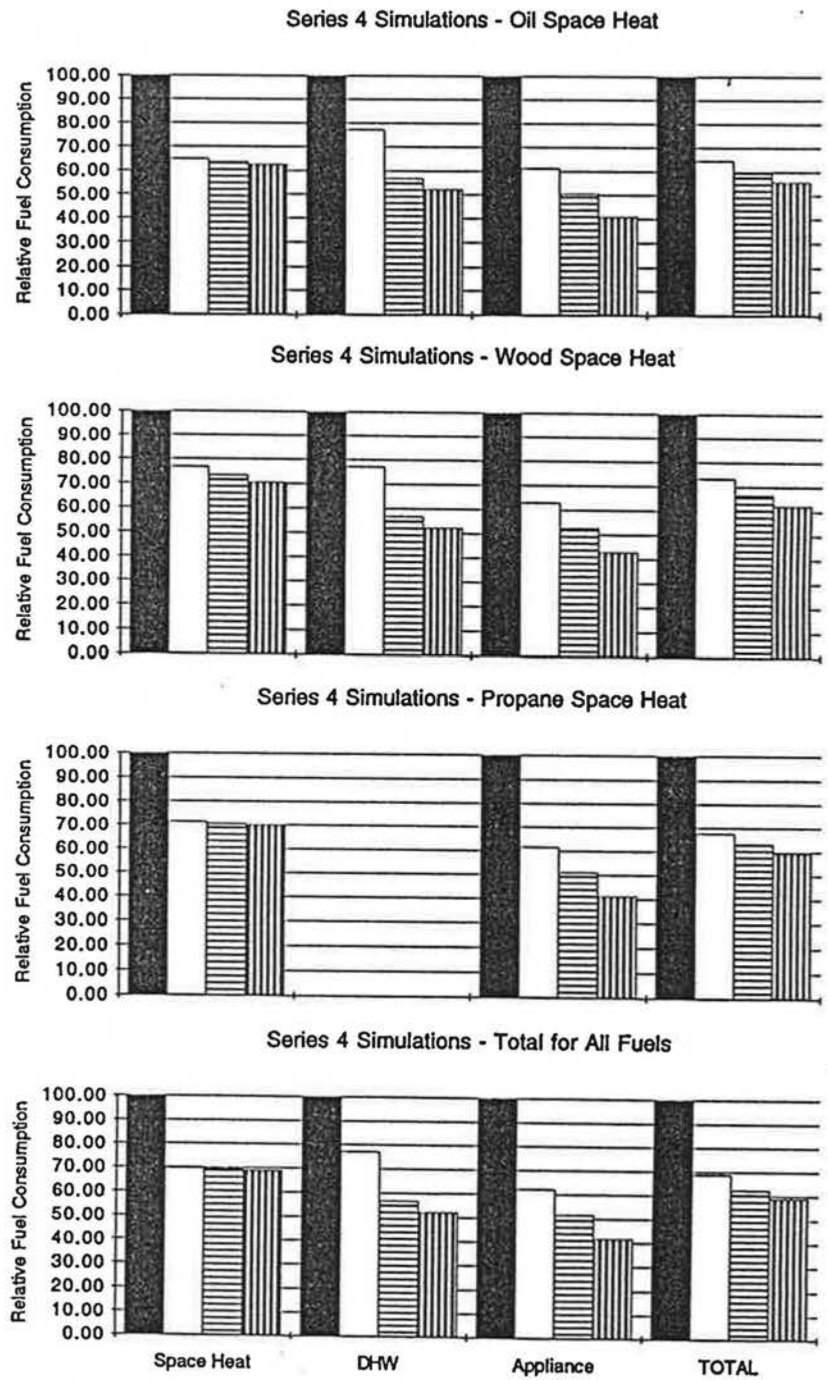
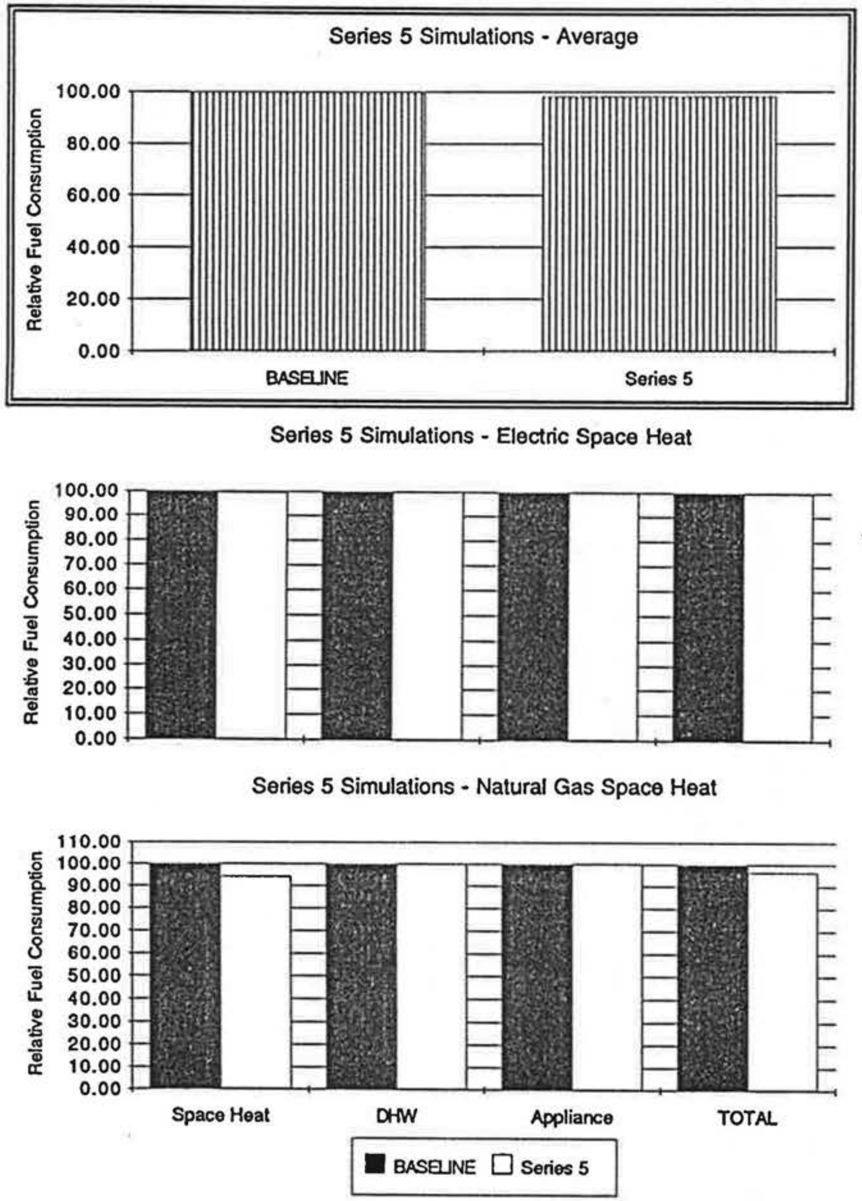


Figure 5. Series 4 simulation results

Table 14. Series 5 Simulation Results

All Values in GJ				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
Baseline	16878	8368	12539	37785
Series 5	16813	8368	12539	37720
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
Baseline	42182	10894	16967	70043
Series 5	39676	10892	16971	67540
Oil				
	Space Heat	DHW	Appliance	TOTAL
Baseline	21997	2029	9381	33407
Series 5	21997	2029	9381	33407
Wood				
	Space Heat	DHW	Appliance	TOTAL
Baseline	220	29	81	330
Series 5	220	29	81	330
Propane				
	Space Heat	DHW	Appliance	TOTAL
Baseline	288	0	166	453
Series 5	288	0	166	453
Total				
	Space Heat	DHW	Appliance	TOTAL
Baseline	81565	21319	39135	142019
Series 5	78994	21317	39139	139450
	Ave. House			
Baseline	152			
Series 5	149			

Relative Values				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
Series 5	100	100	100	100
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
Series 5	94	100	100	96
Oil				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
Series 5	100	100	100	100
Wood				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
Series 5	100	100	100	100
Propane				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	N/A	100	100
Series 5	100	N/A	100	100
Total				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
Series 5	97	100	100	98
	Average			
BSLN	100			
Series 5	98			



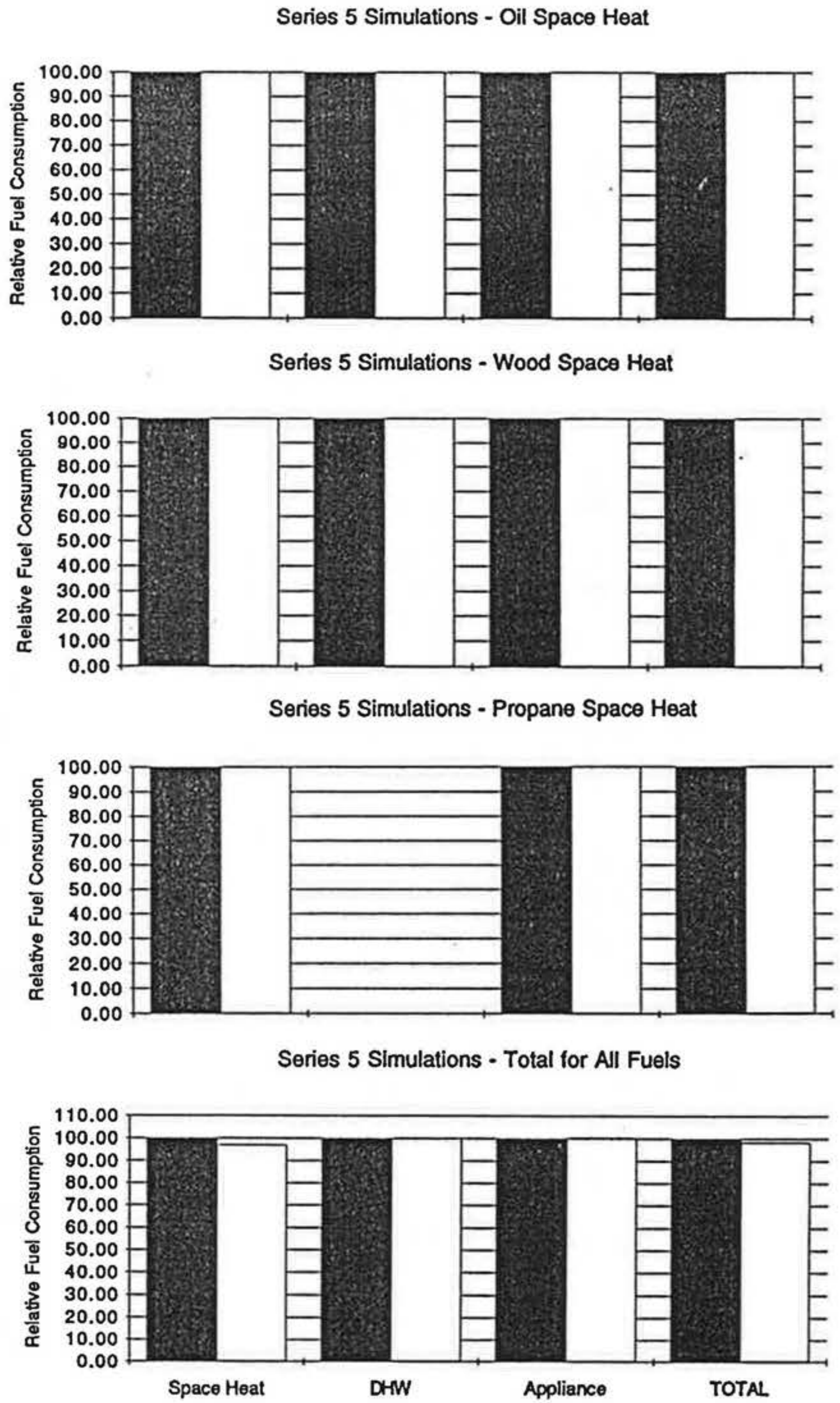


Figure 6. Series 5 simulation results

5.3.6 Results of Series 6 Simulations

In these series of simulations, the effects of night temperature setback and improvements on appliance efficiency are evaluated. The results are given in Table 15 and Figure 7. Out of the 937 houses in the Expanded STAR, 264 houses do not have temperature setback at night, thus temperature setback are applied to these houses.

