THE SUSTAINABLE HOME WATER SYSTEM

at the Alberta Sustainable Home/Office

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Abstract

The Sustainable Home Water System (SHWS) at the Alberta Sustainable Home/ Office reduces total residential water use by 78 % compared with average Calgary households.

Collected rainwater is treated on demand to satisfy potable water requirements and meets Canadian Drinking Water Quality Guidelines (1996) for all parameters tested, however aesthetic objectives are slightly exceeded for temperature.

Heat from greywater is reclaimed through the counter current and drum storage greywater heat exchangers contributing 7.4 % and 4.4 % respectively to hot water heating. In-series operation accounts for 16.8% of the hot water heating required at the ASH home/ office.

The greywater is treated using slow sand filters, soil box subirrigation, and a Greywater Garden Wall. The treated greywater conforms to non-potable water guidelines from several U.S. states, apart from the elevated levels of total suspended solids. This reuse water satisfies 86% of the total ASH home/ office water demand (i.e. ultra low flush toilet, bathing, clothes washing, and subsurface irrigation).

The Sustainable Home Water System is a cost-effective, environmentally-friendly, safe home water system which can easily be installed in new homes, and SHWS components can be incorporated into existing residential water systems. Maintenance and operation requirements are inexpensive and require limited time, however, a complete understanding of the system is required. Further research, monitoring, and adaptations to the water treatment system will be continued to improve the SHWS.

Executive Summary

The Sustainable Home Water System (SHWS) at the Alberta Sustainable Home/ Office is an autonomous residential water supply system that incorporates rainwater collection and treatment for potable water, greywater collection, greywater heat recovery and treatment for non-potable reuse. Human waste is treated through a composting toilet which eliminates it from entering any water supply. The SHWS significantly reduces potable water demands to 3% and total water demands to 22% of the total potable water consumption of an average Calgary residence. This is achieved through a two-tiered water supply system. Potable water demands, representing 14% of the total water demands at the ASH home/ office, are satisfied through rainwater collection and treatment to Canadian Drinking Water Quality Guidelines. Non-potable demands (86% of the total SHWS water demand) are met through reuse water. Reuse water is supplied by treating greywater through three treatment options which emulate natural water purification systems: slow sand filtration, indoor subsurface irrigation in planter boxes, and an aquatic system called the Greywater Garden Wall.

Design of the SHWS incorporated water conservation fixtures, detailed water demand and supply calculations, and considered local rainfall patterns. The SHWS was installed and commissioned in the ASH home/ office as a demonstration prototype and monitoring was conducted to evaluate its performance. Water quality of the rainwater, potable supply, greywater, and reuse supply was determined. The counter current and drum storage greywater heat exchangers were evaluated by monitoring the temperature differences across the greywater heat exchangers and calculating their contribution to the hot water heating demands of the SHWS. This information gained from the monitoring of the SHWS was used to determine the viability of the SHWS in the Canadian Housing market as a retrofit and for new home installations.

Water quality of the potable water supply conformed to the Canadian Drinking Water Quality Guidelines (1996) for all parameters tested, however aesthetic objectives are slightly exceeded for temperature. Apart from total suspended solids, the reuse water supply conforms to non-potable water guidelines of several U.S. states. There are currently no Canadian greywater or reuse water guidelines.

The actual pattern of water use (frequency and volume) by the current two occupants at the ASH home/ office is much lower than expected in the SHWS design which was sized for a family of four. This has resulted in an imbalance in water supplies and water demands during the initial commissioning period and less than optimal operation of the water treatment systems. Each greywater treatment option relies on biological processes for purification in addition to natural physical and chemical purification processes. Therefore, time and regular cycling of greywater through the system is required to establish stable ecosystems for optimal and efficient water treatment. Due to time constraints of the project, monitoring was conducted prior to complete formation of established biological communities (eg. schmutzdecke layer formation in the slow sand filters, and substantial plant growth and rooting in the soil boxes, hydroponic

troughs, and marshes). Currently the various greywater treatment options are operating as parallel systems to evaluate their individual water purification performances. At a later date, the treatment options will be plumbed in-series to improve the overall purification process.

Heat reclaimed from the counter current greywater heat exchanger contributes to 7.4% of the hot reuse water heating demands for the SHWS. Contributions by the drum storage heat exchanger represent 4.4% of the hot reuse water heating demands, while in-series operation of the greywater heat exchanger system accounts for 16.8%. These results are lower than expected compared with the theoretical performance. Reasons for the poor performance can be categorized within design decisions (i.e. retrofit location constraints), system commissioning errors (i.e. incorrect plumbing configurations), and monitoring problems (i.e. instrumentation). The current operation and design of the SHWS limits the potential for the greywater heat exchangers due to low temperature gain potential of the ambient (i.e. 18^0C) inlet reuse water and extreme water conservation practices. Conventional patterns of hot water use would produce higher performances for the greywater heat exchangers due to higher hot water demands and frequency of use, as well as a greater temperature gain potential since municipally supplied inlet water to the greywater heat exchangers would be much colder (i.e. 5^0C).

Further refinement and monitoring of the SHWS will be conducted over the long term to optimize its performance, simplify the components and operation, and reduce the operational and capital costs of the SHWS. The experimental results of the SHWS greywater heat exchangers are unreliable and the actual performances have not yet been determined with confidence. Further monitoring will be conducted with appropriate and well calibrated instrumentation and a modified monitoring protocol. Long term monitoring to match the water use patterns of the occupants at the ASH home/ office will give more realistic performance results compared with the experimental performance which were determined using peak water demands. Further research is needed to characterize greywater and to determine applicable types of treatment required for residential greywater reuse. Reuse and greywater guidelines need to be developed in Canada to define acceptable water quality parameters and appropriate uses for greywater and reuse water. When these guidelines are defined, then substantial water conserving sustainable home water systems can be incorporated into the Canadian residential housing market. These sustainable home water systems will help us realize the benefits of water reuse and resource reclamation while maintaining good safety and health standards.

Sommaire

Le système de gestion durable des eaux domestiques (SGDED) de l'Alberta Sustainable Home/Office est un système autonome d'alimentation en eau résidentiel qui réunit le captage et le traitement des eaux de pluie aux fins d'utilisation comme eau potable, le captage des eaux ménagères, la récupération de chaleur des eaux ménagéres et le traitement de celles-ci pour utilisation comme eau non potable. Les eaux usées sanitaires sont prises en charge par un cabinet à compost, qui les empêche de parvenir dans tout système de gestion des eaux. Le système de gestion durable des eaux domestiques réduit considérablement les besoins en eau potable, soit à 3 %, et le total des besoins en eau, à 22 % de la consommation en eau potable totale d'une résidence moyenne de Calgary, ce qui est possible grâce à un système d'alimentation à deux niveaux. Les besoins en eau potable, qui représentent 14 % du total des besoins en eau de l'Alberta Sustainable Home/Office sont comblés par la collecte des eaux de pluie et leur traitement conformément aux Lignes directrices canadiennes en matière de qualité de l'eau potable. Les besoins en eau non potable (86 % du total des besoins en eau du système de gestion durable des eaux domestiques) sont comblés par l'utilisation des eaux réutilisées. Les eaux réutilisées sont obtenues au moyen de trois options différentes de traitement des eaux ménagères, qui imitent la purification naturelle de l'eau : la filtration lente sur sable; l'irrigation souterraine intérieure dans des jardinières; et un système de traitement des eaux par aquaculture appelé le Greywater Garden Wall.

La conception du système de gestion durable des eaux domestiques a incorporé des appareils sanitaires de type favorisant l'économie des eaux, des calculs détaillés des besoins et de l'approvisionnement en eau, ainsi que les configurations des pluies locales prises en compte. Le SGDED a été installé et mis en service dans l'Alberta Sustainable Home/Office à titre de prototype de démonstration, et on l'a soumis à un contrôle afin d'en évaluer la performance. On a déterminé la qualité de l'eau de l'alimentation en eau de pluie, en eau potable, en eaux ménagères et en eaux réutilisées. Les échangeurs de chaleur des eaux ménagères à plaques à contre courant et à stockage en fûts ont été évalués par le contrôle des différences de température de part et d'autre des échangeurs de chaleur des eaux ménagères et par le calcul de leur contribution aux besoins en énergie de chauffage de l'eau du système de gestion durable des eaux domestiques. Cette information obtenue grâce au contrôle du SGDED a été utilisée pour déterminer la viabilité de ce système sur le marché de l'habitation canadien comme système d'adaptation et pour les installations des maisons neuves.

La qualité de l'eau potable s'est révélée conforme aux Lignes directrices canadiennes en matière de qualité de l'eau potable (1996) relativement à tous les paramètres éprouvés; les objectifs de nature esthétique ont toutefois été légèrement dépassés en ce qui a trait aux dispositifs de régulation de la température. Outre le total des solides en suspension, l'alimentation en eaux réutilisées est conforme aux lignes directrices sur l'eau non potable de plusieurs États des États-Unis. Présentement, il n'existe pas de lignes directrices sur les eaux réutilisées ou sur les eaux ménagères au Canada.

La configuration actuelle de la consommation d'eau (fréquence et volume) par les deux occupants actuels de l'Alberta Sustainable Home/Office est de beaucoup inférieure aux prévisions dans la conception du système de gestion durable des eaux domestiques, lesquelles avaient été établies pour une famille de quatre personnes. Cela a eu pour résultat de créer un déséquilibre entre l'alimentation en eau et les besoins en eau au cours de la période initiale de mise en service et une exploitation des systèmes de traitement de l'eau en deçà du niveau optimal. Chacune des options de traitement des eaux ménagères repose sur des processus biologiques d'épuration, en plus des processus d'épuration physiques et chimiques naturels. Par conséquent, le séjour et la circulation régulière des eaux ménagères dans le système sont requis pour établir des écosystèmes stables permettant un traitement efficace et optimal des eaux. En raison des contraintes de temps imposées au projet, le contrôle a été effectué avant que soit achevée la formation de peuplements biologiques établis (p. ex., formation en couches de film biologique dans les filtres à sable lent, et croissance considérable des plantes et racinement dans les jardinières, les auges hydroponiques et les marais). On met actuellement en oeuvre les diverses options de traitement des eaux ménagères comme systèmes parallèles dans le but d'évaluer leurs performances respectives en termes d'épuration d'eau. Ultérieurement, les diverses options de traitement seront de les réunir dans le but d'améliorer le processus global d'épuration.

La chaleur récupérée de l'échangeur de chaleur des eaux ménagères à contre courant contribue pour 7,4 % des besoins en énergie de chauffage de l'eau chaude réutilisée pour le système de gestion durable des eaux domestiques. L'apport de l'échangeur de chaleur à stockage en fûts couvre 4,4 % des besoins en eau chaude réutilisée, alors que l'exploitation en série du système d'échangeur de chaleur des eaux ménagères représente 16,8 % de ces besoins. Ces résultats sont inférieurs à ce que laissait prévoir la performance théorique. Il est possible de catégoriser les raisons de la performance médiocre selon les décisions de conception (soit les contraintes liées à l'emplacement des adaptations), les erreurs de mise en service des systèmes (soit les mauvaises configurations de plomberie) et les problèmes de contrôle (soit l'instrumentation). L'exploitation et la conception actuelles du SGDED limitent le potentiel des échangeurs de chaleur des eaux ménagères, en raison du faible potentiel de gain de température des eaux réutilisées à l'admission à la température ambiante (soit 18 °C) et des pratiques trop pointues d'économie des eaux. Les configurations classiques d'utilisation de l'eau chaude généreraient des performances supérieures des échangeurs de chaleur des eaux ménagères en raison de la fréquence et des besoins plus élevés en eau chaude, de même qu'un gain de température supérieur, compte tenu de la température beaucoup plus basse (5 °C) de l'eau à l'admission qui est contribuée aux échangeurs de chaleur des eaux ménagères par la municipalité.

On effectuera des interventions supplémentaires de perfectionnement et de contrôle à long terme du système de gestion durable des eaux domestiques afin d'en optimiser les performances, d'en simplifier les composantes et l'exploitation et d'en réduire les coûts d'utilisation et d'immobilisation. Les résultats expérimentaux des échangeurs de chaleur des eaux ménagères du SGDED ne sont pas fiables, et leurs performances réelles n'ont pu encore être déterminées avec certitude. D'autres interventions de contrôle auront lieu, au moyen d'instruments appropriés et correctement étalonnés, ainsi que d'un protocole de contrôle modifié. Le contrôle à long terme, dans le but d'apparier les configurations d'utilisation d'eau des occupants de l'Alberta Sustainable Home/Office donnera des résultats de performance plus réalistes que ceux de la performance expérimentale, déterminés en fonction des charges de pointe. D'autres efforts de recherche sont requis pour caractériser les eaux ménagères et déterminer quels sont les types de traitement qui s'appliquent à la réutilisation résidentielle des eaux ménagères. Il serait nécessaire de mettre au point des lignes directrices sur l'eau réutilisée et les eaux ménagères au Canada, pour pouvoir définir les paramètres acceptables de qualité de l'eau et les usages appropriés des eaux réutilisées et des eaux ménagères. Une fois ces lignes directrices définies, il deviendra possible d'incorporer sur le marché de l'habitation au Canada des systèmes de gestion durable des eaux domestiques offrant un potentiel appréciable d'économie des ressources en eau. De tels systèmes de gestion durable des eaux domestiques nous feront mieux réaliser les avantages de la réutilisation des eaux et de la récupération des ressources dans le respect de normes minimales de santé et de sécurité.

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1.0 INTRODUCTION

The Sustainable Home Water System (SHWS) at the Alberta Sustainable Home/ Office (ASH) in Calgary, Alberta is an autonomous residential water supply system that incorporates rainwater collection, treatment and distribution, greywater heat recovery, greywater treatment and reuse. The SHWS is intended to reduce residential water consumption and demonstrate an environmentally responsible alternative to centralized, municipal water supply and wastewater treatment.

An average household in Calgary consumes 336,000 litres of potable water annually (City of Calgary,1998). In comparison, the total annual ASH home/ office water demand, incorporating the SHWS design, is estimated at 75,200 litres for a family of four. The potable water demand supplied by treated rainwater is only 14% of the total annual ASH home/ office water demand or 10, 900 litres. This represents a substantial reduction in residential potable water consumption to just 3% of the average household in Calgary. The remaining 86% of the ASH home/ office water demand is non-potable and is supplied by reuse water.

The autonomous nature of the SHWS with a cyclic balance water treatment which emulates natural systems provides an environment conducive to creating assets out of wastewaters that are usually deemed liabilities. Conventional wastewater systems mix blackwater, greywater, and often industrial effluent. The SHWS does not produce heavy metal or toxic chemicals as a byproduct to treatment. Usable humus and nutrients from greywater are reclaimed and reused to benefit mini ecosystems within the ASH home/ office.

1.1 Objectives

The objectives of the Sustainable Home Water System (SHWS) project are:

- to design an autonomous home water system which includes a rainwater collection, storage, and treatment system; greywater heat recovery; and a greywater treatment and recycling system

- install the SHWS at the Alberta Sustainable House as a demonstration prototype

- monitor and evaluate the performance of the SHWS and greywater heat exchangers

- determine the SHWS viability in the Canadian Housing Industry as a retrofit and for new home installations

2.0 SUSTAINABLE HOME WATER SYSTEM (SHWS) DESIGN

2.1 Water Demand

The first step in the SHWS design process is to determine the water demand at the Alberta Sustainable Home/ Office (ASH). Based on the water conserving appliances and fixtures at the ASH, both the frequency of use and the volume per use is estimated for a conserving family of four. The average total volume of water to be used by each appliance and fixture is calculated per day, per month, and per year. Sub-totals for each water use location (i.e. bathroom) are determined, then totaled to give the total daily, monthly, and annual water demand for a typical conserving family of four (Table 1). Therefore estimated water demand at the ASH house using the SHWS design is 206 litres per day, 6184 litres per month or 75239 litres per year.

The water demand requirements are characterized by percent (%) hot, percent (%) cold, and water source for each water demand fixture and appliance. The water demand is two-tiered, divided into potable and non-potable requirements. The total potable water demand represents 14% of the total water requirements at the ASH. Potable water is supplied to the kitchen sink, dishwasher, and an upstairs bathroom sink. Reuse water demands (i.e. shower/bath, laundry, bathroom basins, ultra-low flush vacuum toilet, plant watering) account for the remaining 86%. These figures are further divided into total hot and cold demands to aid in the sizing of various components in the SHWS including the two greywater heat exchangers.

