RATIONALIZATION OF HOUSE ENERGY SYSTEMS

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Final Report

Prepared for: Research Division
Canada Mortgage and Housing Corporation

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Executive Summary

As building envelopes improve through tighter construction, very efficient windows and high insulation levels the appliance, lighting, ventilation, water heating and space cooling energy consumptions become dominant. Further significant reductions in overall house energy consumption require that existing energy uses be interconnected in such a way that the net waste is reduced. This study was initiated to determine within the context of healthy housing, what energy system rationalization options make sense. This goal was to be achieved by analyzing household energy use and assessing a variety of integrated systems.

The water-loop system, which is widely used in large commercial buildings, was used as a convenient means of integrating household energy systems within the DOE-2.1D program. A list of energy system options that could be evaluated was generated and software models were added to accommodate most of these within the program. To determine the sensitivity of the performance of these options, to size of envelope load and climatic factors, each was simulated in old, code and advanced envelopes in Vancouver, Winnipeg and Toronto. Options were evaluated individually as components and in combination as systems, to permit the understanding of the contribution of each. The results show that large energy savings and peak demand reductions (up to 13,539 kWh and 31.6kW or 52 and 93% respectively) are available with some of the options investigated.

Simple paybacks based on energy savings alone were under five years, for some (envelope and location) applications for more efficient fans, water-loop cooled refrigerator and freezer condensers, dryer exhaust heat recovery, efficient lighting and appliances and heat recovery ventilators. When incentives for peak demand reduction were assumed to be available solar thermal collectors, additional south facing windows, high efficiency heat pumps, loop-connected heat pump water heater, grey water heat recovery and a natural-gas-fired cogeneration system with absorption cooling were added to the list of economically attractive options.

The high degree of promise offered by energy system interconnection suggests that further efforts in this area should be actively pursued.

Résumé

À mesure que l'enveloppe du bâtiment s'améliore grâce à une construction des plus étanches, à des fenêtres très performantes et à une excellente isolation, la consommation énergétique des appareils d'éclairage, de ventilation, de chauffage de l'eau, de chauffage des locaux et de climatisation devient prédominante. Pour pouvoir diminuer encore davantage la consommation globale d'énergie dans une habitation, il faudra que les installations consommant de l'énergie soient reliées entre elles de manière à réduire leurs résidus nets. Cette étude vise à déterminer, dans le contexte des maisons saines, quelles sont les meilleures façons d'accroître l'efficacité énergétique des installations domestiques. Pour ce faire, la consommation d'énergie domestique est analysée et divers types d'installations intégrées sont évalués.

Le système à boucle d'eau, largement utilisé dans les grands immeubles commerciaux, sert à intégrer les installations énergétiques domestiques au programme DOE-2.1D. Une liste d'installations énergétiques susceptibles d'être évaluées a été dressée et des logiciels de modélisation ont été employés pour incorporer la plupart d'entre elles au programme. Pour déterminer la sensibilité de la performance de ces installations, selon la charge de l'enveloppe et les facteurs climatiques, chacune d'elles a fait l'objet d'une simulation par rapport à l'enveloppe d'une vieille maison, à celle d'une maison construite selon les exigences actuelles du code du bâtiment et à une maison dotée d'une enveloppe perfectionnée. Ces évaluations ont été menées à Vancouver, Winnipeg et Toronto. Chaque installation a été évaluée individuellement, en tant qu'élément d'un ensemble, puis en association avec d'autres installations, en vue de comprendre le rôle de chacune. Les résultats montrent qu'il est possible de réaliser d'importantes économies d'énergie et de diminuer la demande de pointe chez certaines installations évaluées (soit jusqu'à 13 539 kWh et 31,6 kW ou 52 p. 100 et 93 p. 100 respectivement).

On a obtenu un délai de récupération simple des coûts inférieur à cinq ans pour les seules économies d'énergie réalisées grâce à certaines applications (type d'enveloppe et emplacement) et à des dispositifs plus efficients tels les ventilateurs d'extraction, les condenseurs de réfrigérateur et de congélateur à refroidissement par boucle d'eau, la récupération de la chaleur produite par la sécheuse, l'éclairage et les appareils éconergiques de même que les ventilateurs-récupérateurs de chaleur. Lorsqu'il a semblé que les mesures d'encouragement à la réduction de la demande énergétique de pointe étaient offertes, les éléments suivants ont pu être ajoutés à la liste des installations permettant de réaliser des économies : capteurs solaires, fenêtres additionnelles au sud, pompes à chaleur à haute efficacité, pompe à chaleur pour le chauffage de l'eau domestique, récupérateur de la chaleur des eaux ménagères et installation de cogénération au gaz naturel avec refroidissement par absorption.

Les progrès très prometteurs que laisse entrevoir le raccordement entre elles des installations énergétiques portent à croire que de plus amples efforts devraient être consacrés à ce secteur.

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1 INTRODUCTION

In Canada the residential sector accounts for approximately 25 percent of the country's energy consumption. The potential for greatly reducing household energy use has been clearly demonstrated in the Shrewsbury house built by Saunders (1) the Minimum Energy house by LeBoeuf and Christensen (2) and many R2000 houses (3). In these buildings significant reductions in energy use were achieved through envelope improvements. To a lesser extent domestic energy consumption was reduced as well. While these buildings provide valuable demonstration of the reductions that may be achieved, there were some shortcomings. The designs displaying the lowest consumptions tended to experience indoor temperature swings that would not be readily accepted by many people and some may also produce poor electric utility load factors. Generally, significant waste heat streams still existed.

To provide perspective on these advances a comparison of the energy used by several similarly-sized, single-family houses, whose energy consumptions span a broad range, is presented in Figure 1. As the building envelope is improved through tighter construction, very efficient windows and high insulation levels, the appliance, lighting, ventilation, water heating and space cooling energy consumptions become dominant.

In 1976, the United States Energy Research and Development Administration, recognizing significant potential for economic recovery of waste heat, initiated a program to accelerate consumer use of integrated appliances designed to save energy. To this end Lee et al. (4) undertook a study to identify the most promising integrated appliance candidates and recommend a demonstration program. A long list of possible devices that could be created through the combination of existing appliances was generated and the most promising ones were selected. Three concepts chosen for further development and demonstration were the furnace/water heater, the central air conditioner/water heater and the commercial range heat recovery water heater. Eliminated in the final selection were the refrigerator/water heater, the residential building drain heat recovery water heater and the commercial building drain heat recovery water heater.

In 1980, Tu et al. (5) reported on tests performed at the NBS on three products which were variations on the central air conditioner/water heater concept. In these, a heat exchanger (essentially a desuperheater) added to a heat pump, rather than a central air conditioner, delivered heat to the domestic hot water system.

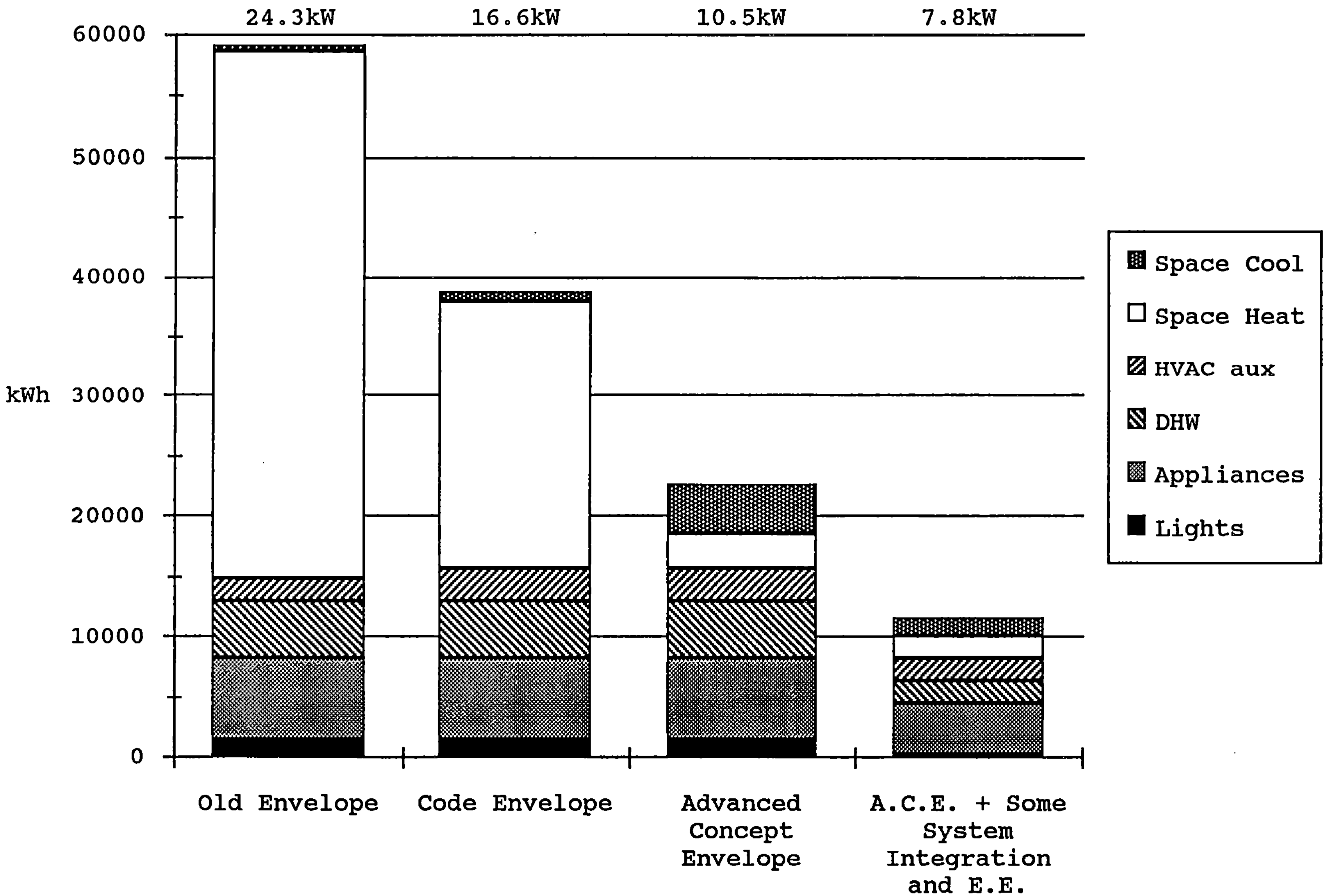

Figure 1 House Energy Use and Peak Demand

In 1987 Allen et al. (6) evaluated six integrated appliance concepts which involved, in some cases, more than two functions. This work lead to the development of the SOLMATE ™ Integrated Mechanical System (7) which was installed in the Advanced House in 1990 and currently provides space heating and cooling, domestic water heating, exhaust-air and grey water heat recovery (8). While this house and system demonstrate substantial energy savings (9), every house energy system must be scrutinized if the true potential for minimum house energy consumption is to be achieved.

1.1 OBJECTIVE

The primary objective of this study was to determine, through the analysis of household energy use and the assessment of a variety of integrated systems, what options make sense in the rationalization of house energy use. All options considered were to fit within the context of healthy housing.

A secondary objective was to provide good documentation of the energy system rationalization options to facilitate reassessment as technology developments improve performance and/or reduce costs.

1.2 SCOPE

This study has specifically included only single-family dwellings, however it does cover a broad range of the domestic-to-envelope load ratio. In general terms the results may be roughly applicable to some multi-unit applications where these ratios are the same.

Wherever possible, the systems evaluated were powered by electrical energy because single energy source accounting avoids the complication of including combustion efficiency and ratio of gas to electric energy costs as variables. As such, heat is added to the systems through electric resistance elements. While a single energy source is very convenient for making system intercomparisons it is not intended to suggest that resistance heat is the preferred method of supplying heat. In fact in most cases it is expected that further benefits would ensue from the provision of this heat through high-efficiency combustion of natural gas or heat pumping from air, water, or ground sources.

2 APPROACH

The approach used to determine what energy system rationalization options make sense consisted of three main components:

1. Option list generation and culling
2. Model implementation and development
3. Simulation and analysis of results

In generating the option list, the intent was to create an extensive list which accounted for all significant energy flows in typical Canadian homes. A preliminary evaluation of the options on this list included rough estimations of potential benefit and cost and the review of relevant literature. Options removed from the list included those that were judged to hold little promise of becoming practical, and some whose performance could be adequately predicted without computer modelling. A water-loop system, shown schematically in Figure 2, was used to permit the thermal interconnection of as many subsystems as was desired.

Three house models which spanned a wide range of envelope efficiency levels were assembled within a sophisticated, hour by hour computer model along with as many of the energy system options as could practically be incorporated. This exercise included the specification of realistic equipment use patterns and occupancy schedules.

Each system was simulated in each house type in three Canadian cities, selected for their diverse climates. The system costs were estimated and the results tabulated and analyzed.

2.1 SIMULATION SOFTWARE

The simulations were performed using the building energy analysis program DOE-2.1D. This program was selected because of its wide use in the engineering/architecture community (10), and the fact that its publicly available water-loop heat pump model has been incorporated into other building programs, such as LoadShaper. For those measures which exceeded the capabilities of the water-loop heat pump model, subroutines were added and engineering calculations were performed using building load and system performance information supplied by the DOE-2.1D program.

The following is a brief description of the DOE-2.1D program. DOE-2.1D is the current version of the DOE-2 building energy analysis program developed by Lawrence Berkeley

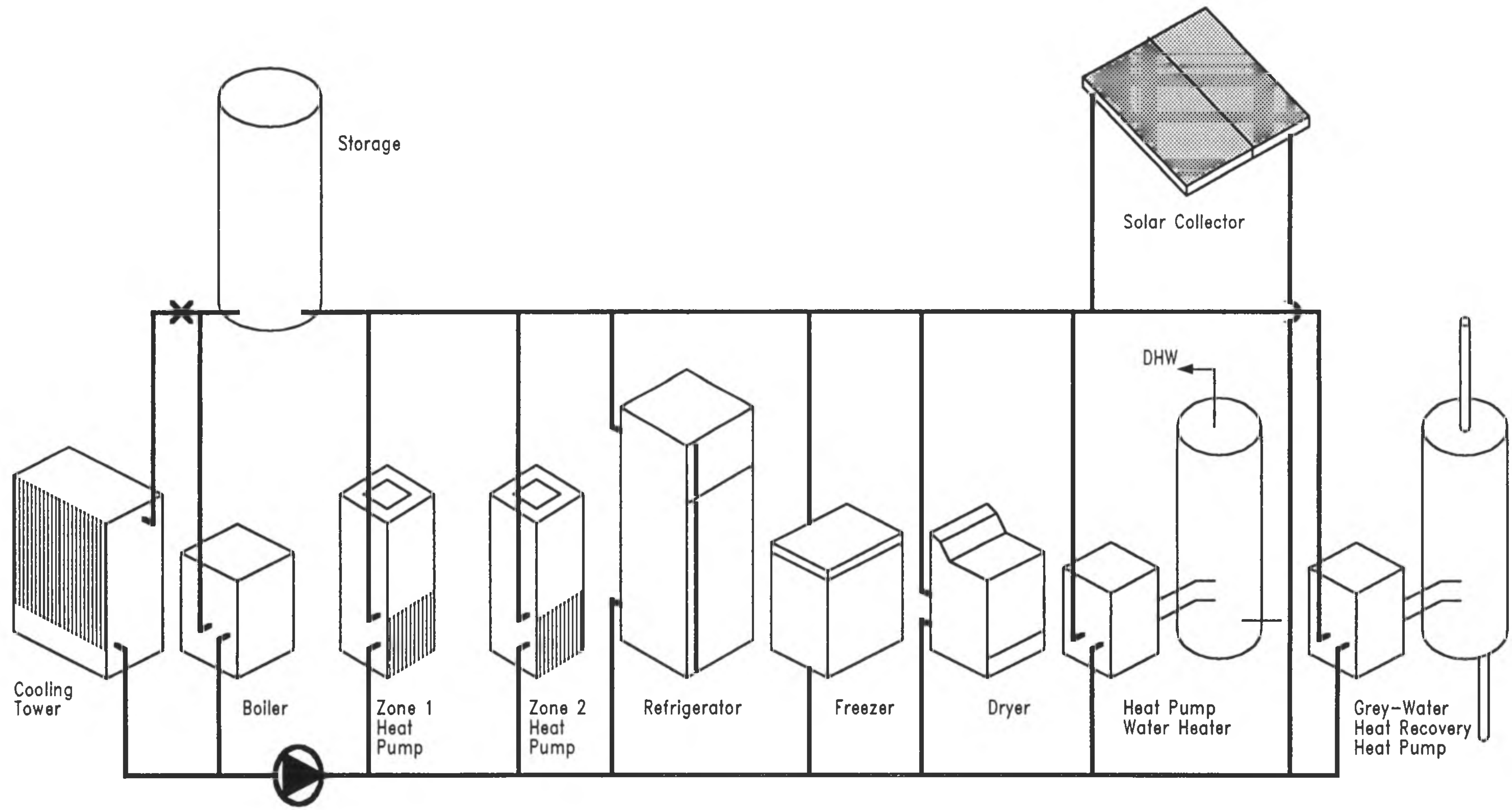

Figure 2 Generalized Water-Loop System

Laboratory for the United States Department of Energy. The program evaluates building energy requirements on an hour-by-hour basis, up to 8760 hours per year, using local weather data (temperature, solar radiation, relative humidity, wind speed and direction). The program consists of four sequential subprograms: loads, systems, plant and economics.

The loads subprogram calculates hourly heating and cooling loads based on heat gains and losses through the building envelope. Infiltration loads are based on either the crack method or the air-change method. Internal lighting, equipment and occupant loads are calculated based on user-defined schedules.

The systems subprogram simulates performance of the secondary HVAC equipment used to control the temperature and humidity within each zone of the building. It uses the hourly output from the loads subprogram to calculate the hourly thermal and electrical energy requirements of the HVAC system.

The plant subprogram calculates the performance of the primary energy conversion equipment (cooling tower, boiler) based on hourly operating conditions and part-load performance characteristics. The user selects the type and size of equipment or can allow the program to automatically size the equipment based on either peak heating or cooling loads or design day conditions.

A more detailed description of the program and its models is provided in Appendix A. This description includes details of seven models added to the program to simulate the heat recovery ventilator, grey water heat recovery, solar-thermal collector, heat pump water heater, dryer exhaust heat recovery and economizer cooling.

2.2 DESCRIPTION OF HOUSES

The houses simulated in this report consisted of two floors of living space (total area of 186 m^2, volume of 457 m^3) and a basement (area of 93 m^2, volume of 242 m^3). Varying insulation levels helped to define three separate types of housing stock while using the same basic floorplan. The insulation levels for the old, code and advanced concept envelope houses are listed in Table 1. The code levels of insulation satisfy the 1986 Ontario Building Code, in Toronto.