It can be seen from these results that the reduction in total energy consumption as a result of introducing temperature setback in those houses which do not have temperature setback is quite small (slightly more than 1%). This is due to the fact that majority of the houses in Expanded STAR (72%) already have temperature setback[9].

Once all houses are assigned night temperature setback (Series 6.A), further reductions in total energy consumption with improved appliance efficiency is similar to that found in Series 1 simulations.

5.3.7 Results of Series 7 Simulations

In these series of simulations, the combined effects of improvements in insulation in the houses to medium insulation level, night temperature setback, retrofitting with HRVs and improvements in appliance and furnace efficiencies are evaluated. The results are given in Table 16 and Figure 8. Based on these results, the following trends can be identified:

1. In houses where the primary space heating fuel is electricity:

   a) Space heating energy requirement is slightly lower in comparison to the baseline for the Level 1 appliance efficiency improvements. This is because the reduction in space heating requirement due to the combined effect of improvements (i.e. improved insulation to medium insulation level, night temperature setback, retrofitting with HRVs) is higher than the increased heating requirement due to the reduced heat gain from higher efficiency appliances. With Level 2 and Level 3 improvements in appliance efficiency, the energy consumption for space heating increases above the baseline level because the further reductions in appliance heat gains have to be made up by the heating system whose efficiency remains constant (at 100%).
   b) The total energy consumption decreases by close to 30% with the highest efficiency appliances and other improvements.

2. In houses where the primary heating fuel is other than electricity, energy consumption for space/DHW heating and appliances reduce as the improvements are applied. The reduction in heating energy consumption is also due to the increase in heating system efficiencies.

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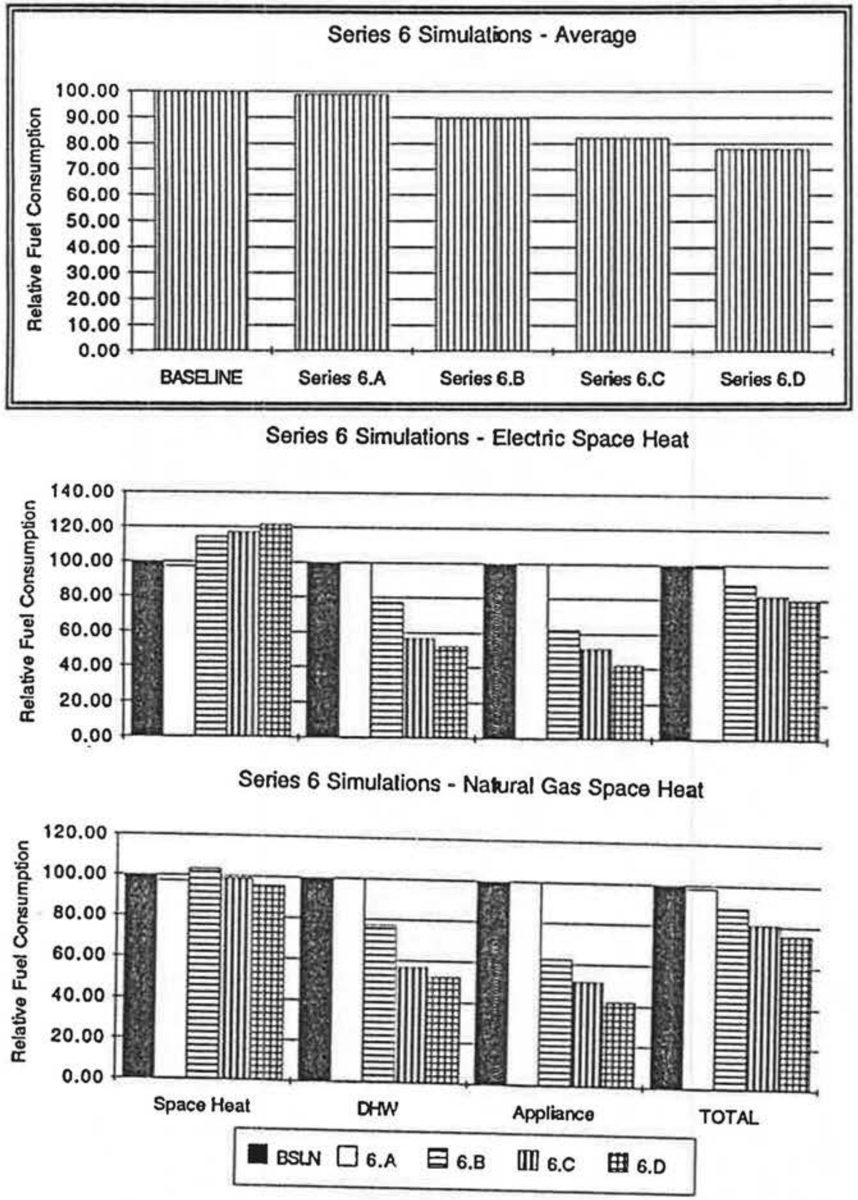
9. This is the same as the figures published by Statistics Canada: 72% of all households in Canada either have programmable thermostats or manually reduce the temperature in winter. (Statistics Canada, Households and the Environment 1991, Cat. No. 11-526, July 1992.)

Table 15. Series 6 Simulation Results

All Values in GJ				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
Baseline	16878	8368	12539	37785
Series6.A	16415	8369	12535	37319
Series 6.B	19267	6461	7798	33527
Series 6.C	19781	4763	6464	31007
Series6.D	20490	4383	5264	30136
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
Baseline	42182	10894	16967	70043
Series6.A	41026	10898	16964	68888
Series 6.B	43564	8400	10560	62524
Series 6.C	41752	6186	8747	56686
Series6.D	40405	5690	7124	53219
Oil				
	Space Heat	DHW	Appliance	TOTAL
Baseline	21997	2029	9381	33407
Series6.A	21986	2029	9381	33396
Series 6.B	23372	1566	5740	30678
Series 6.C	22594	1154	4743	28491
Series6.D	21917	1062	3832	26810
Wood				
	Space Heat	DHW	Appliance	TOTAL
Baseline	220	29	81	330
Series6.A	220	29	81	330
Series 6.B	232	22	51	305
Series 6.C	219	16	43	278
Series6.D	209	15	35	258
Propane				
	Space Heat	DHW	Appliance	TOTAL
Baseline	288	0	166	453
Series6.A	284	0	166	449
Series 6.B	310	0	102	411
Series 6.C	302	0	85	387
Series6.D	296	0	68	364
Total				
	Space Heat	DHW	Appliance	TOTAL
Baseline	81565	21319	39135	142019
Series6.A	79930	21325	39128	140382
Series 6.B	86744	16449	24252	127445
Series 6.C	84649	12119	20081	116849
Series6.D	83317	11149	16322	110788
	Ave. House			
Baseline	152			
Series6.A	150			
Series 6.B	136			
Series 6.C	125			
Series6.D	118			

Relative Values				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
6.A	97	100	100	99
6.B	114	77	62	89
6.C	117	57	52	82
6.D	121	52	42	80
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
6.A	97	100	100	98
6.B	103	77	62	89
6.C	99	57	52	81
6.D	96	52	42	76
Oil				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
6.A	100	100	100	100
6.B	106	77	61	92
6.C	103	57	51	85
6.D	100	52	41	80
Wood				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
6.A	100	100	100	100
6.B	106	77	61	92
6.C	99	57	53	84
6.D	95	52	43	78
Propane				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	N/A	100	100
6.A	99	N/A	100	99
6.B	108	N/A	61	91
6.C	105	N/A	51	85
6.D	103	N/A	41	80
Total				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
6.A	98	100	100	99
6.B	106	77	62	90
6.C	104	57	51	82
6.D	102	52	42	78
	Average			
BSLN	100			
6.A	99			
6.B	90			
6.C	82			
6.D	78			



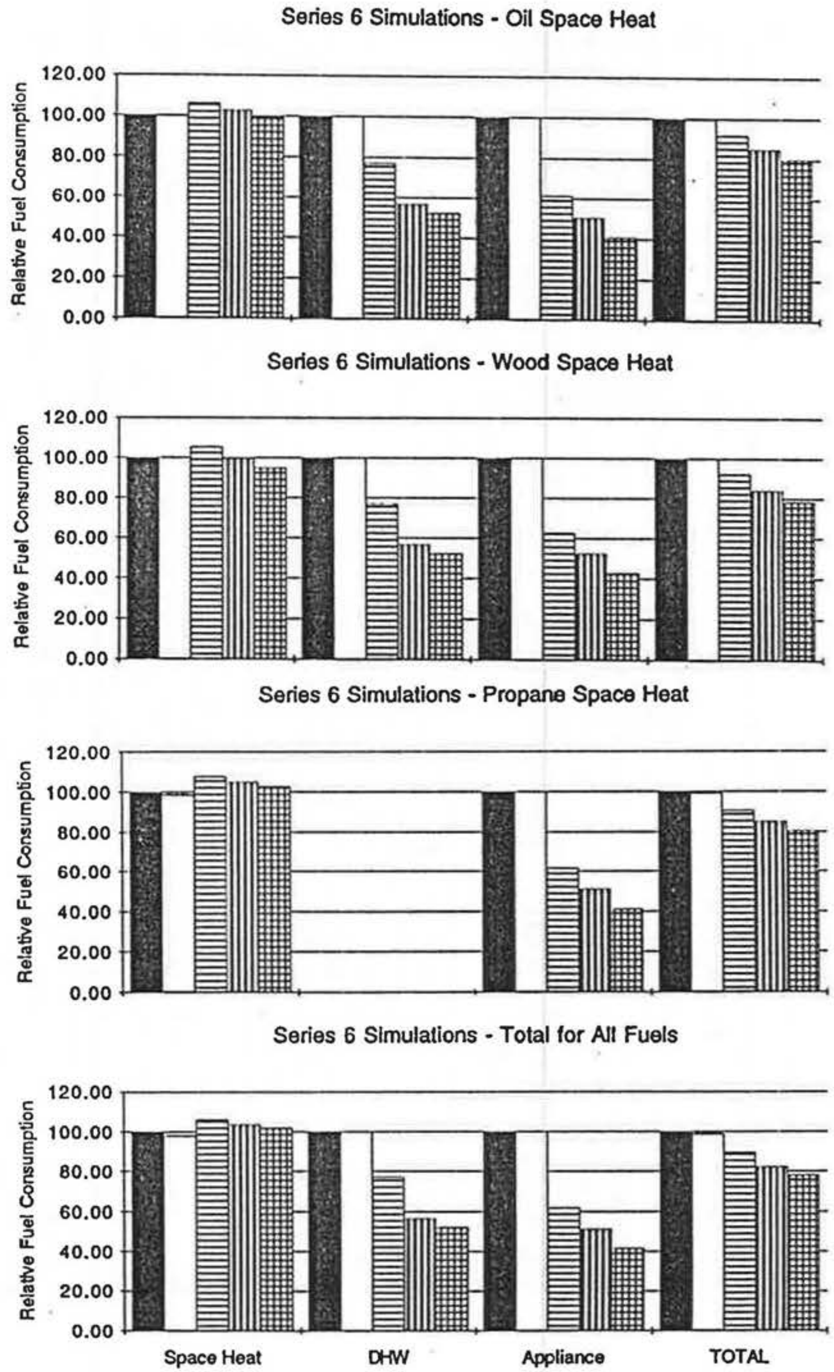
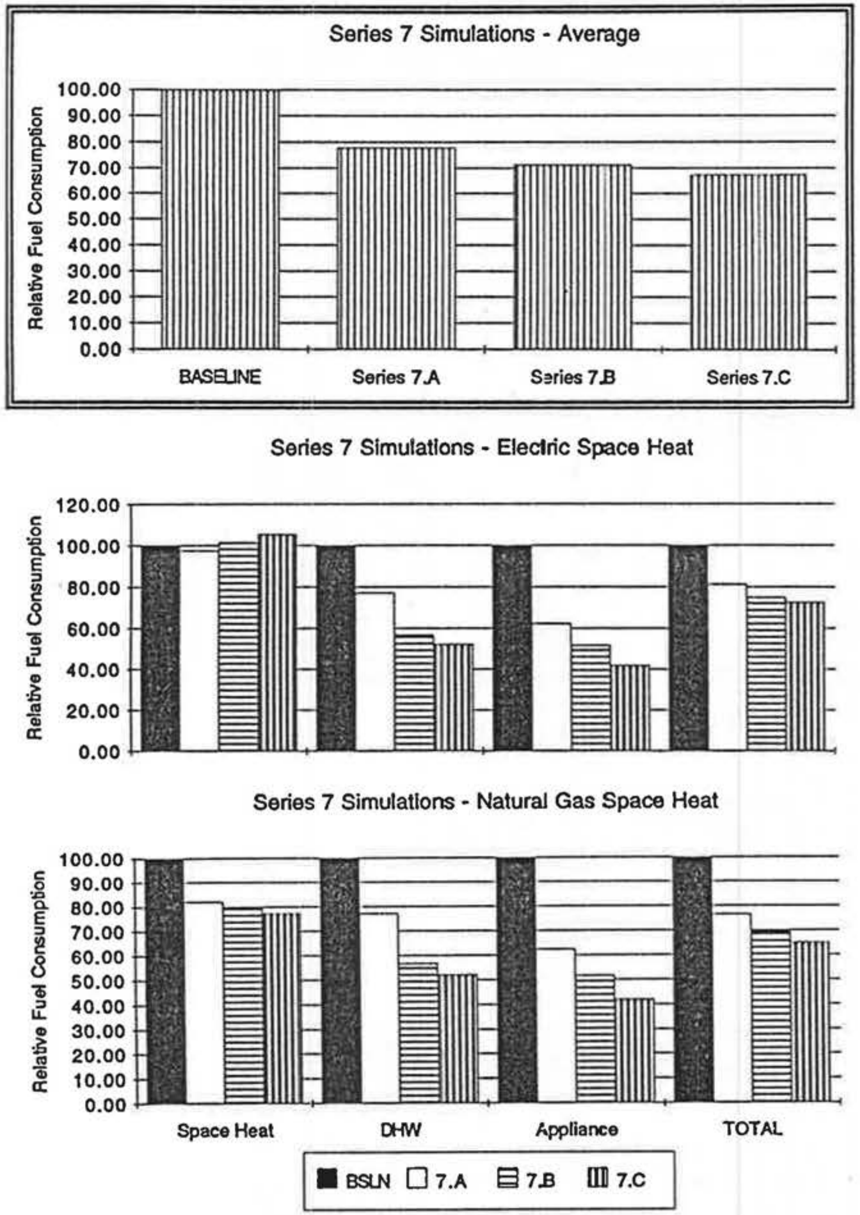