2.2 Water Supply

Identification and characterization of the various water sources, including quality and quantity considerations are also paramount in the design process. The potable demand is satisfied through rainwater collection and treatment. Calgary, Alberta has an average annual rainfall (based on Calgary International Airport climatic data) of 300.0 mm (1951-1980) or 300.1 mm (1981-1990). Using the average monthly rainfall totals, and the ASH roof collection area of 204.4 m^2, the average annual rainfall collection potential is 61380 L or 5.12 m^3 per month (Table 2). The average available rainwater collection in theory could satisfy up to 82% of the total water demand using the SHWS. However, due to great seasonal variability in rainfall and a limited cistern storage capacity of 17956 L, the actual theoretical contribution of rainwater to the total water demand of the SHWS is up to 70%. Since the total potable demand is only 14% of the total water demand, all potable water needs are easily met by rainwater treated to potable water standards. In a worst case scenario such as startup of the system during winter months of low rainfall accumulation there would be a deficit of 2539 L in the first year only. Subsequent years would be deficit-free based on current climatic data, even in a semiarid environment like Calgary.

Table 1

Theoretical Water Demand at the Alberta Sustainable Home/ Office

		Frequency of Use/ Av. Family of 4				Total Volume Used (L)			Water Supply Characteristics		
Appliance and Fixture	**Frequency of Use**	**Per Day**	**Per Month**	**Per Year**	**Volume/Use**	**Per Day**	**Per Month**	**Per Year**	**Water Supply**	**% Cold**	**% Hot**
BATHROOM						**50**	**1487**	**18086**	**reuse water**		
Ultra Low Flush VacuumToilet	3 flushes/c/day	10	300	3650	0.6 L/ flush	6	180	2190	reuse water	100	0
Sink (6.82 L/ min)	3 uses/c/day	12	360	4380	0.2 L/ use	2	72	876	reuse water	30	70
Shower (8.23 L/min)	1 use/c/4 days	1	30	365	41.15 L/ shower	41	1235	15020	reuse water	20	80
UTILITY ROOM						**33**	**996**	**12112**	**reuse water**		
Washing Machine	0.25 load/c/day	1	15	183	63.64 L/ load	32	955	11614	reuse water	60	40
Laundry Tub (6.82 L/ min)	1 use/c/20 days	0.2	6	73	6.82 L/ use	1	41	498	reuse water	60	40
KITCHEN						**29**	**870**	**10585**	**potable water**		
Food Preparation/ Drinking	3uses/c/day	3	90	1095	1L/capita/meal	12	360	4380	potable water	100	0
Sink Dish Washing	1 use/day	1	30	365	1.25 L/c/ load	5	150	1825	potable water	0	100
Dishwasher	1 use/ 2 days	1	15	183	24 L/ load	12	360	4380	potable water	0	100
GREENHOUSE						**3**	**84**	**1022**	**reuse water**		
Plant Watering (4 sq. m)	1 use/week	0.14	4	51	5L/m2/week	3	84	1022	reuse water	100	0
UPPER BATHROOM						**92**	**2748**	**33434**	**reuse water**		
Phoenix Composting Toilet	3 uses/c/day	12	360	4380	0.0 L/ use	0	0	0	N/A	0	0
Hot Water Sink (6.82 L/ min)	2 uses/c/day	4	120	1460	0.2 L/ use	1	24	292	reuse water	30	70
Cold Water Sink (6.82 L/min)	1 use/c/day	4	120	1460	0.2 L/ use	1	24	292	reuse water	100	0
Bath Tub/ Shower	1 use/c/4 days	1	30	365	90 L/ bath	90	2700	32850	reuse water	20	80
YARD						**0**	**0**	**0**	**reuse/rainwater**		
Garden	0 uses/c/day	0	0	0	N/A	0	0	0	reuse/rainwater	100	0
Lawn Sprinker	0 uses/c/day	0	0	0	N/A	0	0	0	reuse/rainwater	100	0
Car Washing	0 uses/c/day	0	0	0	N/A	0	0	0	reuse/rainwater	100	0
					TOTAL	206	6184	75239			

Summary of Water Distribution	L/ day	L/ month	L/ year	% of demand
DEMAND				
Cold Potable Water	13	384	4672	6
Hot Potable Water	17	510	6205	8
Total Potable Water	**30**	**894**	**10877**	**14**
Cold Reuse Water	56	1677	20404	27
Hot Reuse Water	120	3613	43958	58
Total Reuse Water	**176**	**5290**	**64362**	**86**
Total Water Demand	**206**	**6184**	**75239**	**100**
SUPPLY				
Average Available Rainwater Collection	168	5115	61381	82
Water Recovery for Reuse	193	5800	70567	94
Water Lost from System	13	384	4672	6
Disposal of Extra Reuse	17	510	6205	8

Table 2 Rainwater Supply at the Alberta Sustainable Home/ Office

Total Size of Cisterns =	17.956 m^3 or 3950 Imp. Gal.		
Roof Rainfall Collection Area =	204.4 m^2		
Average Annual Rainfall =	0.3000 m		
Average Annual Rainfall Collection Available =	61.38 m^3 =	5.12	m^3/month
Average Annual Water Demand w\ 0% Reuse=	75.24 m^3 =	6.27	m^3/month
Avg. Annual Water Demand w\ 86% Reuse =	10.88 m^3 =	0.89	m^3/month

Rainfall Data at Calgary Int'l.	Average Rainfall (mm)		Rainwater Volume in Cistern Storage (L)			
Month	1951-1980	1981-1990	Available	@ 0% Reuse	@86% Reuse	cont. 2nd yr
January	0.2	0.2	41	-6229	-853	15397
February	0.3	0.2	61	-6209	-833	14564
March	0.2	1.5	41	-6229	-853	13711
April	10.2	9.2	2085	-4185	1191	14902
May	41.1	43.9	8401	2131	8698	17956
June	87.6	76.7	17905	13766	17956	17956
July	65.4	69.9	13368	17956	17956	17956
August	55.4	48.7	11324	17956	17956	17956
September	33.2	42.7	6786	17956	17956	17956
October	6.0	6.4	1226	12912	17956	17956
November	0.3	0.6	61	6704	17123	17123
December	0.1	0.1	20	454	16250	16250
Annual Total	300.0	300.1	61320	-22852	-2539	0 deficit

Rainwater Summary

Average Annual Water Demand	Rainwater satisfies % of annual demand	Rainwater Supply Deficit (L)	
		initial year	ea. add'l. year
with 0% reuse water use	70	-22852	-22397
with 86% reuse water use	100	-2539	0

The water source for the non-potable or reuse demand is treated greywater (i.e. reuse water) with treated rainwater as a backup supply. Recovery of reuse water (at 94% of total water demand) exceeds the reuse water demand (86% of total water demand). Losses from the reuse system have been calculated as 13L/day or 4672 L/ year. Therefore there is an excess accumulation of reuse water of 17 L/ day or 6205 L/ year which needs to be disposed. This could easily be put to beneficial use in the subirrigation system since the outdoor water demands have not been included in the total water demand figures.

3.0 DESCRIPTION OF THE SUSTAINABLE HOME WATER SYSTEM (SHWS)

The SHWS design promotes conservation of water resources and allows the users to lead conserver lifestyles using appropriate water fixtures and appliances. All the fixtures in the house are low flow models, the house water pressure is reduced, and low water use appliances have been incorporated.

The SHWS design is a two-tiered water system which satisfies potable water demands with treated rainwater, and secondary demands are supplied by greywater treated to reuse standards. The major components of the SHWS include a rainwater collection and storage system, potable water treatment and supply, a composting toilet, greywater collection and heat recovery system, and a greywater treatment and reuse supply system.

Black water generation (i.e. human waste) is eliminated from this system by using a waterless composting toilet. An ultra-low flush vacuum toilet (0.6 L/flush) is used as a second toilet and also feeds into the composting chamber. This approach to human waste disposal reduces the annual four person household water consumption by approximately 165, 700 litres per year based on conventional flush toilet consumption (Table 3). It also allows for reclamation of valuable resources (i.e. reuse water, compost, and nutrients) found in household wastewater instead of creating a liability with mixed sewage.

3.1 Rainwater Collection

Rainwater is collected from the roof of the ASH home/ office which is covered with an elastomeric polymer surface. The rainwater is physically strained before entering the rain barrels to remove large particulates (ie. leaves and other debris). The water is temporarily stored in the rain barrels for outdoor use, which then overflows into underground cisterns via 4"ϕ ABS underground pipes. The first cistern is a 3411 L (750 Imp. Gal.) settlement tank with a baffle dividing it into two chambers. Any particulate matter present in the rainwater settles and any contaminants such as oils or greases float to the surface of the water in the first chamber. This allows the relatively clean water to pass into the second chamber of the first cistern. When full, the water overflows into the second 14,550 L (3200 Imp. Gal.) storage cistern (fig.1).

Table 3

Comparison of the Theoretical Water Consumption between the Alberta Sustainable Home/Office and an Average Calgarian Family of Four

	Frequency of Use/ Av. Family of 4			Alberta Sustainable House				Average Calgarian Family of Four			
				Volume/ Use	Total Volume Used (L)			Volume/ Use	Total Volume Used (L)		
Appliance and Fixture	Per Day	Per Month	Per Year		Per Day	Per Month	Per Year		Per Day	Per Month	Per Year
BATHROOM					50	1487	18086		310	9294	113077
Ultra Low Flush Vacuum Toilet	10	300	3650	0.6 L/ flush	6	180	2190	23 L/ flush	230	6900	83950
Sink (6.82 L/ min)	12	360	4380	0.2 L/ use	2	72	876	0.4 L/ use	5	144	1752
Shower (8.23 L/min)	1	30	365	1.15 L/ show	41	1235	15020	75 L/ shower	75	2250	27375
UTILITY ROOM					33	996	12112		120	3600	43800
Washing Machine	0.5	15	183	63.64 L/ load	32	955	11614	230 L/ load	115	3450	41975
Laundry Tub (6.82 L/ min)	0.2	6	73	6.82 L/ use	1	41	498	25 L/ use	5	150	1825
KITCHEN					29	870	10585		54	1620	19710
Food Preparation/ Drinking	3	90	1095	L/capita/mea	12	360	4380	L/capita/mea	12	360	4380
Sink Dish Washing	1	30	365	5 L/ load	5	150	1825	10 L/ load	10	300	3650
Dishwasher	0.5	15	183	24 L/ load	12	360	4380	64 L/ load	32	960	11680
GREENHOUSE					3	84	1022		3	84	1022
Plant Watering (4 sq. m)	0.14	4	51	5L/m2/week	3	84	1022	5L/m2/week	3	84	1022
UPPER BATHROOM					92	2748	33434		93	2796	34018
Phoenix Composting Toilet	10	300	3650	0.0 L/ use	0	0	0	23 L/ use	230	6900	83950
Hot Water Sink (6.82 L/ min)	4	120	1460	0.2 L/ use	1	24	292	0.4 L/ use	2	48	584
Cold Water Sink (6.82 L/min)	4	120	1460	0.2 L/ use	1	24	292	0.4 L/ use	2	48	584
Bath Tub/ Shower	1	30	365	90 L/ bath	90	2700	32850	90 L/ bath	90	2700	32850
YARD					0	0	0		985	29591	119313
Garden (16 weeks)	1	30	112	0 L/ min	0	0	0	15.8 L/ min	158	4740	18960
Lawn Sprinker (16 weeks)	0.14	4	16	0 L/ min	0	0	0	15.8 L/ min	813	24377	97509
Car Washing (6 months)	0.03	1	6	0 L/ min	0	0	0	15.8 L/ min	14	474	2844
				TOTAL	206	6184	75239	TOTAL	1565	46985	330940