Window insulation values also varied with envelope construction, as shown in Table 1. In order to maximize solar gain and reduce window heat loss, interior shading was applied

Table 1
Insulation Levels and Ventilation Rates

	HOUSE ENVELOPE		
	OLD	CODE	ADVANCED CONCEPT
Insulation (RSI (R) value)			
Ceiling	1.9 (10.8)	5.3 (30.3)	13.9 (79.0)
Walls above grade	1.6 (8.9)	2.5 (14.1)	8.6 (48.7)
Basement walls - first 60 cm below grade	0.4 (2.4)	2.5 (14.2)	8.8 (49.7)
Basement walls - remaining	0.4 (2.4)	0.4 (2.4)	8.8 (49.7)
Basement floor	0.4 (2.4)	0.4 (2.4)	2.6 (14.9)
Windows	0.2 (1.0)	0.4 (2.0)	1.0 (5.4)
Natural Infiltration (ach)			
Winter	0.32	0.20	0.05
Summer	0.0	0.0	0.0
Mechanical Ventilation (ach)			
Winter	0.00	0.12	0.27
Summer	0.27	0.27	0.27

to the windows during winter at night only and during summer through the daytime only. The interior shading reduced the radiation and conduction heat transfer through the window by 50%.

Infiltration of outdoor air into the house varied with the envelope type but there was no infiltration during the (summer) months of May to September. To maintain identical amounts of outdoor air entering each house, the mechanical ventilation rate also varied with building envelope. As there was no infiltration in summer, the mechanical ventilation rate was identical for all three houses. Infiltration and mechanical ventilation rates are also shown in Table 1.

The house was modeled with a total occupancy of four people. During weekdays the house was assumed to be vacant from 9:00 to 18:00 with full occupancy in the living space otherwise. The living space occupancy schedule varied on weekends and holidays. The basement had one occupant for four hours a day on weekends only. The heat gain per person was assumed to be 130 watts.

Lighting levels in the house were influenced by the assumed occupancy pattern and time of day and year. The peak lighting level during evening hours corresponded to approximately 3.3 W/m^2 of living area. This value represents actual lighting in use, not installed lighting capacity. Outdoor lighting was not factored into the house simulation. Basement lighting was equal to 1.2 W/m^2 during periods when the basement was occupied. 100% of the lighting energy enters the space as heat gain.

In DOE-2.1D, appliances in the house are not modeled individually. Instead, their hourly electrical consumption is summed and treated via a fluctuating energy use schedule. Generally 100% of the energy consumed by the appliances resulted in heat gain to the space, the exceptions being an assumed energy loss to the outdoors attributable to a clothes dryer and an energy gain to the water-loop when the refrigerator and freezer condensers are considered to be connected to the loop. The annual energy consumption of the major appliances is shown in Table 2 (11, 12, 13). A freezer was assumed to operate in the basement of the house, while the other appliances were located in the living space.

Table 2

Annual Domestic Energy Consumption
(kWh)

Light & Appliances	Standard	High Efficiency (Best Refrigerator)	High Efficiency (Good Refrigerator)
Refrigerator	1350	240[1]	691
Range	1209	780[1]	780[1]
Freezer	1485	504[1,2]	504[1,2]
Clothes Dryer	864	836	836
Dishwasher *	394	252[1]	252[1]
Microwave	394	256	256
Clothes Washer *	160	124	124
Colour TV	450	292	292
Other	567	520	520
Lighting	1307[3]	249[1]	249[1]
Total	8180[4]	4053	4504
Domestic Hot Water	4739[5]	4739	4739

Notes
* Excluding hot water usage
1 Advanced-concept house guidelines
2 Best Canadian product
3 Average conventional ~ 5 W/m^2 (140%)
4 Based on R2000 Monitoring Average = 8176 kWh/year
5 Based on R2000 Monitoring Average (+ 20W for standard tank loss)

2.3 ENERGY SYSTEMS

Space heating and cooling was available year round in the houses modeled with a water-loop system. The space temperature was maintained at a maximum of 24 °C year round, and a minimum of 22 °C in the living area during the winter. During the summer months of June through September, the temperature in the living area was allowed to drop to 18°C before heating would be initiated. The minimum temperature of the basement was kept lower than the living area at values of 18 °C and 16 °C during the winter and summer, respectively.

The water source heat pumps that conditioned the basement and living area were modeled with a rated coefficient of performance (COP) in heating of 3.9 and an energy efficiency ratio (EER) in cooling of 12.2. The water-loop, to which the heat pumps were connected, contained 140 litres of water. As heat was either removed from or rejected to the loop, the water temperature varied between 16 °C and 32 °C. The lower temperature limit was maintained by an electric hot water boiler and the upper limit by a cooling tower. The water in the loop was circulated by an 85 watt pump, of which 90% of the pump energy was transferred to the water in the form of heat.

The residential system (non-water-loop) used the same thermostat setpoints for the above-grade living area but the basement zone temperature *floated* as it did not have a thermostat.

In the base case house, domestic water heating was performed by electric resistance. The annual energy consumption closely matched the average consumption in R-2000 homes (3), and the range of values given by Ontario Hydro (14).

2.4 SIMULATED SYSTEM OPTIONS

Each of the 36 systems simulated is described in Appendix B. These systems have been divided into three categories:

Reference Systems are conventional systems that provide a basis against which the thermal performance and cost of other options may be compared.

Component Systems are system options that feature one key component, simulated for individual assessment.

Combination Systems are system options comprised of combinations of promising components to allow their assessment when functioning in concert.

Additional details are provided in the remainder of this section.

2.4.1 Reference Systems

The *Systems numbered 1 to 4*, for each house envelope and location, act as residential system references covering the following cases: heating only; heating and cooling only; heating with ventilation; and heating and cooling with ventilation. While only the last two include mechanical ventilation, which is a requirement for reliably good indoor air quality, together they serve to quantify the energy impact of the heating and cooling envelope loads and the ventilation load. Heating was available for October through May and cooling for June through September.

System 5 is essentially the same as *System 4* but it has a baseboard heater added to the basement zone and heating and cooling availability extended to 365 days of the year. This permits improved temperature control particularly in avoiding low temperatures in the basement.

System 6 is also a reference residential system but it is based on a water-loop system which has the inherent flexibility of facilitating the interconnection of numerous energy sources and sinks throughout the house. Like *Systems 1 to 5*, it has two zones, the basement and the above-grade living space, and like *System 5* the basement zone has its own thermostat (but in this case for both heating and cooling). The below-grade space temperature may therefore be controlled just as closely as on the upper floors, in heating and cooling. There is of course an energy consumption penalty associated with maintaining comfort conditions in the basement, however the usefulness of the space is enhanced and comfort conditions need not be maintained when it is unoccupied. Continuous operation of an efficient circulating pump (which consumes 745 kWh annually), year-round cooling control in the basement and efficiency differences resulting from heating and cooling with water-loop heat pumps cause some difference in the total annual energy consumption between *Systems 5 and 6*.

2.4.2 Component Systems

Sixteen *component systems* simulated include a 5-zone water-loop system and a series of 2-

zone systems each including a feature or sub-system which has energy saving potential (*Systems 7 through 22*). These features included: thermal storage (454 L of water) added to the water-loop; 9.3 m^2 of additional south-facing windows (with and without thermal storage); very efficient appliances (consuming 55% of reference system appliance energy); moderately efficient appliances (62% of reference appliance consumption); a heat recovery ventilator (with and without summer bypass); high efficiency water-loop heat pumps; a heat pump water heater using the water-loop as a heat source; refrigerator and freezer with water-loop-cooled condensers; grey water heat recovery heat pump with water-loop-cooled condenser; dryer exhaust heat recovery; water-loop connected 5.72 m^2 solar collector (with and without water-loop thermal storage) and more efficient fans.

Evaluation of the *component systems* is based on their performance and incremental cost relative to the reference water-loop system, *System 6*. In this way the cost and benefit associated with a component allow its relative importance to be determined.

2.4.3 Combination Systems

Systems 23 through 34 are *combination systems* built-up through the combination of promising options that were simulated individually as *component systems*. The energy and demand savings attributed to *combination systems* are evaluated relative to the reference water-loop *System 6*, (similar systems for maximum precision), while the economic performance incorporates incremental costs relative to the conventional (reference) residential *System 5*. In this way economic decisions are made relative to the current norm. As noted above, details of these systems are tabulated in Appendix B.

2.4.4 Other Systems

Obviously there are some options that have not been simulated. Limited project resources clearly restricted the options which could be included, particularly those that required additions to the software. Some options, that would produce predictable results were omitted to permit the inclusion of options with less obvious results. One of these is the use of a ground source heat pump to replace boiler heat in the loop. A properly sized system would be expected to operate with a heating seasonal performance factor (HSPF, equivalent to seasonal system COP) of approximately 3.6, as estimated in Appendix C. This implies that the electrical energy consumed in adding heat to the loop could be divided by the HSPF, if the boiler were replaced with a ground-coupled water-to-water heat pump. Boiler energy is typically 60-70% of the tabulated space heating energy but may be as little as 30% for multi-heat-source loops in low load buildings. Ground source heat pumps could be used in conjunction with virtually all of the system options investigated except *Systems 35 and 36.*

Similarly, the benefit of replacing the electric boiler with a gas-fired unit in *Systems 6 through 34* may be assessed without additional simulations. Electric boiler energy divided by the efficiency of a gas replacement, gives the gas consumption. Expected demand reductions would be approximately equal to the boiler rating divided by the HSPF for the GSHP and the boiler rating itself for the gas boiler case.

3 RESULTS

3.1 SIMULATED PERFORMANCE: ENERGY AND DEMAND

The simulated energy consumptions for space heating, space cooling, fans/pumps/controls (HVAC Aux), domestic water heating, lighting and appliances are tabulated in Appendix D along with peak annual demand (including time of occurrence) for each system option, house envelope and location. The energy and demand savings (relative to reference *System 6*) for each system option, house envelope and location are summarized in Tables 3 and 4.

The tabulated energy *savings* include some negative values in cases where that particular system option has a total energy consumption greater than that of the reference system, for that house envelope and location. Operation of the circulating pump, required by the water-loop system, for example, tends to increase total energy consumption particularly when there is a cooling load of significance.

In *System 7*, increasing the number of zones from 2 to 5, allowed each floor of the living space to be divided into north and south areas, each controlled independently. This permitted the heat removed from cooled zones to offset the need to add heat to the loop for the heated zones. Moving heat from one area to another in this way (as opposed to simple mixing, if the two zones were adjacent) reduced the heat that must be added to the loop for the heated zones while increasing heat pump operation and therefore cooling energy, in the removal of heat from the cooled zones. The end result was a net energy savings in larger heating load cases (327 kWh in the Winnipeg old envelope) and an increase in consumption when the extracted energy could not be put to use (856 kWh in the Winnipeg advanced envelope). Demand was generally reduced, presumably because all five heat pumps were not operating at the time of peak demand.

The addition of thermal storage in the form of 454 L of water, in *System 8* results in modest energy savings in each of the cases examined. The greatest benefit occurred for the advanced concept envelope houses. Simulated demand was unchanged.

In *System 9*, 9.3 m^2 of additional south-facing window was added to the reference system and in *System 10* this was combined with thermal storage. In the code envelope houses the added windows alone saved between 627 and 2052 kWh in Vancouver and Winnipeg respectively. When combined with thermal storage, these savings increased to 1099 and

Table 3
Energy Savings

#	Units - kWh Component System Description	Incremental Cost ($)**	Vancouver Old	Vancouver Code	Vancouver Adv.	Winnipeg Old	Winnipeg Code	Winnipeg Adv.	Toronto Old	Toronto Code	Toronto Adv.
6	WL - two zones - reference	0									
7	WL - five zones	2860	119	-434	-454	327	-112	-856	53	193	-437
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	375	23	79	82	35	82	94	15	32	73
9	WL - two zones - 9.3 m2 more south windows	1550/1200/1200	-186	627	-1310	-601	2052	630	-1365	794	-472
10	WL - two zones - more window, plus 0.454 m3 storage	1925/1575/1575	-69	1099	-1175	-496	2310	1058	-1321	967	-343
11	WL - two zones - with efficient applicances, best refrigerator	2795	854	1480	4811	613	1136	3534	1208	1559	4225
12	WL - two zones - with efficient appliances, good refrigerator	1500	750	1339	4389	514	1028	3217	1056	1383	3868
13	WL - two zones - heat recovery ventilator (HRV)	1450	3	1805	1368	29	3516	4817	117	2857	2391
15	WL - two zones - high efficiency heat pumps	1050	-3	79	999	12	91	741	91	190	908
16	WL - two zones - 100% heat pump water heater	2015	65	390	2013	115	343	1551	343	607	1802
17	WL - two zones - fridge, freezer loop connected compressors	100	37	226	1483	74	141	1040	193	369	1324
18	WL - two zones - grey water heat recovery (GWHR)	2015	2110	1802	393	2332	2156	1014	2042	1954	624
19	WL - two zones - dryer exhaust heat recovery	200	483	378	21	533	472	129	489	410	47
20	WL - two zones - 5.75 m2 solar collector (solar)	2125	2493	1998	240	4038	3475	1040	3009	2605	601
21	WL - two zones - solar with 0.454m3 storage	2500	2722	2271	290	4252	3835	1474	3179	3024	724
22	WL - two zones - more efficient fans	100	334	509	1450	344	428	1063	347	527	1262
	Combination System Description										
6	WL - two zones - reference	1455									
23	WL - two zones - Note 1	8815	756	3446	7671	569	4704	9944	1371	4782	8002
24	WL - two zones - Note 1, 9.3 m2 more south windows	10365/10015/10015	814	5218	6774	218	7426	10530	-111	5936	7887
25	WL - two zones - Note 1, lower loop temperature limits	8815	969	4925	8169	471	4944	10384	1233	5415	8515
26	WL - two zones - Note 2	6120	736	2992	6651	346	1294	4855	1049	2420	5816
27	WL - two zones - Note 2, HRV	7570	753	4834	7814	358	4819	10056	1057	5189	8260
28	WL - two zones - Note 2, grey water heat recovery	8135	2945	5054	7392	2790	3553	6115	3146	4442	6742
29	WL - two zones - Note 2, 0.454 m3 of storage	6495	738	3021	6985	405	1365	5136	1175	2602	6042
30	WL - two zones - Note 2, 5.75 m2 solar collector	8245	4000	5781	7545	4932	5446	6660	4626	5617	7152
31	WL - two zones - Note 2, 20 m2 solar collector	11385	7849	8107	7773	12206	11467	7296	9507	8749	7498
32	WL - two zones - Note 2, HRV, GWHR	9585	2965	6877	8391	2801	7075	10999	3155	7208	8977
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	12085	6186	9528	9224	7373	11332	12420	6777	10454	10141
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	12185	6588	10181	10533	7711	11562	13539	7123	11022	11359
35	TPFC - two zones - gas DHW + space heating, electric cooling	1780	-17066	-10477	-885	-37375	-25201	-2662	-23886	-12619	-1848
36	TPFC - two zones - cogen with absorption chiller, gas DHW	10510	-24063	-24916	-39036	-36560	-25857	-34745	-26810	-24412	-38062

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

----/----/---- represents varying prices for old, code and advanced concept houses.

** Components relative to reference system 5, systems relative to reference system 6.

Table 4
Demand Savings

	Units - kW	Incremental	Vancouver			Winnipeg			Toronto		
#	Component System Description	Cost ($)**	Old	Code	Adv.	Old	Code	Adv.	Old	Code	Adv.
6	WL - two zones - reference	0									
7	WL - five zones	2860	0.10	0.26	0.07	-0.24	0.26	0.16	0.26	0.12	0.00
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	375	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	WL - two zones - 9.3 m2 more south windows	1550/1200/1200	-0.90	-0.14	-0.52	-0.71	-0.07	0.81	-1.32	-0.20	-0.62
10	WL - two zones - more window, plus 0.454 m3 storage	1925/1575/1575	-0.90	-0.14	-0.52	-0.71	-0.07	0.81	-1.32	-0.20	-0.62
11	WL - two zones - with efficient applicances, best refrigerator	2795	0.16	0.16	1.05	0.14	0.15	0.14	0.01	0.14	0.33
12	WL - two zones - with efficient appliances, good refrigerator	1500	0.17	0.17	1.05	0.15	0.16	0.15	0.04	0.15	0.34
13	WL - two zones - heat recovery ventilator (HRV)	1450	0.01	0.63	0.36	0.01	0.72	2.78	0.01	0.83	0.43
15	WL - two zones - high efficiency heat pumps	1050	0.01	0.01	0.44	0.01	0.01	0.00	0.01	0.01	0.20
16	WL - two zones - 100% heat pump water heater	2015	-0.16	-0.16	0.73	-0.16	-0.16	-0.16	-0.16	-0.16	0.04
17	WL - two zones - fridge, freezer loop connected compressors	100	0.00	0.01	0.50	0.03	0.01	0.00	-0.04	0.01	0.22
18	WL - two zones - grey water heat recovery (GWHR)	2015	0.32	0.32	0.00	0.31	0.32	0.32	0.32	0.32	0.00
19	WL - two zones - dryer exhaust heat recovery	200	3.36	1.42	0.00	2.33	1.06	2.46	3.37	2.88	0.00
20	WL - two zones - 5.75 m2 solar collector (solar)	2125	0.49	0.49	0.00	1.93	1.21	1.63	0.95	1.11	0.00
21	WL - two zones - solar with 0.454m3 storage	2500	0.49	0.49	0.00	1.93	1.21	1.63	0.95	1.11	0.00
22	WL - two zones - more efficient fans	100	-0.02	-0.03	0.18	-0.02	-0.04	-0.04	-0.08	-0.03	0.17
	Combination System Description										
6	WL - two zones - reference	1455									
23	WL - two zones - Note 1	8815	-0.01	0.61	1.73	-0.03	0.69	3.01	-0.15	0.80	1.26
24	WL - two zones - Note 1, 9.3 m2 more south windows	10365/10015/10015	-0.91	0.46	1.61	-0.82	0.60	2.99	-1.07	0.50	1.16
25	WL - two zones - Note 1, lower loop temperature limits	8815	0.18	1.14	1.72	-0.61	0.75	2.59	0.07	1.88	1.27
26	WL - two zones - Note 2	6120	0.15	0.54	0.88	-0.60	-0.12	-0.43	0.08	1.13	0.19
27	WL - two zones - Note 2, HRV	7570	0.16	1.14	1.72	-0.59	0.75	2.61	0.08	1.87	1.27
28	WL - two zones - Note 2, grey water heat recovery	8135	0.47	0.86	1.19	-0.28	0.19	-0.11	0.39	1.44	0.51
29	WL - two zones - Note 2, 0.454 m3 of storage	6495	0.15	0.54	0.88	-0.60	-0.12	-0.43	0.08	1.13	0.19
30	WL - two zones - Note 2, 5.75 m2 solar collector	8245	0.65	1.03	1.42	1.72	1.51	1.20	1.03	2.12	1.28
31	WL - two zones - Note 2, 20 m2 solar collector	11385	1.89	2.25	2.76	2.91	3.12	4.44	3.40	4.48	2.47
32	WL - two zones - Note 2, HRV, GWHR	9585	0.47	1.46	2.04	-0.28	1.07	2.92	0.39	2.19	1.59
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	12085	0.97	1.96	2.58	2.04	3.00	4.55	1.35	3.28	2.57
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	12185	1.02	2.16	2.55	1.95	3.15	4.51	1.28	3.47	2.72
35	TPFC - two zones - gas DHW + space heating, electric cooling	1780	13.44	7.77	1.94	25.96	15.15	4.17	15.91	8.50	1.89
36	TPFC - two zones - cogen with absorption chiller, gas DHW	10510	18.69	13.17	8.65	31.61	21.08	10.79	22.03	14.63	8.42

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

----/----/---- represents varying prices for old, code and advanced concept houses.