Figure 7. Series 6 simulation results

Table 16. Series 7 Simulation Results

All Values in GJ				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
Baseline	16878	8368	12539	37785
Series7.A	16428	6459	7799	30686
Series 7.B	20277	4761	6466	31504
Series 7.C	20992	4382	5266	30640
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
Baseline	42182	10894	16967	70043
Series7.A	34614	8400	10563	53577
Series 7.B	33570	6182	8751	48503
Series 7.C	32674	5686	7126	45486
Oil				
	Space Heat	DHW	Appliance	TOTAL
Baseline	21997	2029	9381	33407
Series7.A	18391	1565	5739	25696
Series 7.B	17897	1153	4742	23792
Series 7.C	17473	1061	3830	22364
Wood				
	Space Heat	DHW	Appliance	TOTAL
Baseline	220	29	81	330
Series7.A	210	22	51	283
Series 7.B	199	16	43	258
Series 7.C	190	15	35	240
Propane				
	Space Heat	DHW	Appliance	TOTAL
Baseline	288	0	166	453
Series7.A	245	0	102	347
Series 7.B	241	0	85	326
Series 7.C	238	0	68	306
Total				
	Space Heat	DHW	Appliance	TOTAL
Baseline	81565	21319	39135	142019
Series7.A	69889	16446	24254	110589
Series 7.B	69015	12112	20083	101210
Series 7.C	68376	11142	16321	95840
	Ave. House			
Baseline	152			
Series7.A	118			
Series 7.B	108			
Series 7.C	102			

Relative Values				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
7.A	97	77	62	81
7.B	101	57	52	75
7.C	105	52	42	73
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
7.A	82	77	61	76
7.B	80	57	51	71
7.C	77	52	42	65
Oil				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
7.A	84	77	61	77
7.B	81	57	51	71
7.C	79	52	41	67
Wood				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
7.A	95	77	63	86
7.B	90	57	53	78
7.C	86	52	43	73
Propane				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	N/A	100	100
7.A	85	N/A	61	77
7.B	84	N/A	51	72
7.C	83	N/A	41	68
Total				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
7.A	86	77	62	78
7.B	85	57	51	71
7.C	84	52	42	67
	Average			
BSLN	100			
7.A	78			
7.B	71			
7.C	67			



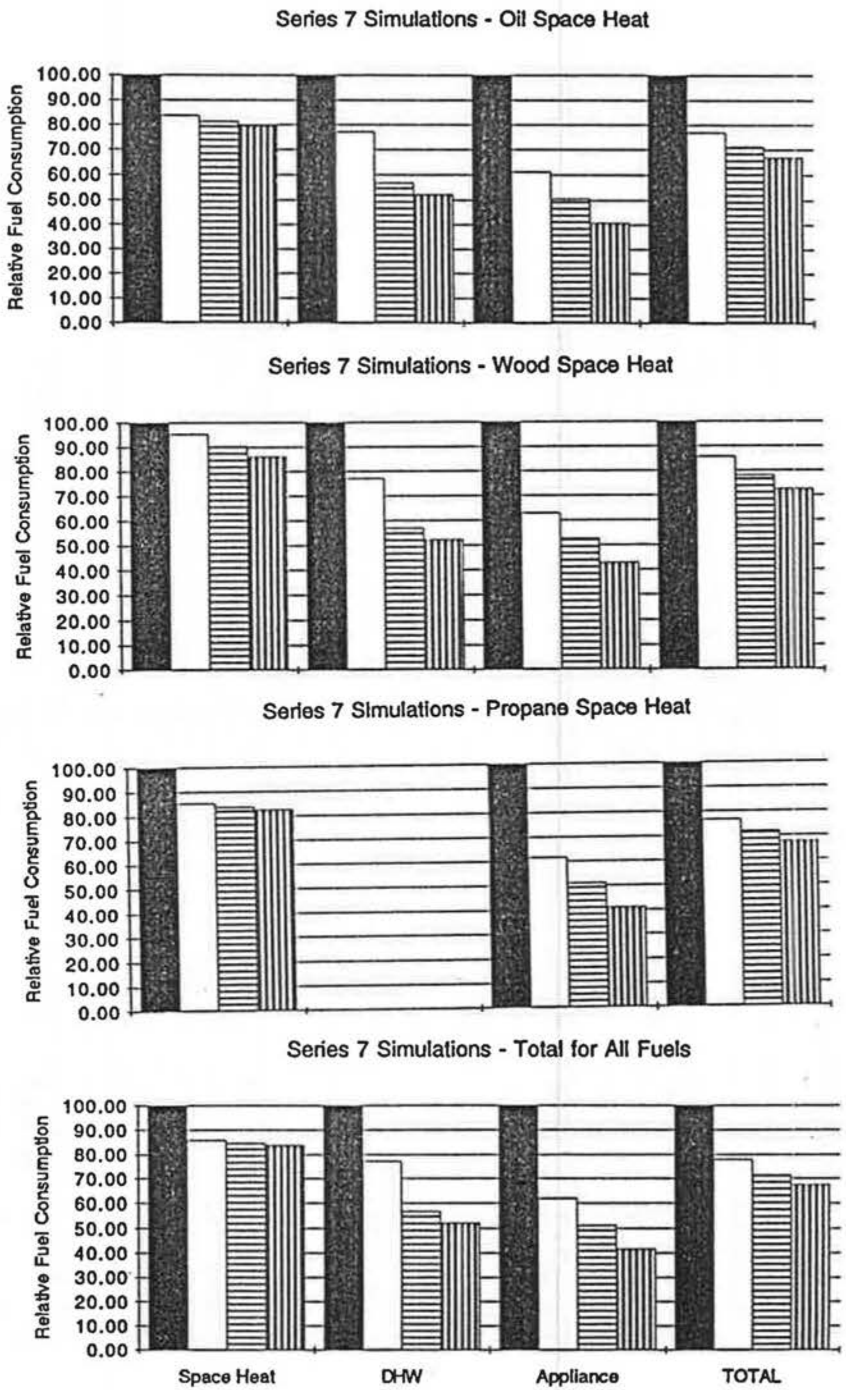


Figure 8. Series 7 simulation results

3. The reduction in total energy consumption for all houses in Expanded STAR with the highest level of efficiency improvements is more than 30%.

5.3.8 Results of Series 8 Simulations

In these series of simulations, the combined effects of improvements in insulation in the houses to high insulation level, night temperature setback, retrofitting with HRVs and improvements in appliance and furnace efficiencies are evaluated. The results are given in Table 17 and Figure 9.

Conclusions similar to those for Series 7 simulations can be drawn from these results. It should however be noted that:

a) In houses where the primary space heating fuel is electricity, total end-use energy consumption decreases by 30, 36 and 38% with appliance efficiencies of Level 1, 2 and 3, respectively. These savings are, as expected, higher than those seen in Series 7 simulations because of the higher level of insulation and air tightness. It can thus be seen that combining improvements in building envelope and mechanical systems with the use of higher efficiency appliances presents a large potential for residential energy savings.

b) In houses where the primary heating fuel is other than electricity, total end-use energy consumption decreases even more (except for wood, which has a low energy conversion efficiency of about 45%). The savings are as high as 45% for Level 3 appliance efficiency with natural gas as the space and DHW heating fuel. It is therefore clear that, no matter what fuel is used for space and DHW heating, improving building envelope and mechanical systems along with appliance efficiencies would result in large savings in residential end-use energy consumption.

c) The reduction in total end-use energy consumption for all houses in Expanded STAR with the highest level of efficiency improvements is more than 40%.

5.3.9 Results of Series 9 Simulations

In these series of simulations, the effects of variations in load curves on energy consumption are evaluated. The results and discussion of the results are presented in Appendix 12.

5.3.10 Results of Series 10 Simulations

In these series of simulations, the effect of the presence of appliances on end-use energy consumption is evaluated by comparing the baseline results with the results of simulations carried out after removing all appliances (except, of course, the furnace fan is left) from the house files in Expanded STAR. The results are given in Table 18 and Figure 10.

It can be seen that when appliances are removed from the house files, the heating energy consumption's increase by 32-46%, depending on the fuel used. However, since the reduction in the appliance energy consumption is greater than the increase in heating energy consumption, the total end-use energy consumption is reduced by 8-16% for all fuels except for wood (wood consumption increases by 6% due to the low utilization efficiency of wood). The overall end-use energy consumption for all houses in Expanded STAR decreases by 8%.

These results indicate the relative importance of appliance energy consumption in overall residential energy consumption.