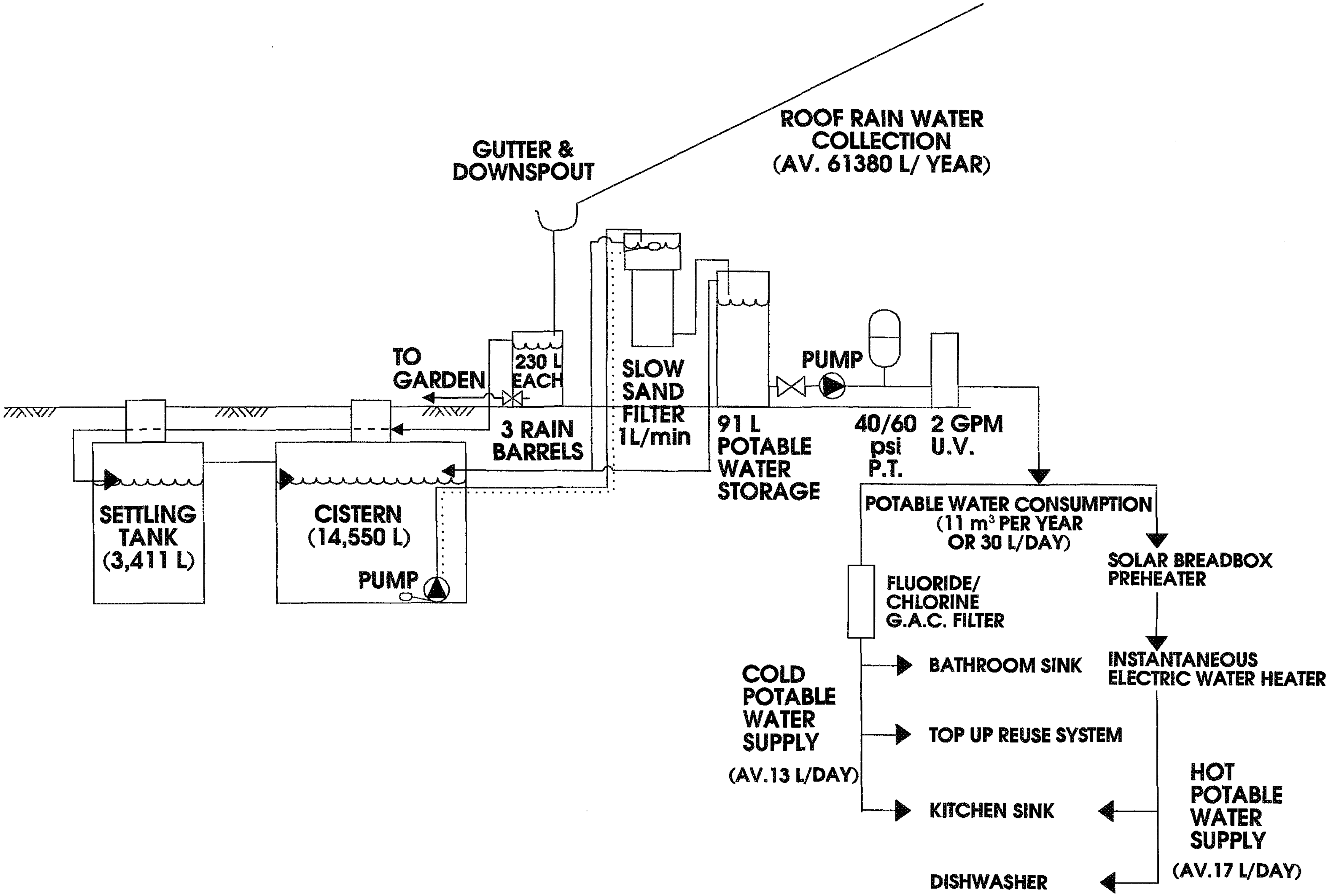

FIGURE 1 Potable Water System at the Alberta Sustainable Home/ Office

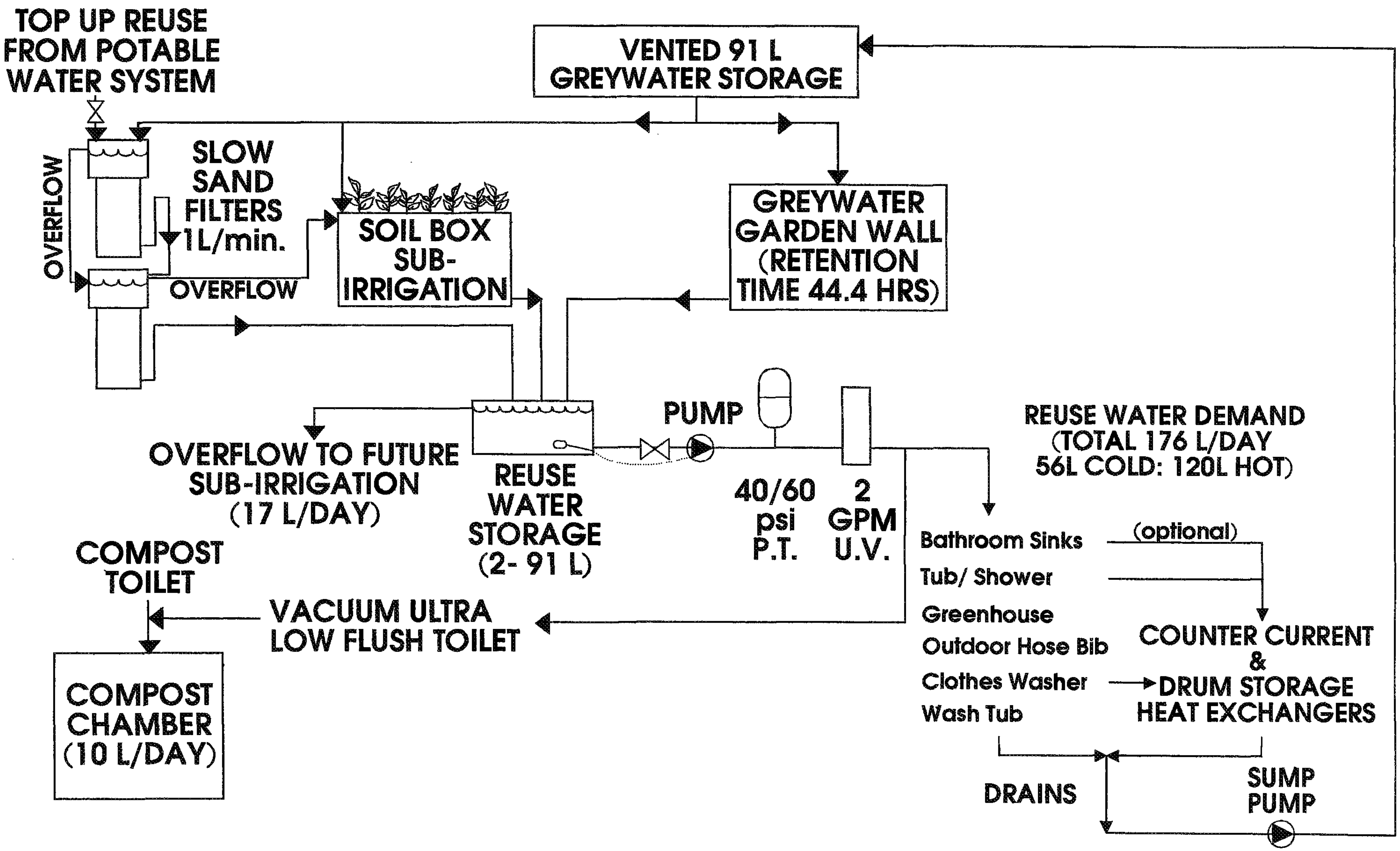

FIGURE 2 Reuse Water System at the Alberta Sustainable Home/ Office

3.2 Potable Water Treament and Supply

As potable water is required, the rainwater from the storage cistern is treated on-demand. Treatment to potable water quality standards is achieved by slow sand filtration, and ultraviolet (U.V.) disinfection (fig.1). When city water utilities were being used, prior to the commissioning of the SHWS, the potable water was treated with a chlorine and fluoride removal system. This system remains as a back-up treatment for the potable supply which consists of a 0.4 micron polypropylene scrubber (to remove sediment and particulate matter), a 0.2 micron polypropylene filter (to remove bacteria), and a 15" column of silver infused granular activated carbon (GAC). Odour, colour, taste, sediment, chlorine, and organics (i.e. pesticides (2,4 -D), PCB's, chloroform, phenol, vinyl chlorides) are removed from the water (Mountain Fresh Canada Ltd. brochure, 1987).

Potable water is supplied to the kitchen tap, dishwasher, and one upper floor bathroom sink (fig.1). Periodically the potable water will be used to top up the reuse water system due to losses from the system (i.e. evapotranspiration, evaporation, outdoor uses). The estimated potable demand for the ASH home /office (family of four) is 30 L per day or 10, 800 L per year. Cold potable water supply is estimated at 13 L/day. Hot potable water demands (17 L/day) include the kitchen sink and dishwasher. A solar breadbox preheater and an instantaneous electric water heater will be incorporated to satisfy these hot potable demands.

3.3 Greywater Heat Exchangers

Heat is reclaimed from the hot/warm greywater sources through two types of heat exchangers: counter current for continuous flow greywater sources (i.e. showers), and a drum storage heat exchanger for non-continuous flow applications (i.e. bathtub, clothes washer, or dishwasher). Currently at the ASH home /office only the shower/ bath tub, and clothes washer are hooked up to the greywater heat recovery system (fig.7). Reclaimed heat is used to preheat the incoming reuse water before it goes to the solar storage tank which acts as the domestic hot water heater. After passing through the greywater heat exchangers, the greywater is collected in a sump and pumped to the greenhouse for treatment.

3.4 Greywater Treatment and Reuse Supply

In the greenhouse, greywater is currently gravity-fed through three parallel treatment options (fig.2) which emulate natural water purification systems: slow sand filtration, subsurface soil-bed irrigation, and a greywater garden wall (explained in detail below.) The SHWS design allows for flexibility in treatment of the greywater with respect to volume control to each treatment option, and order of treatment options (i.e. in-series treatments). This treated reuse water is temporarily stored, pressurized, then further treated on-demand with ultraviolet irradiation as reuse water is required.

Non-potable or reuse demands include showers, bathing, sink basins, clothes washing, plant watering, and ultra-low flush vacuum toilet flushing. When there is an excess of reuse water then outdoor demands can be satisfied such as subsurface drip irrigation to ornamental plants, shrubs, and trees. The estimated total reuse water demand is 176 litres per day or 64400 litres per year representing 86% of the total water demand of the ASH home /office. Cold reuse water demands total 56 L per day. Hot reuse water demands (120 L/day) are satisfied by first preheating through the greywater heat exchangers and then further heated in the 364 L (80 Imp.Gal.) solar storage tank. Heat is supplied to the solar storage tank through several heat exchange coils. The sources of heat currently include solar vacuum tubes and masonry heater coils (i.e. fireplace). In the future a ground source heat pump and a stirling engine may be incorporated.

3.4.1 Slow Sand Filtration

The slow sand filtration treatment option at the Alberta Sustainable Home /Office emulates a natural water purification process. In the potable water system one slow sand filter is used to treat the rainwater from the cistern before it is treated on demand through the ultraviolet irradiation unit. Two slow sand filters have been commissioned in series to treat greywater in the greenhouse at the ASH home/ office.

The slow sand filter technology currently operating at the ASH house is available on the market as the Canadian Water Filter. It can be purchased by contacting David Manz at DAVNOR Water Treatment Technologies Ltd., Calgary, AB. The original purpose of the slow sand filter was to treat water to potable water standards acting as a polishing filter. Slow sand filtration effectively reduces turbidity, hardness, BOD, colour, odour, taste and treats microbial contamination. Total and fecal coliform bacteria are removed up to 99 - 100%. Removal of viruses are 99.9 - 100% (Manz, Buzunis, and Morales, 1993). Slow sand filtration also removes heavy metals such as mercury, cadmium, chromium, lead, iron, and manganese from water.

Water to be treated first enters a diffuser basin to distribute the water evenly over the filter area and prevent disturbance of the layers (fig.3). The water is gravity-fed or passively filtered through a column of sand with layers of progressively coarser grain size. The top layer of very fine sand is 4 cm in depth. The next layers consist of 36 cm of fine sand (0.15-0.3mm dia.) and 4.5 cm coarse sand. The bottom layer consists of 7.5 cm of coarse gravel. The flow rate through the filter can be adjusted by the outlet valve and the water supply is controlled by a valve upstream of the slow sand filter. Acceptable flow rates are between 0.33 L and 1 L/min. Slow filter rates are optimal and increase the quality of the filtered water.

A schmutzdecke layer forms within and on the top surface of the sand. This is a community of aerobic microorganisms which purify the water by consuming organic matter and nutrients present within the water. Provided that the water source remains relatively constant with respect to quality or composition and characteristics, the schmutzdecke layer remains relatively stable once established. The greywater then filters through the various layers of sand. Aerobic conditions are maintained through the column of sand as long as there is only a few centimetres head of water over the schmutzdecke layer and the filter is not left in stagnant conditions.

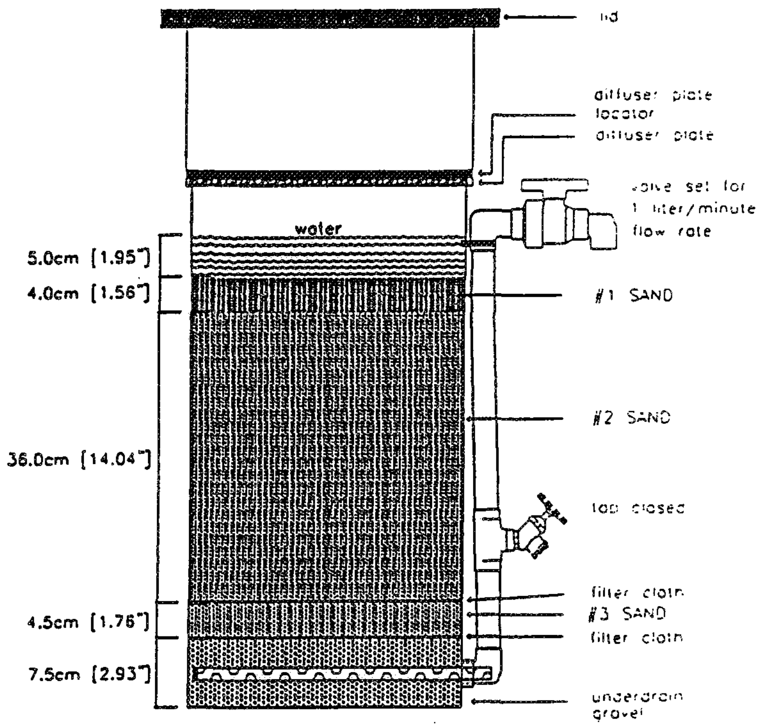

Figure 3 Schematic of the Canadian Water Filter

The filtered greywater flows through each slow sand filter sequentially and then is collected in a reuse water storage tank. This reuse water is then pressurized and is treated further on-demand with an ultraviolet disinfection unit.

Maintenance of the slow sand filters includes observation of the performance at least once a week to ensure an appropriate flow rate from the filter. Periodic replacement of the top 2 to 4 cm of sand is required when the water discharge rate decreases below acceptable limits. An optional geotextile membrane could be placed on top of the upper most sand layer. Its main advantage is for ease of maintaining the filter when the schmutzdecke layer needs to be removed.

Using slow sand filters for greywater treatment is a new application for this technology. Two slow sand filters have been installed in series as a prototype to determine their performance in handling this wastewater stream. Initially, the performance of the slow sand filters will be monitored as to how well they purify the greywater on their own. Then the slow sand filters will be tested as polishing filters downstream of one of the other SHWS treatment options.

A new modification to the Canadian Water Filter is that it could be set up as a self-cleaning unit. Water is allowed to periodically backwash when the discharge rate becomes too slow. Backwashing is conducted at a very low flow rate so that the bed will not become fluidized, which may disturb the stratified layers of sand and may introduce air locks within the column. There is an arm-like rake that breaks up the top layer of the sand or schmutzdecke and it is drained off. A new schmutzdecke layer would then be allowed to develop. The system would then take approximately two to three weeks to restabilize and operate at peak performance. This modified slow sand filter would be particularly beneficial for greywater treatment applications since greywater tends to have relatively high total suspended and dissolved solids and turbidity. The resulting sediment and precipitate build up would require more frequent maintenance compared with a slow sand filter used for potable water treatment.

3.4.2 Soil Box Subirrigation

The soil box greywater treatment option at the Alberta Sustainable Home /Office emulates an efficient method of natural water purification. When the greywater storage tank is filled above a set volume the greywater overflows into a flexible tube leading to the first soil box. The SHWS soil box design was fashioned after the Clivus Multrum Greywater System (fig.4); however, instead of using pressure activated pipe, the greywater is gravity-fed through a soaker hose and the flow rate can be adjusted with an upstream valve. Greywater percolates through the soaker hose to the root zone of various types of plants in two indoor planter boxes. The type of plants growing in the soil box include edible non-root vegetables, fruit, flowers, and herbs, as well as native species, and plants useful for medicinal purposes or air and water purification. Water and nutrients are taken up by the roots of the plants and soil bacterial activity helps purify the water.

Each greywater soil box is layered with 14.5 feet of 5/8" soaker hose placed just underneath the top layer which is 2"- 4" of mulch. Below the mulch is 1 foot of sandy loam soil, 6" concrete mix sand, and 4" of coarse sand. A geotextile membrane is optional between the coarse sand and the remaining 8" layer of pea-sized gravel to ensure a distinct boundary between the two layers for optimal percolation rates.

The greywater filters through the soil box media to a reservoir at the bottom of each soil box. Controlled by a float valve, this water is pumped to the second soil box for further treatment. Once the greywater is filtered through the soil boxes, the water is collected in a reuse water storage tank. This water is then pressurized and is treated further on-demand with an ultraviolet disinfection unit.

The volume of greywater generated at the Alberta Sustainable House for a family of four is 206 litres/day (45 Imp.Gal./day). With an ideal flow rate between 1 and 2.4 Gal./s.f./day

(Clivus Multrum Inc.,1992), the soil box size requirements are 18.75 s.f. to 45 s.f. If good sandy loam is used in the indoor soil box, then it can handle loads up to 2-3 Gal./s.f./day with a 10 ft injection pipe. There is 19.5 s.f. of available indoor soil area in the two planter boxes which converts to a flow rate of 2.3 Imp.Gal./s.f./day. The flow rate is on the high end for the capacity of the soil box, however, the volume of greywater requiring treatment will be lower since there will be some losses through evaporation, and other treatment options share the total greywater treatment load.

The optimal volume for each greywater dose through the soil box corresponds to a 2.5 cm (1 inch) flooding depth. This equates to 1.625 c.f. of greywater per dose (46 litres per dose). Therefore, the required number of doses per day is 4.5 which gives a dose cycle length of 5 hours and 20 minutes.

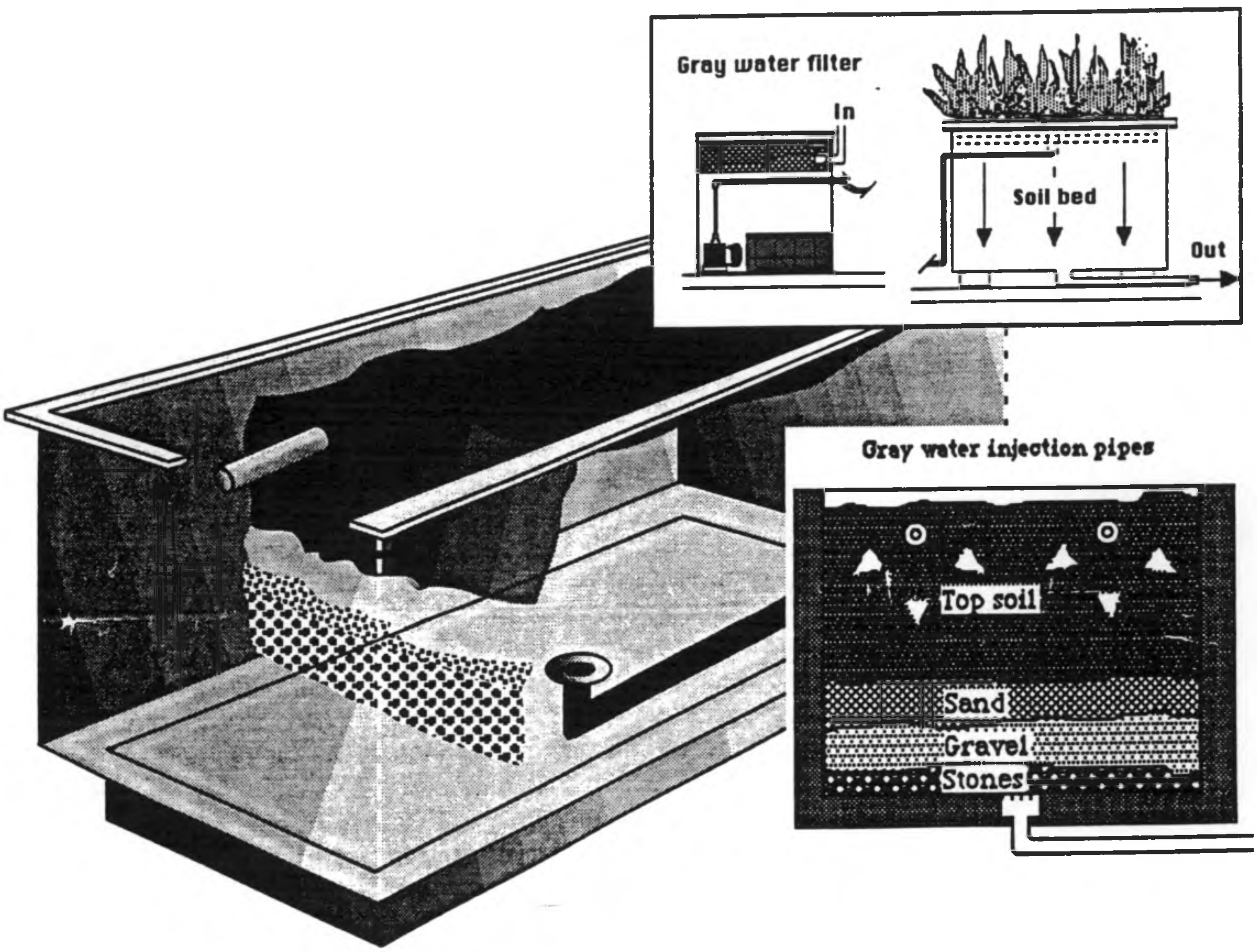

FIGURE 4 Clivus Multrum Greywater prefilter and soilbed injection in which the SHWS Soil Box Greywater Treatment was emulated.