** Components relative to reference system 5, systems relative to reference system 6.

2310 kWh. However in the old envelope houses, where single glazed windows were used, the added window area with and without added thermal storage caused increased energy use. The advanced concept envelope only benefitted in the Winnipeg location and the energy saving there increased 68% to 1058 kWh with the incorporation of the extra thermal storage. This envelope and location showed an associated reduction in demand while each of the other cases experienced an increase.

More efficient light fixtures and appliances replaced average consumption lights and appliances in *Systems 11 and 12.* A very efficient refrigerator (240 kWh/year) combined with other efficient but commonly available appliances and high-efficiency lights reduced appliance and lighting consumption by 50% relative to the reference case in *System 11.* In *System 12,* the refrigerator was replaced with a lower cost, moderately high efficiency unit, for a combined lighting and appliance consumption that was 45% lower than in the reference system. These options increase the space heating but reduce the cooling energy required. Reducing lighting and appliance energy use by 4126 and 3675 kWh resulted in total energy savings of up to 4811 and 4389 kWh, for the best and good appliance groups respectively in the advanced concept envelope in Vancouver. The advanced concept envelope house in Toronto also saved more energy than the reduction in lighting and appliance consumption itself. The net savings, although substantial, were less than this in the Winnipeg advanced concept envelope house and in each of the code and old envelopes, however there was a reduction in simulated demand for each of the envelopes and locations examined.

A heat recovery ventilator (HRV) was added to the reference in *System 13.* In the code and advanced concept envelopes, energy savings ranged between 1368 and 4817 kWh, with the greatest benefit occurring in the coldest location. Significant demand reductions were also simulated for these cases. Energy consumption reductions in the old envelope houses were small because mechanical ventilation was used only in summer in these houses, eliminating most of the ventilation load and along with it the opportunity for savings.

An HRV, with the heat recovery core bypassed in summer, was simulated as *System 14.* It increased overall energy consumption , relative to the conventional HRV, in all cases.

High efficiency heat pumps replaced conventional equipment in *System 15.* While this change had only a minor effect on heating energy consumption (since reduced compressor energy must be made up by another source), it resulted in cooling energy savings of up to 999 kWh and demand reductions in some cases.

In *System 16*, a heat pump water heater that uses the water-loop as its heat source, replaced the electric resistance water heater of the reference System. It was sized with a 545 L storage tank to allow 100% of the water heating load to be met without in-tank resistance heat. Annual savings ranged between 65 and 2013 kWh, depending on how much excess heat was available from the loop when required for water heating. Simulated demand was generally increased by 160 watts.

In *System 17*, water-loop-cooled condensers replaced the conventional air-cooled units used on the reference system refrigerator and freezer. Seventy-five percent of the refrigerator and freezer electrical consumption is assumed transferred into the water-loop while the remaining 25% becomes a heat gain to the surroundings. Annual energy savings that result range from modest in the old envelope houses (37 to 193 kWh) to substantial (1040 to 1483 kWh) in the advanced concept envelopes. Demand savings were simulated to be small or non-existent in the old envelopes but as great as 0.5 kW in the Vancouver advanced concept envelope.

A grey-water tank contributed heat to the water-loop through a small water to water heat pump in *System 18*. Since the heat pump was working with a temperature rise averaging roughly 10°C (source 6°C; sink 16°C) it operated with a COP of 4.9. Energy savings for this option were greatest in cases where there were large space heating loads (2332 kWh in the Winnipeg old envelope house) and least where the heating load is small (393 kWh in the Vancouver advanced concept envelope house). Simulated demand savings were typically 320 watts but the advanced envelope houses in Toronto and Vancouver experienced no demand reduction.

System 19 employed an air-to-water heat exchanger to transfer dryer exhaust heat to the loop when it was beneficial to do so. Annual energy savings ranged from 21 kWh in the Vancouver advanced concept envelope house to 533 kWh in the Winnipeg old envelope house. Demand savings were simulated to be zero and 2.33 kW for the same two cases respectively.

A south-facing solar collector (gross area 5.75 m^2) delivered heat to the water-loop in *System 20* and in *System 21* it was combined with additional loop thermal storage (454 L of water). Energy savings were 4038 kWh for the collector alone in the Winnipeg old envelope house and 4252 kWh when combined with additional storage. Low heating load envelopes experienced much smaller savings (240 and 290 kWh in the Vancouver advanced concept envelope house). Simulated demand savings, between zero and almost 2 kW, were unchanged by the presence of additional storage.

System 22 employed fans that were twice as efficient as those used in the reference system, for air distribution and ventilation. Energy and demand savings were greatest in cases with large cooling loads (1450 kWh and 180 watts in the Vancouver, advanced concept envelope house).

A number of component options that are oriented to saving energy in an efficient envelope were combined to create *System 23*. The components included thermal storage, high efficiency lighting and appliances (including the best refrigerator), a heat recovery ventilator, high efficiency heat pumps, a heat pump water heater (which supplies 80% of the dhw load) and loop-cooled refrigerator and freezer condensers. The net result was an annual energy saving of between 7671 and 9944 kWh and simulated demand reductions between 1.3 and 3 kW in the advanced concept envelope houses. In the code envelope houses, energy savings were very roughly half these values and significantly less than this in the old envelope houses.

The addition of 9.3 m^2 of south-facing window to this combination in *System 24* increased the energy saved in the Winnipeg advanced concept envelope by 586 kWh but reduced it in Toronto and Vancouver. Each of the code houses benefitted from the windows (1154 to 2722 kWh) but the single-glazed old envelope houses generally experienced reduced savings. While demand reductions between .46 and 3 kW occurred in each code and advanced envelope house, these were smaller than those simulated for the reference window area.

System 25 is physically the equivalent of *System 23* but it is operated with revised control setpoints that maintain the water-loop temperature in the range 7 to 16^{0}C rather than 16 to 32^{0}C. Energy savings were reduced by 98 and 138 kWh in the Winnipeg and Toronto old envelope houses but were increased (213 to 1479 kWh) in all other cases. Simulated demand increased, relative to *System 23*, in the Winnipeg old and advanced envelope houses, remained essentially unchanged in the two other advanced envelope houses and dropped in each code envelope house and in the Toronto and Vancouver old envelope houses.

Another combination of component options, *System 26*, included efficient lighting and appliances (including a moderately high efficiency refrigerator as in *System 12*), high efficiency heat pumps, a heat pump water heater (which supplies 100% of the dhw load), loop-cooled refrigerator and freezer condensers and lower water-loop temperature limits. Annual energy savings varied between 4855 and 6651 kWh in the advanced envelope houses and 346 and 1049 kWh in the old envelope houses. Simulated demand reductions between 80 and 1130 watts occurred in all Toronto and Vancouver houses but the Winnipeg houses showed demand increases of 120 to 600 watts.

The addition of an HRV to the previous combination converts it into *System 27.* Energy and demand savings increased for all houses, relative to the reference *System 6*, by 358 to 10056 kWh and -0.59 to 2.61 kW. On average, the energy savings due to the HRV are essentially the same whether it is used alone or in the combination system defined here.

System 28 adds grey-water heat recovery to the *System 26* combination. Unlike *System 26* GWHR has the greatest benefit in the large heat load cases. Alone in *System 18*, it saved as much as 2332 kWh in the Winnipeg old house and as little as 393 kWh in the Vancouver advanced house. As an addition to *System 26* it saved 2444 and 741 kWh in the same two houses. The increased savings are likely due to the added need for heat in the water-loop to supply the heat pump water heater. Demand, relative to *System 26,* is reduced for each house envelope and location.

Thermal storage was added to the combination *System 26* to create *System 29.* In general its benefit is greater than when evaluated as a single component in *System 8*, however energy savings were reduced in Vancouver and Winnipeg code houses and the Vancouver old house. Simulated demand was not changed by the addition of storage.

System 30 was the combination *System 26* with a 5.75 m^2 solar system added to the loop and in *System 31* this was replaced by a 20 m^2 solar system. The smaller solar system, which saved between 240 and 4038 kWh per year on its own in *System 20,* saved between 894 and 4586 kWh per year in this combination system. Simulated demand reduction, relative to *System 26,* is from 490 watts to over 2kW. As with the grey water heat recovery system, the enhanced benefits are believed to be due to an increased water-loop heat requirement. The larger solar collector adds a further 228 to 7274 kWh to the savings, depending on the heat load of the house in question. Simulated demand reductions were also substantial, being approximately 2.9 kW on average, relative to *System 26*, and 3.1 kW relative to the reference *System 6.*

Systems 32, 33 and 34 are further combinations of the components included in *System 26* with some or all of the following: a heat recovery ventilator; grey water heat recovery; solar system; thermal storage; and efficient fans. The HRV, GWHR and solar system components contribute most towards reducing the need to purchase heating energy while thermal storage and efficient fans tend to contribute most when cooling loads are greatest. When combined together in *System 34* the net results were annual energy savings of between 6588 and 7711 kWh in the old houses and between 10533 and 13539 kWh in the advanced concept houses, relative to the reference, *System 6*. Corresponding simulated demand savings were between 1 and 2 kW and 2.5 and 4.5 kW respectively.

Systems 35 and 36 are different from all of the previous systems in that they use natural gas and electricity to meet system energy needs. *System 35* is essentially a gas-heated and electric-cooled equivalent to the reference water-loop, *System 6*. Since gas combustion efficiencies are less than 100%, the combined gas and electric energy consumption is greater than in the equivalent all electric system. On the other hand, significant peak electrical demand reductions result, particularly in the old and code houses (7.8 - 26 kW).

System 36 represents a major effort to reduce electrical demand and utility supplied electrical energy by incorporating a natural gas co-generation system to supply electricity and heat and an absorption chiller to provide cooling. Further increased energy consumption resulted because electrical co-generation efficiency is less than one and cooling C.O.P.s are low relative to conventional electric systems. Simulated demand was however reduced to between 1.8 and 2.4 kW compared to corresponding demands of 10.5 to 34 kW in the conventional all electric houses.

3.2 ECONOMIC PERFORMANCE

3.2.1 Energy Savings and Peak Demand Reductions

Approximately one-third of the electrical energy sold in Canada is supplied to residential customers. As reductions in the demand for generation and distribution capacity can result in large avoided costs by the electrical utility, this factor must be considered along with energy savings, in the economic analysis.

While a utility's capacity costs are driven by the average demand occurring during one peak period per year, that may last for a couple of hours or for sixteen hours (or longer), the period of concern will be different for each utility. Further complicating the issue is the fact that in the future, changing loads may significantly change the nature and timing of this peak. For example, the City of Toronto is now a summer peaking utility while its supplier, Ontario Hydro, is a winter peaking utility.

In this work the reduction in demand, at the system peak for a given energy system option is approximated by the difference in simulated peak electrical demand for a reference house system and that for the optional house/system in question. As such, the result is not specific to a particular generation mix, location and year.

The economic benefit associated with the predicted energy savings for a component or system are evaluated through the calculation of the simple payback period using the value of energy saved at 8.4 cents/kWh and the associated incremental cost.

The economic benefit resulting from demand reduction was assessed at two different levels. One was modelled on a current Ontario Hydro program which offers an incentive of $500 per avoided kW. While the utility incentive is restricted to a maximum equal to half of the cost of the measure taken to reduce demand, this limit (which ensures customer interest) was not imposed here. This incentive was applied as a one-time reduction to the first-cost of the option in question prior to calculation of the simple payback period.

The second approach is essentially the same except that a value of $5000 per avoided kW is used (to conservatively approximate the cost of installing new electrical generation and distribution capacity) to reduce the first cost of the option, before the simple payback is calculated.

3.2.2 Simple Payback

The simple payback, based on energy savings only, for each successful option, house envelope and location is summarized in Table 5. Simple paybacks for a $500/kW demand reduction incentive appear in Table 6 and in Table 7 for an incentive of $5000/kW. In each of these tables, component paybacks are based on incremental component costs while system paybacks include the cost of upgrading to a water-loop based system. In this way the relative attractiveness of the individual components may be evaluated. If these paybacks are viewed in absolute terms it must be assumed that the $1455 cost of upgrading to a water-loop system has been justified by improved comfort/use of space, future flexibility to add in other systems and the use of the loop as a fire-sprinkler supply. Systems on the other hand have this upgrade cost built-in so that direct comparisons to conventional systems do not require the same subjective assumptions.

Table 5
Simple Payback Period
($0.084/kWh, $0.198/m3 - energy savings only)

Units - years		Incremental	Vancouver			Winnipeg			Toronto		
#	Component System Description	Cost ($)**	Old	Code	Adv.	Old	Code	Adv.	Old	Code	Adv.
6	WL - two zones - reference	0									
7	WL - five zones	2860	286.6	*	*	104.0	*	*	639.4	176.1	*
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	375	190.5	56.4	54.4	127.0	54.4	47.6	304.7	138.5	60.9
9	WL - two zones - 9.3 m2 more south windows	1550/1200/1200	*	22.8	*	*	7.0	22.7	*	18.0	*
10	WL - two zones - more window, plus 0.454 m3 storage	1925/1575/1575	*	17.1	*	*	8.1	17.7	*	19.4	*
11	WL - two zones - with efficient applicances, best refrigerator	2795	39.0	22.5	6.9	54.3	29.3	9.4	27.5	21.3	7.9
12	WL - two zones - with efficient appliances, good refrigerator	1500	23.8	13.3	4.1	34.7	17.4	5.6	16.9	12.9	4.6
13	WL - two zones - heat recovery ventilator (HRV)	1450	5891.5	9.6	12.6	589.1	4.9	3.6	147.3	6.0	7.2
15	WL - two zones - high efficiency heat pumps	1050	*	158.0	12.5	1066.6	137.6	16.9	137.6	65.6	13.8
16	WL - two zones - 100% heat pump water heater	2015	368.1	61.5	11.9	207.8	69.9	15.5	69.9	39.5	13.3
17	WL - two zones - fridge, freezer loop connected compressors	100	32.6	5.3	0.8	16.1	8.4	1.1	6.2	3.2	0.9
18	WL - two zones - grey water heat recovery (GWHR)	2015	11.4	13.3	61.1	10.3	11.1	23.7	11.7	12.3	38.4
19	WL - two zones - dryer exhaust heat recovery	200	4.9	6.3	116.1	4.5	5.0	18.5	4.9	5.8	50.8
20	WL - two zones - 5.75 m2 solar collector (solar)	2125	10.1	12.7	105.3	6.3	7.3	24.3	8.4	9.7	42.1
21	WL - two zones - solar with 0.454m3 storage	2500	10.9	13.1	102.6	7.0	7.8	20.2	9.4	9.8	41.1
22	WL - two zones - more efficient fans	100	3.6	2.3	0.8	3.5	2.8	1.1	3.4	2.3	0.9
	Combination System Description										
6	WL - two zones - reference	1455									
23	WL - two zones - Note 1	8815	138.8	30.5	13.7	184.3	22.3	10.6	76.6	21.9	13.1
24	WL - two zones - Note 1, 9.3 m2 more south windows	10365/10015/10015	151.6	22.8	17.6	566.3	16.1	11.3	*	20.1	15.1
25	WL - two zones - Note 1, lower loop temperature limits	8815	108.3	21.3	12.8	223.0	21.2	10.1	85.1	19.4	12.3
26	WL - two zones - Note 2	6120	99.1	24.4	11.0	210.5	56.3	15.0	69.5	30.1	12.5
27	WL - two zones - Note 2, HRV	7570	119.7	18.6	11.5	251.9	18.7	9.0	85.2	17.4	10.9
28	WL - two zones - Note 2, grey water heat recovery	8135	32.9	19.2	13.1	34.7	27.3	15.8	30.8	21.8	14.4
29	WL - two zones - Note 2, 0.454 m3 of storage	6495	104.7	25.6	11.1	191.1	56.7	15.1	65.8	29.7	12.8
30	WL - two zones - Note 2, 5.75 m2 solar collector	8245	24.5	17.0	13.0	19.9	18.0	14.7	21.2	17.5	13.7
31	WL - two zones - Note 2, 20 m2 solar collector	11385	17.3	16.7	17.4	11.1	11.8	18.6	14.3	15.5	18.1
32	WL - two zones - Note 2, HRV, GWHR	9585	38.5	16.6	13.6	40.7	16.1	10.4	36.2	15.8	12.7
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	12085	23.3	15.1	15.6	19.5	12.7	11.6	21.2	13.8	14.2
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	12185	22.0	14.2	13.8	18.8	12.5	10.7	20.4	13.2	12.8
35	TPFC - two zones - gas DHW + space heating, electric cooling	1780	0.8	1.3	4.2	0.4	0.6	2.3	0.7	1.2	3.6
36	TPFC - two zones - cogen with absorption chiller, gas DHW	10510	3.7	5.7	16.3	1.8	2.8	10.6	3.2	5.1	14.3

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

* = has an infinite payback period; 0.0 = immediate payback period; ----/----/----/ represents varying prices for old, code and advanced concept houses.