Table 17. Series 8 Simulation Results

All Values in GJ

Electricity

	Space Heat	DHW	Appliance	TOTAL
Baseline	16878	8368	12539	37785
Series8.A	12309	6453	7819	26580
Series8.B	12944	4754	6477	24176
Series8.C	13597	4375	5273	23245

Natural Gas

	Space Heat	DHW	Appliance	TOTAL
Baseline	42182	10894	16967	70043
Series8.A	26553	8392	10587	45532
Series 8.B	25956	6175	8766	40897
Series 8.C	25456	5679	7138	38273

Oil

	Space Heat	DHW	Appliance	TOTAL
Baseline	21997	2029	9381	33407
Series8.A	14241	1564	5746	21551
Series 8.B	13970	1152	4746	19869
Series 8.C	13747	1060	3833	18640

Wood

	Space Heat	DHW	Appliance	TOTAL
Baseline	220	29	81	330
Series8.A	169	22	51	242
Series 8.B	161	16	43	220
Series 8.C	155	15	35	205

Propane

	Space Heat	DHW	Appliance	TOTAL
Baseline	288	0	166	453
Series8.A	202	0	102	304
Series 8.B	200	0	85	284
Series 8.C	198	0	68	267

Total

	Space Heat	DHW	Appliance	TOTAL
Baseline	81565	21319	39135	142019
Series8.A	53474	16430	24305	94209
Series 8.B	53231	12097	20117	85446
Series 8.C	53153	11130	16347	80629

	Ave. House
Baseline	152
Series8.A	101
Series 8.B	91
Series 8.C	86

Relative Values

Electricity

	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
8.A	73	77	62	70
8.B	77	57	52	64
8.C	81	52	42	62

Natural Gas

	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
8.A	63	77	62	65
8.B	62	57	52	58
8.C	60	52	42	55

Oil

	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
8.A	65	77	61	65
8.B	64	57	51	59
8.C	62	52	41	56

Wood

	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
8.A	77	77	63	73
8.B	73	57	53	67
8.C	71	52	43	62

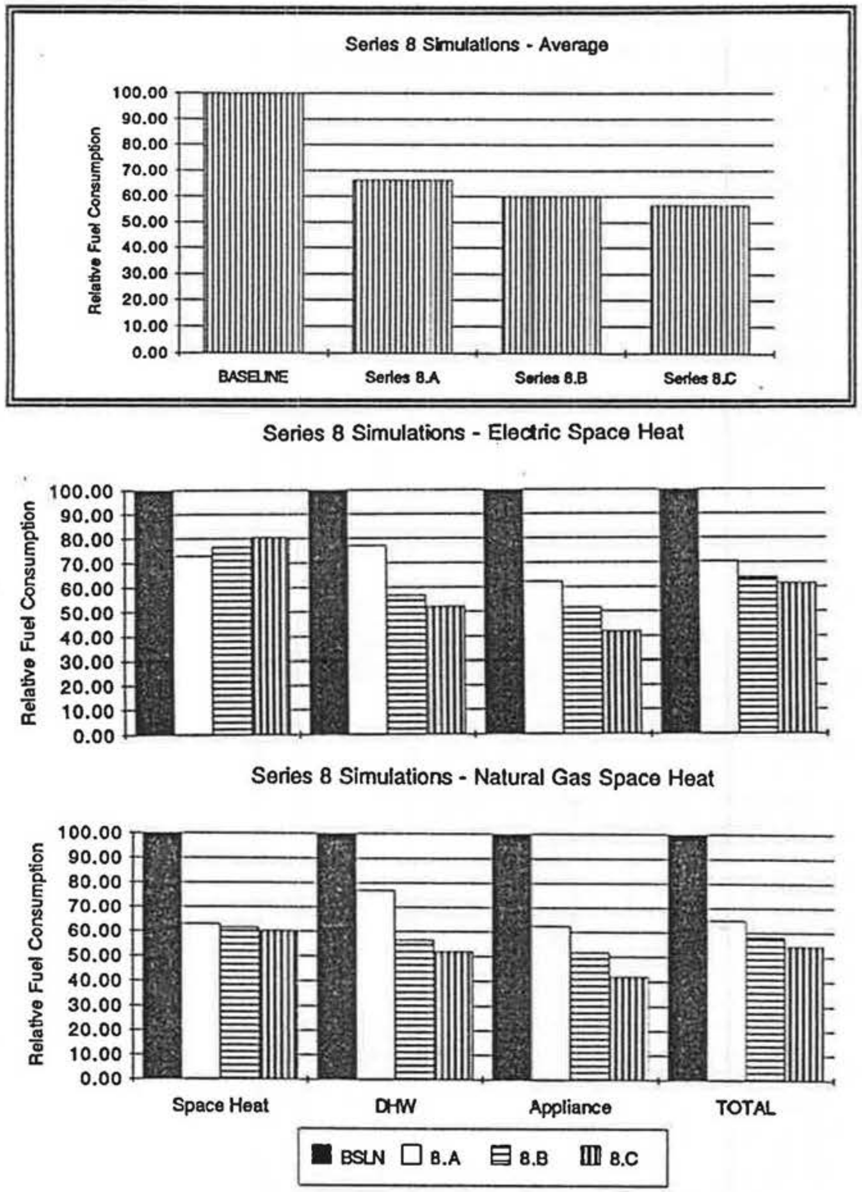
Propane

	Space Heat	DHW	Appliance	TOTAL
BSLN	100	N/A	100	100
8.A	70	N/A	61	67
8.B	69	N/A	51	63
8.C	69	N/A	41	59

Total

	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
8.A	66	77	62	66
8.B	65	57	51	60
8.C	65	52	42	57

	Average
BSLN	100
8.A	66
8.B	60
8.C	57



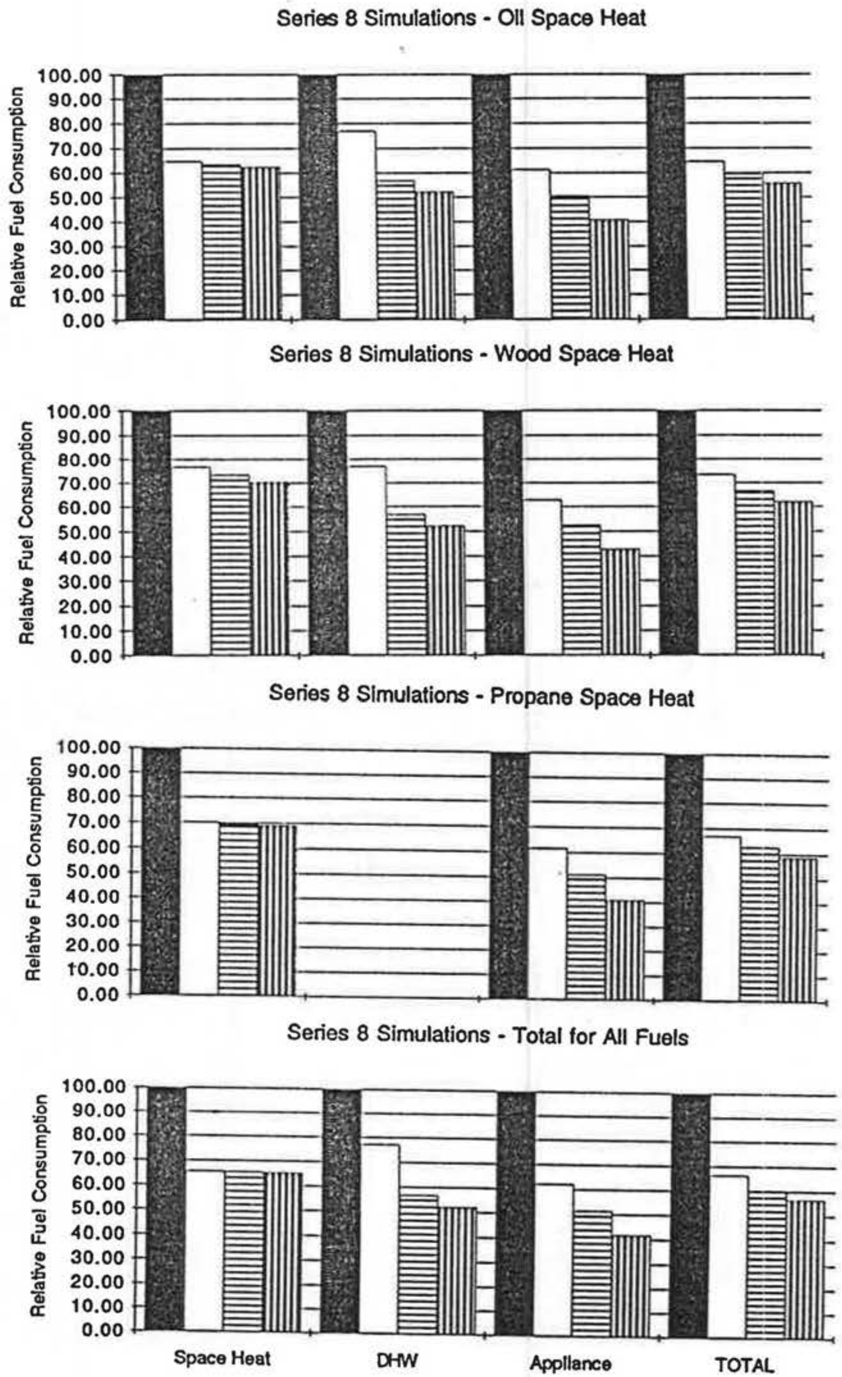
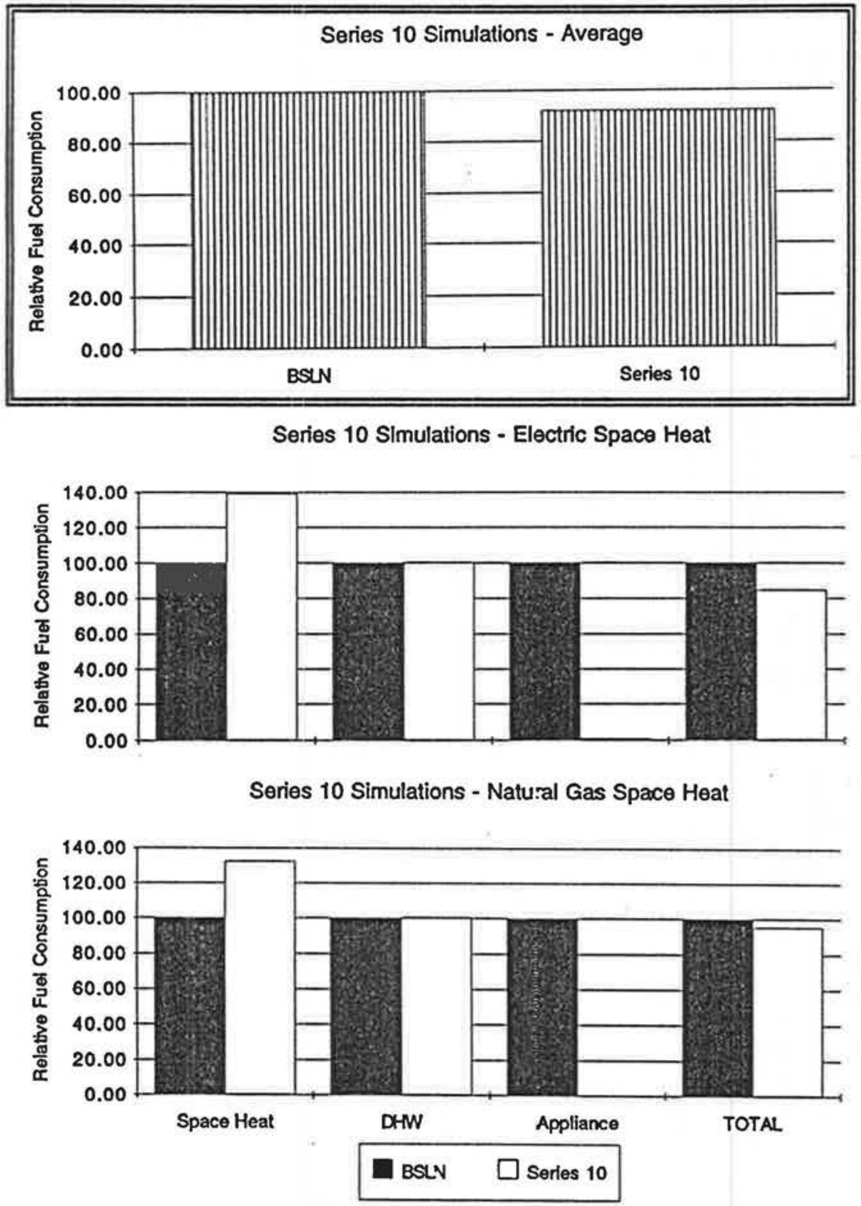


Figure 9. Series 8 simulation results

Table 18. Series 10 Simulation Results

All Values in GJ				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
Baseline	16878	8368	12539	37785
Series 10	23497	8396	105	31998
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
Baseline	42182	10894	16967	70043
Series 10	55806	10921	0	66728
Oil				
	Space Heat	DHW	Appliance	TOTAL
Baseline	21997	2029	9381	33407
Series 10	29528	2034	0	31562
Wood				
	Space Heat	DHW	Appliance	TOTAL
Baseline	220	29	81	330
Series 10	322	29	0	351
Propane				
	Space Heat	DHW	Appliance	TOTAL
Baseline	288	0	166	453
Series 10	401	0	0	401
Total				
	Space Heat	DHW	Appliance	TOTAL
Baseline	81565	21319	39135	142019
Series 10	109554	21380	105	131040
	Ave. House			
Baseline	152			
Series 10	140			

Relative Values				
Electricity				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
Series 10	139	100	1	85
Natural Gas				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
Series 10	132	100	0	95
Oil				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
Series 10	134	100	0	94
Wood				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
Series 10	146	101	0	106
Propane				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	N/A	100	100
Series 10	139	N/A	0	88
Total				
	Space Heat	DHW	Appliance	TOTAL
BSLN	100	100	100	100
Series 10	134	100	0	92
	Average			
BSLN	100			
Series 10	92			