3.4.3 Greywater Garden Wall

The Greywater Garden Wall (GWGW) is an integral part of the greywater treatment for the SHWS. It relies on a balanced ecosystem of living organisms to recapture usable nutrients (i.e. organic carbon and nitrogen) from the greywater. The design objectives of the Greywater Garden Wall are to reduce the amount of organic wastes from the greywater and those inherent to the system (i.e. fish wastes), and recapture these usable organic nutrients through conversion to edible biomass. Challenges for the system design are the limited space available for the system, use of low cost and reusable materials, minimal maintenance, and operation at various light and temperature extremes.

Dale Hampshire designed the Greywater Garden Wall which has similar design principles to the Living Technologies, Inc. wastewater treatment systems in which Dr. John Todd of Ocean Arks International was instrumental in designing. These living systems emulate natural purification processes and nutrient cycling found in freshwater ecosystems; however, the GWGW is unique in that it is confined to a 270 cm (H) x 30 cm (W) x 180 cm (L) space within the ASH greenhouse. Although it is a small scale residential system, the biologically active GWGW demonstrates the feasibility of domestic food production through hydroponics, and fish and crustacean culture in addition to purification of greywater. The Greywater Garden Wall was sized to accommodate and treat the full 206 L per day of greywater produced at the at the ASH home/ office although currently the greywater load is shared by the other greywater treatment options: slow sand filtration, and soil bed subirrigation.

The Greywater Garden Wall consists of several components that serve various ecological, physical, and chemical functions in treating the greywater. Greywater is strained as it enters a cascading series of well aerated gravel filter cells. Airstones are positioned within a central pipe of each of the four cells to act as an airlift, drawing water from the bottom of each gravel filter cell. The water develops a convection current through the gravel providing adequate circulation (fig.5). Aerobic bacteria decompose the organic matter in the greywater, converting nitrogen compounds to nitrates. When a dose of greywater or aquarium water is cycled to the gravel filters, the water overflows and cycles through each cell then into a water cascade en route to the hydroponic troughs. Further aeration of the water occurs as the water falls over baffles down the water cascade thus releasing dissolved gases such as nitrogen gas. Nitrates are taken up by plant roots in the hydroponic troughs. The pea-sized gravel that is used as the planting material acts as a wet-dry filter, further enhancing microbial decomposition. Edible plants that can be harvested relatively quickly and in abundance such as lettuce and basil are appropriate for this hydroponic system at the ASH home/ office.

Greywater flows into Marsh #1 which contains an aerated gravel media as a substrate for emergent plants such as Water Hawthorn. Floaters including Duckweed (*Lemna*), Water Lettuce (*Pistia*), Water Hyacinth (*Eichornia*) and Hornwort *(Ceratophyllum*

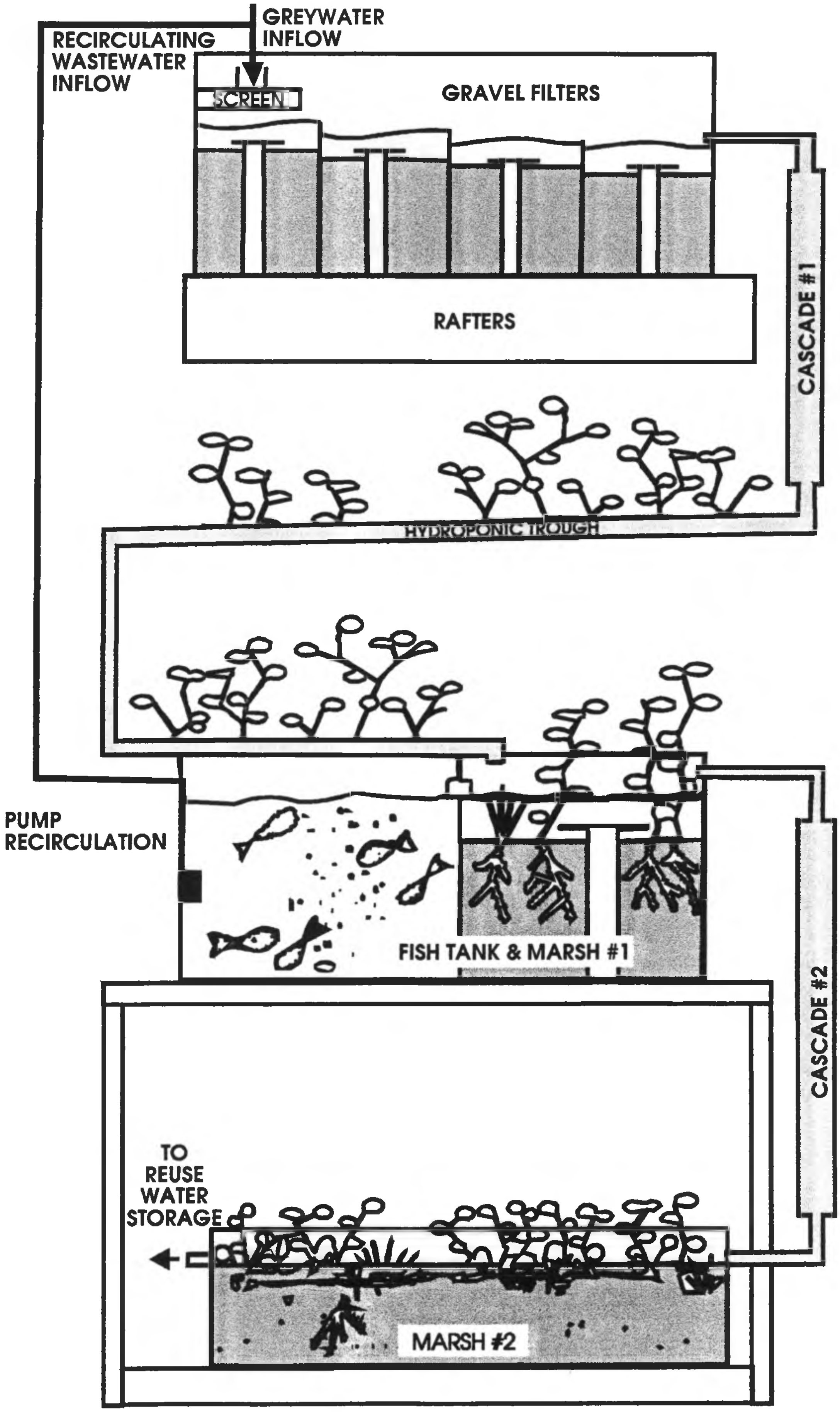

FIGURE 5 Schematic of the Greywater Garden Wall

demersum) and *Hygrophilia polysperma* are thriving and act as a food source and protective cover for the fish, and limit evaporation. Duckweed helps purify the water by utilizing available nitrogen and phosphorus and provides shade which keeps algae populations in balance. Duckweed also aids in reducing total suspended solids and biochemical oxygen demand. Kangkong (Filipino) or Tong Choi (Chinese), which is edible and aids in purifying the water, is also being raised in both marshes.

The marsh contains various organisms such as bacteria, microalgae, filamentous algae, zooplankton, rotifers, snails (*Lymnea sp.*), whitecloud mountain minnows (*Tanichthyis sp.*), Paradise fish, and freshwater prawns (*Macrobrachium rosenbergi*). There is an open connection between the marsh and a fish tank to allow passage of water, nutrients, and several of the species noted above. Tilapia or other edible fish can be raised in the fish tank. Currently there are 5 Comet Goldfish and they consume some of the decomposing organic solids and detritus. Periodically they are fed wilted lettuce and other herbivorous table scraps. A pump situated in the aquarium circulates 15 L of water back up to the gravel filters every half an hour. The water then cascades back down through the treatment system and cycles as a closed loop with an average retention time of 36 hours. When an additional volume of greywater is introduced to the Greywater Garden Wall system, an equivalent volume of water flows through a second cascade from Marsh #1 to Marsh #2. The retention time within marsh #2 is 8 to 9 hours. This treated water overflows into the reuse water storage tank. On demand it is then pressurized and pumped through an ultraviolet disinfection unit before it supplies the house with reuse water for non-potable demands.

The selection of appropriate plant and animal species was also a challenge in the design process. Compatibility of and symbiotic relationships between the organisms chosen is paramount to a successful and balanced ecosystem especially at this small scale. Each species plays a role in the food web to create edible biomass for human consumption and improve the quality of the greywater to reuse standards.

Other factors that affected the choice of species' type, quantity and stage in life cycle, were availability, cost, palatability for edible biomass, and physical environmental parameters such as temperature, light, habitat, and water quality. Solar powered full spectrum lighting has been added to the system to supplement natural lighting during seasonal variation. The ASH home /office is primarily heated by passive and active solar systems which creates an indoor environment of 16 - 20 ^{0}C during the winter and 22 - 30 ^{0}C during the summer. Species were chosen with tolerances within these indoor temperature ranges. Harvesting and rotation of species could also be entertained to match the changes in the environmental parameters of the system (i.e. alternating trout and Tilapia species due to temperature tolerances). Table 4 summarizes the organisms selected and their roles in the mini ecosystem.

Table 4 Organisms Selected and Their Roles in the Community (Hampshire, 1997)

Organism	Roles in the Greywater Garden Wall Community
Bacteria	Microbial decomposition of organic matter Conversion of carbon to biomass Processing of nitrogen to nitrate form
Algae	Uptake of carbon and nitrate Capture of light energy and production of oxygen Food for higher organisms
Zooplankton	Assist in the passing of nutrients from the microscopic community to larger animals
Plants	Utilization of carbon and nitrate Capture of light energy and production of oxygen (during daylight) Elimination of carbon from the system when harvested
Snails (*Lymnea sp*)	Physical breakdown of and processing of detritus and small pieces of organic matter Control of algae
Prawns (*M. rosenbergi*)	Physical breakdown of and processing of detritus and small pieces of organic matter Control of algae Elimination of carbon from the system when harvested
Whitecloud Minnows (*Tanichthyis sp.*)	Physical breakdown of and processing of detritus and small pieces of organic matter Control of algae
Tilapia or other edible fish species	Physical breakdown of and processing of detritus and large pieces of organic matter Elimination of carbon from the system when harvested

4.0 WATER QUALITY FOR THE SUSTAINABLE HOME WATER SYSTEM

4.1 Water Quality Monitoring Objectives

The objectives for the water quality monitoring of the SHWS are to:

1) determine the water quality of the two-tiered water supply system using approved standard procedures and quality control/ quality assurance methods

2) evaluate the performance of the potable and reuse water treatment systems through a comparison of the water quality results from specific sampling sites (Tables 6, 7, & 8) for pre and post treatment options

3) summarize the treatment effectiveness of each water treatment method for the various water quality parameters tested

4.2 Water Quality Monitoring Protocol

Preliminary water quality testing has occurred by various organizations and institutions to date. Water quality analysis (including volatile organic carbon) of the rainwater collected at the ASH home/ office was undertaken in May 1996 by the Glenmore Waterworks Laboratory, Engineering and Environmental Services Department, City of Calgary. Analysis of both cistern water and greywater was undertaken by Mount Royal College Environmental Technology students in March 1998. Further water quality analysis of the potable and reuse systems was conducted through the Civil Engineering Department at the University of Calgary in October 1998.

Each water quality testing session was unique with different perspectives and priorities, as well as monitoring protocol. All procedures followed standard methods and quality control/ quality assurance procedures. Different water quality parameters were tested and water sampling sites were not the same for each group.

The water quality sampling of rainwater occurred at the ASH home/ office during a rainfall event on May 2, 1996. Four samples were taken, two duplicate samples from the SW corner downspout, and two duplicate samples from the NW corner downspout. Samples were transported to the Glenmore Waterworks Laboratory and analysed for volatile organic compounds, Total Organic Carbon, pH, and conductivity.

Mount Royal College Environmental Technology students sampled the greywater and cistern water on March 16, 23, and 30, 1998. In-situ tests included dissolved oxygen, temperature, conductivity, total dissolved solids, and pH. Ex-situ analysis, completed at Mount Royal College laboratories, included hardness, suspended solids, total phosphorus, biochemical oxygen demand, iron, colour, turbidity, nitrate, *E. coli*, and total coliform bacteria. Greywater samples were composite samples proportional to water demand (i.e. 71% shower/bath water, 18% clothes washer, 9% kitchen greywater, and 2% bathroom sink basin greywater). Composite sampling was used to collect a representative greywater sample since the greywater collection system was not fully commissioned at the time of sampling.

Water quality sampling of the potable and reuse systems was conducted through the Civil Engineering Department at the University of Calgary on October 26, 1998. Potable water samples were taken in a series of locations to determine any changes of water quality through the treatment process from rainwater through to potable supply. The locations are as follows: rain barrels, pre slow sand filtration, post slow sand filtration, and the kitchen potable faucet. In-situ tests included temperature, pH, dissolved oxygen, and conductivity. Ex-situ water quality analysis was undertaken at the Civil Engineering laboratories, University of Calgary by a laboratory technician. Parameters analyzed include ammonia, alkalinity, biochemical oxygen demand, coliforms, dissolved solids, hardness, nitrate, reactive phosphorus, sulphate, and suspended solids.

Water quality analysis will be undertaken on a regular basis to ensure the quality of both the potable and reuse water subsystems of the Sustainable Home Water System. The monitoring protocol for the long term water quality analysis is summarized in Table 5. Further studies that we hope to conduct will include comparisons of water quality improvement through each water treatment option being demonstrated at the ASH home/ office. Participation on the part of Mount Royal College Environmental Technology students through a practicum each year may continue as well; therefore providing additional information as to the performance of the Sustainable Home Water System.

TABLE 5 Protocol for Future Water Quality (WQ) Monitoring

POTABLE WATER TESTING

Source: rainwater collected from the roof and stored in an underground cistern
Treatment: rain gutter screens, rain barrels, settlement tank, cistern, slow sand filtration, on demand ultraviolet disinfection, activated carbon filter.

Locations for collection:	Determines:
1) downspouts (before cistern)	WQ of rainwater
2) pre slow sand filter	WQ of cistern water
3) post slow sand filter	WQ of filtered water
4) post U.V. disinfection @ kitchen tap	WQ of potable water

REUSE WATER TESTING

Source: greywater collected from various drains in the ASH home/ office
Treatment: temporary storage (heat removal and settlement), slow sand filtration, soil box subirrigation, Greywater Garden Wall, on demand ultraviolet disinfection

Locations for collection:	Determines:
1) greywater storage tank	WQ of greywater
2) post slow sand filter #1	WQ of single pass filtered water
3) post slow sand filter #2	WQ of double pass filtered water
4) post soil box #1	WQ of single pass infiltrated water
5) post soil box #2	WQ of double pass infiltrated water
6) post Greywater Garden Wall	WQ of biologically treated water
7) U.V. disinfection @ reuse taps	WQ of treated reuse water

WQ PARAMETERS:

Microbial
- Fecal Coliform (*E. coli*)
- Total Coliform

Physical/ Chemical
- Temperature
- Turbidity
- pH
- Alkalinity
- Hardness
- Conductivity
- COD
- Odour
- Taste
- Total Suspended Solids
- Total Dissolved Solids
- BOD_5

Organics
- Total Organic Carbon
- Volatile Organic Carbons

Inorganic
- Nitrate
- Nitrite
- Ammonium
- Total Phosphorus
- Dissolved Oxygen
- Potassium
- Sodium
- Chloride
- Sulphate
- Sulphide (H_2S)

Heavy Metals
- Chromium
- Copper
- Lead
- Mercury
- Iron
- Manganese
- Zinc

4.3 Water Quality Monitoring Results

4.3.1 Potable Water System Quality

Locations for potable water quality sampling include : downspouts to the rain barrels, cistern and pre slow sand filtration, post slow sand filtration, and the kitchen potable faucet.

Water quality analysis of the **rainwater** collected at the ASH home /office was undertaken in May 1996 and October 1998. Parameters tested include volatile organic compounds, Total Organic Carbon, pH, conductivity, temperature, dissolved oxygen, ammonia, alkalinity, biochemical oxygen demand, coliforms, dissolved solids, hardness, nitrate, reactive phosphorus, sulphate, and suspended solids (Table 6).