** Components relative to reference system 5, systems relative to reference system 6.

Table 6
Simple Payback Period
(with $500/kW demand reduction incentive - no maximum limit)

Units - years		Incremental	Vancouver			Winnipeg			Toronto		
#	Component System Description	Cost ($)**	Old	Code	Adv.	Old	Code	Adv.	Old	Code	Adv.
6	WL - two zones - reference	0									
7	WL - five zones	2860	281.8	*	*	N/A	*	*	610.0	172.3	*
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	375	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9	WL - two zones - 9.3 m2 more south windows	1550/1200/1200	*	N/A	*	*	N/A	15.0	*	N/A	*
10	WL - two zones - more window, plus 0.454 m3 storage	1925/1575/1575	*	N/A	*	*	N/A	13.2	*	N/A	*
11	WL - two zones - with efficient applicances, best refrigerator	2795	37.8	21.8	5.6	52.9	28.5	9.2	27.5	20.8	7.4
12	WL - two zones - with efficient appliances, good refrigerator	1500	22.5	12.6	2.6	33.0	16.5	5.3	16.7	12.3	4.1
13	WL - two zones - heat recovery ventilator (HRV)	1450	5877.8	7.5	11.1	586.6	3.7	0.1	146.6	4.3	6.1
15	WL - two zones - high efficiency heat pumps	1050	*	157.6	9.9	1059.4	137.0	N/A	137.1	65.4	12.5
16	WL - two zones - 100% heat pump water heater	2015	382.8	N/A	9.8	216.3	N/A	N/A	N/A	N/A	13.2
17	WL - two zones - fridge, freezer loop connected compressors	100	N/A	5.1	0.0	13.7	8.2	N/A	N/A	3.1	0.0
18	WL - two zones - grey water heat recovery (GWHR)	2015	10.5	12.3	N/A	9.5	10.2	21.8	10.8	11.3	N/A
19	WL - two zones - dryer exhaust heat recovery	200	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	N/A
20	WL - two zones - 5.75 m2 solar collector (solar)	2125	9.0	11.2	N/A	3.4	5.2	15.0	6.5	7.2	N/A
21	WL - two zones - solar with 0.454m3 storage	2500	9.9	11.8	N/A	4.3	5.9	13.6	7.6	7.7	N/A
22	WL - two zones - more efficient fans	100	N/A	N/A	0.1	N/A	N/A	N/A	N/A	N/A	0.2
	Combination System Description										
6	WL - two zones - reference	1455									
23	WL - two zones - Note 1	8815	N/A	29.4	12.3	N/A	21.4	8.7	N/A	20.9	12.2
24	WL - two zones - Note 1, 9.3 m2 more south windows	10365/10015/10015	N/A	22.3	16.2	N/A	15.6	9.6	*	19.6	14.2
25	WL - two zones - Note 1, lower loop temperature limits	8815	107.2	19.9	11.6	N/A	20.3	8.6	84.8	17.3	11.4
26	WL - two zones - Note 2	6120	97.8	23.3	10.2	N/A	N/A	N/A	69.1	27.3	12.3
27	WL - two zones - Note 2, HRV	7570	118.4	17.2	10.2	N/A	17.8	7.4	84.8	15.2	10.0
28	WL - two zones - Note 2, grey water heat recovery	8135	31.9	18.2	12.1	N/A	26.9	N/A	30.0	19.9	13.9
29	WL - two zones - Note 2, 0.454 m3 of storage	6495	103.5	24.5	10.3	N/A	N/A	N/A	65.4	27.1	12.6
30	WL - two zones - Note 2, 5.75 m2 solar collector	8245	23.6	15.9	11.9	17.8	16.4	13.7	19.9	15.2	12.7
31	WL - two zones - Note 2, 20 m2 solar collector	11385	15.8	15.1	15.3	9.7	10.2	15.0	12.1	12.4	16.1
32	WL - two zones - Note 2, HRV, GWHR	9585	37.5	15.3	12.2	N/A	15.2	8.8	35.4	14.0	11.7
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	12085	22.3	13.9	13.9	17.9	11.1	9.4	20.0	11.9	12.7
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	12185	21.1	13.0	12.3	17.3	10.9	8.7	19.3	11.3	11.3
35	TPFC - two zones - gas DHW + space heating, electric cooling	1780	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	TPFC - two zones - cogen with absorption chiller, gas DHW	10510	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

* = has an infinite payback period; 0.0 = immediate payback period; N/A = no demand reduction; ----/----/---- represents varying prices for old, code and advances concept houses.

** Components relative to reference system 5, systems relative to reference system 6.

Table 7
Simple Payback Period
(with $5000/kW demand reduction incentive - no maximum limit)

#	Units - years	Incremental	Vancouver			Winnipeg			Toronto		
#	Component System Description	Cost ($)**	Old	Code	Adv.	Old	Code	Adv.	Old	Code	Adv.
6	WL - two zones - reference	0									
7	WL - five zones	2860	238.9	*	*	N/A	*	*	345.9	138.0	*
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	375	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
9	WL - two zones - 9.3 m2 more south windows	1550/1200/1200	*	N/A	*	*	N/A	0.0	*	N/A	*
10	WL - two zones - more window, plus 0.454 m3 storage	1925/1575/1575	*	N/A	*	*	N/A	0.0	*	N/A	*
11	WL - two zones - with efficient applicances, best refrigerator	2795	27.9	16.1	0.0	40.6	21.4	7.0	26.8	15.8	3.2
12	WL - two zones - with efficient appliances, good refrigerator	1500	10.7	6.0	0.0	17.1	8.3	2.8	14.8	6.4	0.0
13	WL - two zones - heat recovery ventilator (HRV)	1450	5754.6	0.0	0.0	563.6	0.0	0.0	140.7	0.0	0.0
15	WL - two zones - high efficiency heat pumps	1050	*	154.0	0.0	995.1	131.5	N/A	132.1	63.6	0.8
16	WL - two zones - 100% heat pump water heater	2015	515.5	N/A	0.0	292.0	N/A	N/A	N/A	N/A	12.1
17	WL - two zones - fridge, freezer loop connected compressors	100	N/A	3.9	0.0	0.0	5.8	N/A	N/A	1.9	0.0
18	WL - two zones - grey water heat recovery (GWHR)	2015	2.5	2.9	N/A	2.2	2.3	5.2	2.6	2.7	N/A
19	WL - two zones - dryer exhaust heat recovery	200	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	N/A
20	WL - two zones - 5.75 m2 solar collector (solar)	2125	0.0	0.0	N/A	0.0	0.0	0.0	0.0	0.0	N/A
21	WL - two zones - solar with 0.454m3 storage	2500	0.1	0.2	N/A	0.0	0.0	0.0	0.0	0.0	N/A
22	WL - two zones - more efficient fans	100	N/A	N/A	0.0	N/A	N/A	N/A	N/A	N/A	0.0
	Combination System Description										
6	WL - two zones - reference	1455									
23	WL - two zones - Note 1	8815	N/A	19.8	0.2	N/A	13.6	0.0	N/A	11.9	3.8
24	WL - two zones - Note 1, 9.3 m2 more south windows	10365/10015/10015	N/A	17.6	3.4	N/A	11.3	0.0	*	15.1	6.3
25	WL - two zones - Note 1, lower loop temperature limits	8815	97.1	7.6	0.3	N/A	12.2	0.0	81.9	0.0	3.5
26	WL - two zones - Note 2	6120	86.5	13.6	3.1	N/A	N/A	N/A	65.2	2.3	10.6
27	WL - two zones - Note 2, HRV	7570	107.1	4.6	0.0	N/A	9.4	0.0	80.9	0.0	1.7
28	WL - two zones - Note 2, grey water heat recovery	8135	23.4	9.1	3.5	N/A	24.0	N/A	23.4	2.4	9.9
29	WL - two zones - Note 2, 0.454 m3 of storage	6495	92.2	14.9	3.6	N/A	N/A	N/A	62.0	3.9	10.9
30	WL - two zones - Note 2, 5.75 m2 solar collector	8245	14.9	6.3	1.8	0.0	1.6	4.0	7.9	0.0	3.1
31	WL - two zones - Note 2, 20 m2 solar collector	11385	3.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	WL - two zones - Note 2, HRV, GWHR	9585	29.0	4.0	0.0	N/A	7.1	0.0	28.8	0.0	2.2
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	12085	13.9	2.9	0.0	3.1	0.0	0.0	9.4	0.0	0.0
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	12185	12.8	1.6	0.0	3.8	0.0	0.0	9.7	0.0	0.0
35	TPFC - two zones - gas DHW + space heating, electric cooling	1780	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	TPFC - two zones - cogen with absorption chiller, gas DHW	10510	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

* = has an infinite payback period; 0.0 = immediate payback period; N/A = no demand reduction; ----/----/---- represents varying prices for old, code and advances concept houses.

** Components relative to reference system 5, systems relative to reference system 6.

When energy savings alone are used as the sole justification for considering these systems, only a few options appear to be very attractive. The application of more efficient fans to advanced concept houses resulted in paybacks of 1.1 years or less and in all other cases 3.6 years or less. The water-loop connected refrigerator and freezer payback was under 1.1 years in all of the advanced envelope houses but the success of this option in other locations and envelopes appeared to be highly dependent on the size of the cooling load.

Dryer exhaust heat recovery had a payback of 5 years or less in each old house envelope and in the Winnipeg code house. The HRV was attractive in the Winnipeg code and advanced concept houses with paybacks under 5 years. In Toronto and Vancouver the corresponding paybacks were 6 years and over while in all the old houses, the HRV had little opportunity to be useful in saving energy. Efficient appliances (with the moderately efficient refrigerator) had paybacks of 4.1 and 4.6 years in the Vancouver and Toronto advanced concept houses and 5.6 years in Winnipeg. The active solar options and additional south facing window area were not very far behind with paybacks under 8 years in some Winnipeg applications.

The paybacks on system options were generally less attractive than those on components since the $1455 cost of upgrading to a water-loop system was included in the first cost. The two natural gas system options did, however, demonstrate significant advantage from the relatively low cost of the fuel (22% of the electricity cost per unit of purchased energy). The gas-heating/electric-cooling hybrid had paybacks of 4.2 years or less in each case evaluated. The cogeneration/absorption cooling system had paybacks of 5.7 years or less in each old or code envelope house.

When an incentive of $500 per kilowatt of demand reduction is added into the calculation of simple payback, six additional component cases and two more system cases are added to the list of options with paybacks of 5 years or less. Dryer heat recovery became an immediate payback option in all cases except the Vancouver and Toronto advanced concept houses. In the Winnipeg old house, the 5.75 m^2 solar system had paybacks of 4.3 and 3.4 years, with and without added thermal storage (respectively) and the HRV payback dropped from 6.0 to 4.3 years in the Toronto code envelope house. The natural-gas heating/electric cooling system become an immediate payback option in all cases except the Vancouver and Toronto advanced concept houses, where the payback periods were under two years. The cogeneration/absorption cooling system had an immediate payback in the Toronto old and Winnipeg old and code houses. Payback periods were 2.1 years or less in the other old and code houses.

When the incentive is increased to $5000 per kilowatt of demand reduction, all of the components, except five zones, grey water heat recovery and thermal storage, became immediate payback options in at least one envelope and location. Most component options became attractive for several envelopes and/or locations. With the increased incentive, all of the system options had paybacks of 3.6 years or less in the Vancouver advanced concept house and every envelope and location had at least three combination system options (including the two gas options) with paybacks under 3 years.

3.3 DISCUSSION

The water-loop system used in this work may be viewed from two different perspectives. The water-loop may be considered to be simply a convenient conceptual tool which allows the thermal interconnection of as many household energy systems as desired. Once the relative merits of the various system combinations are evaluated, the means of connection may be changed to that which is most appropriate. From the second perspective the water-loop is actually a viable means of interconnecting household energy systems both now and as others become available. The estimated $1455 incremental cost for such a system suggests that the latter view of the loop system is probably realistic, particularly if one considers the comfort/use-of-space benefits associated with zone control and its potential for use as a fire-sprinkler system supply.

3.3.1 Ranking the Options

The value to society of avoided electrical energy use and reduced peak demand is open to much discussion and debate. To determine what the actual value is, the true life-cycle costs of the options should be evaluated with an estimated cost of emissions included in each case. The answer is different for each utility and changes dramatically (depending on how closely peak demand matches available capacity) with time. In the discussion that follows it is assumed that the societal benefit of avoided peak demand is $5000/kW.

The relative economic attractiveness of the options have been ranked in Table 8. Relative attractiveness is taken as ascending order of length of the payback period, with lower capital cost options being more attractive when paybacks are equal. The ranking is different for each location and envelope type and only options with simple paybacks of less than 10 years have been ranked.

Table 8
Option Ranking
(with $5000/kW demand reduction incentive - no maximum limit)

Units - rank order (payback - years)		Incremental	Vancouver			Winnipeg			Toronto		
#	Component System Description	Cost ($)**	Old	Code	Adv.	Old	Code	Adv.	Old	Code	Adv.
6	WL - two zones - reference	0									
7	WL - five zones	2860									
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	375									
9	WL - two zones - 9.3 m2 more south windows	1550/1200/1200					8 (6.6)	2 (0.0)			
10	WL - two zones - more window, plus 0.454 m3 storage	1925/1575/1575					9 (7.7)	4 (0.0)			
11	WL - two zones - with efficient applicances, best refrigerator	2795			7 (0.0)			11 (7.0)			6 (3.2)
12	WL - two zones - with efficient appliances, good refrigerator	1500		8 (6.0)	5 (0.0)		10 (9.0)	9 (2.8)		8 (6.5)	4 (0.0)
13	WL - two zones - heat recovery ventilator (HRV)	1450		2 (0.0)	4 (0.0)		2 (0.0)	3 (0.0)		2 (0.0)	3 (0.0)
15	WL - two zones - high efficiency heat pumps	1050			3 (0.0)						5 (0.8)
16	WL - two zones - 100% heat pump water heater	2015			6 (0.0)						
17	WL - two zones - fridge, freezer loop connected compressors	100		7 (3.9)	1 (0.0)	1 (0.0)	7 (5.9)	7 (1.1)	6 (6.1)	5 (1.9)	1 (0.0)
18	WL - two zones - grey water heat recovery (GWHR)	2015	4 (2.5)	6 (2.9)		5 (2.2)	5 (2.3)	10 (5.2)	4 (2.6)	7 (2.7)	
19	WL - two zones - dryer exhaust heat recovery	200	1 (0.0)	1 (0.0)		2 (0.0)	1 (0.0)	1 (0.0)	1 (0.0)	1 (0.0)	
20	WL - two zones - 5.75 m2 solar collector (solar)	2125	2 (0.0)	3 (0.0)		3 (0.0)	3 (0.0)	5 (0.0)	2 (0.0)	3 (0.0)	
21	WL - two zones - solar with 0.454m3 storage	2500	3 (0.1)	4 (0.2)		4 (0.0)	4 (0.0)	6 (0.0)	3 (0.0)	4 (0.0)	
22	WL - two zones - more efficient fans	100	5 (3.6)	5 (2.3)	1 (0.0)	6 (3.5)	6 (2.8)	7 (1.1)	5 (3.4)	6 (2.3)	1 (0.0)
	Combination System Description										
6	WL - two zones - reference	1455									
23	WL - two zones - Note 1	8815			8 (0.2)			3 (0.0)			10 (3.8)
24	WL - two zones - Note 1, 9.3 m2 more south windows	10365/10015/10015			12 (3.4)			6 (0.0)			11 (6.3)
25	WL - two zones - Note 1, lower loop temperature limits	8815		9 (7.6)	9 (0.3)			3 (0.0)		4 (0.0)	9 (3.5)
26	WL - two zones - Note 2	6120			11 (3.1)					10 (2.3)	
27	WL - two zones - Note 2, HRV	7570		7 (4.6)	2 (0.0)		8 (9.6)	2 (0.0)		2 (0.0)	6 (1.7)
28	WL - two zones - Note 2, grey water heat recovery	8135		10 (9.1)	13 (3.5)					11 (2.5)	12 (9.9)
29	WL - two zones - Note 2, 0.454 m3 of storage	6495			14 (3.6)					12 (3.9)	
30	WL - two zones - Note 2, 5.75 m2 solar collector	8245		8 (6.3)	10 (1.8)	2 (0.0)	6 (1.6)	11 (4.0)	4 (8.0)	3 (0.0)	8 (3.1)
31	WL - two zones - Note 2, 20 m2 solar collector	11385	3 (2.9)	3 (0.2)	5 (0.0)	4 (0.0)	3 (0.0)	8 (0.0)	3 (0.0)	7 (0.0)	3 (0.0)
32	WL - two zones - Note 2, HRV, GWHR	9585		6 (4.0)	3 (0.0)		7 (7.2)	5 (0.0)		5 (0.0)	7 (2.2)
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	12085		5 (2.9)	6 (0.0)	5 (3.1)	4 (0.0)	9 (0.0)	5 (9.4)	8 (0.0)	4 (0.0)
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	12185		4 (1.6)	7 (0.0)	6 (3.8)	5 (0.0)	10 (0.0)	6 (9.7)	9 (0.0)	5 (0.0)
35	TPFC - two zones - gas DHW + space heating, electric cooling	1780	1 (0.0)	1 (0.0)	1 (0.0)	1 (0.0)	1 (0.0)	1 (0.0)	1 (0.0)	1 (0.0)	1 (0.0)
36	TPFC - two zones - cogen with absorption chiller, gas DHW	10510	2 (0.0)	2 (0.0)	4 (0.0)	3 (0.0)	2 (0.0)	7 (0.0)	2 (0.0)	6 (0.0)	2 (0.0)

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

0.0 = immediate payback period; ----/----/---- represents varying prices for old, code and advances concept houses.

** Components relative to reference system 5, systems relative to reference system 6.

Component option rankings give an indication of the relative attractiveness of the individual components, but as evident in the system performance results, the performance may be better or worse when operating in combination with other components in a system. It is important to consider the payback as well as the rank, since in different cases, options with the same ranking may have either very short or rather long paybacks. The relative performance of options depends on many assumptions; if for example, the DHW and reference furnace fan consumptions had been assumed to be greater, then heat supplying options and more efficient fans would, respectively, become more attractive.

In general, heat supplying component options such as dryer exhaust heat recovery, solar thermal collectors (with and without additional loop thermal storage) and grey water heat recovery tended to be attractive in the code and old envelope houses in all locations and also in the Winnipeg advanced concept envelope where the heating load was still substantial despite the high insulation levels. The addition of south facing windows (with and without added thermal storage) was also an attractive option for this case.

The heat recovery ventilator was attractive in every code and advanced concept envelope in every application. It would have been even more attractive in the old envelope houses if they had been assumed to be tight enough to require wintertime mechanical ventilation to supplement air leakage. In real houses of this vintage some mechanical ventilation is most likely desirable in the shoulder seasons and throughout the year when efforts have been made to tighten the envelope. In other words the poor economic performance of the HRV in the old envelopes represents an extreme case.

Component options that work best when there is a significant cooling load, such as more efficient fans, loop-connected refrigerator and freezer, and efficient lighting and appliances were generally attractive in the advanced house envelopes. High efficiency heat pumps also fit into this category in Vancouver and Toronto as did the loop-connected heat pump water heater in Vancouver.