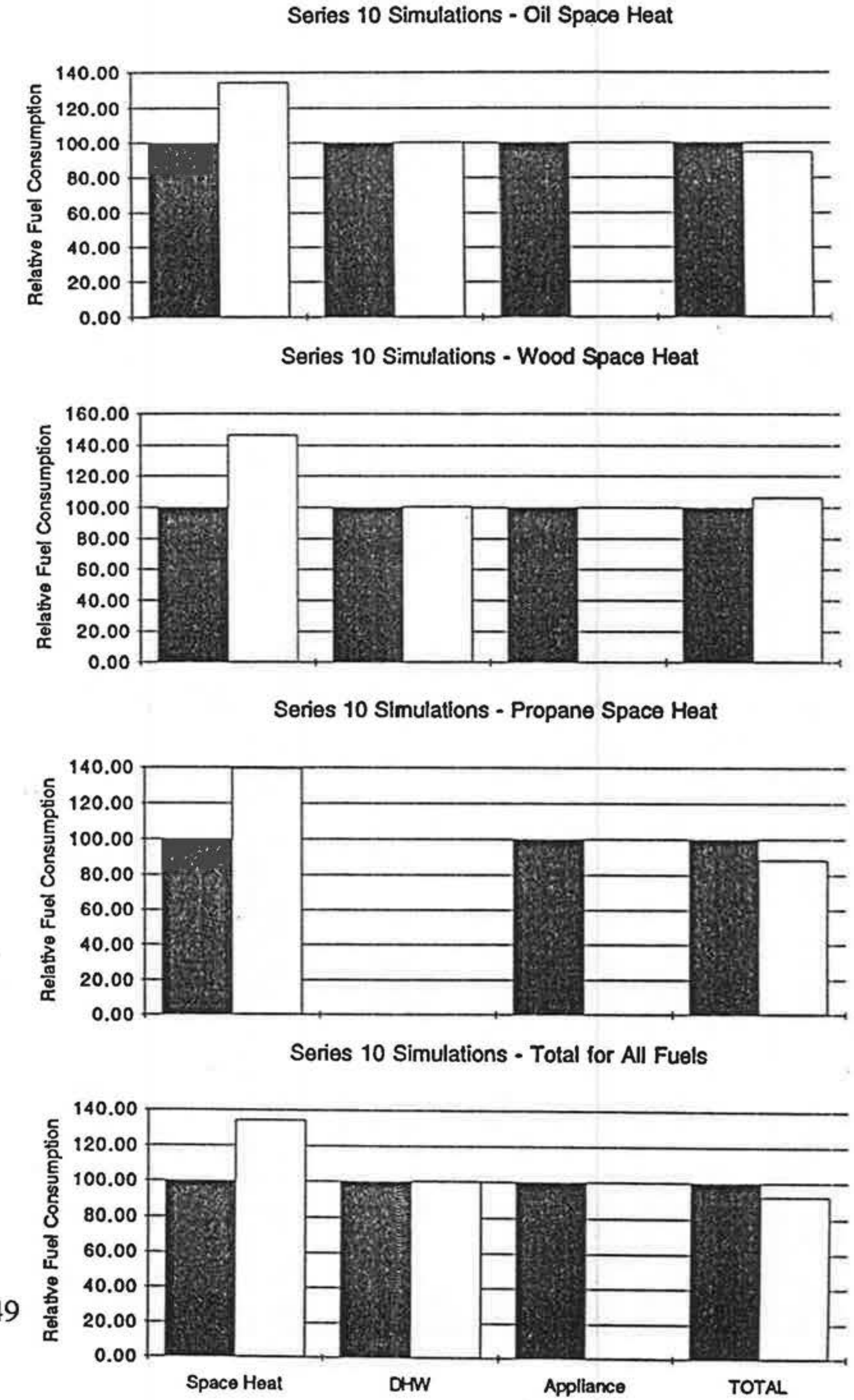


Figure 10. Series 10 Simulation Results

6.0 IMPACT OF APPLIANCE EFFICIENCY ON RESIDENTIAL ENERGY CONSUMPTION IN CANADA

A breakdown of residential energy consumption in Canada with respect to the different fuel types is given in Table 19. Table 20 shows the relative values of residential energy consumption for each scenario and fuel type. Based on the relative values and total fuel consumption data, the resultant savings in residential end use fuel consumption at the national level were calculated and tabulated in Table 21.

The estimates presented in Table 21 represent the reduction in residential energy consumption if the energy saving measures were applied in all residences in Canada (i.e. 100% penetration of energy saving measures). Since it is not realistic to assume that these measures would be adopted in 100% of the housing stock, the figures in Table 21 are higher than can be reasonably expected. To obtain a more realistic representation of the impact of appliance efficiency on residential energy consumption in Canada, two levels of market penetration levels are assumed for adoption of energy saving measures. The results for market penetration level of 10% are presented in Table 22, and the results for market penetration level of 20% are presented in Tables 23. Although the results are self-explanatory, it may be worthwhile to point out the following observations:

1. Regardless of the scenario adopted, the residential consumption of electricity decreases. The magnitude of electricity savings varies between negligibly small (results of Series 5 simulations, for installation of HRV's only) and 4.7% with 10% penetration, and 9.3% with 20% penetration (results of Series 4.C and 8.C simulations). However, the same cannot be said for all other fuels. Depending on the scenario evaluated, increases in the consumption of other fuels (which are used for space and DHW heating) are seen for certain scenarios, most notably for Series 2 simulations which involved improvement of appliance efficiencies only. As discussed earlier, when only the appliance efficiencies are improved, the heat gain that comes from the appliances has to be replaced by the heating fuel, and this causes the increase in the consumption of that fuel.

2. Regardless of the scenario evaluated, there is a decrease in total residential energy consumption. The overall savings in energy consumption varies between 0.12% and 4.21% of the total for 10% penetration of energy saving measures, and between 0.25% and 8.43% for 20% penetration. The savings associated with the improvement of only appliance efficiencies varies between 0.33% and 0.71% for 10% penetration, and 0.66% and 1.42% for 20% penetration. These results clearly indicate that although improving appliance efficiency would result in about 1-2% reduction in the overall residential energy consumption, for a more significant impact, energy saving measures such as improved building envelope and control of mechanical systems should be applied along with improving appliance efficiency.

3. The magnitude of energy savings increase linearly with market penetration level of energy saving measures.

Table 19. Residential Fuel Consumption in Canada

1992 Figures (unit: Terajoule)
Source: Statistics Canada, Quarterly Report on Energy Supply-Demand in Canada, 1992-IV, Cat. 57-003, June 1993 (excluding coal)
Data for wood: 1992 NRCan Estimates, Efficiency and Alt. Energy Branch

	Electricity	Natural Gas	Oil	Wood	NGL (*)	Total
Canada 1992	471,862	553,321	138,046	96,046	14,246	1,274,149

(*) NGL - Natural gas liquids assumed to be all propane.

Table 20. Relative Fuel Consumption with Different Scenarios for all of Canada

	Electricity	Natural Gas	Oil	Wood	Propane
Baseline	100.00	100.00	100.00	100.00	100.00
1.A	78.11	99.55	103.85	102.04	109.23
1.B	70.09	92.32	98.89	94.59	106.66
1.C	64.77	88.74	95.69	89.89	104.56
2.A	78.11	105.77	110.83	112.40	116.33
2.B	70.09	104.31	112.39	114.16	120.53
2.C	64.77	106.11	115.33	117.85	124.94
3.A	74.01	87.20	83.10	93.13	86.76
3.B	65.96	80.67	79.33	86.43	85.29
3.C	60.61	77.71	77.18	82.35	84.19
4.A	67.52	71.55	65.81	76.77	71.21
4.B	59.37	65.91	62.97	71.37	70.45
4.C	53.95	63.73	61.66	68.41	69.99
5	99.91	95.27	100.00	100.00	100.00
6.A	99.27	97.83	99.95	100.00	98.55
6.B	77.63	97.90	103.80	102.04	107.59
6.C	69.31	90.32	98.84	94.59	105.06
6.D	63.99	86.85	95.64	89.89	102.98
7.A	73.22	81.04	8306	93.13	85.32
7.B	65.16	74.90	79.29	86.43	83.88
7.C	59.80	72.27	77.14	82.35	82.79
8.A	66.89	65.84	65.78	76.77	70.18
8.B	58.74	60.54	62.94	71.37	69.42
8.C	53.31	58.66	61.63	68.41	68.96

Table 21. Savings in Residential Fuel Consumption in Canada with Different Scenarios

(100% Penetration of Energy Saving Measures)

(unit: Terajoule)

	Electricity	Natural Gas	Oil	Wood	Propane	Total	% of Total
Canada	471,862	553,321	138,046	96,674	14,246	1,274,149	100
Series	**Savings**						
1.A	103,304	2,515	-5,313	-1,975	-1,315	97,216	7.63
1.B	141,137	42,510	1,526	5,226	-949	189,450	14.87
1.C	166,229	62,323	5,949	9,773	-649	243,626	19.12
2.A	103,304	-31,941	-14,955	-11,983	-2,327	42,098	3.30
2.B	141,137	-23,852	-17,109	-13,692	-2,924	83,559	6.56
2.C	166,229	-33,832	-21,159	-17,252	-3,553	90,433	7.10
3.A	122,630	70,848	23,325	6,641	1,887	225,330	17.68
3.B	160,625	106,952	28,532	13,119	2,095	311,324	24.43
3.C	185,854	123,308	31,498	17,063	2,253	359,976	28.25
4.A	153,274	157,394	47,199	22,454	4,101	384,421	30.17
4.B	191,714	188,639	51,117	27,678	4,210	463,359	36.37
4.C	217,299	200,686	52,929	30,535	4,275	505,724	39.69
5	443	26,145	0	0	0	26,588	2.09
6.A	3,437	12,008	66	0	207	15,718	1.23
6.B	105,545	11,599	-5,243	-1,975	-1,081	108,846	8.54
6.C	144,794	53,561	1,595	5,226	-720	204,455	16.05
6.D	169,931	72,785	6,015	9,773	-425	258,080	20.26
7.A	126,348	104,898	23,382	6,641	2,092	263,361	20.67
7.B	164,389	138,901	28,588	13,119	2,297	347,294	27.26
7.C	189,665	153,418	31,553	17,063	2,451	394,150	30.93
8.A	156,214	189,017	47,237	22,454	4,248	419,170	32.90
8.B	194,700	218,361	51,155	27,678	4,356	496,250	38.95
8.C	220,331	228,739	52,967	30,535	4,422	536,994	42.15

Table 22. Savings in Residential Fuel Consumption in Canada with Different Scenarios

(10% Penetration of Energy Saving Measures)

(unit: Terajoule)

	Electricity	Natural Gas	Oil	Wood	Propane	Total	% of Total
Canada	471,862	553,321	138,046	96,674	14,246	1,274,149	100
Series	**Savings**						
1.A	10,330	252	-531	-198	-132	9,722	0.76
1.B	14,114	4,251	153	523	-95	18,945	1.49
1.C	16,623	6,232	595	977	-65	24,363	1.91
2.A	10,330	-3,194	-1,496	-1,198	-233	4,210	0.33
2.B	14,114	-2,385	-1,711	-1,369	-292	8,356	0.66
2.C	16,623	-3,383	-2,116	-1,725	-355	9,043	0.71
3.A	12,263	7,085	2,332	664	189	22,533	1.77
3.B	16,063	10,695	2,853	1,312	210	31,132	2.44
3.C	18,585	12,331	3,150	1,706	225	35,998	2.83
4.A	15,327	15,739	4,720	2,245	410	38,442	3.02
4.B	19,171	18,864	5,112	2,768	421	46,336	3.64
4.C	21,730	20,069	5,293	3,054	427	50,572	3.97
5	44	2,614	0	0	0	2,659	0.21
6.A	344	1,201	7	0	21	1,572	0.12
6.B	10,555	1,160	-524	-198	-108	10,885	0.85
6.C	14,479	5,356	159	523	-72	20,446	1.60
6.D	16,993	7,279	601	977	-42	25,808	2.03
7.A	12,635	10,490	2,338	664	209	26,336	2.07
7.B	16,439	13,890	2,859	1,312	230	34,729	2.73
7.C	18,967	15,342	3,155	1,706	245	39,415	3.09
8.A	15,621	18,902	4,724	2,245	425	41,917	3.29
8.B	19,470	21,836	5,116	2,768	436	49,625	3.89
8.C	22,033	22,874	5,297	3,054	442	53,699	4.21