All the samples tested in May 1996 showed a high degree of foaming and extremely high levels of total organic carbons (more than ten times the levels of typical finished water from the Glenmore water treatment plant) but no detectable levels of volatile organic compounds (Hargesheimer, 1996). Both the pH (8.46) and conductivity (277 µS/cm) results were also high compared with typical rainwater characteristics (below or near pH 7.0). These results may indicate that the elastomeric polymer roof surfacing still had not fully cured after ten months and might have been leaching various organic compounds into the water. This is despite the fact that the water soluble compounds (i.e. ethylene glycol, and surfactants including potassium tripolyphosphate, and ammonium polyacrylate) found in the elastomeric polymer should have leached out completely after a few rainfalls (Personal communication, Thomas Urbanek, Polymer Science Corp.,1996). October 1998 rainwater quality results showed significant improvement in the pH (6.4) and conductivity (50 µS/cm); however visual inspection of the rainwater shows that some foaming is still occurring.

Total dissolved solids, total coliforms, nitrate, and sulphate results were within acceptable limits of the 1996 Canadian Drinking Water Quality (CDWQ) Guidelines. Various parameters that were analysed currently are not regulated under the CDWQ Guidelines including total suspended solids, conductivity, hardness, total alkalinity, dissolved oxygen, ammonia, BOD_5, phosphorus, and Total Organic Carbon. Temperature and pH of the rainwater were not within the 1996 Canadian Drinking Water Quality (CDWQ) Guidelines. The temperature of the rainwater is higher than expected and may be due to passive solar gain of the rain barrels.

Cistern water analysis was conducted in March 1998, and October 1998. Parameters that were within the CDWQ Guidelines' maximum acceptable levels include pH, nitrate, sulphate, and iron. Temperature, total dissolved solids, turbidity, fecal coliform, and total coliform had mixed results both within and exceeding the maximum acceptable CDWQ Guidelines. Total alkalinity and phosphorus, although not regulated, seemed elevated. Total alkalinity of the cistern water (908 mg/L, as $CaCO_3$) increased dramatically from the low levels found in the rainwater (12.8 mg/L, as $CaCO_3$). Considerable leaching from the

Table 6 Potable Water Quality Results for the Sustainable Home Water System

Water Quality Parameter	Units	From Rain Barrel	From Cistern	From SSF	From Kitchen Faucet	1996 CDWQG[4] Max. Acceptable Levels for Domestic Consumption
Physical/ Chemical						
Temperature	°C	18.1[1]	20.5[1]	22.4[1]	20.7[1]	LE 15
	°C		3 [2]			
	°C		3.0 [2]			
	°C		5 [2]			
Colour	% Abs.		0.012 [2]			LE 15 TCU (true colour unit)
	% Abs.		0.0113 [2]			
	% Abs.		0.017 [2]			
Ttl. Suspended Solids	mg TSS /L	3.00[1]	4.05[1]	5.23[1]	4.82[1]	N.R.
	mg TSS /L		39 [2]			
	mg TSS /L		21 [2]			
Total Dissolved Solids	mg TDS/L	95.00[1]	92.10[1]	86.67[1]	50.00[1]	LE 500 (AO)
	mg TDS/L		700 [2]			
	mg TDS/L		700 [2]			
Conductivity	μS/cm	50[1]	270[1]	252[1]	256[1]	N.R.
	μS/cm		71 [2]			
	μS/cm		800 [2]			
	μS/cm	277 [3]				
Turbidity	NTU		1.10 [2]			LE 1.0
	NTU		0.60 [2]			
	NTU		0.63 [2]			
Hardness, as $CaCO_3$	mg/L	14.04[1]	110.73[1]	105.92[1]	120.36[1]	N.R.
	mg/L		514.7 [2]			
	mg/L		504.9 [2]			
	mg/L		482.8 [2]			
Total Alkalinity as $CaCO_3$	mg/L	12.8[1]	908[1]	72.4[1]	92[1]	N.R.
Dissolved Oxygen	mg D.O./L	5.6[1]	3.1[1]	3.1[1]	0.7[1]	N.R.
	mg D.O./L		690 [2]			
	mg D.O./L		6.0 [2]			
	mg D.O./L		6.8 [2]			
Ammonia	mg/L as N	0.56[1]	0.07[1]	0.04[1]	0.03[1]	N.R.

KEY:
LE = less than or equal to; LT = less than; N.R. = not regulated; ND = non-detectable; AO = aesthetic objective

[ ] Parameter within CDWQG   [shaded] Parameter not within CDWQG

Table 6 Potable Water Quality Results for the Sustainable Home Water System Continued

Water Quality Parameter	Units	From Rain Barrel	From Cistern	From SSF	From Kitchen Faucet	1996 CDWQG[4] Max. Acceptable Levels for Domestic Consumption
pH	-	6.4[1]	7.5[1]	7.3[1]	7.3[1]	6.5 - 8.5
	-		7.93 [2]			
	-		7.73 [2]			
	-		7.70 [2]			
	-	8.46[3]				
Nitrate (NO_3^-)	mg/L as N	3.1[1]	0.9[1]	0.7[1]	0.6[1]	LE 10
	mg/L as N		1.10 [2]			
	mg/L as N		2.00 [2]			
	mg/L as N		1.80 [2]			
BOD_5	mg/LBOD_5	1.46[1]	0.98[1]	0.22[1]	0[1]	N.R.
	mg/LBOD_5		7.97 [2]			
	mg/LBOD_5		0.25 [2]			
	mg/LBOD_5		0.25 [2]			
Inorganics:						
Phosphorus	mg PO_4^{3-}/L	1.4[1]	0.4[1]	0.9[1]	0.2[1]	N.R.
	mg PO_4^{3-}/L		0.325 [2]			
Sulphate	mg/L as SO_4^-	0[1]	28[1]	28[1]	28[1]	LE 500 (AO)
Iron	mg Fe/L		0.036 [2]			LE 0.3 (AO)
	mg Fe/L		0.01 [2]			
Organics:						
TotalOrganic Carbon	mg TOC/L	10.05 [3]				N.R.
	mg TOC/L	12.85 [3]				
Microbiological:						
Fecal Coliform	cfu/100 ml		0; 0 [2]			ND
	cfu/100 ml		1 [2]			
Total Coliform	cfu/100 ml	0[1]	0[1]	0[1]	0[1]	LE 10
	cfu/100 ml		present [2]			
	cfu/100 ml		not present[2]			
	cfu/100 ml		present [2]			

1 October 26, 1998. David Blakely and Heather Mills, Civil Engineering Department, University of Calgary
2 March 16, 23, & 30, 1998. Kerri Wilson, Trevor Robinson, Aaron Mozer, and Stacey Schorr, Department of Chemical and Biological Sciences, Mount Royal College
3 May 2, 1996. Erica Hargesheimer, Ph.D., Glenmore Waterworks Laboratory, Engineering & Environmental Services Department, City of Calgary
4 Health Canada, 1996. Guidelines for Canadian Drinking Water Quality, Sixth Edition, Minister of Supply and Services Canada, Ottawa, Canada.

cement cistern walls is indicated as the source. After treatment through the slow sand filter the alkalinity of the water decreased.

Analysis of the filtered water from the **slow sand filter** was conducted in October 1998. The quality of the water was acceptable except for temperature. Although currently not regulated, the phosphorus content of the water from the slow sand filter was elevated (0.9 mg PO_4^{3-}/L) from the cistern water value of 0.4 mg/L as PO_4^{3-}. Phosphorus could have leached from the sand within the slow sand filter. The phosphorus concentration of the rainwater was also high indicating that leaching from the roof membrane may be a likely source. High phosphorus levels in water tend to affect water treatment processes, stimulate algal growth, and affect taste and odour (McNeely, *et al.*, 1984). Further testing may reveal whether the phosphorus content in the water will prove detrimental to the quality of the drinking water at the ASH home/ office. Elevated water temperature ramifications are discussed below.

The water from the **kitchen faucet** conformed to the CDWQ Guidelines' maximum acceptable limits for all parameters tested in October 1998 except temperature. The maximum acceptable limit of temperature for drinking water is less than or equal to (LE) 15 ^{0}C; primarily reflecting aesthetic considerations such as palatability, and refreshment. However, high water temperatures may affect the efficiency of some water treatment processes, increase the risk of biological growth within the supply lines, decrease the oxygen solubility yet increase solubility of some chemical compounds, and affect taste and odour (McNeely, *et al.*, 1984). The kitchen water faucet temperature was close to ambient due to retention time within the ASH home /office as the water is treated through the slow sand filter, then temporarily stored and pressurized before being U.V. disinfected on demand. The U.V. disinfection may also contribute to warming of the potable water. Further treatment through the Mountain Fresh chlorine/ fluoride granular activated carbon (G.A.C.) filter ensures potable water on demand at the kitchen sink and limits the risk factors associated with slightly elevated water temperatures.

4.3.2 Greywater Quality

Greywater analysis was undertaken in March 1998 and October 1998. Table 7 compares the SHWS greywater quality results with typical greywater and residential wastewater characteristics. Several sources were used to determine typical residential greywater and wastewater characteristics. For each parameter there was often a considerable difference between the values and ranges indicated by the various sources. BOD_5 was the only parameter that had results both consistently and significantly lower than both typical residential greywater and wastewater characteristics. All the other water quality parameters that were tested and have typical data for comparison were greater than the typical greywater characteristics but below or within typical ranges for the residential wastewater properties found by other authors (Table 7). This may be due to the fact that the greywater at the ASH home/ office has been circulated several times through the reuse system. The greywater results show that the quality of the greywater has degraded significantly from March through to October of 1998. The October 1998 testing was completed during a time when the treatment options were not functioning properly due to a lack of balance in the supply and demand of the greywater and reuse water. A reason for this is that the sizing of the SHWS components were for a family of four and the water use of the current two occupants is significantly less than half that of a family of four.

4.3.3 Reuse Water Quality

Water quality sampling of the reuse water occurred in October 1998 when the treatment options were not operating at optimal levels. This was due to insufficient number of plants planted in the soil bed, and extremely low discharge rates from the slow sand filters. The reuse water quality results (Table 8) reflect these temporary problems, especially in the high total suspended and dissolved solids, hardness, and conductivity. Parameters that are not currently regulated by reuse guidelines but exceed the CDWQ Guidelines include temperature and total dissolved solids. Despite the difficulties in balancing the greywater treatment systems with supply and demand cycles of use, several of the reuse water quality results were within acceptable reuse water guidelines (Table 8) and even meet the CDWQ Guidelines for potable water. These parameters include pH, total coliforms, nitrate, and sulphate. The BOD_5 result is within acceptable reuse guidelines but although not regulated under the CDWQ Guidelines, is above the suggested level of less than 4 mg/L. The reuse water is unacceptable by reuse water standards for total suspended solids. The result is 147.50 mg TSS/L compared with a non-potable reuse guideline of 20 mg TSS/L. Based on visual inspection, the greywater treatment systems now appear to be operating more effectively than in October 1998. Further monitoring will reveal quantitative results to determine the effectiveness of the various greywater treatment systems and whether the reuse water quality has significantly improved.

Comparison of the greywater results with the reuse water quality results indicates that there was some improvement in water quality during the less than optimal performance period of the greywater treatment systems. This was the case for ammonia, BOD_5, total

Table 7 Greywater Quality Results for the Sustainable Home Water System

Water Quality Parameter	Units	SHWS Greywater Results	Typical Greywater Characteristics	Residential Wastewater Characteristics
Physical/ Chemical:				
Temperature	°C	23.7 [4]	-	-
	°C	19 [5]	-	-
	°C	16.9 [5]	-	-
	°C	20 [5]	-	-
Colour	% Abs.	0.575 [5]	-	39 - 55 PCU
	% Abs.	0.452 [5]	-	39 - 55 PCU
	% Abs.	0.573 [5]	-	39 - 55 PCU
Total Suspended Solids	mg TSS /L	248.00 [4]	160 [1]; 42 - 80 [3]	500 [1]; 64 - 406 [2]
	mg TSS /L	208.5 [5]	160 [1]; 42 - 80 [3]	500 [1]; 64 - 406 [2]
	mg TSS /L	83 [5]	160 [1]; 42 - 80 [3]	500 [1]; 64 - 406 [2]
	mg TSS /L	464 [5]	160 [1]; 42 - 80 [3]	500 [1]; 64 - 406 [2]
Total Dissolved Solids	mg TDS/L	1140.00 [4]	300 [3]	554 [2]
	mg TDS/L	790 [5]	300 [3]	554 [2]
	mg TDS/L	400 [5]	300 [3]	554 [2]
Conductivity	µS/cm	1495 [4]	-	-
	µS/cm	1034 [5]	-	-
	µS/cm	600 [5]	-	-
Turbidity	NTU	300.63 [5]	-	78 - 152 FTU [2]
	NTU	255.0 [5]	-	78 - 152 FTU [2]
	NTU	388.33 [5]	-	78 - 152 FTU [2]
Hardness, as $CaCO_3$	mg/L	1220.45 [4]	-	84 - 672 [2]
	mg/L	2.01 [5]	-	84 - 672 [2]
	mg/L	186.9 [5]	-	84 - 672 [2]
	mg/L	172.4 [5]	-	84 - 672 [2]
Total Alkalinity, as $CaCO_3$	mg/L	380.00 [4]	-	91 - 426 [2]
Dissolved Oxygen	mg D.O./L	0.38 [5]	-	-
	mg D.O./L	400 [4]	-	-
	mg D.O./L	8.4 [4]	-	-
	mg D.O./L	8.2 [4]	-	-

Table 7 Greywater Quality Results for the Sustainable Home Water System continued

Water Quality Parameter	Units	SHWS Greywater Results	Typical Greywater Characteristics	Residential Wastewater Characteristics
pH	-	7.3 [4]	-	7.0 - 7.6 [2]
	-	7.24 [5]	-	7.0 - 7.6 [2]
	-	7.49 [5]	-	7.0 - 7.6 [2]
	-	7.35 [5]	-	7.0 - 7.6 [2]
Ammonia	mg/L as N	2.75 [4]	-	13.8 - 35 [2]
Nitrate (NO_3^-)	mg/L as N	8.6 [4]	-	0.09 - 1.52 [2]
	mg/L as N	1.20 [5]	-	0.09 - 1.52 [2]
	mg/L as N	0.55 [5]	-	0.09 - 1.52 [2]
	mg/L as N	1.35 [5]	-	0.09 - 1.52 [2]
BOD_5	mg/LBOD_5	68.3 [4]	300[1]; 100 - 191 [3]	500[1]; 82 -279 [2]
	mg/LBOD_5	0.41; 7.4; 7.4 [5]	300[1]; 100 - 191 [3]	500[1]; 82 -279 [2]
Inorganics:				
Phosphorus	mg PO_4^{3-}/L	12.6 [4]	6 - 27 [1]; 1 - 2 [3]	14 - 30 [1]; 3.0 - 13 (ortho-P) [2]
	mg PO_4^{3-}/L	1.747; 1.639 [5]	6 - 27 [1]; 1 - 2 [3]	14 - 30 [1]; 3.0 - 13 (ortho-P) [2]
Sulphate	mg/L as SO_4^-	440 [4]	-	-
Iron	mg Fe/L	0; 0.09; 0.025 [5]	-	1.24 - 3.54 [2]
Microbiological:				
Fecal Coliform	cfu/100 ml	8; 0; 0; 10;[5]	-	-
Total Coliform	cfu/100 ml	0 [4]	-	-
	not/present	present	-	-
	not/present	present	-	-
	not/present	present	-	-
	not/present	present	-	-

KEY:

(unshaded box)	SHWS greywater result is less than or equal to typical characteristic
(shaded box)	SHWS greywater result exceeds typical characteristic

1 Lindstrom, Carl R., 1992. Greywater, Clivus Multrum Inc., Cambridge, MA
2 Williams, Robert B., Wastewater Reuse - An Assessment of the Potential and Technology, Ch.5, Table XI, p.111
3 Townsend, A.R., April 1993. Advancing the Light Grey Option - Making Residential Greywater Reuse Happen, Research Division, CMHC, National Office
4 Blakely, David and Heather Mills, October 26, 1998. Civil Engineering Department, University of Calgary
5 Wilson, Kerri, Trevor Robinson, Aaron Mozer, and Stacey Schorr, March 16, 23, & 30, 1998. Department of Chemical and Biological Sciences, Mount Royal College

Table 8 Reuse Water Quality Results for the Sustainable Home Water System

Water Quality Parameter	Units	Reuse Water Quality Results	Non-Potable Reuse Water Guidelines (U.S.)	1996 CDWQG Max. Acceptable Levels for Domestic Consumption [2]
Physical/Chemical:				
Temperature	°C	22.4 [1]	N.R.	LE 15 [2]
Total Suspended Solids	mg TSS /L	147.50 [1]	LE 5.0 (SI) ; LE 20 (NP) [3]	N.R. [2]
Total Dissolved Solids	mg TDS/L	1071.40 [1]	N.R.	LE 500 (aesthetic) [2]
Conductivity	µS/cm	1538 [1]	N.R.	N.R. [2]
Hardness, as $CaCO_3$	mg/L	1309.52 [1]	N.R.	N.R. [2]
Total Alkalinity as $CaCO_3$	mg/L	415.60 [1]	N.R.	N.R. [2]
Dissolved Oxygen	mg D.O./L	3.29 [1]	N.R.	N.R. [2]
pH	-	7.7 [1]	6.5 - 8.3 [3]	6.5 - 8.5 [2]
Ammonia	mg/L as N	0.93 [1]	N.R.	N.R. [2]
Nitrate (NO_3^-)	mg/L as N	6.8 [1]	180.0 (WW) [3]	LE 10 [2]
Phosphorus	mg PO_4^{3-}/L	6.7 [1]	N.R.	N.R. [2]
Sulphate	mg/L as SO_4^-	430 [1]	LE 500.0 (WW) [3]	LE 500 (aesthetic) [2]
BOD_5	mg/LBOD_5	10.5 [1]	LE 20 (NP) [3]	N.R. [2]
Microbiological:				
Total Coliform	cfu/100 ml	0 [1]	1000 [3]	LE 10 [2]

Key:

LE = less than or equal to
SI = subirrigation
LT = less than
WW = wash water
N.R. = not regulated
NP = non-potable

(unshaded box) Guideline is not exceeded by SHWS reuse water result

(shaded box) Guideline is exceeded by SHWS reuse water result

1 Blakely, David and Heather Mills, October 26, 1998. Civil Engineering Department, University of Calgary

2 Health Canada, 1996. Guidelines for Canadian Drinking Water Quality, Sixth Edition, Minister of Supply and Services Canada, Ottawa, Canada.