Wherever natural gas is available the gas heating/electric cooling option (*System 35*) is the most attractive system because of its immediate payback and low first cost. (Of course it is also available at even lower cost, with only single zone capability, as the most commonly installed system in new single-family houses so it too may be considered a reference). Immediate payback is also available on a large number of other system options including *System 36* with gas-fired cogeneration and absorption cooling, and several other systems that do not require the availability of natural gas. *System 31*, which included efficient lights and appliances, loop connected refrigerator, freezer and heat pump water heater, high efficiency heat pumps, low loop temperature range and a 20 m^2 solar system, offered an immediate payback for all cases except the Vancouver code and old envelope houses where the paybacks were 0.2 and 2.9 years. For some envelope and location cases other all-electric options are more attractive; for each case the system ranking provides an indication of which options make the most sense.

Overall energy savings, for a given location and envelope, were as much as 13.5 MWh, in the Winnipeg advanced concept house. This corresponds to a 52% saving relative to the 26.1 MWh consumed in the same house with the reference system equipment and appliances. The simulated demand was reduced by 4.5 kW or 35% of the reference 12.9 kW. Maximum demand savings occurred with the cogeneration system in the Winnipeg old house where a 34 kW peak was reduced by 93% to 2.4 kW.

That most of the simulated peak demands occurred around noon on weekends, when clothes dryer operation was scheduled, suggests that dryer operation contributed directly to the peak, in most cases. It follows that simple load shedding systems should permit significant reductions in this peak, as did dryer exhaust heat recovery, in most cases.

Some results were unexpected. It was anticipated that larger energy savings would result from subdividing the space into more zones, since overheating, from solar and internal gains in some areas, would be turned into useful heating in other zones. While this did occur in some applications, the maximum energy benefit was only 327 kWh in the Winnipeg old house. While it is very likely that improved comfort would result, energy savings provide insufficient rationale. The benefits associated with increased water-loop thermal storage were also smaller than expected, but in this case, the cost of the option ($375) was modest.

The cogeneration/absorption cooling system, which was modelled using equipment performance data for a Kohler 5 kW cogeneration unit and a Dometic/Servel 3 ton chiller, showed very encouraging results particularly if credit is given for demand reduction.

4 CONCLUSIONS

Based on the evaluation of house energy system rationalization options it is concluded:

- The interconnection of household energy systems holds large energy saving and demand reduction potential.

- Several *water-loop integrated* energy systems have been shown to be economically feasible.

- The water-loop appears to be one viable means of energy system interconnection.

For Component Options

- More efficient fans, loop-cooled refrigerator and freezer condensers, heat recovery ventilators, efficient lighting and appliances and dryer exhaust heat recovery are economically attractive, in some applications, based on energy savings alone.

- An avoided peak demand incentive of $500/kW allows the above listed options to become economically attractive in more applications and a 5.75 m^2 solar-thermal system to become attractive as well.

- An incentive of $5000/kW adds additional south facing windows, even more efficient appliances, high efficiency heat pumps, heat pump water heater and grey water heat recovery to the list of economically attractive component options.

For System Options

- A natural gas fired cogeneration system with absorption cooling was economically attractive without any demand reduction incentive, in more than half of the cases examined.

- An incentive of $5000/kW adds twelve all electric systems to the list of economically attractive options.

5 RECOMMENDATIONS

Since the foregoing demonstrates that a large number of energy system rationalization options hold promise for very significant economic reductions in energy consumption and electrical demand, it is recommended that the subject be actively pursued. More specifically it is suggested that follow on work better define the potential benefits, and within an appropriate, well-defined set of financial criteria, select the most promising options. Subsequent design competition followed by prototype demonstration would be one route to foster interest, encourage development and implementation and allow field assessment of the technology.

In this process, some options that this study was unable to include should be assessed. These include photovoltaic cells, economizer cooling (for very efficient envelope houses), systems with both hot and cold storage and load-shedding demand control. The gas options appeared very attractive; more should be evaluated and an environmental impact assessment, including a comparison of emissions, should be undertaken. The relative environmental attractiveness of gas options will likely depend on the electrical generation mix being used at the locations of interest. The economics of improved envelope efficiency should be compared to that of energy system options.

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APPENDIX A

The DOE 2.1 Program

The DOE 2.1D Program

1. DOE Loads Model

The subprogram, LOADS, contained within the DOE-2.1D program calculates the hourly heating and cooling loads. Heat transfer by conduction and radiation through the building's walls, roofs, floors, windows and doors is computed based on response weighting factors. The response factors are calculated within the DOE-2.1D program and are functions of thermal mass, location of insulation, amount of solar radiation, and building location and geometry.

The calculation of heating and cooling loads are performed each hour. The hourly simulation calculates the internal heat gain or loss due to people, lights, and equipment for each thermal zone. These three variables are described by the user by a maximum value (i.e. maximum number of people in the zone) and a schedule showing the percent of the maximum corresponding to the correct value for the present hour. If infiltration is to be calculated using the air-change method, then its contribution to the heat gain or loss is calculated for the current thermal zone.

Each thermal zone is described with a minimum of six surfaces (i.e. four walls, a floor and a ceiling). Some of these surfaces may be "airwalls" if they do not represent a physical barrier to the outside or another zone. The direct solar radiation is projected onto each external surface in the zone and the corresponding heat conduction through the surface to the zone is calculated. If infiltration is calculated using the crack method, the air flow rate through the surface is calculated.

For each window on a surface in a zone, the heat conduction (gain or loss) through the window to the zone is calculated as well as the solar gain from radiation on the window. Similarly the heat conducted through a door is also calculated (glass doors are treated as windows). Again, if infiltration is calculated using the crack method the appropriate air flow rate through the window or door is calculated.

After the heat gain or loss for each window or door has been calculated for a particular surface, calculations are performed for the next surface in the same thermal zone. After all calculations have been performed for each surface of a thermal zone, the total zone heat gain and loss are operated upon by the response weighting factors to produce the zone cooling/heating loads. The procedure then continues to the next thermal zone. After each thermal zone in the building has had its loads calculated, the entire procedure is repeated for the next hour in the simulation period.

The loads calculated are not based on the actual zone temperature but on an estimate given by the user. The loads are updated in the following subprogram, SYSTEMS, based on the actual zone temperatures to produce the heating and cooling loads which must be met by the HVAC system.

2 Water-Loop Heat Pump System Model

The DOE-2.1D model for the water-loop heat pump system, is divided into four components. The first three components consist of calculations for each zone connected to the water-loop system. In each, the available heat pump capacity, the extraction or rejection rates for heating or cooling, and the zone air temperature are calculated. The performance of the heat pump is then simulated. After the zone calculations the temperature of the fluid contained in the loop, and any requirement for heat addition to, or extraction from, the loop to maintain temperature limits, is determined. For more detail than described here the DOE-2 Engineers Manual should be consulted.

To calculate the **heat pump capacity** for heating or cooling in a zone, the entering liquid and air conditions must be determined. The entering air temperature is the mixed air temperature of the prescribed incoming outdoor air and the previous hour's zone air temperature. The temperature rise across the heat pump fan is added to this mixed air temperature. The total cooling capacity is based on the design capacity modified by the previous hour's fluid temperature and the coil entering wet bulb temperature. The sensible cooling capacity is modified by the previous hour's fluid temperature and the entering wet bulb temperature, and is corrected for entering dry bulb temperatures that differ from design.

If the sensible cooling capacity, mixed air temperature, and air flow rate are known, the minimum zone supply air temperature may be calculated. The difference between the zone supply air temperature and the previous hour's zone air temperature, multiplied by the air flow rate (adjusted for moist air conditions) yields the **maximum cooling rate** of the zone. If the heat pump compressor is not operating, although the fan is, the cooling rate of the zone is dependent on the difference between the previous hour's zone air temperature and the mixed air temperature.

In a similar way, the **heating capacity**, which is dependent on the entering dry bulb temperature and the fluid temperature, the maximum supply air temperature, and the maximum heating rate, may be calculated.

To calculate the current hour's **zone temperature**, a subroutine external to the water-loop subroutine is called. This subroutine calculates the current hour ending temperature dependent on the temperature of the previous three hours (a weighting factor equation), the zone load, the effect of adjacent spaces, and the effect of thermostat control. The heat extraction and addition rates are modified. The current hour's zone temperature is the average of the past hour ending temperature and the current hour ending temperature. The mixed air temperature is updated with the current hour's zone temperature.

Simulation of the **heat pump performance** begins with calculation of the supply air temperature leaving the heat pump. When there is no outdoor air being delivered, the supply air temperature is equal to the current air temperature, plus the temperature rise across the fan, less the sensible cooling or heating capacity (dependent on the load on the heat pump[1] divided by the air flow rate and a specific heat specific volume of dry air conversion factor (equal to 1207 $J/m^3 - ^0 C$ at standard conditions). If the outdoor air ratio is greater than zero, the supply air temperature is equal to the current hour temperature less the current heat extraction rate divided by the air flow rate and the same correction factor.

The decision as to whether the heat pump is in cooling or heating mode is based on the hour ending temperature. If this temperature is greater than the cooling setpoint, the unit is in cooling. If this temperature is less than the heating setpoint, the unit is in heating. Otherwise, there is no need for compressor operation.

The **supply air flow** rate is equal to the design air flow rate, if outdoor air is being introduced (i.e. constant fan operation), or is equal to the heating or cooling load, divided by the maximum heat addition or extraction rate, multiplied by the design air flow rate, if there is no outdoor air (i.e. fans are cycling).

Simulation of the heat pump in **cooling mode** is more involved than in heating mode because a moisture balance on the zone must be performed. First the cooling coil surface temperature is calculated based on the supply air temperature leaving the coil and the coil bypass factor. The coil bypass factor, with a default value of 0.241, is used in determining the coil surface temperature, which in turn is used to determine the cooling coil surface humidity ratio. The coil surface humidity ratio is a function of the surface temperature and

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[1] Heating capacity is represented as a negative value.

the outdoor atmospheric pressure.

The coil exit humidity ratio, is equal to the coil bypass factor, multiplied by the mixed air humidity ratio, summed with one minus the coil bypass factor multiplied by the coil surface humidity ratio. The latent cooling load imposed on the heat pump is equal to the difference between the mixed air and the coil exit humidity ratios, multiplied by the air flow rate for the hour and a conversion factor. In the calculation of the mixed air humidity ratio, infiltration air flow to the zone is added to the outdoor ventilation air flow.

If the calculated coil surface humidity ratio is greater than the mixed air humidity ratio, the coil is dry and the cooling load is all sensible. This load is equal to the difference between the mixed air and supply air temperatures, multiplied by the air flow rate and a conversion factor. The **total cooling load** on the zone is the sum of the sensible and latent loads.

The entering air wet bulb temperature is recalculated using current hour values for the mixed air temperature, humidity ratio, and atmospheric pressure. This leads to a better estimate of the available cooling capacity.

In calculating **compressor energy**, DOE-2 utilizes a term called the energy input ratio (EIR), the inverse of coefficient of performance (COP). The hourly value of EIR is equal to the rated EIR (inverse of the rated COP at ARI Standard 320-86 conditions) multiplied by three modifying factors. These three factors are for off-design entering wet bulb and fluid temperatures, for compressor part-load effect, and for off-design air flow rates. The part-load ratio is defined as the total cooling load divided by total cooling capacity, and the off-design air flow rate as the maximum air flow divided by the design air flow rate.

Similarly, when the unit is in heating the load is equal to the difference in the mixed and supply air temperature multiplied by the air flow rate and a conversion factor. The heating capacity of the heat pump is recalculated to account for an updated zone dry bulb temperature. Again, the EIR for the heat pump in heating is modified by three curves as the cooling EIR was. Whether the heat pump is in heating or cooling, the compressor energy is equal to the EIR multiplied by the available capacity and a conversion factor.
Each heat pump is assumed to receive fluid at the same temperature (i.e. the heat pumps are connected in parallel). The hourly fluid temperature is affected by the net heat gain or loss from heat pumps in cooling or heating. When a unit is in cooling the heat rejected to the loop is the sum of the cooling load plus the compressor energy. When the unit is

in heating the heat removed from the loop is the difference between the heating load and the compressor energy. Fan energy, calculated by the product of air flow rate and a kilowatt per unit air flow input value, is not added to the loop. The user specified temperature rise across the fan, however, is included in the mixed air temperature as previously described.

After all energy to or from each zone to the water-loop has been calculated, the fluid temperature for the current hour is calculated as the previous hour's temperature, plus the net energy rejected from the space into the loop, divided by the user inputted fluid heat capacity per degree of temperature. If this temperature is outside the specified range for the water-loop a load is passed to the plant (i.e. boiler or cooling tower) based on the difference in the current fluid temperature and the violated temperature limit, multiplied by the fluid heat capacity per degree of temperature. The new fluid temperature is set equal to the violated temperature limit.

Simulation of the cooling tower and boiler is performed external to the water-loop heat pump model in the Plant subprogram. The boiler model is straightforward; the electrical energy consumed by the boiler is equal to the sum of the load and any losses, multiplied by the boiler energy input ratio (DOE-2 default of one). The cooling tower model is much more involved. It attempts to correct cooling tower performance for off design temperature and flow conditions. It also attempts to stage the cooling tower with "pump only" and "pump plus fan" control options.

3. Additional System Options

The DOE-2.1D program allows the user to custom program FORTRAN subroutines into the simulation. This feature, the functional value, allowed modifications to the DOE-2 LOADS and SYSTEMS calculations without recompiling the program.

Seven subroutines were written and used in simulations where the desired modification to the water-loop system was not possible within the limits of the DOE-2.1D program. These modifications consisted of the addition of an economizer, heat recovery ventilator, heat pump water heater, loop connected refrigerator and freezer condensers, grey water heat recovery, recovery of clothes dryer exhaust heat and a solar collector. The following describes how each of these devices are modeled and details the assumptions involved.

Economizer. A dry bulb temperature economizer was added to the water-loop system to take advantage of "free cooling" when possible. Whenever the cooling load on the house was greater than the heating load, and the outdoor dry bulb temperature was between 2 °C and 18 °C, the amount of outdoor air introduced into the house was increased up to a maximum of 100% of supply air, based on a ratio between mixed, return and outdoor dry bulb air temperatures. Results from this model appeared to be suspect.

Heat Pump Water Heater. The heat pump water heater removed energy from the water-loop to help satisfy the domestic hot water load. The heat pump operated at a constant coefficient of performance of 2.6. The daily hot water load distribution was the same as with the conventional electric water tank. Two cases were modeled; one where the heat pump satisfied 100% of the hot water load, and one where the heat pump satisfied 80% of the hot water load and electric resistance heat satisfied the remaining 20%.

Heat recovery ventilator. The heat recovery ventilator was modeled assuming a constant sensible heat transfer effectiveness of 80% over all air temperatures. Therefore, the ventilation air temperature was increased or decreased by 80% of the difference between the room return air temperature and the outdoor air temperature. The heat recovery ventilator did not consume any energy itself, as it was assumed that the heat pump fans could satisfy the ventilation flow requirements, as a fraction of the total air flow (as is typical in their commercial application).

Grey water heat recovery. Whenever the heating load on the house was greater than the cooling load, 313 watts of heat was transferred by a heat pump, at a constant coefficient of performance of 4.9, from a grey water holding tank to the water-loop. If continuous operation is assumed, 313 watts is the average power available if the system cool the grey water to 6 °C, where the daily grey water consisted of 323 litres of water at an average temperature of 26 °C. The available power agrees well with 55% of dhw energy consumption leaving the house in drainwater (15), given an average mains water temperature of 8 °C.

Clothes dryer exhaust heat recovery. Whenever the clothes dryer was operating (four hours per weekend during the winter, two hours per weekend during the summer) and the heating load of the house exceeded the cooling load, 80% of the dryer exhaust heat energy (4500 watts) was recovered and added to the water-loop. The performance of this option was dependent on the use schedule of the clothes dryer, which for these simulations was approximately midday on weekends.

Solar collector. Monthly data for the average daily total solar radiation on a south facing slope, for the cities of interest, was obtained from Hay (16) and converted to hourly total solar radiation using the method of Liu and Jordan. The solar collector was modeled with an inclined slope of 60 ^{0}, and the performance characteristics of a Canadian product ($F_R U_L$ = 4.04 W/m ^{2} - ^{0}C, $F_R \tau\alpha$ =0.636). The energy from the solar collector was added to the water-loop (assumed water temperature of 16 ^{0}C) whenever the heating load of the house exceeded the cooling load.

Loop-cooled condensers. The water-loop cooled refrigerator condenser transferred 75% of the refrigerator energy consumed to the loop. The remaining 25% was assumed to be a heat gain to the kitchen. The water-loop cooled freezer condenser transfers 100% of the freezer energy consumed to the loop. Appliance energy consumption is conservatively assumed to be unchanged although the condenser temperature should, on average be lower than in the conventional air-cooled case.

APPENDIX B

System Options

Description of System Options

Building System Option	1 - Residential: heating only	2 - Residential: heating/cooling
Base system that option has been added to:	Reference system.	Reference system.
Description of operation:	Two zone residential system without mechanical ventilation. Heating is supplied by an electric furnace. Heating is available from mid-September to the end of May. The basement and living space are separate zones with the thermostat located in the above-grade living space. System airflow rate is 2540 L/s; fan energy consumption corresponds to 630 W electrical input power.	Two zone residential system with heating and cooling but without mechanical ventilation. Heating is supplied by an electric furnace, cooling is supplied by a central air conditioner. Cooling is available from the start of May to mid-October.
Estimated incremental cost of option (tax included):		

Building System Option	3 - Residential: heating with ventilation	4 - Residential: heating/cooling with ventilation
Base system that option has been added to:	Reference system.	Reference system.
Description of operation:	Two zone residential system with heating and mechanical ventilation. Heating is supplied by an electric furnace. Ventilation system operates only during the heating season from mid-October to mid-April. The ventilation fan consumes 150 W.	Two zone residential system with heating and cooling and with mechanical ventilation. Heating is supplied by an electric furnace, cooling is supplied by a central air conditioner. Ventilation occurs year round.
Estimated incremental cost of option (tax included):		

Note: Systems #1 and #2, without mechanical ventilation, are artificial references provided for information only.
Systems #3 and #4 represent reference residential systems.

Description of System Options (cont'd)

Building System Option	5 - Residential: heating/cooling with ventilation	6 - Water Loop - two zones
Base system that option has been added to:	Reference system.	System #5. (This system acts as the reference water loop system to which options are added.)
Description of operation:	Similar to #4, but operated with heating and cooling always available, and a baseboard heater in the basement to allow reasonable comparison with water loop system. Ventilation occurs year round.	Heating and cooling are supplied via water source heat pumps connected in parallel to a water-loop. Temperature limits of the water-loop are maintained by an electric hot water boiler and a cooling tower. Heating and cooling are always available. One zone represents the basement of the house, the other zone represents the upstairs living areas. DHW is heated electrically. Heating COP = 3.92, cooling EER = 12.2 at rated conditions.
Estimated incremental cost of option (tax included):	Estimated cost of system: Ductwork = $800. Furnace = $890. Air conditioner = $2430. (reference: Flair Homes project). Total system cost = $4120.	Estimated two water source heat pumps = $3240. 12 kW hot water boiler (2*151 litre tanks) = $575. Two pipe water loop = $570. Circulating pump = $220. Cooling tower = $570. Ductwork = $400. Total incremental cost = $5575 - $4120 = $1455.