Table 23. Savings in Residential Fuel Consumption in Canada with Different Scenarios

(20% Penetration of Energy Saving Measures)

(unit: Terajoule)

	Electricity	Natural Gas	Oil	Wood	Propane	Total	% of Total
Canada	471,862	553,321	138,046	96,674	14,246	1,274,149	100
Series	Savings						
1.A	20,661	503	-1,063	-395	-263	19,443	1.53
1.B	28,227	8,502	305	1,045	-190	37,890	2.97
1.C	33,246	12,465	1,190	1,955	-130	48,725	3.82
2.A	20,661	-6,388	-2,991	-2,397	-465	8,420	0.66
2.B	28,227	-4,770	-3,422	-2,738	-585	16,712	1.31
2.C	33,246	-6,766	-4,232	-3,450	-711	18,087	1.42
3.A	24,526	14,170	4,665	1,328	377	45,066	3.54
3.B	32,125	21,390	5,706	2,624	419	62,265	4.89
3.C	37,171	24,662	6,300	3,413	451	71,995	5.65
4.A	30,655	31,479	9,440	4,491	820	76,884	6.03
4.B	38,343	37,728	10,223	5,536	842	92,672	7.27
4.C	43,460	40,137	10,586	6,107	855	101,145	7.94
5	89	5,229	0	0	0	5,318	0.42
6.A	687	2,402	13	0	41	3,144	0.25
6.B	21,109	2,320	-1,049	-395	-216	21,769	1.71
6.C	28,959	10,712	319	1,045	-144	40,891	3.21
6.D	33,986	14,557	1,203	1,955	-85	51,616	4.05
7.A	25,270	20,980	4,676	1,328	418	52,672	4.13
7.B	32,878	27,780	5,718	2,624	459	69,459	5.45
7.C	37,933	30,684	6,311	3,413	490	78,830	6.19
8.A	31,243	37,803	9,447	4,491	850	83,834	6.58
8.B	38,940	43,672	10,231	5,536	871	99,250	7.79
8.C	44,066	45,748	10,593	6,107	884	107,399	8.43

7.0 IMPACT OF APPLIANCE EFFICIENCY ON CARBON DIOXIDE EMISSIONS IN CANADA

To estimate the reduction in CO_2 emissions as a result of appliance efficiency improvements and other energy efficiency measures, it is necessary to determine the amount of CO_2 generated for each unit of electricity generated in Canada. Electricity generation in Canada is from six sources: coal, natural gas, light and heavy fuel oil, hydro and nuclear. The amounts of electricity produced from each one of these sources are given in Table 24. The amounts of CO_2 generated as a result of combusting different fuels are given in Table 25. Using the values in Tables 24 and 25, and estimated fuel-electricity conversion efficiencies given in Table 26, the amount of CO_2 generated per unit of electricity generation is calculated to be 220.6 Tonnes/GWh (61.3 Tonnes/TJ) as shown in Table 26. This value is relatively low because of the high percentage of hydro-electrical generation in Canada.

Using 61.3 Tonnes CO_2/GJ of emissions for electricity consumed, and the energy savings identified in Tables 21, 22, and 23 the reduction in CO_2 emissions in Canada for each scenario and each fuel was calculated for 100%, 10% and 20% penetration of energy efficiency measures in the Canadian housing stock.[10] The following observations can be made from the results which are presented in Tables 27-29:

1. A comparison of Tables 21, 22, 23 and Tables 27-29 indicate that the reductions in CO_2 emissions (in percent of total CO_2 emissions from residential energy consumption) are very close in magnitude to savings in energy consumption.

2. The potential to reduce the CO_2 emissions by improving <u>only</u> the appliance efficiencies is less than 1% (or negligible) regardless of the level of efficiency improvements for a 10% penetration of improved appliances in the residential market. The reduction in emissions would increase to twice of the 10% penetration values for a penetration level of 20% (reduction is linearly proportional with market penetration level). Clearly, these reductions are not significant; however, if house envelopes and mechanical systems are improved along with appliance efficiencies, the potential for reduction of CO_2 emissions increases to as much as 4.2% for a market penetration level of 10%, and to 8.4% for a market penetration level of 20%. These reductions are clearly substantial reductions and present objectives worth pursuing especially in the light of the 1988 Toronto Protocol which requires 20% reductions in CO_2 emissions by 2005.

3. It is clear from Tables 27-29 that there is a potential for reducing the CO_2 emissions significantly by improving appliance efficiencies and house characteristics. Thus, in conducting cost-benefit analysis for the energy efficiency measures evaluated here, the

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10. It should be clear that the emission reductions presented here are correct at the national level only. Since sources of electricity generation vary widely from one province to another, reductions for individual provinces will be significantly different.

intrinsic benefit of the reductions in CO_2 emissions should be considered as these reductions are clearly not insignificant, but are of the same magnitude as energy savings. Thus, improving appliance efficiencies, house envelopes and mechanical systems would present a valuable opportunity to approach the objectives of the 1988 Toronto Protocol.

4. The magnitude of the reductions in CO_2 emissions increase linearly with the market penetration level of energy saving measures.

Table 24. Breakdown of Electricity Generation in Canada with Respect to Fuel Used, 1992 figures
Source: Quarterly Report on Energy Supply-Demand in Canada, Statistics Canada, Cat. No.57-003, 1992-IV

	GWh	%
Coal	85,388	18.38
Natural Gas	7,220	1.55
Light Fuel Oil	760	0.16
Heavy Fuel Oil	12,184	2.62
Hydro	283,036	60.92
Nuclear	76,019	16.36
Total	464,607	100.00

Table 25. CO_2 Coefficients of Different Fuels
(Source: EMR, 1990)

	CO_2
Coal (*)	92
Natural Gas	49.7
LPG's (**)	59.8
Light Fuel Oil	73.1
Heavy Fuel Oil	74
Wood	81.5

(*) Average Value (**) Used for Propane

Table 26. Fossil Fuel Consumption for Electricity Generation in Canada and the Associated CO_2 Generation

	Electricity Prod'n (GWh)	Electricity Prod'n (TJ)	Conversion Efficiency (*)	Fuel Input (TJ)	Tonnes of CO_2 Generated
Coal	85,388	307,397	32%	960,615	88,376,580
Natual Gas	7,220	25,992	35%	74,263	3,690,864
Light Fuel Oil	760	2,736	34%	8,047	588,240
Heavy Fuel Oil	12,184	43,862	33%	132,916	9,835,811
Hydro	283,036	1,018,930	N/A	1,018,930	N/A
Nuclear	76,019	273,668	N/A	273,668	N/A
Total	464,607	1,672,585	N/A	2,468,439	102,491,495
	Tonnes of CO_2 generated for each Gwh of electricity generated: 102,491,495 / 464,607=				220.6
	Tonnes of CO_2 generated for eachTJ of electricity generated: 102,491,495 / 1,672,585=				61.3

(*) Assumed Overall Electricity Generation Efficiency

Table 27. Reductions in CO_2 Emissions with 100% Penetration of Energy Efficiency Measures

Units: Tonnes of CO_2 (negative values indicate increases)

	Electricity	Natural Gas	Oil	Wood	Propane	Total	% of Total
Canada	2.89e+075	2.75e+07	1.01e+075	7.88e+06	8.52e+05	7.52e+07	100
Series	**Reduction**						
1.A	6.33e+06	1.25e+05	-3.88e+053	-1.61e+05	-7.86e+04	5.83e+06	7.75
1.B	8.65e+06	2.11e+06	1.12e+05	4.26e+05	-5.68e+04	1.12e+07	14.95
1.C	1.02e+07	3.10e+06	4.35e+05	7.97e+05	-3.88e+04	1.45e+07	19.26
2.A	6.33e+06	-1.59e+06	-1.09e+06	-9.77e+05	-1.39e+05	2.54e+06	3.37
2.B	8.65e+06	-1.19e+06	-1.25e+06	-1.12e+06	-1.75e+05	4.92e+06	6.55
2.C	1.02e+07	-1.68e+06	-1.55e+06	-1.41e+06	-2.12e+05	5.34e+06	7.11
3.A	7.52e+06	3.52e+06	1.71e+06	5.41e+05	1.13e+05	1.34e+07	17.82
3.B	9.85e+06	5.32e+06	2.09e+06	1.07e+06	1.25e+05	1.84e+07	24.52
3.C	1.14e+07	6.13e+06	2.30e+06	1.39e+06	1.35e+05	2.13e+07	28.39
4.A	9.40e+06	7.82e+06	3.45e+06	1.83e+06	2.45e+05	2.27e+07	30.24
4.B	1.18e+07	9.38e+06	3.74e+06	2.26e+06	2.52e+05	2.74e+07	36.40
4.C	1.33e+07	9.97e+06	3.87e+06	2.49e+06	2.56e+05	2.99e+07	39.77
5	2.71e+04	1.30e+06	0.00e+00	0.00e+00	0.00e+00	1.33e+06	1.76
6.A	2.11e+05	5.97e+05	4.79e+06	0.00e+00	1.24e+04	8.25e+05	1.10
6.B	6.47e+06	5.76e+05	-3.83e+05	-1.61e+05	-6.46e+04	6.44e+06	8.56
6.C	8.88e+06	2.66e+06	1.17e+05	4.26e+05	-4.31e+04	1.20e+07	16.01
6.D	1.04e+07	3.62e+06	4.40e+05	7.97e+05	-2.54e+04	1.52e+07	20.27
7.A	7.75e+06	5.21e+06	1.71e+06	5.41e+05	1.25e+05	1.53e+07	20.39
7.B	1.01e+07	6.90e+06	2.09e+06	1.07e+05	1.37e+05	2.03e+07	26.96
7.C	1.16e+07	7.62e+06	2.31e+06	1.39e+06	1.47e+05	2.31e+07	30.71
8.A	9.58e+06	9.39e+06	3.45e+06	1.83e+06	2.54e+05	2.45e+07	32.59
8.B	1.19e+07	1.09e+07	3.74e+06	2.26e+06	2.61e105	2.90e107	38.62
8.C	1.35e+07	1.14e+07	3.87e+06	2.49e+06	2.64e+05	3.15e+07	41.89

Table 28. Reductions in CO_2 Emissions with 10% Penetration of Energy Efficiency Measures

Units: Tonnes of CO_2 (negative values indicate increases)

	Electricity	Natural Gas	Oil	Wood	Propane	Total	% of Total
Canada	2.89e+07	2.75e+07	1.01e+07	7.88e+06	8.52e+05	7.52e+07	100
Series	**Reduction**						
1.A	6.33e+05	1.25e+04	-3.88e+04	-1.61e+04	-7.86e+03	5.83e+05	0.78
1.B	8.65e+05	2.11e+05	1.12e+04	4.26e+04	-5.68e+03	1.12e+06	1.50
1.C	1.02e+06	3.10e+05	4.35e+04	7.97e+04	-3.88e+03	1.45e+06	1.93
2.A	6.33e+05	-1.59e+05	-1.09e+05	-9.77e+04	-1.39e+04	2.54e+05	0.34
2.B	8.65e+05	-1.19e+05	-1.25e+05	-1.12e+05	-1.75e+04	4.92e+05	0.65
2.C	1.02e+06	-1.68e+05	-1.55e+05	-1.41e+05	-2.12e+04	5.34e+05	0.71
3.A	7.52e+05	3.52e+05	1.71e+05	5.41e+04	1.13e+04	1.34e+06	1.78
3.B	9.85e+05	5.32e+05	2.09e+05	1.07e+05	1.25e+04	1.84e+06	2.45
3.C	1.14e+06	6.13e+05	2.30e+05	1.39e+05	1.35e+04	2.13e+06	2.84
4.A	9.40e+05	7.82e+05	3.45e+05	1.83e+05	2.45e+04	2.27e+06	3.02
4.B	1.18e+06	9.38e+05	3.74e+05	2.26e+05	2.52e+04	2.74e+06	3.64
4.C	1.33e+06	9.97e+05	3.87e+05	2.49e+05	2.56e+04	2.99e+06	3.98
5	2.71e+03	1.30e+05	0.00e+00	0.00e+00	0.00e+00	1.33e+05	0.18
6.A	2.11e+04	5.97e+04	4.79e+02	0.00e+00	1.24e+03	8.25e+04	0.11
6.B	6.47e+05	5.76e+04	-3.83e+04	-1.61e+04	-6.46e+03	6.44e+05	0.86
6.C	8.88e+05	2.66e+05	1.17e+04	4.26e+04	-4.31e+03	1.20e+06	1.60
6.D	1.04e+06	3.62e+05	4.40e+04	7.97e+04	-2.54e+03	1.52e+06	2.03
7.A	7.75e+05	5.21e+05	1.71e+05	5.41e+04	1.25e+04	1.53e+06	2.04
7.B	1.01e+06	6.90e+05	2.09e+05	1.07e+05	1.37e+04	2.03e+06	2.70
7.C	1.16e+06	7.62e+05	2.31e+05	1.39e+05	1.47e+04	2.31e+06	3.07
8.A	9.58e+05	9.39e+05	3.45e+05	1.83e+05	2.54e+04	2.45e+06	3.26
8.B	1.19e+06	1.09e+06	3.74e+05	2.26e+05	2.61e+04	2.90e+06	3.86
8.C	1.35e+06	1.14e+06	3.87e+05	2.49e+05	2.64e+04	3.15e+06	4.19