3 Townsend, A.R., April 1993. Advancing the Light Grey Option - Making Residential Greywater Reuse Happen, Research Division, CMHC, National Office.

dissolved and suspended solids, nitrate, reactive phosphate, and sulphate. Some of the results indicated a decline in the quality of reuse water compared to the greywater although not out of acceptable reuse guidelines. These parameters include conductivity, alkalinity, and hardness.

4.4 Water Quality Discussion

Currently the various greywater treatment options are being operated as parallel systems to determine their individual performance for treating greywater to reuse standards. Each treatment option is currently plumbed with flexible food grade tubing so modifications to the design are easily accomplished. The performance of the slow sand filter is poor due to the high suspended solids in the greywater. Currently the slow sand filters clog rapidly, requiring frequent maintenance. The slow sand filter is appropriate as a polishing filter so the greywater will be routed first through the soil box then pumped up to the series of slow sand filters. Reuse water quality results should improve after this modification is made.

Actual water demand patterns of reuse water has not matched the design and frequency of use required to optimize the performance of the SHWS. The occupants do not use much water and, when the water is used, it is an intensive use (i.e. several laundry loads, or bathing/showering events at once). This has caused an imbalance in the supply and demand of the greywater and reuse water. A result is stagnation of the greywater in the drum storage heat exchanger or the sump where it's quality degrades and odour is produced due to anaerobic conditions developing. Currently aerobic microbial enzymes (i.e. Fenic FE, Kleen Kill, and EM) are added to the greywater collection system to control the odour. The system was designed for larger volumes of use at higher frequencies of circulation and the greywater was never intended to stagnate untreated for more than twenty-four hours. The sump pump was expected to transfer the greywater four times per day; however, with the volumes of water being used currently the sump pump is activated an average of only once every 5 days.

When the water is finally transferred to the temporary greywater storage, then treated, the result is an excess of treated reuse water beyond the capacity of the reuse storage tank and the treatment systems back up. Each treatment option would work more effectively if regular doses of water were delivered for treatment each day instead of stressing each system to peak performance and then letting it sit dormant for several days. A more stable pattern of water use would benefit the health of the natural treatment systems and result in improved quality of reuse water. Since the current quality of the reuse water is questionable the occupants are hesitant to use it and this continues the cycle of degrading greywater and reuse water quality.

The soil box distribution pipes are made of soaker hoses which work well under pressure; however, the first soil box is gravity-fed and the weeping of greywater through the soaker hoses is slow. With slow velocities, the greywater may deposit suspended solids on the inside of the soaker hoses thus clogging the pipes. If this proves to be a problem at a later date, larger holes could be drilled within the soaker hose or the soaker hoses may be replaced. A pressure activated distribution system similar to the Clivus Multrum greywater treatment system could be an alternative.

One reason for the high suspended solids found in the greywater is the cycling of the greywater multiple times before the treatment options were fully commissioned and operating effectively. Therefore, solids increased dramatically and have not been removed from the system. Any settlement that does occur in the sump or temporary greywater storage tank becomes churned up and re-suspended into the greywater whenever the sump pump is activated. This excess of sediment due to initial commissioning should be removed from the system by pumping out the bottom accumulated sludge from the sump and the temporary greywater storage tank. Improvements to the design could include strainers on each fixture drain to decrease the introduction of particulates into the greywater initially. A coarse dirt filter could be installed just before the greywater inlets to the slow sand filters and the first soil box to prevent clogging of the treatment systems. An alternative to the basic design of the slow sand filters is to replace them with the new self-cleaning version which uses a low velocity backflush and a scrapper to remove the top layer of sand, debris, and the old schmutzdecke layer.

The Greywater Garden Wall is operating satisfactorily. Plant and aquatic species have been introduced to the system gradually since its commissioning so as not to shock the mini-ecosystem. Additional plant life will be continued to be added to improve the filtering and treating capacity of the marshes. The air pumps supplying the air stones within the gravel filters and the marshes may be undersized. Improved circulation and aeration should enhance the bacterial decomposition and treatment of the greywater. The flexible clear food grade tubing currently used could be replaced with opaque solid pipe to limit the growth of algae within the distribution pipes and to reduce maintenance.

4.5 Water Quality Recommendations

In order to improve the greywater treatment systems in general, supplemental lighting in the greenhouse can be incorporated. This is especially true for the bottom marsh of the Greywater Garden Wall which is shaded by the soil box subirrigation planter boxes. The hydroponics require additional attention and maintenance to ensure optimal plant growth and harvesting.

One modification to the SHWS to improve potable water quality would be to apply an inert sealant suitable for potable water to coat the inside of the cisterns to prevent increases in hardness, total alkalinity, and conductivity. Another option would be to install the salt-free water softener, currently at the ASH home/ office but not being used, at the kitchen potable water supply to alleviate the elevated hardness and associated total alkalinity and conductivity. Replacement of the elastomeric polymer roof surfacing to a more inert option appropriate for potable water use (eg. clay or concrete tiles, prepainted galvanized steel roofing) is advised due to the apparent continued leaching of surfactants into the rainwater. The elastomeric polymer surfacing is also cracking in some locations which is allowing potential leaching of hydrocarbons from the asphalt shingles below.

Further research and water quality monitoring is required to fully characterize greywater since current reuse guidelines in various U.S. states are incomplete and do not yet address many important water quality parameters. Canadian reuse water quality guidelines should be developed for reuse water applications. Standardization of these guidelines is required, including subdivision into end use applications (i.e. subirrigation, wash water, or non-potable use in general). These guidelines should be updated periodically as relevant and reliable information becomes available. With this information the level and types of treatment required to provide a safe supply of reuse water and regain valuable resources from our residential greywater could be determined.

5.0 GREYWATER HEAT EXCHANGER (GWHX) SYSTEM

5.1 Greywater Heat Exchanger Precedents

Several greywater heat exchanger precedents are discussed below for the counter current and drum storage greywater heat exchangers. The precedents include work conducted by Glenn Nelson, Chuck Price, Vaughn's GFX -Gravity Falling-film heat eXchange, DrainGain, and Earthstar's Graywater Heat Reclaimer (GHR).

5.1.1 Counter Current Greywater Heat Exchangers

Counter current heat exchangers promise effective heat recovery for use with continuous flow sources of hot greywater. Glenn Nelson (1981) developed a 5' long counter current greywater heat exchanger with greywater and potable water flowing in opposite directions through a double-wall tube. The potable water flowed through a copper heat exchange tube which was housed within a 1¼" dia. PVC pipe for the greywater flow. A unique design feature that Nelson used was to wrap a wire helix around the copper tube to enhance greywater turbulence. Positive leak protection was integrated as well for health considerations. The cost of materials for the counter current greywater heat exchanger was US $53.00 (1981).

At a shower low flow rate of 8 L/min the exchanger transfers heat at a rate of 3000 watts which equates to 17% of the hot water demand being supplied by the exchanger (Nelson, 1981). Glenn Nelson extrapolated the data to a 10 ft. exchanger and expects at least a 30% contribution to annual hot water energy demand by the counter current greywater heat exchanger.

GFX-Gravity Falling-film heat eXchange

The GFX manufactured by Vaughn Corporation cools wastewater by transferring the waste heat to the incoming cold water supply. The heat exchanger is oriented vertically to take advantage of the formation of films of drain water on the inner surface of the copper drain pipe. Due to the effects of gravity and surface tension, a film thickness of 12 to 27 mils develops which is ideal for a high degree of heat transfer. The incoming cold water supply copper tube is wrapped around the outside of the drain pipe in a tight coil. Copper pipes are beneficial for high heat transfer and naturally inhibit organic growth. The system can be plumbed as equal flow in which the preheated water is plumbed to both the hot water heater and the cold feed line to hot water demand fixtures such as the shower. An alternative is to plumb as unequal flow where the preheated water is fed only to the cold feed line of the shower.

Benefits include maintenance-free operation as the system is self-cleaning, and shower water capacity boost for water heaters. A further benefit is that the cost of a shower is reduced by half. Environmental savings include cutting CO_2 emissions. The GFX has been installed in the Toronto Healthy House and performance monitoring is being conducted. The GFX performance has been determined through a 1996 DOE study indicating an average energy savings of 34%. Assuming a low flow rate of 2.25 gpm for a 12 minute shower, an electric rate of $0.086/kWh and 86% electric water heater energy factor, the annual electric water heating savings would be $180. If showers with high flow rate are used, $340 annual savings could be realized.

5.1.2 Drum Storage Greywater Heat Exchangers

Drum storage heat exchangers also promise effective heat recovery for non-continuous or batch flow sources of hot greywater such as bath water, dishwasher, or clothes washer. Glenn Nelson (1981) developed a greywater storage heat exchanger. To promote temperature stratification, a tall 55 gal. drum was chosen with greywater entering at the top of the drum. Colder greywater exits the drum from the bottom of the drum via a 2" dia. PVC tube. Potable water flows into the 1" dia. polybutylene tubing at the bottom of the drum and is cylindrically coiled on the inside of the drum then exits the top of the drum. There is a flexible polyethylene liner which separates the greywater from the potable water tubing to prevent cross-contamination due to any leaks in the exchanger. The drum was insulated with 2" flexible polyurethane foam to limit heat loss to the surroundings. Material costs in 1981 were US $93.00 to construct the drum storage greywater heat exchanger.

Performance of Nelson's storage heat exchanger ranged from 30-40% contribution to total hot water requirements (to 50°C) over a range of water demand characteristics. With greater demands the performance decreased. For a 36 L shower demand, the performance was 25%. At a 10 minute interval between showers, the performance decreased to 10% of the total hot water requirements being met by the storage heat exchanger. For a 90 L bath, the exchanger's performance is less than 13%.

Chuck Price designed a greywater heat exchanger that consists of 160 L potable water tank which is submerged within a 190 L hot greywater tank to preheat the potable water before entering the gas-fired domestic hot water tank. A pressure-type vacuum breaker is used to protect the municipal water supply if the pressure drops and there is a leak in the potable water tank. Greywater sources include dishwasher, washing machine, bath tub, shower but exclude the kitchen and bathroom sinks due to high solids and potential grease and oil content. This hot greywater enters the greywater tank by flowing onto the top of the potable water tank to reduce turbulence and maintain thermal stratification within the greywater tank. Thermal stratification occurs in both the greywater storage tank and the potable water tank. The coldest greywater from the bottom of the greywater tank is allowed to pass to the sewer. The warmest potable water flows to the domestic hot water heater.

Monitoring of this system was completed over a five month period resulting in a contribution of 26.6% of the heat required for domestic hot water heating. Based on 1984 electrical and natural gas prices, the resulting payback periods were 2.18 years and 6.14 years respectively. Suggested modifications to the design by Chuck Price include raising the potable water tank out of the greywater storage tank to increase the temperature differential between the two water sources thus increasing the rate of heat transfer. The top of the potable water tank would be insulated and the tank should have a high surface to volume ratio. Therefore a tank with tall and slim dimensions would allow an increase in thermal stratification and heat transfer potential. Chuck Price suggests that these modifications could improve performances by 5-6%.

DrainGain

DrainGain is a drum storage wastewater heat exchanger which takes advantage of heat reclamation from batch type sources of wastewater (bath, sinks, washing machines). Cold potable water is preheated by reclaimed heat from draining wastewater before the potable water enters the domestic hot water heater.

The DrainGain system includes three components: Xcluder, Standby Tank, and the DrainGain tank. Solids are removed in the Xcluder which permits liquid wastewater to flow into the self-cleaning Standby Tank and into the lower flat-spiral copper coil heat exchanger of the DrainGain. PebblePipe technology is incorporated into the copper coil to increase turbulence in the wastewater. This prevents unwanted material deposition and fouling of the heat exchanger and maintains high heat transfer. The wastewater then flows to the sewer. The DrainGain plastic tank is covered and insulated. It is filled with clean water to act as the heat transfer and storage medium. As wastewater enters the lower heat exchanger, This clean water in the DrainGain tank warms up from any hot or warm wastewater flow and rises to the top of the tank via a vertical two-way separated duct in the center of the tank. Any cold wastewater input cools the bottom tank water which remains at the bottom of the tank due to its greater density and is directed by the cold current funnel. Cold potable water enters the upper copper-coiled heat exchanger of the DrainGain (where the hottest DrainGain tank water is located) to be preheated then flows to the domestic hot water heater for further heating.

Independent and long-term testing of the DrainGain System has indicated between 40.8% and 50% heat recovery. DrainGain is cost effective and low in maintenance (i.e. an occasional quick flush of the lower heat exchanger to prevent deposition of solids). There are no moving parts and no power use. Average payback time is three years and the life expectancy of the unit is 15-20 years.

Earthstar Graywater Heat Reclaimer (GHR)

The Earthstar Graywater Heat Reclaimer is a drum style greywater heat exchanger. The GHR is plumbed with greywater from selected hot water drains (i.e. showers, baths, dishwasher, clothes washer, and sink basins where predominantly hot water is used) and thus takes advantage of both batch and continuous type hot greywater flow.

The tank is an insulated and durable 50 gallon tank which collects and stores the hot greywater for heat transfer. Cold greywater tends to enter the tank, sink to the bottom and exit relatively quickly via a central outlet pipe to the sewer. Hotter greywater rises in the tank from the inlet pipe. Heat exchange occurs between the hottest greywater and the potable water which flows through two ½" thick coiled polybutylene tubing. Polybutylene is used since it is seamless and non-corroding which decreases the risk of cross contamination between the greywater and the potable water supply. The potable water tubing enters the GHR tank near the top, then continues vertically downward for approximately two thirds of the tank height before spiraling up towards the top of the tank where the hottest greywater is found. This prewarmed potable water then flows to the domestic hot water tank to be heater further.

The GHR uses no energy, has no moving parts, and is constructed of non-corroding materials. Installation is simple and maintenance is minimal. Maintenance includes the periodic (i.e. every six months) addition of organic microbe enzymes (i.e. Microbe Lift) down the drain to prevent fouling, deposition of hair, grease or particulates, and maintain high heat transfer.

Performance of the GHR is indicated by an average temperature rise of 30% between the cold water supply and the 120°F domestic hot water supply. Therefore savings of at least 30% on hot water heating costs can be realized. The tank maintains an average temperature of 80-85°F and loses only 2°F overnight.

5.2 Design Description of the Greywater Heat Exchangers

Reclaimed heat energy from the greywater heat exchangers is used to preheat incoming reuse water before going to the solar storage tank (which acts as the domestic hot water heater) at the ASH home/ office. The prewarmed reuse water enters the solar storage tank and is heated further by solar collectors, and the fireplace hydrocoil. The prewarmed reuse water is also plumbed to the cold water side of the bath/shower. The counter current and drum storage greywater heat exchangers are plumbed in-series to maximize the potential heat recovery from different types of flow applications. The counter current greywater heat exchanger is useful for reclaiming heat energy from continuous flow greywater sources such as showers. For non-continuous flow applications (i.e. bathtub, clothes washer, or dishwasher), the drum storage greywater heat exchanger is beneficial. Currently at the ASH home/ office only the shower/ bath tub, and clothes washer are hooked up to the greywater heat recovery system.