Building System Option	7 - Water Loop - five zones	8 - addition of thermal storage
Base system that option has been added to:	Two zone water-loop system (#6).	Two zone water-loop system (#6).
Description of operation:	As #5 except the house is modeled with five zones: the basement, the north side of the first floor, the north side of the second floor, the south side of the first floor, and the south side of the second floor.	0.454 m3 of water (120 US gallons) has been added to the water-loop to increase the thermal capacity of the system (added to 0.136 m3 in the reference system). The insulated storage tank containing the extra volume cannot be heated independently of the water-loop.
Estimated incremental cost of option (tax included):	As #5 except delete 2 heat pumps and add 5 heat pumps. Five heat pumps = $6100, two heat pumps = $3240. Additional cost = $2860.	0.454 m3 closed insulated storage tank = $375.

Description of System Options (cont'd)

Building System Option	9 - additional south facing windows	10 - added window and storage
Base system that option has been added to:	Two zone water-loop system (#6).	Two zone water-loop system (#6).
Description of operation:	9.3 m2 (100 ft2) of window was added to the south side of the house to increase the solar gain. Single glazed, double glazed and double glazed low E are used in the old, code and advanced concept envelopes, respectively.	The previous two options have been combined for this option. If the house is overheated due to solar gain, the addition of thermal storage will allow the heat to be saved for later use.
Estimated incremental cost of option (tax included):	100 ft2 of standard window (code house) @ $15.50/ft2 less 100 ft2 of wall @ $3.50/ft2 = $1200. It is assumed that a utility rebate results in an equal cost for the advanced concept house, and renovation on the old house equals the cost for the code window ($1550).	0.454 m3 closed insulated storage tank = $375. For code and advanced concept houses, window = $1200, then total cost = $1575. For old house, window = $1550, total cost = $1925.

Building System Option	11 - high efficiency appliances	12 - efficient appliances
Base system that option has been added to:	Two zone water-loop system (#6).	Two zone water-loop system (#6).
Description of operation:	More efficient appliances were installed in the house. Annual energy consumption of appliances (kWh) (excluding hot water): Standard / High-eff. — Stand. / High-eff. Refrigerator 1350 240 — Clother Washer 160 124 Range 1209 780 — Colour TV 450 292 Dishwasher 394 252 — Microwave 394 256 Freezer 1485 504 — Other 567 520 Clothes Dryer 864 836 — Lighting 1307 249	Rather than using an extremely high efficiency refrigerator (high cost) a more moderate efficiency from a commercially popular manufacturer was chosen. This refrigerator selection was added to the high efficiency appliances and lighting of option #11. Annual energy consumption of this refrigerator is 691 kWh.
Estimated incremental cost of option (tax included):	Refrigerator upgrade = $1445 (very high efficiency). Other appliances upgrades = $750. Lighting upgrade = $600. Total cost = $2795.	Appliance upgrade = $900. Lighting upgrade = $600 Total cost = $1500.

Description of System Options (cont'd)

Building System Option	13 - heat recovery ventilator	14 - heat recovery ventilator with bypass
Base system that option has been added to:	Two zone water-loop system (#6).	Two zone water-loop system (#6).
Description of operation:	House is modeled with a continuous summer ventilation level of 53 L/s. Winter ventilation varies from zero in the old house, to 23 L/s in the code house and 53 L/s in the advanced house. The heat recovery ventilator is a passive heat exchanger between the house exhaust and outdoor supply air streams. 80% of the heat difference between the air streams is recovered. Modeled HRV is a Nutech Energy Systems Lifebreath 195 DEC with eff.=81% at 0 C, eff.=77% at -25 C (110 cfm).	The heat recovery ventilator of #13 is only operated from October to April. Flow through the ventilator is bypassed during the summer months.
Estimated incremental cost of option (tax included):	Total cost = $1450 (installed - reference: Flair Homes project).	As this option failed to lower energy consumption in any of the computer simulations, it was not priced.

Building System Option	15 - high efficiency heat pumps	16 - heat pump water heater
Base system that option has been added to:	Two zone water-loop system (#6).	Two zone water-loop system (#6).
Description of operation:	High efficiency heat pumps (COP of 5.1, EER of 16.2) replaced regular heat pumps (COP of 3.9, EER of 12.2) to reduce heat pump compressor energy consumption.	A water-to-water heat pump connects the circulating loop to the hot water tank, therefore, heat rejected from space to the water-loop can be utilized for DHW heating. If the heat pump supplies 100% of the hot water (as in present case), the incremental cost includes the cost of a larger storage tank (to increase the volume). If the heat pump only supplies 80% of the hot water, an additional storage tank is not required.
Estimated incremental cost of option (tax included):	According to a supplier of WaterFurnace high efficiency heat pumps, incremental cost for small heat pumps is $350/ton. For estimated three tons, cost is $1050.	Therma-stor (DEC International) HP-52 (52 gallons) has a retail price of $1965. Assuming an installation charge of $50 to connect the water heater to the water-loop, total cost = $2015. When the additional storage tank is not required, total cost = $1590 (i.e. $425 credit for the tank).

Description of System Options (cont'd)

Building System Option	17 - loop connected compressors	18 - grey water heat recovery
Base system that option has been added to:	Two zone water-loop system (#6).	Two zone water-loop system (#6).
Description of operation:	Rather than allowing the compressor energy of the refrigerator and freezer to add heat to the surroundings, the heat is transferred to the water-loop where it can be distributed as required. It is assumed that 25% of the refrigerator energy consumption is lost to the space directly (i.e. evaporator fan, etc.).	Whenever there is a requirement for heat to be added to the water-loop, 313 Watts (plus compressor energy) are transferred from the grey water tank by a heat pump working with a COP of 4.94.
Estimated incremental cost of option (tax included):	Water-cooled condenser should cost the same as, or less than, air-cooled. Water-loop connection allowance of $50 per connection. Total cost = $100.	It is assumed that grey water heat recovery will cost the same as the heat pump water heater (similar components). Total cost = $2015.

Building System Option	19 - dryer exhaust heat recovery	20 - 5.75 m2 solar collector
Base system that option has been added to:	Two zone water-loop system (#6).	Two zone water-loop system (#6).
Description of operation:	If the water-loop system requires energy to maintain its lower limit while the clothes dryer is operating, the clothes dryer exhaust energy (4.5 kW) is passed through a heat exchanger (80% effectiveness) to add the exhaust heat to the loop.	Whenever there is a requirement for heat to be added to the water-loop, a 5.75 m2 solar panel is available to add heat. Mean monthly values of daily solar energy were converted to hourly data using the method of Liu and Jordan. Collector is modeled with Solcan 2100 Solar Collector parameters of Fr=0.636 and FrUl=4.04.
Estimated incremental cost of option (tax included):	Estimated cost of heat exchanger = $200.	Based on retail cost of Thermodynamics "solar boiler", total installed cost = $2125 (hardware = $1720, installation = $405).

Description of System Options (cont'd)

Building System Option	21 - solar collector with storage	22 - more efficient fans
Base system that option has been added to:	Two zone water-loop system with a 5.75 m2 solar collector (#20).	Two zone water-loop system (#6).
Description of operation:	The solar collector of option #20 is combined with the thermal storage of option #7.	The energy consumption of the fans moving the ventilation and supply air was reduced by 50% (295W to 148W). The temperature rise of the air flow across the fan was also reduced by 50% (0.43 C to 0.22 C).
Estimated incremental cost of option (tax included):	0.454 m3 closed insulated storage tank = $375.	Assumed incremental cost of $100.

Building System Option	23 - combination 1	24 - added south facing windows
Base system that option has been added to:	Two zone water-loop system (#6).	Two zone water-loop system with a combination of options (#23).
Description of operation:	The previous options of high efficiency appliances (#11), 454 litres storage (#7), heat recovery ventilator (#13), high efficiency heat pumps (#15), a heat pump water heater (#16), and loop connected compressors (#17) were combined in one house. The heat pump water heater in this option only supplies 80% of the hot water load.	The additional south facing windows of option #8 are added to the options combined in option #23.
Estimated incremental cost of option (tax included):	Efficient appliances = $2795; storage = $375; HRV = $1450; high efficiency heat pumps = $1050; 80% HPWH = $1590; loop connected compressors = $100. Total cost = $7360.	Additional windows = $1200 for advanced concept and code houses; = $1550 for old house.

Description of System Options (cont'd)

Building System Option	25 - lower loop limits	26 - combination 2
Base system that option has been added to:	Two zone water-loop system with a combination of options (#23).	Two zone water-loop system (#6).
Description of operation:	The house of option #23 is operated with a lower water-loop temperature range. The conventional limits were 16 C to 32 C while this run maintained temperature limits of 7 C to 16 C.	The previous options of efficient appliances, with common refrigerator energy levels (#12), high efficiency heat pumps (#15), a heat pump water heater (#16), loop connected compressors (#17), and lower water-loop temperature range were combined in one house. The heat pump water heater in this option supplies 100% of the hot water load.
Estimated incremental cost of option (tax included):	This control option incurs no additional cost. (Note: this is true as long as the water-loop piping does not require insulation to prevent excessive condensation.)	Efficient appliances = $1500; high efficiency heat pumps = $1050; 100% heat pump water heater = $2015; loop connected compressors = $100. Total cost = $4665.

Building System Option	27 - heat recovery ventilator	28 - grey water heat recovery
Base system that option has been added to:	Two zone water-loop system with a combination of options (#26).	Two zone water-loop system with a combination of options (#26).
Description of operation:	The heat recovery ventilator (#13) operating year round is added to the combined option house of #26.	The grey water heat recovery system (#18) is added to the combined option house of #26.
Estimated incremental cost of option (tax included):	Heat recovery ventilator = $1450.	Grey water heat recovery = $2015.

Description of System Options (cont'd)

Building System Option	29 - addition of thermal storage	30 - 5.75 m2 solar collector
Base system that option has been added to:	Two zone water-loop system with a combination of options (#26).	Two zone water-loop system with a combination of options (#26).
Description of operation:	The addition of 0.454 m3 of water to act as thermal storage (#7) is combined with the other options of #26.	The 5.75 m2 solar collector of #20 is added to the combined option house of option #26.
Estimated incremental cost of option (tax included):	0.454 m3 closed insulated storage tank = $375.	Cost of collector = $2125.

Building System Option	31 - 20 m2 solar collector	32 - addition of an HRV and GWHR
Base system that option has been added to:	Two zone water-loop system with a combination of options (#26).	Two zone water-loop system with a combination of options (#26).
Description of operation:	Rather than adding 5.75 m2 of solar collector to the combined option house of option #26, as done previously, 20 m2 of solar collector area has been added.	The heat recovery ventilator (#13) and grey water heat recovery (#18) have been added to option #26.
Estimated incremental cost of option (tax included):	Initial Thermodynamics 5.75 m2 system = $2125. 5 additional three square metre panels @ $628 = $3140. Total incremental cost = $5265.	Grey water heat recovery = $2015. Heat recovery ventilator = $1450. Total incremental cost = $3465.

Description of System Options (cont'd)

Building System Option	33 - addition of storage and a solar collector	34 - addition of more efficient fans
Base system that option has been added to:	Two zone water-loop system with a combination of options including HRV and GWHR (#32).	Two zone water-loop system with a combination of options ($33).
Description of operation:	The 5.75 m2 solar collector and 0.454 m3 of thermal storage from option #21 have been added to the heat recovery ventilator and grey water heat recovery system contained in option #32 (along with all the other system options included in #32).	The higher efficient fans of #22 have been added to the combined options of #33. The list of options now includes: efficient appliances (moderate refrig. levels), high efficient heat pumps, 100% heat pump water heater, loop connected compressors, lower loop temperature operating range, heat recovery ventilator, grey water heat recovery, thermal storage, a solar collector and more efficient fans.
Estimated incremental cost of option (tax included):	0.454 m3 closed insulated storage tank = $375. Cost of collector = $2125. Total incremental cost = $2500.	More efficient fans = $100.

Building System Option	35 - gas heating and electric cooling	36 - cogeneration and absorption cooling
Base system that option has been added to:	Two zone water-loop system (#6).	Two zone two pipe fan coil system of option #35.
Description of operation:	The water-loop system has been replaced with a two pipe fan coil system. Heating is supplied from a gas hot water boiler and cooling from an electric chiller (EER = 9.0). DHW is supplied from a gas water heater. The gas boiler and heater have annual efficiencies of 67%.	A natural gas cogeneration system is installed providing up to 5 kW of electricity. Heat is recovered from the cogen unit for space heating/cooling and water heating. The house is served by the same fan coil system as #35. Additional heat is supplied from a gas hot water boiler, while cooling is provided from an absorption chiller. Backup water heating is gas-fired. Recovered heat satisfies any space heating or chiller load first, then DHW loads.
Estimated incremental cost of option (tax included):	Compared with basic water-loop system (#6): Electric chiller = $2250. Ductwork = $400. Fan coil units = $1805. Gas hot water boiler = $655. Piping = $570. Circulation pump = $220. Total cost = $5900. Total incremental cost = $5900 - $5575 = $325.	Compared with basic water-loop system (#6): Absorption chiller = $3705. Ductwork = $400. Cogeneration unit = $7275. Fan coil units = $1805. Gas hot water boiler = $655. Piping = $570. Circulation pump = $220. Total cost = $14630. Total incremental cost = $14630 - $5575 = $9055.

APPENDIX C

Ground Source Heat Pump Performance

Ground Source Heat Pump Performance

The heating season performance of a ground source heat pump, (with appropriate-sized ground coil) connected to the water-loop has been estimated as follows:

(1) The mean ground coil return temperature (or heat pump entering water temperature) is approximated as the average of the mean annual undisturbed soil temperature (which equals the average annual air temperature) and the freezing temperature of water.

(2) Manufacturers performance data for a low temperature water-to-water heat pump is interpolated to derive values for COP and power draw at the entering water temperature defined by (1) and the water-loop low-temperature setpoint (15.5 °C).

(3) The steady-state C.O.P. is adjusted for ground loop pumping power.

(4) A degradation factor to account for part load operation in heating, reported for northern U.S. cities (Minneapolis and Dayton) (20), is applied to determine the estimated heating season performance factor (HSPF).

For Toronto:

$$\bar{T}_{\text{ground coil}} = (46.1\,^\circ F + 32\,^\circ F)/2 = 39.05\,^\circ F\ (3.9\,^\circ C)$$

Interpolated COP	=	4.45
Interpolated power	=	1950 W
Water-loop pump power	=	195 W
Part load degradation factor	=	0.88
Estimated HSPF	=	4.45 X 0.88 X 1950/ (1950 +195)
	=	3.56

APPENDIX D

Simulated Energy Consumption
and
Peak Demand

VANCOUVER - OLD HOUSE

Units - kWh

#	Description	Space Heat	Space Cool	HVAC Aux	DHW	Lights	Appl.	Total	Peak (kW)	Month	Day	Hour
1	Residential system - Heating only, no vent.	28462	0	791	4738	1307	6868	42165	26.02	12	8	11
2	Residential system - Heating and cooling, no vent.	28702	404	827	4738	1307	6868	42846	25.77	12	8	11
3	Residential system - Heating only, plus vent.	33557	0	1463	4738	1307	6868	47933	20.94	12	8	11
4	Residential system - Heating and cooling, plus vent.	34741	457	2585	4738	1307	6868	50695	20.99	12	8	11
5	Residential system - Improved comfort control	36569	472	2585	4738	1307	6868	52538	21.00	12	8	11
6	WL - two zones	36537	35	2075	4738	1307	6868	51560	20.71	12	8	11
7	WL - five zones	35863	439	2226	4738	1307	6868	51441	20.61	12	8	11
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	36516	32	2075	4738	1307	6868	51536	20.71	12	8	11
9	WL - two zones - 9.3 m2 more south windows	36443	208	2182	4738	1307	6868	51745	21.61	12	8	11
10	WL - two zones - more window, plus 0.454 m3 storage	36335	199	2182	4738	1307	6868	51628	21.61	12	8	11
11	WL - two zones - with efficient applicances, best refrigerator	39877	3	2039	4738	249	3800	50705	20.55	12	8	11
12	WL - two zones - with efficient appliances, good refrigerator	39531	6	2035	4738	249	4251	50810	20.54	12	8	11
13	WL - two zones - heat recovery ventilator (HRV)	36557	12	2075	4738	1307	6868	51557	20.70	12	8	11
14	WL - two zones - HRV with summer bypass	36554	26	2075	4738	1307	6868	51568	20.70	12	8	11
15	WL - two zones - high efficiency heat pumps	36548	26	2075	4738	1307	6868	51563	20.70	12	8	11
16	WL - two zones - 100% heat pump water heater	39390	32	2075	1822	1307	6868	51494	20.87	12	8	11
17	WL - two zones - fridge, freezer loop connected compressors	36437	76	2097	4738	1307	6868	51523	20.70	12	8	11
18	WL - two zones - grey water heat recovery (GWHR)	34427	35	2075	4738	1307	6868	49450	20.39	12	8	11
19	WL - two zones - dryer exhaust heat recovery	36053	35	2075	4738	1307	6868	51076	17.35	4	14	11
20	WL - two zones - 5.75 m2 solar collector (solar)	34014	64	2075	4738	1307	6868	49066	20.22	12	8	11
21	WL - two zones - solar with 0.454m3 storage	33800	50	2075	4738	1307	6868	48838	20.22	12	8	11
22	WL - two zones - more efficient fans	36865	35	1413	4738	1307	6868	51226	20.73	12	8	11
23	WL - two zones - Note 1	42285	18	2046	2406	249	3800	50804	20.72	12	8	11
24	WL - two zones - Note 1, 9.3 m2 more south windows	42071	56	2164	2406	249	3800	50745	21.62	12	8	11
25	WL - two zones - Note 1, lower loop temperature limits	41884	15	2237	2406	249	3800	50590	20.53	12	8	11
26	WL - two zones - Note 2	42244	23	2233	1822	249	4251	50824	20.55	12	8	11
27	WL - two zones - Note 2, HRV	42227	23	2233	1822	249	4251	50807	20.55	12	8	11
28	WL - two zones - Note 2, grey water heat recovery	40035	23	2233	1822	249	4251	48615	20.24	12	8	11
29	WL - two zones - Note 2, 0.454 m3 of storage	42241	23	2233	1822	249	4251	50821	20.55	12	8	11
30	WL - two zones - Note 2, 5.75 m2 solar collector	38919	85	2233	1822	249	4251	47560	20.06	12	8	11
31	WL - two zones - Note 2, 20 m2 solar collector	34732	434	2222	1822	249	4251	43711	18.82	12	8	11
32	WL - two zones - Note 2, HRV, GWHR	40015	23	2233	1822	249	4251	48594	20.24	12	8	11
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	36739	82	2230	1822	249	4251	45374	19.74	12	8	11
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	37076	82	1491	1822	249	4251	44971	19.68	12	8	11
35	TPFC - two zones - gas DHW + space heating, electric cooling	52350	18	4021	6279	1307	6868	70842	7.27	2	17	11
36	TPFC - two zones - cogen with absorption chiller, gas DHW	17293	29	16821	2833	6598	34700	78275	2.02	12	8	11