Table 29. Reductions in CO_2 Emissions with 20% Penetration of Energy Efficiency Measures

Units: Tonnes of CO_2 (negative values indicate increases)

	Electricity	Natural Gas	Oil	Wood	Propane	Total	% of Total
Canada	2.89e+07	2.75e+07	1.01e+07	7.88e+06	8.52e+05	7.52e+07	100
Series				**Reduction**			
1.A	1.27e+060	2.50e+04	-7.77e+04	-3.22e+04	-1.57e+04	1.17e+06	1.55
1.B	1.73e+060	4.23e+05	2.23e+04	8.52e+04	-1.14e+04	2.25e+06	2.99
1.C	2.04e+060	6.19e+05	8.70e+04	1.59e+05	-7.76e+03	2.90e+06	3.85
2.A	1.27e+060	-3.17e+05	-2.19e+05	-1.95e+05	-2.78e+04	5.07e+05	0.67
2.B	1.73e+060	-2.37e+05	-2.50e+05	-2.23e+05	-3.50e+04	9.85e+05	1.31
2.C	2.04e+060	-3.36e+05	-3.09e+05	-2.81e+05	-4.25e+04	1.07e+06	1.42
3.A	1.50e+060	7.04e+05	3.41e+05	1.08e+05	2.26e+04	2.68e+06	3.56
3.B	1.97e+060	1.06e+06	4.17e+05	2.14e+05	2.51e+04	3.69e+06	4.90
3.C	2.28e+060	1.23e+06	4.61e+05	2.78e+05	2.69e+04	4.27e+06	5.68
4.A	1.88e+060	1.56e+06	6.90e+05	3.66e+05	4.90e+04	4.55e+06	6.05
4.B	2.35e+060	1.88e+06	7.47e+05	4.51e+05	5.03e+04	5.47e+06	7.28
4.C	2.66e+060	1.99e+06	7.74e+05	4.98e+05	5.11e+04	5.98e+06	7.95
5	5.43e+036	2.60e+05	0.00e+00	0.00e+00	0.00e+00	2.65e+05	0.35
6.A	4.21e+040	1.19e+05	9.58e+02	0.00e+00	2.48e+03	1.65e+05	0.22
6.B	1.29e+060	1.15e+05	-7.66e+04	-3.22e+04	-1.29e+04	1.29e+06	1.71
6.C	1.78e+060	5.32e+05	2.33e+04	8.52e+04	-8.61e+03	2.41e+06	3.20
6.D	2.08e+060	7.23e+05	8.79e+04	1.59e+05	-5.08e+03	3.05e+06	4.05
7.A	1.55e+06	1.04e+06	3.42e+05	1.08e+05	2.50e+04	3.07e+06	4.08
7.B	2.02e+06	1.38e+06	4.18e+05	2.14e+05	2.75e+04	4.06e+06	5.39
7.C	2.33e+06	1.52e+06	4.61e+05	2.78e+05	2.93e+04	4.62e+06	6.14
8.A	1.92e+06	1.88e+06	6.91e+05	3.66e+05	5.08e+04	4.90e+06	6.52
8.B	2.39e+06	2.17e+06	7.48e+05	4.51e+05	5.21e+04	5.81e+06	7.72
8.C	2.70e+06	2.27e+06	7.74e+05	4.98e+05	5.29e+04	6.30e+06	8.38

8.0 IMPACT OF APPLIANCE EFFICIENCY AND FUEL SUBSTITUTION ON FUEL CONSUMPTION AND CARBON DIOXIDE EMISSIONS IN CANADA

There is an opportunity to reduce end-use fuel consumption and CO_2 emissions in Canada by switching from oil and propane to natural gas and electricity for space and DHW heating. To study the impact of fuel switching and improving appliance efficiency two fuel switching scenarios are evaluated:

Fuel Switching Scenario 1:	Switch 20% of oil and 20% of propane consumption to natural gas
Fuel Switching Scenario 2:	Switch 20% of oil and 20% of propane consumption to electricity

For Fuel Switching Scenario 1, it is assumed, keeping with the current practice, that the new furnaces that are installed in place of existing oil and propane furnaces would be high or medium efficiency furnaces, with a minimum efficiency of 80%.

To evaluate the impact of adopting these two scenarios, first it is necessary to determine the energy requirement for each fuel used. The energy requirement can be calculated from equivalent fuel consumption using the following equation:

Energy requirement for fuel (I) in TJ =
(Equivalent fuel consumption for fuel (I) in TJ) x (utilization efficiency for fuel (I))

Utilizing the efficiencies for the fuels used are given in Table 2 and the projected energy savings for each scenario and penetration rate. The energy requirements from each fuel were calculated.

For each of the scenarios, the end-use fuel consumption values from each fuel are calculated as follows:

- reduce the oil and propane energy by 20% and add these amounts on to natural gas or electricity energy,
- calculate the new equivalent fuel consumption values using the equation above, and 80% fuel utilization efficiency for new natural gas furnaces, 100% for electric space heat.
- calculate the new fuel consumption values using the heating value of the fuels,
- calculate the savings for each fuel with respect to the actual fuel consumption in Canada.

The results of these calculations are shown in Appendix 14 with corresponding reductions in CO_2 generation. The analysis is shown for 10%, 20%, and 100% penetration rates.

The actual end-use fuel savings attributable to fuel switching alone are also calculated. The end-use fuel savings attributable to fuel switching alone (assuming 20% penetration of energy saving measures) can be calculated by subtracting total projected savings, as given in Appendix 14 from the values in Table 23 for each scenario. These calculations were carried out, and the results are presented in Tables 30 and 31. Similarly, the comparison of reductions in CO_2 emissions with and without fuel switching are summarized in Table 32.

The following observations can be made from this analysis:

1. By switching to natural gas from oil and propane (fuel switching scenario no.1), the natural gas consumption increases while oil and propane consumption decreases. It should also be noted that there is a slight decrease in total fuel energy consumption (see last two columns of Table 30). This decrease is as a result of the higher average efficiency of replacement natural gas fired furnaces (assumed to be 80%) compared to that of oil and propane fired furnaces (70.3% and 77%, respectively).

2. By switching to electricity from oil and propane (fuel switching scenario no.2), oil and propane consumption decreases while electricity consumption increases. Since the end-use energy conversion efficiency of electric resistance heating is nearly 100%, there is actually a reduction in the total end-use energy consumption as seen in the last two columns of Table 31.

3. Depending on the fuel switching scenario selected and the assumptions for market penetration of energy efficiency measures, the reductions and shift in fuel consumption can be significant. Thus, promotional or incentive programs can be utilized to modify the fuel mix in the residential market. The impact of any fuel switching scenario can be evaluated using the approach presented here.

4. The impact of fuel switching on CO_2 emissions is significant as can be seen from Table 32. The reduction in CO_2 emissions is about the same with both scenarios evaluated here.

5. Depending on the fuel switching scenario selected and the assumptions for market penetration of energy efficiency measures, the reduction in CO_2 emissions can be as high as 9.5% for a market penetration level for energy efficiency measures of 20%. This is clearly a significant reduction indicating that fuel switching and energy efficiency improvements are viable options for controlling CO_2 emissions.

Table 30. Net Fuel Savings Due To Fuel Switching Scenario No. 1

(20% penetration of energy saving measures) (negative values indicate increases)

	Natural Gas (GWh)	Oil (ML)	Propane (ML)	Natural Gas (%)	Oil (%)	Propane (%)	Energy TJ	Energy (%)
Canada	14,607	3,569	558	100	100	100	705,613	100
Simulation	**Savings**			**Savings**			**Savings**	
1.A	-719	719	114	-4.92	20.15	20.37	3482	0.49
1.B	-712	712	113	-4.88	19.96	20.27	3449	0.49
1.C	-708	708	113	-4.85	19.83	20.18	3427	0.49
2.A	-729	729	115	-4.99	20.43	20.65	3530	0.50
2.B	-732	731	116	-5.01	20.50	20.82	3542	0.50
2.C	-736	736	117	-5.04	20.61	21.00	3562	0.50
3.A	-689	690	109	-4.72	19.32	19.47	3339	0.47
3.B	-684	684	108	-4.68	19.17	19.41	3313	0.47
3.C	-681	681	108	-4.66	19.09	19.37	3299	0.47
4.A	-665	665	105	-4.55	18.63	18.85	3220	0.46
4.B	-661	661	105	-4.53	18.52	18.82	3201	0.45
4.C	-659	659	105	-4.51	18.47	18.80	3192	0.45
5	-713	714	112	-4.88	20.00	20.00	3455	0.49
6.A	-713	714	111	-4.88	20.00	19.94	3454	0.49
6.B	-719	719	113	-4.92	20.15	20.30	3482	0.49
6.C	-712	712	113	-4.88	19.95	20.20	3448	0.49
6.D	-708	708	112	-4.85	19.83	20.12	3426	0.49
7.A	-689	690	108	-4.72	19.32	19.41	3338	0.47
7.B	-684	684	108	-4.68	19.17	19.36	3313	0.47
7.C	-681	681	108	-4.66	19.09	19.31	3298	0.47
8.A	-665	665	105	-4.55	18.63	18.81	3219	0.46
8.B	-661	661	105	-4.53	18.52	18.78	3200	0.45
8.C	-659	659	105	-4.51	18.46	18.76	3191	0.45

Table 31. Net Fuel Savings Due To Fuel Switching Scenario No. 2

(20% penetration of energy saving measures) (negative values indicate increases)

	Electricity (GWh)	Oil (ML)	Propane (ML)	Electricity (%)	Oil (%)	Propane (%)	Energy TJ	Energy (%)
Canada	131,073	3,569	558	100	100	100	624,155	100
Simulation	Savings			Savings			Savings	
1.A	-6,054	719	114	-4.62	20.15	20.37	8930	1.27
1.B	-5,997	712	113	-4.58	19.96	20.27	8846	1.25
1.C	-5,960	708	113	-4.55	19.83	20.18	8790	1.25
2.A	-6,138	729	115	-4.68	20.43	20.65	9054	1.28
2.B	-6,160	731	116	-4.70	20.50	20.82	9085	1.29
2.C	-6,197	736	117	-4.73	20.61	21.00	9139	1.30
3.A	-5,803	690	109	-4.43	19.32	19.47	8561	1.21
3.B	-5,760	684	108	-4.39	19.17	19.41	8497	1.20
3.C	-5,736	681	108	-4.38	19.09	19.37	8460	1.20
4.A	-5,597	665	105	-4.27	18.63	18.85	8257	1.17
4.B	-5,566	661	105	-4.25	18.52	18.82	8209	1.16
4.C	-5,551	659	105	-4.23	18.47	18.80	8187	1.16
5	-6,001	714	112	-4.58	20.00	20.00	8855	1.25
6.A	-5,999	714	111	-4.58	20.00	19.94	8853	1.25
6.B	-6,051	719	113	-4.62	20.15	20.30	8927	1.27
6.C	-5,995	712	113	-4.57	19.95	20.20	8843	1.25
6.D	-5,958	708	112	-4.55	19.83	20.12	8788	1.25
7.A	-5,800	690	108	-4.43	19.32	19.41	8558	1.21
7.B	-5,758	684	108	-4.39	19.17	19.36	8494	1.20
7.C	-5,733	681	108	-4.37	19.09	19.31	8458	1.20
8.A	-5,596	665	105	-4.27	18.63	18.81	8255	1.17
8.B	-5,564	661	105	-4.24	18.52	18.78	8207	1.16
8.C	-5,549	659	105	-4	18.46	18.76	8185	1.16