5.2.1 Counter Current Greywater Heat Exchanger

The counter current greywater heat exchanger is situated in the ceiling of the main floor of the ASH home/ office in close proximity to the upper floor tub/shower and sink basins. The heat exchanger consists of a 3 m long double walled chamber. Reuse water flows in a 19 mm (¾") ø copper pipe which fits inside a 38 mm (1-½") ø ABS pipe.

Greywater flows in the outer ABS pipe in the opposite direction to the flow of the pressurized reuse water. Shrink wrap tubing was placed over the copper pipe in order to prevent cross-contamination between the greywater and reuse water flows and provide positive leak protection through an air-vented double wall. The effective heat exchange length of the counter current heat exchanger is 2.9 metres. The slope of the counter current heat exchanger is 2% over the 3 metre span. This promotes adequate drainage for the greywater. Table 9 summarizes the construction materials used and the associated costs. The total retail material cost for the counter current greywater heat exchanger is $ 86.00 (1994 CDN $). Labour costs are not included for the installation due to the simplicity of the system and thus the D-I-Y potential.

Table 9 Material Costs for the Counter Current Greywater Heat Exchanger

Components	Cost ($)
3 m of 19 mm (¾") ø copper pipe	20
3 m of 38 mm (1-½") ø ABS	4
copper fittings	12
ABS fittings	15
3 m of 38 mm (1-½") ø shrink wrap tubing	30
1 pair of nylon fittings	5
Total material costs	**86**

5.2.2 Drum Storage Greywater Heat Exchanger

The drum storage greywater heat exchanger is made from a recycled 136 L (35 gal.) drum (965mm (H) x 500 mm ø) with a tight fitting, removable lid (fig.6). A flexible 6 mil poly liner is sealed between the top of the drum and the lid as a safeguard to cross contamination and act as a greywater holding medium (80 L). The drum storage heat exchanger receives greywater from the bath/shower, and clothes washer. This greywater enters the drum horizontally via an elbow at the top of the heat exchanger to promote thermal stratification. Incoming hot greywater displaces colder greywater from the bottom of the greywater drum storage chamber through an inner rigid vertical ABS tube. The hottest greywater prewarms the outgoing reuse water.

Pressurized reuse water flows through 18 metres of 19 mm (¾") ø polybutylene tubing which is coiled between the outer surface of the liner and along the inner surface of the drum. There are spacers between each coil to act as structural support and to ensure optimal heat transfer. The reuse water enters the coils at the bottom of the drum and is prewarmed as it flows through the coils towards the top of the drum. The reuse water coils have a capacity of 16 L. There is a 40% effective heat exchange surface area between the flexible greywater liner and the reuse water coil.

An optional connection, which has not currently been utilized at the ASH home/ office, includes hooking up the clothes drier exhaust (with lint filter) to the outer chamber of the drum to enhance the temperature of the reuse water by reclaiming drier exhaust heat. Drier air inlet temperature would be approximately 30-60°C and the outlet would be in the range of 25 - 40°C. Currently there is no insulation surrounding the drum storage heat exchanger, or inlet and outlet plumbing, however, it will be added at a later date. The total retail material cost for the drum storage heat exchanger is $75.00 (1994 CDN $). Table 10 summarizes the construction materials used and the associated costs.

Table 10 Material Costs for the Drum Storage Greywater Heat Exchanger

Components	**Cost ($)**
reused 136 L (35 gal.) drum	12
18 m of 19 mm (¾") ø polybutylene tubing	40
fittings	15
90 cm length of rigid tube ABS	3
liner	5
Total material costs	**75**

Theoretical performances have been determined for both heat exchangers based on a number of assumptions. These include supply and demand temperatures, water demand volumes, frequency of use, and flow rates. Inlet and outlet temperatures for each heat exchanger were calculated using the experimental temperature efficiency results. This allows a direct comparison between theoretical temperature values and experimental results. The experimental temperature efficiencies are within the expected ranges found by other authors.

Theoretical performances for the counter current heat exchanger and drum storage heat exchanger were determined for both independent and in-series scenarios. Design assumptions are summarized for both the Alberta Sustainable Home/ Office and a Conventional (i.e. average Calgary) house (Table 11). The frequency of water use and the supply and demand temperatures to the fixtures and appliances associated with potential heat exchange remain constant for both scenarios; however, the flow rates and daily water demands vary due to water conservation efforts.

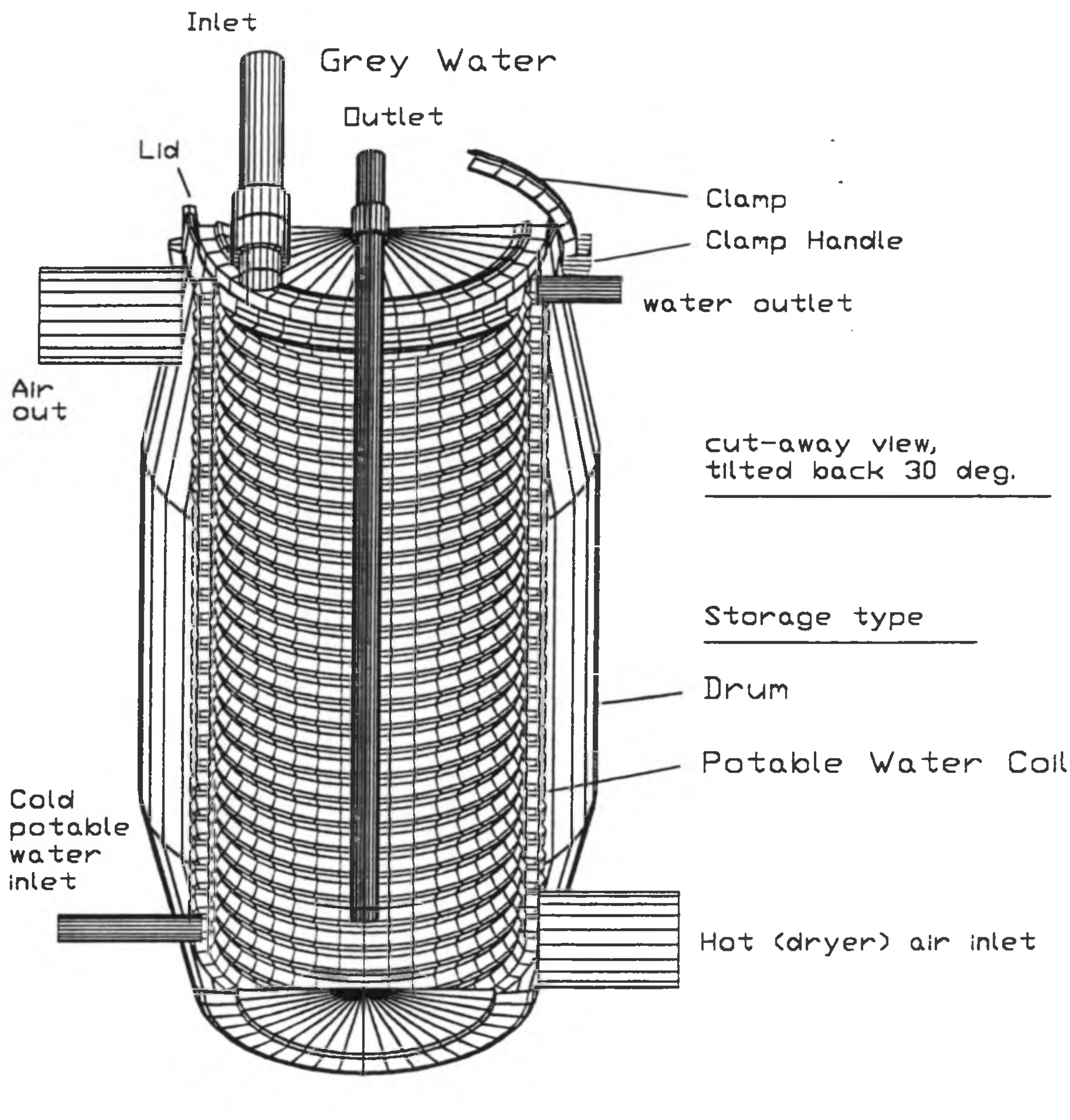

FIGURE 6 Design schematic of the Drum Storage Greywater Heat Exchanger. Please note that where potable water is mentioned in the diagram it refers to reuse water in the case of the SHWS at the ASH home/ office. For conventional residential installations potable water would apply.

TABLE 11 Design Assumptions for the Greywater Heat Exchangers

Assumptions:

Solar Storage Tank water temperature (for the ASH home/ office) = 49°C
Domestic Hot Water Heater temperature (for an average Calgary residence) = 49°C
Negligible line losses between fixtures and appliances (insulated where possible)
Greywater temperature losses = Reuse water temperature gain (negligible losses to ambient)
Note: CCHX = Counter Current Greywater Heat Exchanger; DSHX = Drum Storage Greywater Heat Exchanger

CCHX temperature efficiency = 33.0%
DSHX temperature efficiency = 20.8%
In-series temperature efficiency = 43.5 %

Fixture/ Appliance	Frequency of Use (flow+drain)	Flow Rate	Total Daily Volume	Reuse Water Temperature In	Reuse Water Temperature Out	ΔT For Reuse Water	Greywater Temperature In	Greywater Temperature Out	ΔT For Grey-water
	min/day	L/min	L	°C	°C	°C	°C	°C	°C
AT THE ASH HOME/ OFFICE									
Shower	5	8.23	41	45	-	3	-	42	-
Bath	11 + 2	8.23	90	45	-	5	-	40	-
Laundry	7.5 + 2.5	4.27	32	37	-	5	-	32	-
INDEPENDENT OPERATION:									
CCHX	18	8.23	131	18	25.6	7.6	41	33.4	-7.6
DSHX	28	8.23	163	18	22.8	4.8	41	36.2	-4.8
IN-SERIES OPERATION:									
CCHX	18	8.23	131	21.5	27.9	6.4	41	34.6	-6.4
DSHX	28	8.23	163	18	21.5	3.5	34.6	31.1	-3.5
TOTAL	28	8.23	163	18	27.9	9.9	41	31.1	-9.9
AT AN AVERAGE CALGARY RESIDENCE									
Shower	5	15	75	45	-	3	-	42	-
Bath	11 + 2	15	90	45	-	5	-	40	-
Laundry	7.5 + 2.5	15	115	37	-	5	-	32	-
INDEPENDENT OPERATION:									
CCHX	18	15	165	5	17	12	41	29	-12
DSHX	28	15	280	5	12.5	7.5	41	33.5	-7.5
IN-SERIES OPERATION:									
CCHX	18	15	165	10.6	20.6	10	41	31	-10
DSHX	28	15	280	5	10.6	5.6	31	25.4	-5.6
TOTAL	28	15	280	5	20.6	15.6	41	25.4	-15.6

5.3 Greywater Heat Exchanger (GWHX) Monitoring

5.3.1 GWHX Monitoring Objective/ Performance Criteria

The objective for the monitoring phase of this study is to evaluate the performance of the two greywater heat exchanger prototypes: counter current, and drum storage. This is accomplished by determining the temperature and thermal efficiencies of each heat exchanger unit.

Additional information will be used to calculate utility cost reductions, construction costs, and simple pay-back. This combined analysis will be used to determine the feasibility and viability of the greywater heat exchangers in the Canadian housing industry useful for both retrofit and new home applications.

5.3.2 GWHX Monitoring Protocol

The total water demand at the ASH home/ office has been very low at 2400L/month for the two occupants. Greywater flow through the heat exchangers is generated from the upper floor water fixtures, currently only including the tub and shower (two sink basins are optional). Therefore, the average expected daily flow rates through the exchangers are quite low at 90 L/day for a family of four. With such small volumes of water to rely on for monitoring procedures tests of short duration (flow tests of 10-20 minutes) are used to evaluate the efficiencies for the greywater heat exchangers through the following **four scenarios**:

a) greywater flowing and reuse water stagnant (i.e. draining the bath or sinks)
b) greywater stagnant and reuse water flowing (i.e. in the case of drawing a bath)
c) both greywater and reuse water flowing (i.e. shower)
d) both greywater and reuse water stagnant (i.e. no water demand, static or stabilizing towards ambient temperatures)

Long term observations and monitoring however will focus on the usual pattern of water usage at the ASH home/ office.

Expected **heat energy flows** are as follows:

i) heat energy absorbed in the incoming reuse water as it passes through both heat exchangers
ii) heat energy released by the greywater as it flows through the heat exchangers
iii) heat energy gained or lost to the ambient surroundings

Monitoring of the counter current and drum storage greywater heat exchangers is accomplished through both separate and integrated monitoring sessions. Initial emphasis was placed on monitoring the heat exchangers independently through scenario c: with both reuse water and greywater flowing (i.e. shower). Subsequent testing included testing both heat exchangers concurrently through all scenarios (i.e. scenario d: static temperatures, scenario c: shower, scenario b: drawing a bath, scenario a: draining the bath, scenario d: stabilization).

Inlet and outlet temperatures for both the greywater and reuse flows are measured to and from each heat exchanger (fig.7). Measurements are accomplished by positioning eight K-type thermocouples with leads at the inlet and outlet of each heat exchanger. The leads were placed on the underside of each pipe as close to the inlet or outlet of the exchangers and on conductive material if available. The leads were secured with several wraps of insulating tape to ensure proper contact with the pipe, stabilize its position and limit ambient influences to the temperature readings. A two channel analog temperature meter was used to read the inlet and outlet temperatures for the greywater heat exchangers. Each thermocouple pair was measured in a specific sequence throughout each testing session and was allowed to stabilize before measuring the next pair. Average time duration between measurements of the same thermocouple pair was 2-3 minutes. Testing sessions lasted an average of 13 minutes.

Greywater and reuse flow rates are determined using two methods. At least two times during initial monitoring sessions the greywater flow rate was measured by collecting a known volume of greywater flowing through the heat exchangers over a corresponding time. The warm reuse water flow rate is measured by noting both the time and the analog flow meter readings on the discharge side of the drum storage heat exchanger at the beginning and end of each monitoring session. The total reuse water flow rate is determined by reading the analog meter situated in the greenhouse. The total reuse flow less the warm reuse flow indicates the total reuse water contribution from the solar storage tank.

Both temperature and flow rates of the reuse water are maximized during testing procedures to determine the maximum potential heat exchange of each heat exchanger. The temperature of the incoming hot water, however, is variable since there is not a traditional preset temperature style domestic hot water heater. The prewarmed reuse water is stored in the solar storage tank and indirectly heated though a solar evacuated heat-pipe hot water collector. Therefore the degree of hot water varies hourly, daily, and seasonally. The water supply flowing from the solar storage tank is then tempered though a mixing valve to prevent any risk of scalding. This variability may help to evaluate heat exchanger efficiencies as a function of the outgoing greywater temperature.