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

VANCOUVER - CODE HOUSE

Units - kWh

#	Description	Space Heat	Space Cool	HVAC Aux	DHW	Lights	Appl.	Total	Peak (kW)	Month	Day	Hour
1	Residential system - Heating only, no vent.	14512	0	632	4738	1307	6868	28057	18.35	12	8	12
2	Residential system - Heating and cooling, no vent.	14515	434	658	4738	1307	6868	28519	18.40	12	8	12
3	Residential system - Heating only, plus vent.	17735	0	1379	4738	1307	6868	32026	15.14	12	8	11
4	Residential system - Heating and cooling, plus vent.	18626	460	2585	4738	1307	6868	34583	15.19	12	8	11
5	Residential system - Improved comfort control	19909	501	2585	4738	1307	6868	35908	15.17	12	8	11
6	WL - two zones	19109	340	3329	4738	1307	6868	35691	15.01	12	8	11
7	WL - five zones	18646	1236	3329	4738	1307	6868	36124	14.75	12	8	11
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	19039	331	3329	4738	1307	6868	35612	15.01	12	8	11
9	WL - two zones - 9.3 m2 more south windows	17659	1163	3329	4738	1307	6868	35064	15.15	12	8	11
10	WL - two zones - more window, plus 0.454 m3 storage	17240	1110	3329	4738	1307	6868	34592	15.15	12	8	11
11	WL - two zones - with efficient applicances, best refrigerator	22045	50	3329	4738	249	3800	34211	14.85	12	8	11
12	WL - two zones - with efficient appliances, good refrigerator	21720	64	3329	4738	249	4251	34352	14.84	12	8	11
13	WL - two zones - heat recovery ventilator (HRV)	17369	275	3329	4738	1307	6868	33886	14.38	12	8	11
14	WL - two zones - HRV with summer bypass	17609	319	3329	4738	1307	6868	34170	14.38	12	8	11
15	WL - two zones - high efficiency heat pumps	19109	261	3329	4738	1307	6868	35612	15.00	12	8	11
16	WL - two zones - 100% heat pump water heater	21667	308	3329	1822	1307	6868	35301	15.17	12	8	11
17	WL - two zones - fridge, freezer loop connected compressors	19007	217	3329	4738	1307	6868	35465	15.00	12	8	11
18	WL - two zones - grey water heat recovery (GWHR)	17304	343	3329	4738	1307	6868	33889	14.69	12	8	11
19	WL - two zones - dryer exhaust heat recovery	18725	346	3329	4738	1307	6868	35313	13.59	4	14	11
20	WL - two zones - 5.75 m2 solar collector (solar)	17076	375	3329	4738	1307	6868	33693	14.52	12	8	11
21	WL - two zones - solar with 0.454m3 storage	16824	355	3329	4738	1307	6868	33420	14.52	12	8	11
22	WL - two zones - more efficient fans	20000	234	2035	4738	1307	6868	35182	15.04	12	8	11
23	WL - two zones - Note 1	22408	53	3329	2406	249	3800	32245	14.40	12	8	11
24	WL - two zones - Note 1, 9.3 m2 more south windows	20208	481	3329	2406	249	3800	30473	14.55	12	8	11
25	WL - two zones - Note 1, lower loop temperature limits	20941	41	3329	2406	249	3800	30765	13.87	12	8	12
26	WL - two zones - Note 2	22997	50	3329	1822	249	4251	32699	14.47	12	8	11
27	WL - two zones - Note 2, HRV	21154	50	3329	1822	249	4251	30856	13.87	12	8	12
28	WL - two zones - Note 2, grey water heat recovery	20935	50	3329	1822	249	4251	30637	14.15	12	8	11
29	WL - two zones - Note 2, 0.454 m3 of storage	22971	47	3329	1822	249	4251	32670	14.47	12	8	11
30	WL - two zones - Note 2, 5.75 m2 solar collector	20120	138	3329	1822	249	4251	29910	13.98	12	8	11
31	WL - two zones - Note 2, 20 m2 solar collector	17395	536	3329	1822	249	4251	27584	12.76	12	8	11
32	WL - two zones - Note 2, HRV, GWHR	19112	50	3329	1822	249	4251	28814	13.55	12	8	12
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	16379	132	3329	1822	249	4251	26163	13.05	12	8	11
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	17041	111	2035	1822	249	4251	25510	12.85	12	8	11
35	TPFC - two zones - gas DHW + space heating, electric cooling	28734	179	3329	6279	1307	6868	46696	7.24	4	28	18
36	TPFC - two zones - cogen with absorption chiller, gas DHW	2192	308	17129	1629	6718	35335	63311	1.84	12	8	11

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

VANCOUVER - ADVANCED CONCEPT HOUSE

Units - kWh

#	Description	Space Heat	Space Cool	HVAC Aux	DHW	Lights	Appl.	Total	Peak (kW)	Month	Day	Hour
1	Residential system - Heating only, no vent.	26	0	1475	4738	1307	6868	14413	8.71	10	28	12
2	Residential system - Heating and cooling, no vent.	21	2707	1350	4738	1307	6868	16990	10.56	10	13	12
3	Residential system - Heating only, plus vent.	1453	0	2442	4738	1307	6868	16807	9.61	12	15	11
4	Residential system - Heating and cooling, plus vent.	1456	1972	2585	4738	1307	6868	18925	9.77	8	11	12
5	Residential system - Improved comfort control	1699	2968	2585	4738	1307	6868	20165	10.47	10	6	12
6	WL - two zones	1289	4574	3329	4738	1307	6868	22104	10.73	10	6	12
7	WL - five zones	1386	4931	3329	4738	1307	6868	22559	10.67	10	6	12
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	1216	4565	3329	4738	1307	6868	22022	10.73	10	6	12
9	WL - two zones - 9.3 m2 more south windows	979	6194	3329	4738	1307	6868	23414	11.26	10	6	12
10	WL - two zones - more window, plus 0.454 m3 storage	853	6185	3329	4738	1307	6868	23279	11.26	10	6	12
11	WL - two zones - with efficient applicances, best refrigerator	2672	2505	3329	4738	249	3800	17293	9.69	12	15	11
12	WL - two zones - with efficient appliances, good refrigerator	2505	2643	3329	4738	249	4251	17715	9.68	12	15	11
13	WL - two zones - heat recovery ventilator (HRV)	454	4040	3329	4738	1307	6868	20736	10.38	10	6	12
14	WL - two zones - HRV with summer bypass	454	4477	3329	4738	1307	6868	21173	10.38	10	6	12
15	WL - two zones - high efficiency heat pumps	1289	3575	3329	4738	1307	6868	21105	10.30	10	6	12
16	WL - two zones - 100% heat pump water heater	2350	4415	3329	1822	1307	6868	20092	10.01	12	15	11
17	WL - two zones - fridge, freezer loop connected compressors	1345	3035	3329	4738	1307	6868	20622	10.23	10	6	12
18	WL - two zones - grey water heat recovery (GWHR)	894	4577	3329	4738	1307	6868	21712	10.73	10	6	12
19	WL - two zones - dryer exhaust heat recovery	1269	4574	3329	4738	1307	6868	22084	10.73	10	6	12
20	WL - two zones - 5.75 m2 solar collector (solar)	1046	4577	3329	4738	1307	6868	21864	10.73	10	6	12
21	WL - two zones - solar with 0.454m3 storage	999	4574	3329	4738	1307	6868	21814	10.73	10	6	12
22	WL - two zones - more efficient fans	1661	4046	2035	4738	1307	6868	20655	10.55	10	6	12
23	WL - two zones - Note 1	2107	2543	3329	2406	249	3800	14434	9.00	12	15	11
24	WL - two zones - Note 1, 9.3 m2 more south windows	1626	3920	3329	2406	249	3800	15330	9.12	12	15	11
25	WL - two zones - Note 1, lower loop temperature limits	2233	1919	3329	2406	249	3800	13936	9.02	12	15	11
26	WL - two zones - Note 2	4076	1726	3329	1822	249	4251	15453	9.86	12	15	11
27	WL - two zones - Note 2, HRV	2669	1969	3329	1822	249	4251	14290	9.01	12	15	11
28	WL - two zones - Note 2, grey water heat recovery	3334	1726	3329	1822	249	4251	14712	9.54	12	15	11
29	WL - two zones - Note 2, 0.454 m3 of storage	3756	1711	3329	1822	249	4251	15119	9.86	12	15	11
30	WL - two zones - Note 2, 5.75 m2 solar collector	3109	1799	3329	1822	249	4251	14560	9.32	12	15	11
31	WL - two zones - Note 2, 20 m2 solar collector	2628	2051	3329	1822	249	4251	14331	7.97	12	15	11
32	WL - two zones - Note 2, HRV, GWHR	2092	1969	3329	1822	249	4251	13713	8.70	12	15	11
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	1195	2033	3329	1822	249	4251	12881	8.15	12	15	11
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	1485	1729	2035	1822	249	4251	11572	8.19	12	15	11
35	TPFC - two zones - gas DHW + space heating, electric cooling	1887	3844	3329	6279	1307	6868	23514	8.79	10	6	12
36	TPFC - two zones - cogen with absorption chiller, gas DHW	0	6124	16542	466	6490	34128	63750	2.09	10	6	12

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

WINNIPEG - OLD HOUSE

Units - kWh

#	Description	Space Heat	Space Cool	HVAC Aux	DHW	Lights	Appl.	Total	Peak (kW)	Month	Day	Hour
1	Residential system - Heating only, no vent.	68081	0	1320	4738	1307	6868	82313	40.52	1	6	11
2	Residential system - Heating and cooling, no vent.	67838	442	1533	4738	1307	6868	82726	40.47	1	27	11
3	Residential system - Heating only, plus vent.	74591	0	2272	4738	1307	6868	89776	34.80	2	16	8
4	Residential system - Heating and cooling, plus vent.	76411	472	3662	4738	1307	6868	93457	34.84	2	16	8
5	Residential system - Improved comfort control	82737	530	2629	4738	1307	6868	98808	34.01	2	17	11
6	WL - two zones	83285	255	2664	4738	1307	6868	99115	34.02	2	17	11
7	WL - five zones	82403	618	2855	4738	1307	6868	98788	34.26	2	17	11
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	83252	252	2664	4738	1307	6868	99080	34.02	2	17	11
9	WL - two zones - 9.3 m2 more south windows	83516	492	2796	4738	1307	6868	99717	34.73	1	6	11
10	WL - two zones - more window, plus 0.454 m3 storage	83419	483	2796	4738	1307	6868	99611	34.73	1	6	11
11	WL - two zones - with efficient applicances, best refrigerator	86973	111	2631	4738	249	3800	98502	33.88	1	6	12
12	WL - two zones - with efficient appliances, good refrigerator	86610	126	2627	4738	249	4251	98601	33.87	1	6	12
13	WL - two zones - heat recovery ventilator (HRV)	83334	176	2664	4738	1307	6868	99086	34.01	2	17	11
14	WL - two zones - HRV with summer bypass	83317	243	2664	4738	1307	6868	99136	34.01	2	17	11
15	WL - two zones - high efficiency heat pumps	83331	196	2664	4738	1307	6868	99104	34.01	2	17	11
16	WL - two zones - 100% heat pump water heater	86093	246	2664	1822	1307	6868	99000	34.18	2	17	11
17	WL - two zones - fridge, freezer loop connected compressors	83220	220	2689	4738	1307	6868	99042	33.99	1	6	12
18	WL - two zones - grey water heat recovery (GWHR)	80952	255	2664	4738	1307	6868	96783	33.70	2	17	11
19	WL - two zones - dryer exhaust heat recovery	82751	255	2664	4738	1307	6868	98582	31.69	2	17	8
20	WL - two zones - 5.75 m2 solar collector (solar)	79229	275	2660	4738	1307	6868	95077	32.09	1	6	12
21	WL - two zones - solar with 0.454m3 storage	79021	270	2660	4738	1307	6868	94863	32.09	1	6	12
22	WL - two zones - more efficient fans	83900	252	1708	4738	1307	6868	98772	34.04	1	6	12
23	WL - two zones - Note 1	89358	103	2631	2406	249	3800	98546	34.05	1	6	12
24	WL - two zones - Note 1, 9.3 m2 more south windows	89458	226	2759	2406	249	3800	98898	34.84	1	6	11
25	WL - two zones - Note 1, lower loop temperature limits	89514	108	2568	2406	249	3800	98645	34.63	2	17	11
26	WL - two zones - Note 2	89739	132	2575	1822	249	4251	98769	34.62	2	17	11
27	WL - two zones - Note 2, HRV	89739	120	2575	1822	249	4251	98758	34.61	2	17	11
28	WL - two zones - Note 2, grey water heat recovery	87296	132	2575	1822	249	4251	96326	34.30	2	17	11
29	WL - two zones - Note 2, 0.454 m3 of storage	89684	129	2575	1822	249	4251	98711	34.62	2	17	11
30	WL - two zones - Note 2, 5.75 m2 solar collector	85113	176	2572	1822	249	4251	94183	32.30	2	17	11
31	WL - two zones - Note 2, 20 m2 solar collector	77568	454	2564	1822	249	4251	86910	31.11	2	16	8
32	WL - two zones - Note 2, HRV, GWHR	87296	120	2575	1822	249	4251	96314	34.30	2	17	11
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	82690	158	2572	1822	249	4251	91743	31.98	2	17	11
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	83267	155	1660	1822	249	4251	91405	32.07	2	17	11
35	TPFC - two zones - gas DHW + space heating, electric cooling	119590	246	2575	6279	1307	6868	136865	8.05	4	29	18
36	TPFC - two zones - cogen with absorption chiller, gas DHW	79033	439	15827	4002	6212	32655	138168	2.40	1	27	12

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

WINNIPEG - CODE HOUSE

Units - kWh

#	Description	Space Heat	Space Cool	HVAC Aux	DHW	Lights	Appl.	Total	Peak (kW)	Month	Day	Hour
1	Residential system - Heating only, no vent.	36050	0	974	4738	1307	6868	49937	30.13	2	17	11
2	Residential system - Heating and cooling, no vent.	35860	457	1037	4738	1307	6868	50266	30.01	1	13	11
3	Residential system - Heating only, plus vent.	41031	0	1504	4738	1307	6868	55448	22.88	1	6	11
4	Residential system - Heating and cooling, plus vent.	42520	533	2585	4738	1307	6868	58550	22.93	1	6	11
5	Residential system - Improved comfort control	49440	571	2585	4738	1307	6868	65509	23.29	1	6	11
6	WL - two zones	49139	542	3973	4738	1307	6868	66566	23.29	2	3	11
7	WL - five zones	47583	1603	4579	4738	1307	6868	66677	23.03	1	6	11
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	49065	533	3973	4738	1307	6868	66484	23.29	2	3	11
9	WL - two zones - 9.3 m2 more south windows	45769	1318	4513	4738	1307	6868	64513	23.36	2	3	11
10	WL - two zones - more window, plus 0.454 m3 storage	45538	1292	4513	4738	1307	6868	64255	23.36	2	3	11
11	WL - two zones - with efficient applicances, best refrigerator	52860	196	3587	4738	249	3800	65430	23.14	2	3	11
12	WL - two zones - with efficient appliances, good refrigerator	52496	217	3587	4738	249	4251	65538	23.13	2	3	11
13	WL - two zones - heat recovery ventilator (HRV)	45749	416	3973	4738	1307	6868	63050	22.57	2	3	11
14	WL - two zones - HRV with summer bypass	45904	524	3973	4738	1307	6868	63313	22.57	2	3	11
15	WL - two zones - high efficiency heat pumps	49171	419	3973	4738	1307	6868	66475	23.28	2	3	11
16	WL - two zones - 100% heat pump water heater	51737	516	3973	1822	1307	6868	66223	23.45	2	3	11
17	WL - two zones - fridge, freezer loop connected compressors	49180	378	3954	4738	1307	6868	66424	23.29	2	3	11
18	WL - two zones - grey water heat recovery (GWHR)	46979	545	3973	4738	1307	6868	64409	22.97	2	3	11
19	WL - two zones - dryer exhaust heat recovery	48661	548	3973	4738	1307	6868	66094	22.23	2	16	8
20	WL - two zones - 5.75 m2 solar collector (solar)	45637	568	3973	4738	1307	6868	63091	22.08	2	16	8
21	WL - two zones - solar with 0.454m3 storage	45294	551	3973	4738	1307	6868	62730	22.08	2	16	8
22	WL - two zones - more efficient fans	50442	425	2358	4738	1307	6868	66138	23.33	2	3	11
23	WL - two zones - Note 1	51661	182	3565	2406	249	3800	61862	22.60	2	3	11
24	WL - two zones - Note 1, 9.3 m2 more south windows	47981	580	4123	2406	249	3800	59140	22.70	2	3	11
25	WL - two zones - Note 1, lower loop temperature limits	51444	158	3565	2406	249	3800	61622	22.54	2	3	11
26	WL - two zones - Note 2	55186	176	3587	1822	249	4251	65271	23.41	1	6	11
27	WL - two zones - Note 2, HRV	51664	173	3587	1822	249	4251	61747	22.54	2	3	11
28	WL - two zones - Note 2, grey water heat recovery	52927	176	3587	1822	249	4251	63012	23.10	1	6	11
29	WL - two zones - Note 2, 0.454 m3 of storage	55119	173	3587	1822	249	4251	65201	23.41	1	6	11
30	WL - two zones - Note 2, 5.75 m2 solar collector	50979	231	3587	1822	249	4251	61120	21.78	1	6	11
31	WL - two zones - Note 2, 20 m2 solar collector	44635	554	3587	1822	249	4251	55098	20.17	2	17	8
32	WL - two zones - Note 2, HRV, GWHR	49408	173	3587	1822	249	4251	59491	22.22	2	3	11
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	45107	217	3587	1822	249	4251	55233	20.29	1	6	11
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	46326	188	2167	1822	249	4251	55003	20.14	1	6	11
35	TPFC - two zones - gas DHW + space heating, electric cooling	74207	305	3329	6279	1307	6868	92295	8.14	4	29	18
36	TPFC - two zones - cogen with absorption chiller, gas DHW	34369	563	16438	3279	6449	33912	95008	2.21	12	30	11