Table 32. Reductions in CO_2 Emissions with Fuel Switching

(20% penetration of energy saving measures) (Tonnes/year)

	No Fuel Subtitution		Fuel Switching Scenario No.1		Fuel Switching Scenario No.2	
	Total	% of Total	Total	% of Total	Total	% of Total
Canada	7.52e+07	100	7.52e+07	100	7.52e+07	100
Simulation	**Reduction**					
Baseline	-	-	8.47e+05	1.13	8.64e+05	1.15
1.A	1.17e+06	1.55	2.02e+06	2.69	2.04e+06	2.71
1.B	2.25e+06	2.99	3.09e+06	4.11	3.11e+06	4.14
1.C	2.90e+06	3.85	3.74e+06	4.97	3.75e+06	4.99
2.A	5.07e+05	0.67	1.37e+06	1.83	1.39e+06	1.85
2.B	9.85e+05	1.31	1.85e+06	2.46	1.87e+06	2.49
2.C	1.07e+06	1.42	1.94e+06	2.58	1.96e+06	2.61
3.A	2.68e+06	3.56	3.50e+06	4.65	3.51e+06	4.67
3.B	3.69e+06	4.90	4.50e+06	5.98	4.52e+06	6.01
3.C	4.27e+06	5.68	5.08e+06	6.75	5.10e+06	6.78
4.A	4.55e+06	6.05	5.34e+06	7.10	5.35e+06	7.12
4.B	5.47e+06	7.28	6.26e+06	8.32	6.28e+06	8.34
4.C	5.98e+06	7.95	6.76e+06	8.99	6.78e+06	9.02
5	2.65e+05	0.35	1.11e+06	1.48	1.13e+06	1.50
6.A	1.65e+05	0.22	1.01e+06	1.34	1.03e+06	1.37
6.B	1.29e+06	1.71	2.14e+06	2.85	2.16e+06	2.87
6.C	2.41e+06	3.20	3.25e+06	4.33	3.27e+06	4.35
6.D	3.05e+06	4.05	3.89e+06	5.17	3.91e+06	5.19
7.A	3.07e+06	4.08	3.88e+06	5.17	3.90e+06	5.19
7.B	4.06e+06	5.39	4.87e+06	6.47	4.88e+06	6.49
7.C	4.62e+06	6.14	5.43e+06	7.22	5.44e+06	7.24
8.A	4.90e+06	6.52	5.69e+06	7.57	5.71e+06	7.59
8.B	5.81e+06	7.72	6.59e+06	8.77	6.61e+06	8.79
8.C	6.30e+06	8.38	7.08e+06	9.42	7.10e+06	9.44

9. CONCLUSIONS

In this project, the effect of appliance efficiency on the overall residential end-use energy consumption and atmospheric emissions of CO_2 in Canada is investigated based on simulation studies conducted on the Expanded STAR database using the ENERPASS building simulation program. In addition, the effect of fuel substitution for space and domestic hot water heating on residential end-use energy consumption and atmospheric emissions is evaluated.

Owing to the scale of the project, the key conclusions are presented below under two headings:

1. Those related with the Expanded STAR database,
2. Those related with the findings of the simulation studies conducted using ENERPASS.

9.1 Conclusions: Expanded STAR Data Base

The statistics obtained from Expanded STAR database on the distribution of housing stock amongst the provinces, fuel consumption, and type of space heating fuel were compared with Statistics Canada Data. The following conclusions and recommendations are reached from these comparisons:

Conclusion 1:
The distribution of the Canadian housing stock amongst provinces in the Expanded STAR database is relatively close to the Statistics Canada data. However, it should be noted that:

- the housing stock in Newfoundland, Manitoba, Saskatchewan and British Columbia are over-represented,
- the housing stock in P.E.I., Nova Scotia, New Brunswick, Quebec, Ontario and Alberta are under-represented (there are no houses from P.E.I. in Expanded STAR).

Conclusion 2:
In Expanded STAR:

- oil heating is generally over-represented in all provinces except in N.S. and P.E.I.,
- more houses with natural gas heating are needed in Ontario and B.C.,
- more houses with wood and propane heating are needed in all provinces,
- more houses with electricity heating are needed in Quebec, Ontario, Manitoba and Saskatchewan,
- the distribution of houses according to the principal space heating fuel in Expanded STAR is closer to Statistics Canada data when all of Canada is considered; however, if the provincial distribution is considered, the agreement is not good at all (differences of more than 100% are found for some fuels in some provinces).

Conclusion 3:
The fuel consumption estimates from baseline ENERPASS simulations done on the Expanded STAR show that:

- residential oil and electricity consumption for all of Canada are over estimated, while natural gas, propane and wood consumption are under estimated,
- the estimates fuel consumption for individual fuels in the provinces do not compare well with Statistics Canada data (some are more than 100% higher, while some are 100% lower),
- the average annual energy consumption per household estimated from the baseline simulation done on the entire Expanded STAR database is very close to the Canada-2 housing stock model estimate. The difference is 0.66%, which is insignificant.

Conclusion 4:
From Conclusions 1-3, it is clear that the although Expanded STAR database can be considered acceptably accurate at the national level, it is not statistically accurate at provincial level and requires improvement.

Conclusion 5:
A statistical analysis done on Expanded STAR indicated that the average heating system efficiency for natural gas furnaces is 68.8%. This average efficiency is rather low compared to the efficiency of modern natural gas furnaces, however it probably reflects the lower efficiencies of the previous generation conversion burners. The natural gas furnaces and conversion burners that are being installed now are of higher efficiency, and this is reflected in the analysis done in this project to evaluate the effect of fuel substitution.

Conclusion 6:
Although Expanded STAR is not statistically as accurate as it could be, especially at the provincial level, it is a valuable tool that can be improved with some effort. Once it is improved and is statistically representative of the Canadian housing stock, it would be an invaluable tool to evaluate the consequences of almost any scenario regarding energy consumption in single dwellings in Canada.

9.2 Conclusions: From ENERPASS Simulation Studies

A wide range of scenarios on the impact of appliance efficiency improvements, as well as house envelope and mechanical system improvements on residential end-use energy consumption and atmospheric CO_2 emissions in Canada were evaluated by conducting ENERPASS simulations on the Expanded STAR database. In addition, the consequences of fuel switching on fuel consumption and atmospheric CO_2 emissions were studied using the same approach. The conclusions and recommendations based on the results of these simulation studies are summarized below:

Conclusion 7:
As the efficiency of appliances improves:

- the fuel consumption for DHW heating and appliances decreases, and
- space heating energy requirement increases.

The increase in space heating energy requirement is due to the reduced heat gain from appliances which has to be made up by the heating system. The reason for the reduction in DHW heating energy is the reduced DHW consumption for dish washing, clothes washing and general washing, as well as reduced heat losses from the DHW distribution system.

Conclusion 8:
Unless a very inefficient heating system is used (such as wood burning) for space heating, it is not beneficial to "heat" a house with appliances. There are several reasons for this:

- A large part of the energy in DHW is lost down the drain without any heat gain to the house,
- A large part of the energy used by clothes dryers is exhausted directly to outdoors,
- The heat gain from inefficient appliances is not always "useful" heat gain. When little or no heating is necessary during the warmer periods of shoulder seasons, the heat gain is largely wasted since it does not offset the heating requirement from the furnace or boiler. On the other hand, during the cooling season, the heat gain is a nuisance in non-air-conditioned houses and a source of additional energy waste in air-conditioned houses since the air-conditioner has to work harder to extract this additional heat gain.

Conclusion 9:
Regardless of the scenario adopted, with increased efficiency of appliances, house envelope and mechanical systems, the residential consumption of electricity decreases. Depending on the nature and magnitude of improvements, the magnitude of electricity savings varies between negligibly small and 4.7% with 10% penetration of energy saving measures. The magnitude of savings increase linearly with market penetration level. To obtain the higher levels of energy savings, in addition to energy efficient appliances, improvements in house envelope and mechanical systems are necessary. For all other heating fuels, depending on the scenario evaluated, increases in fuel consumption are seen for certain scenarios, most notably for those which involve improvement of appliance efficiencies only. As discussed earlier, when only the appliance efficiencies are improved, the heat gain that comes from the appliances has to be replaced by the heating fuel, and this causes the increase in the consumption of that fuel.

Conclusion 10:
Regardless of the scenario evaluated, there is a decrease in total residential end-use energy consumption. The overall savings in end-use energy consumption varies between 0.76% and 4.21% of the total for 10% penetration of energy saving measures. The magnitude of savings increase linearly with market penetration level. The savings associated with the improvement of only appliance efficiencies varies between 0.33% and 0.71% for 10% penetration, and 0.66% and 1.42% for 20% penetration. These results clearly indicate that although improving appliance

efficiency would result in about 1-2% reduction in the overall residential end-use energy consumption, for a more significant impact, energy saving measures such as improved building envelope and control of mechanical systems should be applied along with improving appliance efficiency.

Thus, it is clear that to reduce the residential end-use energy consumption, improving only appliance efficiencies is not an effective approach in itself. For more significant reductions in energy consumption, improvement in house envelope and mechanical systems should be considered. Since the energy savings associated with improving appliance efficiencies is not high (less than 1% for a 10% market penetration), it is very important that detailed cost-benefit analyses are carried out in making decisions.

Conclusion 11:
The reductions in CO_2 emissions (in percent of total CO_2 emissions from residential energy consumption) are very close in magnitude to savings in energy consumption.

The potential to reduce the CO_2 emissions by improving only the appliance efficiencies is between 0.34% and 0.71%, depending on the level of efficiency improvements for a 10% penetration of improved appliances in the residential market. The reduction in emissions increase linearly with market penetration level. Clearly, these reductions are not significant; however, if house envelopes and mechanical systems are improved along with appliance efficiencies, the potential for reduction of CO_2 emissions increases to as much as 4.2% for a market penetration level of 10%, and to 8.4% for a market penetration level of 20%. These reductions are clearly substantial reductions and present objectives worth pursuing especially in the light of the 1988 Toronto Protocol which requires 20% reductions in CO_2 emissions by 2005.

Thus, it is clear that there is a potential for reducing the CO_2 emissions significantly by improving appliance efficiencies and house characteristics. Therefore, in conducting cost-benefit analysis for the energy efficiency measures evaluated, the intrinsic benefit of the reductions in CO_2 emissions should be considered as these reductions are clearly significant, and they would present a valuable opportunity to approach the objectives of the 1988 Toronto Protocol.

Conclusion 12:
Depending on how the energy consumption is shifted from certain fuels to others, there can be significant reductions in both total end-use energy consumption and CO_2 emissions in Canada. In this study, two possible scenarios were evaluated, and the associated findings are therefore applicable to these scenarios only. The important conclusion that can be drawn from this study is that the magnitude of the reductions should be calculated specifically for the scenario in question as there are no general conclusions that can be drawn. Simulation studies done using Expanded STAR, especially after it is improved, would be the most suitable approach to evaluate the impact of different scenarios.

Conclusion 13:
The simulation studies conducted to evaluate the sensitivity of energy consumption estimates to the variation in load curves for appliances show that unless completely unrealistic load curves are used, the estimates do not change significantly. This indicates that for the purposes of studying the residential energy consumption, the load curves obtained from the literature are sufficient for accurate results. However, the effect of load curves on the energy consumption of houses with air-conditioning was found to be substantially higher compared to that in houses without air-conditioning, and for this reason accurate load curves are essential to study the impact of high efficiency appliances in air-conditioned houses.

It should also be noted that the effect of load curves on peak electrical demand would most likely be significant (peak electrical demand was not studied in this work). It would therefore be useful to have accurate load curves representing appliance usage for different parts of Canada.

Conclusion 14:
Reductions in $C0_2$ emissions through energy efficiency upgrades will vary regionally due to differences in electricity generation sources. The results of this study are based on the average production of $C0_2$ per unit of electricity generated nationally including all sources (e.g. hydro, nuclear). Additional studies are required to more accurately predict energy and $C0_2$ reductions on a regional basis.

Conclusion 15:
This study illustrates the need to consider the interactive effects of the energy consumption patterns of houses when evaluating the potential impact of energy efficiency measures.

Conclusion 16:
This project demonstrates that housing databases and energy consumption simulation programs are useful tools for analysing the impact of energy efficiency measures on the energy consumed and pollutants generated by the residential sector.

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