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

WINNIPEG - ADVANCED CONCEPT HOUSE

Units - kWh

#	Description	Space Heat	Space Cool	HVAC Aux	DHW	Lights	Appl.	Total	Peak (kW)	Month	Day	Hour
1	Residential system - Heating only, no vent.	639	0	883	4738	1307	6868	14434	10.78	12	22	11
2	Residential system - Heating and cooling, no vent.	633	2546	934	4738	1307	6868	17025	11.00	10	7	12
3	Residential system - Heating only, plus vent.	6672	0	2089	4738	1307	6868	21673	12.61	1	6	11
4	Residential system - Heating and cooling, plus vent.	6704	2033	2585	4738	1307	6868	24235	12.66	1	6	11
5	Residential system - Improved comfort control	7035	2476	2585	4738	1307	6868	25008	12.68	1	6	11
6	WL - two zones	6472	3402	3329	4738	1307	6868	26116	12.90	1	6	11
7	WL - five zones	6631	4099	3329	4738	1307	6868	26971	12.74	1	6	11
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	6384	3396	3329	4738	1307	6868	26022	12.90	1	6	11
9	WL - two zones - 9.3 m2 more south windows	4342	4902	3329	4738	1307	6868	25486	12.09	1	6	11
10	WL - two zones - more window, plus 0.454 m3 storage	3947	4870	3329	4738	1307	6868	25058	12.09	1	6	11
11	WL - two zones - with efficient applicances, best refrigerator	8567	1899	3329	4738	249	3800	22582	12.76	1	6	11
12	WL - two zones - with efficient appliances, good refrigerator	8333	1998	3329	4738	249	4251	22899	12.75	1	6	11
13	WL - two zones - heat recovery ventilator (HRV)	2113	2945	3329	4738	1307	6868	21299	10.12	4	29	12
14	WL - two zones - HRV with summer bypass	2115	3390	3329	4738	1307	6868	21747	10.31	7	21	12
15	WL - two zones - high efficiency heat pumps	6475	2657	3329	4738	1307	6868	25374	12.90	1	6	11
16	WL - two zones - 100% heat pump water heater	7954	3285	3329	1822	1307	6868	24564	13.06	1	6	11
17	WL - two zones - fridge, freezer loop connected compressors	6531	2303	3329	4738	1307	6868	25075	12.91	1	6	11
18	WL - two zones - grey water heat recovery (GWHR)	5453	3408	3329	4738	1307	6868	25102	12.59	1	6	11
19	WL - two zones - dryer exhaust heat recovery	6332	3413	3329	4738	1307	6868	25987	10.44	4	29	12
20	WL - two zones - 5.75 m2 solar collector (solar)	5394	3440	3329	4738	1307	6868	25075	11.27	1	6	11
21	WL - two zones - solar with 0.454m3 storage	4981	3419	3329	4738	1307	6868	24642	11.27	1	6	11
22	WL - two zones - more efficient fans	7076	3030	2035	4738	1307	6868	25053	12.94	1	6	11
23	WL - two zones - Note 1	4509	1878	3329	2406	249	3800	16171	9.89	1	6	11
24	WL - two zones - Note 1, 9.3 m2 more south windows	2643	3159	3329	2406	249	3800	15585	9.91	1	28	11
25	WL - two zones - Note 1, lower loop temperature limits	4533	1415	3329	2406	249	3800	15732	10.31	1	6	11
26	WL - two zones - Note 2	10278	1330	3329	1822	249	4251	21261	13.33	1	6	11
27	WL - two zones - Note 2, HRV	4955	1453	3329	1822	249	4251	16060	10.30	1	6	11
28	WL - two zones - Note 2, grey water heat recovery	9018	1330	3329	1822	249	4251	20001	13.01	1	6	11
29	WL - two zones - Note 2, 0.454 m3 of storage	10012	1316	3329	1822	249	4251	20979	13.33	1	6	11
30	WL - two zones - Note 2, 5.75 m2 solar collector	8377	1427	3329	1822	249	4251	19456	11.70	1	6	11
31	WL - two zones - Note 2, 20 m2 solar collector	7369	1799	3329	1822	249	4251	18820	8.46	1	7	8
32	WL - two zones - Note 2, HRV, GWHR	4011	1453	3329	1822	249	4251	15117	9.98	1	6	11
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	2485	1559	3329	1822	249	4251	13695	8.35	1	6	11
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	2871	1348	2035	1822	249	4251	12577	8.39	1	6	11
35	TPFC - two zones - gas DHW + space heating, electric cooling	8430	3091	3329	6279	1307	6868	29303	8.73	4	29	12
36	TPFC - two zones - cogen with absorption chiller, gas DHW	105	5186	16637	703	6528	34325	63484	2.11	4	29	12

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

TORONTO - OLD HOUSE

Units - kWh

#	Description	Space Heat	Space Cool	HVAC Aux	DHW	Lights	Appl.	Total	Peak (kW)	Month	Day	Hour
1	Residential system - Heating only, no vent.	36261	0	941	4738	1307	6868	50115	34.38	12	30	11
2	Residential system - Heating and cooling, no vent.	35980	519	1048	4738	1307	6868	50459	34.26	12	30	11
3	Residential system - Heating only, plus vent.	40779	0	1673	4738	1307	6868	55365	24.02	12	30	11
4	Residential system - Heating and cooling, plus vent.	42118	577	2949	4738	1307	6868	58557	24.01	12	30	11
5	Residential system - Improved comfort control	43285	650	2434	4738	1307	6868	59282	23.96	12	30	11
6	WL - two zones	43753	478	2267	4738	1307	6868	59410	24.28	12	30	11
7	WL - five zones	43214	908	2322	4738	1307	6868	59357	24.02	12	30	11
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	43742	475	2267	4738	1307	6868	59395	24.28	12	30	11
9	WL - two zones - 9.3 m2 more south windows	44723	759	2381	4738	1307	6868	60775	25.60	12	30	11
10	WL - two zones - more window, plus 0.454 m3 storage	44685	753	2381	4738	1307	6868	60731	25.60	12	30	11
11	WL - two zones - with efficient applicances, best refrigerator	47017	179	2219	4738	249	3800	58202	24.27	12	30	11
12	WL - two zones - with efficient appliances, good refrigerator	46698	202	2215	4738	249	4251	58353	24.25	12	30	11
13	WL - two zones - heat recovery ventilator (HRV)	43768	346	2267	4738	1307	6868	59293	24.27	12	30	11
14	WL - two zones - HRV with summer bypass	43771	475	2267	4738	1307	6868	59424	24.27	12	30	11
15	WL - two zones - high efficiency heat pumps	43771	369	2267	4738	1307	6868	59319	24.28	12	30	11
16	WL - two zones - 100% heat pump water heater	46352	451	2267	1822	1307	6868	59067	24.45	12	30	11
17	WL - two zones - fridge, freezer loop connected compressors	43698	325	2281	4738	1307	6868	59216	24.32	12	30	11
18	WL - two zones - grey water heat recovery (GWHR)	41711	478	2267	4738	1307	6868	57368	23.97	12	30	11
19	WL - two zones - dryer exhaust heat recovery	43264	478	2267	4738	1307	6868	58921	20.91	12	24	18
20	WL - two zones - 5.75 m2 solar collector (solar)	40738	483	2267	4738	1307	6868	56401	23.33	12	30	11
21	WL - two zones - solar with 0.454m3 storage	40571	481	2267	4738	1307	6868	56231	23.33	12	30	11
22	WL - two zones - more efficient fans	44166	475	1509	4738	1307	6868	59063	24.37	12	30	11
23	WL - two zones - Note 1	49212	146	2226	2406	249	3800	58039	24.44	12	30	11
24	WL - two zones - Note 1, 9.3 m2 more south windows	50598	390	2079	2406	249	3800	59521	25.35	2	11	11
25	WL - two zones - Note 1, lower loop temperature limits	49396	158	2167	2406	249	3800	58177	24.22	12	30	11
26	WL - two zones - Note 2	49678	193	2167	1822	249	4251	58361	24.21	12	30	11
27	WL - two zones - Note 2, HRV	49686	176	2167	1822	249	4251	58352	24.21	12	30	11
28	WL - two zones - Note 2, grey water heat recovery	47580	193	2167	1822	249	4251	56263	23.89	12	30	11
29	WL - two zones - Note 2, 0.454 m3 of storage	49558	188	2167	1822	249	4251	58235	24.21	12	30	11
30	WL - two zones - Note 2, 5.75 m2 solar collector	46045	249	2167	1822	249	4251	54784	23.25	12	30	11
31	WL - two zones - Note 2, 20 m2 solar collector	40861	563	2156	1822	249	4251	49903	20.88	12	30	11
32	WL - two zones - Note 2, HRV, GWHR	47589	176	2167	1822	249	4251	56255	23.89	12	30	11
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	43914	229	2167	1822	249	4251	52633	22.93	12	30	11
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	44278	229	1458	1822	249	4251	52287	23.00	12	30	11
35	TPFC - two zones - gas DHW + space heating, electric cooling	66270	615	2268	6279	1307	6868	83607	8.37	7	15	12
36	TPFC - two zones - cogen with absorption chiller, gas DHW	27518	1195	16499	3106	6472	34029	88820	2.25	12	30	11

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

TORONTO - CODE HOUSE

Units - kWh

#	Description	Space Heat	Space Cool	HVAC Aux	DHW	Lights	Appl.	Total	Peak (kW)	Month	Day	Hour
1	Residential system - Heating only, no vent.	17820	0	710	4738	1307	6868	31442	20.95	2	11	12
2	Residential system - Heating and cooling, no vent.	17826	483	769	4738	1307	6868	31990	21.00	2	11	12
3	Residential system - Heating only, plus vent.	21887	0	1405	4738	1307	6868	36204	16.86	2	11	11
4	Residential system - Heating and cooling, plus vent.	23041	633	2585	4738	1307	6868	39172	16.91	2	11	11
5	Residential system - Improved comfort control	23463	653	2585	4738	1307	6868	39614	16.92	2	11	11
6	WL - two zones	22241	861	3329	4738	1307	6868	39344	16.59	2	11	11
7	WL - five zones	21459	1450	3329	4738	1307	6868	39151	16.46	2	11	11
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	22212	858	3329	4738	1307	6868	39312	16.59	2	11	11
9	WL - two zones - 9.3 m2 more south windows	20982	1327	3329	4738	1307	6868	38550	16.79	2	4	11
10	WL - two zones - more window, plus 0.454 m3 storage	20823	1313	3329	4738	1307	6868	38378	16.79	2	4	11
11	WL - two zones - with efficient applicances, best refrigerator	25309	360	3329	4738	249	3800	37786	16.44	2	11	11
12	WL - two zones - with efficient appliances, good refrigerator	24990	404	3329	4738	249	4251	37962	16.44	2	11	11
13	WL - two zones - heat recovery ventilator (HRV)	19593	653	3329	4738	1307	6868	36488	15.76	2	11	11
14	WL - two zones - HRV with summer bypass	19977	856	3329	4738	1307	6868	37074	15.76	2	11	11
15	WL - two zones - high efficiency heat pumps	22244	668	3329	4738	1307	6868	39154	16.58	2	11	11
16	WL - two zones - 100% heat pump water heater	24594	817	3329	1822	1307	6868	38738	16.75	2	11	11
17	WL - two zones - fridge, freezer loop connected compressors	22162	571	3329	4738	1307	6868	38975	16.58	2	11	11
18	WL - two zones - grey water heat recovery (GWHR)	20287	861	3329	4738	1307	6868	37390	16.27	2	11	11
19	WL - two zones - dryer exhaust heat recovery	21825	867	3329	4738	1307	6868	38934	13.70	12	26	8
20	WL - two zones - 5.75 m2 solar collector (solar)	19619	879	3329	4738	1307	6868	36740	15.48	12	30	11
21	WL - two zones - solar with 0.454m3 storage	19212	867	3329	4738	1307	6868	36321	15.48	12	30	11
22	WL - two zones - more efficient fans	23159	712	2035	4738	1307	6868	38818	16.62	2	11	11
23	WL - two zones - Note 1	24489	290	3329	2406	249	3800	34563	15.78	2	11	11
24	WL - two zones - Note 1, 9.3 m2 more south windows	23012	612	3329	2406	249	3800	33408	16.09	2	4	11
25	WL - two zones - Note 1, lower loop temperature limits	23914	231	3329	2406	249	3800	33930	14.71	2	4	12
26	WL - two zones - Note 2	27006	267	3329	1822	249	4251	36924	15.46	12	23	12
27	WL - two zones - Note 2, HRV	24251	252	3329	1822	249	4251	34155	14.72	2	4	12
28	WL - two zones - Note 2, grey water heat recovery	24984	267	3329	1822	249	4251	34903	15.14	12	23	12
29	WL - two zones - Note 2, 0.454 m3 of storage	26833	258	3329	1822	249	4251	36743	15.46	12	23	12
30	WL - two zones - Note 2, 5.75 m2 solar collector	23747	328	3329	1822	249	4251	33728	14.47	12	30	11
31	WL - two zones - Note 2, 20 m2 solar collector	20231	712	3329	1822	249	4251	30596	12.10	12	30	11
32	WL - two zones - Note 2, HRV, GWHR	22233	252	3329	1822	249	4251	32137	14.40	2	4	12
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	18925	314	3329	1822	249	4251	28890	13.30	12	30	11
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	19722	243	2035	1822	249	4251	28323	13.12	12	30	11
35	TPFC - two zones - gas DHW + space heating, electric cooling	34120	589	3329	6279	1307	6868	52491	8.08	6	15	11
36	TPFC - two zones - cogen with absorption chiller, gas DHW	4653	1207	16973	1928	6657	35010	66428	1.96	12	30	11

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range

TORONTO - ADVANCED CONCEPT HOUSE

Units - kWh

#	Description	Space Heat	Space Cool	HVAC Aux	DHW	Lights	Appl.	Total	Peak (kW)	Month	Day	Hour
1	Residential system - Heating only, no vent.	129	0	1041	4738	1307	6868	14082	8.71	11	3	12
2	Residential system - Heating and cooling, no vent.	123	2637	1110	4738	1307	6868	16783	10.50	6	23	12
3	Residential system - Heating only, plus vent.	3147	0	2162	4738	1307	6868	18221	10.37	2	4	11
4	Residential system - Heating and cooling, plus vent.	3156	2332	2585	4738	1307	6868	20985	10.59	7	15	12
5	Residential system - Improved comfort control	3331	2857	2585	4738	1307	6868	21686	10.59	7	15	12
6	WL - two zones	2795	4152	3329	4738	1307	6868	23189	10.50	7	15	12
7	WL - five zones	2795	4588	3329	4738	1307	6868	23625	10.49	7	15	12
8	WL - two zones - with 0.454 m3 of thermal storage (storage)	2728	4146	3329	4738	1307	6868	23115	10.50	7	15	12
9	WL - two zones - 9.3 m2 more south windows	2033	5385	3329	4738	1307	6868	23660	11.12	10	28	12
10	WL - two zones - more window, plus 0.454 m3 storage	1913	5377	3329	4738	1307	6868	23531	11.12	10	28	12
11	WL - two zones - with efficient applicances, best refrigerator	4495	2353	3329	4738	249	3800	18964	10.17	2	4	11
12	WL - two zones - with efficient appliances, good refrigerator	4289	2464	3329	4738	249	4251	19321	10.16	2	4	11
13	WL - two zones - heat recovery ventilator (HRV)	1040	3516	3329	4738	1307	6868	20798	10.07	10	6	12
14	WL - two zones - HRV with summer bypass	1040	4114	3329	4738	1307	6868	21395	10.50	7	15	12
15	WL - two zones - high efficiency heat pumps	2795	3243	3329	4738	1307	6868	22280	10.30	2	4	11
16	WL - two zones - 100% heat pump water heater	4044	4017	3329	1822	1307	6868	21387	10.46	2	4	11
17	WL - two zones - fridge, freezer loop connected compressors	2810	2813	3329	4738	1307	6868	21864	10.28	2	4	11
18	WL - two zones - grey water heat recovery (GWHR)	2168	4155	3329	4738	1307	6868	22565	10.50	7	15	12
19	WL - two zones - dryer exhaust heat recovery	2745	4155	3329	4738	1307	6868	23142	10.50	7	15	12
20	WL - two zones - 5.75 m2 solar collector (solar)	2186	4161	3329	4738	1307	6868	22588	10.50	7	15	12
21	WL - two zones - solar with 0.454m3 storage	2069	4155	3329	4738	1307	6868	22465	10.50	7	15	12
22	WL - two zones - more efficient fans	3249	3730	2035	4738	1307	6868	21926	10.33	2	4	11
23	WL - two zones - Note 1	3123	2280	3329	2406	249	3800	15187	9.24	2	4	11
24	WL - two zones - Note 1, 9.3 m2 more south windows	2238	3279	3329	2406	249	3800	15301	9.33	2	4	11
25	WL - two zones - Note 1, lower loop temperature limits	3164	1726	3329	2406	249	3800	14674	9.23	2	4	11
26	WL - two zones - Note 2	6056	1664	3329	1822	249	4251	17373	10.31	2	4	11
27	WL - two zones - Note 2, HRV	3516	1761	3329	1822	249	4251	14929	9.23	2	4	11
28	WL - two zones - Note 2, grey water heat recovery	5130	1664	3329	1822	249	4251	16447	9.99	2	4	11
29	WL - two zones - Note 2, 0.454 m3 of storage	5839	1655	3329	1822	249	4251	17147	10.31	2	4	11
30	WL - two zones - Note 2, 5.75 m2 solar collector	4632	1752	3329	1822	249	4251	16037	9.22	12	30	11
31	WL - two zones - Note 2, 20 m2 solar collector	3976	2063	3329	1822	249	4251	15691	8.02	7	15	12
32	WL - two zones - Note 2, HRV, GWHR	2798	1761	3329	1822	249	4251	14211	8.91	2	4	11
33	WL - two zones - Note 2, HRV, GWHR, storage, solar	1541	1855	3329	1822	249	4251	13048	7.93	7	15	12
34	WL - two zones - Note 2, HRV, GWHR, storage, solar,eff. fans	1858	1614	2035	1822	249	4251	11830	7.78	7	15	12
35	TPFC - two zones - gas DHW + space heating, electric cooling	4193	3589	3329	6279	1307	6868	25565	8.61	7	15	12
36	TPFC - two zones - cogen with absorption chiller, gas DHW	0	6235	16537	475	6490	34122	63859	2.08	10	13	12

Note 1: efficient appliances (best refrigerator), 0.454 m3 storage, HRV, high efficiency HPs, 80% HPWH, loop connected compressors

Note 2: efficient appliances (good refrigerator), high efficiency HPs, 100% HPWH, loop connected compressors, low loop temperature range