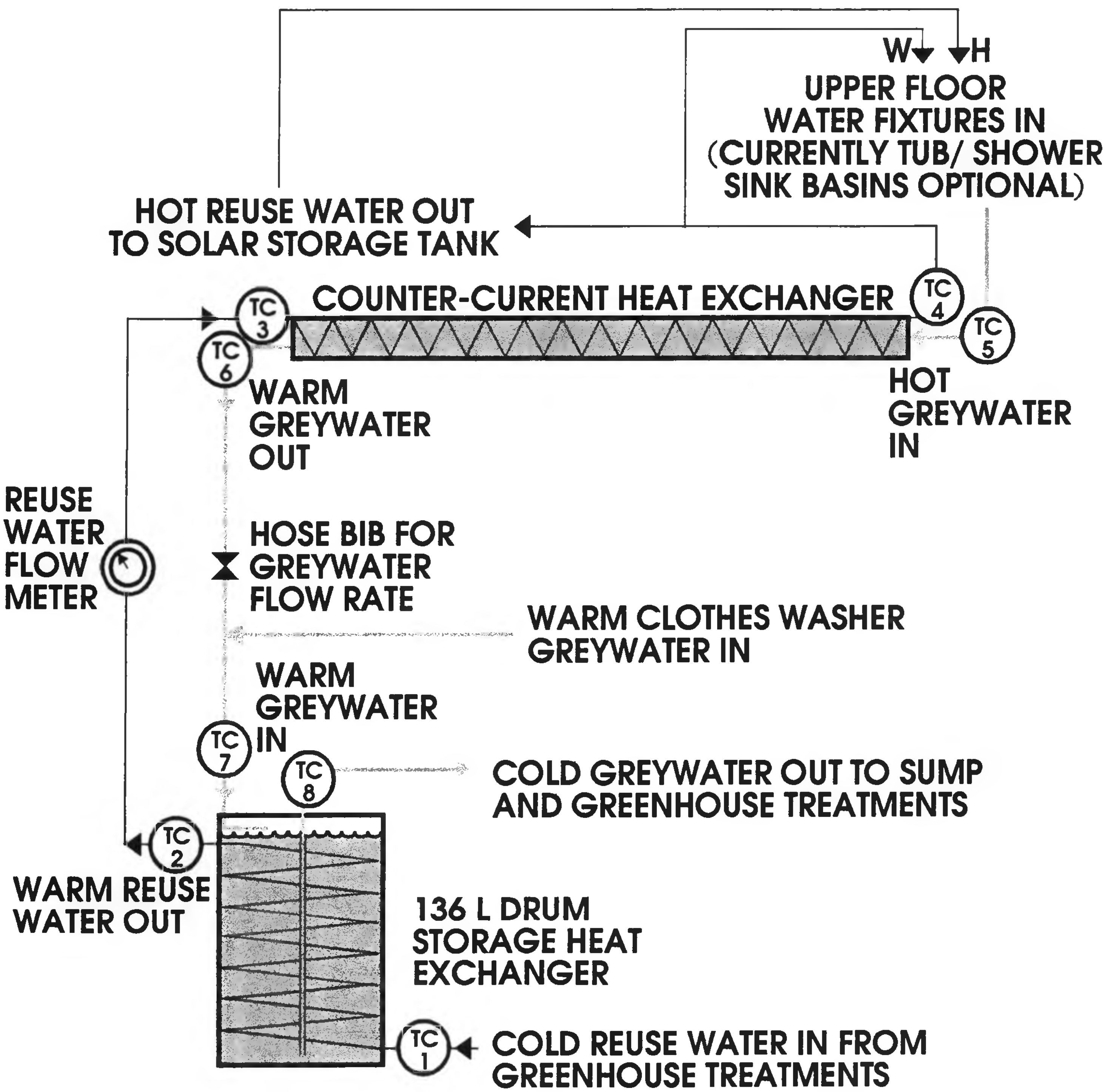

FIG. 7 Schematic of the Greywater Heat Exchangers at the Alberta Sustainable Home/Office
Note the thermocouple (TC) placements and flow of greywater and reuse water.

5.4 Greywater Heat Exchanger Data Analysis

Each monitoring session was tabulated and can be found in Appendix A-1 to A-8. Analysis of the data was conducted to determine the temperature efficiencies of each heat exchanger, the annual energy saved, and the hot water heating contribution. Performance of the heat exchangers is also expressed as the # days of constant use by a 100 W bulb, annual water heating savings (using both electric and natural gas rates), and simple payback.

The thermocouple data is used to determine **temperature efficiencies (E_T)** through the following equation:

eg. $E_T = \dfrac{T_4 - T_3}{T_5 - T_3}$ where T_i represents the thermocouple location temperature (fig.7)

Annual energy saved (kJ) is determined through the following series of calculations:

C_p (kJ/kg^{0}K) = 4.2915 - 3.68 x 10^{-4} x T_{av} (^{o}K) for water @ 0.9 atm, 15-35 ^{0}C, r^2 = 0.8626

r_w (kg/m^3) = 1072.8 - 0.255 x T_{av} (^{o}K) for water @ 0.9 atm, 15-35 ^{0}C, r^2 = 0.9886

$\dot{m}_i$ (kg/s) = $\dot{v}$ (m^3/s) x r_w

$\dot{q}$ (kJ/s)= $\dot{m}$ x C_p x DT (^{0}K)

Annual flow time(s) = reuse & greywater flow frequency (mins/day) x 60 s/min x 365 days/a

Annual energy saved = E/a (kJ) = Annual flow time (s) x $\dot{q}$ (kJ/s)

Hot Water Heating Contribution (%) = $\dfrac{\text{Actual } DT_{RW} \text{ Gain } (^oC)}{\text{Required } DT_{RW} \text{ Gain } (^oC)}$ x 100

where RW = reuse water

Required temperature of the Solar Storage Tank (SST) = 49 ^{0}C

100 W Bulb Constant Use (# days) = $\dfrac{E/a \text{ (kJ) x } 2.77 \text{ x } 10^{-4} \text{ kWh/kJ}}{0.1 \text{ kW bulb x } 24 \text{ h/day}}$

Annual Water Heating Savings ($/a)

For Electric Hot Water Heating, Annual Savings = E/a (kJ) x 2.77 x 10^{-4} kWh/ kJ x $ 0.0614/kWh

For Natural Gas Hot Water Heating, Annual Savings = E/a (kJ) x 10^{-6} GJ/ kJ x $ 2.635/ GJ

Simple Payback (years) = $\dfrac{\text{total material cost of heat exchanger (\$)}}{\text{annual water heating savings (\$/a)}}$

5.5 Greywater Heat Exchanger Monitoring Results

The monitoring results for the greywater heat exchangers are summarized in Table 12 for the Counter Current Heat Exchanger and Table 13 for the Drum Storage Heat Exchanger. To determine the optimal performance of the heat exchangers, scenario c (i.e. shower) is used in which there is water (i.e. greywater and reuse) flow in both directions of the heat exchanger. In the other three scenarios there is water flowing in only one direction or not at all (i.e. static or stabilizing conditions). The performance of each heat exchanger was determined individually but the results do not reflect true independent operation since the heat exchangers are plumbed in-series. The inlet water temperatures of each heat exchanger are therefore affected by the outlet water temperature of the other heat exchanger. Performance of the whole heat exchanger system (i.e. in-series operation) was also determined (Table 14). Comparisons of the experimental results with theoretical performance results for the SHWS at the ASH home/ office and an average Calgary residence are included.

5.5.1 Counter Current Greywater Heat Exchanger (CCHX)

The average temperature efficiency of the counter current heat exchanger at the ASH home/ office is 33.0 % with an average reuse water temperature gain of 2.0 ^{0}C. The annual energy saved by the counter current heat exchanger is 182071 kJ or 0.18 GJ equal to a 100W bulb operating continuously for an average of 21.1 days. This translates to an annual savings of $3.11 for electric heating or $0.48 for natural gas heating. These figures are quite low and initially suggest unacceptable payback periods of 28 and 179 years respectively (based on material costs only). However, these savings reflect several conservation parameters such as frequency and pattern of water use, water demand volumes, flow rates, and inlet temperatures as defined by the SHWS. The degree of conservation measures adopted affect the annual water heating savings ($) and therefore shadow the real benefits of the system. A more representative indicator of the performance of the counter current heat exchanger at the ASH home/ office is the hot water heating contribution (%) which does take into account inlet temperatures and water demand considerations. On average the counter current heat exchanger satisfies 7.4% of the annual water heating requirements.

TABLE 12 **Counter Current Greywater Heat Exchanger Results**

SCENARIO C: SHOWER

	Temperature Efficiencies	Hot Water Heating Contribution	Annual Energy Saved	100 W Bulb Constant Use	Water Heating Savings		D-I-Y Cost of Materials	Simple Payback	
					Electric	Natural Gas		Electric	Natural Gas
	(%)	(%)	kJ/a	# days	$/a	$/a	$	years	years
	Test # 2: August 15, 1998								
	13.3	3.5	141915	16.4	2.42	0.37	86	38.0	245.9
	Test # 3: September 1, 1998								
	27.6	3.3	111856	12.9	1.91	0.29	86	45.9	297.3
	Test # 4: September 12, 1998								
	41.0	6.2	84922	9.8	1.45	0.22	86	60.1	388.7
	Test # 5: September 12, 1998								
	24.0	4.3	147731	17.1	2.52	0.39	86	34.8	225.4
	Test # 6: September 12, 1998								
	40.5	8.1	136744	15.8	2.33	0.36	86	37.4	241.9
	Test # 7: September 17, 1998								
	56.4	15.7	124147	14.4	2.12	0.33	86	49.7	322.0
	Test # 9: October 9, 1998								
	24.8	7.3	272454	31.5	4.65	0.72	86	29.7	192.0
	Test # 10: October 23, 1998								
	26.2	11.1	411955	47.7	7.03	1.09	86	22.7	146.8
Average	**33.0**	**7.4**	**182071**	**21.1**	**3.11**	**0.48**	**86**	**27.7**	**179.3**

	T2 thermocouple calculations for comparison with T3 thermocouple calculations above								
	Temperature Efficiencies	Hot Water Heating Contribution	Annual Energy Saved	100 W Bulb Constant Use	Water Heating Savings		D-I-Y Cost of Materials	Simple Payback	
					Electric	Natural Gas		Electric	Natural Gas
	(%)	(%)	kJ/a	# days	$/a	$/a	$	years	years
	Test # 9: October 9, 1998								
	31.0	9.0	340571	39.4	5.81	0.90	86	14.9	96.3
	Test # 10: October 23, 1998								
	36.0	13.5	517563	59.9	8.83	1.36	86	10.3	66.9
Average	**33.5**	**11.3**	**429067**	**49.7**	**7.32**	**1.13**	**86**	**11.8**	**76.1**

Notes: Each test result shown is the average of the time related data collected for each test of the counter current heat exchanger (scenario c: shower).
The total average of the time related data collected for all tests is shown at the bottom of each table.
A comparison of the results from calculations using thermocouples T3 and T2 is shown above.

TABLE 13 **Drum Storage Greywater Heat Exchanger Results**

SCENARIO C: SHOWER

	Temperature Efficiencies	Hot Water Heating Contribution	Annual Energy Saved	100 W Bulb Constant Use	Water Heating Savings		D-I-Y Cost of Materials	Simple Payback	
					Electric	Natural Gas		Electric	Natural Gas
	(%)	(%)	kJ/a	# days	$/a	$/a	$	years	years
	Test # 1: September 12, 1998								
	30.7	7.3	104727	12.1	1.79	0.28	75	42.0	271.8
	Test # 2: September 17, 1998								
	29.9	4.2	57766	6.7	0.99	0.15	75	76.1	492.7
	Test # 4: October 9, 1998								
	6.6	2.0	121912	14.1	2.08	0.32	75	36.1	233.5
	Test # 5: October 23, 1998								
	8.4	4.2	261521	30.3	4.46	0.69	75	16.8	108.8
Average	**20.8**	**4.4**	**122628**	**14.2**	**2.09**	**0.32**	**75**	**35.9**	**232.1**

Notes: Each test result shown is the average of the time related data collected for each test of the drum storage heat exchanger (scenario c: shower). The total average of the time related data collected for all tests is shown at the bottom of the table.

TABLE 14 **In-Series Greywater Heat Exchanger Results**

SCENARIO C: SHOWER

	Temperature Efficiencies	Hot Water Heating Contribution	Annual Energy Saved	100 W Bulb Constant Use	Water Heating Savings		D-I-Y Cost of Materials	Simple Payback	
					Electric	Natural Gas		Electric	Natural Gas
	(%)	(%)	kJ/a	# days	$/a	$/a	$	years	years
	Test # 7cc/2ds: September 17, 1998								
	67.9	23.5	320030	36.9	5.44	0.84	161	29.6	190.9
	Test # 9cc/4ds: October 9, 1998								
	35.5	10.8	651430	75.2	11.08	1.72	161	14.5	93.8
	Test # 10cc/5ds: October 23, 1998								
	39.1	16.0	979691	113.1	16.66	2.58	161	9.7	62.4
Average	**47.5**	**16.8**	**650384**	**75.1**	**11.06**	**1.71**	**161**	**17.9**	**115.7**

Notes: Each test result shown is the average of the time related data collected for each in-series test of the heat exchangers (scenario c: shower). The total average of the time related data collected for all tests is shown at the bottom of the table.

The theoretical performance expected for the counter current heat exchanger operating truly independent (not individually as explained above) of the drum storage heat exchanger is shown on Table 15. With an average reuse water temperature gain of 7.6^{0}C, the potential annual energy saved could be 3473758 kJ or 3.5 GJ. This figure is based on the assumption that the counter current heat exchanger would be subjected to the same operating conditions and thus perform at an average temperature efficiency of 33.0%. A 100W bulb could operate continuously for 198 days, and save $29.15 (for electric) and $4.52 (for gas) annually for hot water heating. This translates to simple payback periods of 3 years for electric water heating and 19 years for natural gas water heating (based on material costs only). The counter current heat exchanger could potentially contribute 24.5% of the total hot water heating of the ASH home/ office.

This performance data can be extrapolated to an average Calgary residence to give an indication of the benefits that could be realized if counter current heat exchangers are incorporated into an average household water system. For comparison purposes, the same water use frequencies and hot water supply temperatures are assumed to maintain a certain lifestyle, but the water flow rates and volumes required by standard (less conserving) fixtures and appliances, and the inlet water supply temperature vary. Therefore, the potential annual energy saved could be 4955094 kJ or 5.0 GJ which satisfies 27% of the hot water heating demand of an average Calgary residence (Table 16). Average potable water temperature gains are 12^{0}C. This equates to $84.28 (for electric) or $ 13.06 (for natural gas) savings for annual hot water heating. Simple payback would be 1 year for electric or 6.6 years for natural gas water heating.

5.5.2 Drum Storage Greywater Heat Exchanger (DSHX)

The average temperature efficiency of the drum heat exchanger at the ASH home/ office is 20.8 % with an average reuse water temperature gain of 1.2 ^{0}C. The annual energy saved by the drum storage heat exchanger is 122628 kJ or 0.12 GJ (Table 13). A 100W bulb would operate for an average of 14.2 days. This translates to an annual savings of $2.09 for electric water heating or $0.32 for natural gas water heating. As discussed above with the counter current heat exchanger, the results seem extremely low suggesting unacceptable payback periods of 36 years and 232 years respectively. However, the drum storage heat exchanger satisfies 4.4 % of the annual water heating requirements of the ASH home/ office.

The theoretical independent performance expected for the drum storage heat exchanger at the ASH home/ office includes a potential annual energy savings of 1.6 GJ with an average temperature efficiency of 20.8% (Table 15) and an average reuse water temperature gain of 4.8^{0}C. A 100W bulb could operate continuously for 194 days. This translates to a saving of $28.65 (for electric) and $4.44 (for gas) for annual hot water heating. Simple payback periods would be 2.6 years for electric water heating and 17 years for natural gas water heating. The counter current heat exchanger could potentially contribute 15.5% of the total hot water heating of the ASH home/ office.

When extrapolated to an average Calgary residence, the theoretical independent performance of the drum storage heat exchanger would include an average potable water temperature gain of 7.5°C and an annual energy savings of 4.8 GJ which supplies 17% of the hot water heating demand of an average residence in Calgary (Table 16). Annual hot water heating savings of $82.02 (for electric) or $ 12.71 (for natural gas) indicate simple payback periods of less than one year for electric water heating and 6 years for natural gas water heating.

5.5.3 In-Series Operation of the Greywater Heat Exchanger System

The two heat exchangers at the ASH home/ office operate concurrently with a 47.5 % temperature efficiency (Table 14). Average energy savings per year amount to 650384 kJ or 0.7 GJ. For electric hot water heating an annual savings of $11.06 would be realized with a simple payback period of 18 years. An annual savings of $1.71 with an average simple payback period of 116 years would occur if the water is heated by natural gas. The total material cost for both counter current and drum storage heat exchangers is $161 (1994 Cdn.$). The in-series heat exchanger system provides an average of 16.8% of the hot water heating demand at the ASH home/ office.

The theoretical in-series performance of the heat exchanger system (i.e. counter current and drum storage heat exchangers) at the Alberta Sustainable Home/ Office assumes a temperature efficiency of 43.5 % with an average reuse water temperature gain of 9.9°C. A potential annual energy savings of 3.5 GJ is equivalent to an annual hot water heating savings of $59.08 for electric or $9.15 for natural gas (Table 15). Simple payback periods would be 3 and 17 years respectively. Therefore, the counter current and drum storage heat exchangers operating in-series could satisfy 32% of the total hot water heating of the ASH home/ office.

For an average Calgary residence, the theoretical in-series performance of the counter current and drum storage heat exchangers would result in an average potable water temperature gain of 15.6°C and an annual energy savings of 10.0 GJ supplying 35.5% of the hot water heating demand (Table 16). Significant annual hot water heating savings can be realized: $170.24 (for electric) or $ 26.38 (for natural gas). Favourable simple payback periods result in less than one year for electric water heating and 6 years for natural gas water heating.

TABLE 15 **Theoretical Performance Results of the Heat Exchangers in the Alberta Sustainable Home/Office**

SCENARIO C: SHOWER

Heat Exchanger Configuration	Temperature Efficiencies (%)	Hot Water Heating Contribution (%)	Annual Energy Saved kJ/a	100 W Bulb Constant Use # days	Water Heating Savings Electric $/a	Water Heating Savings Natural Gas $/a	D-I-Y Cost of Materials $	Simple Payback Electric years	Simple Payback Natural Gas years
INDEPENDENT OPERATION:									
CCHX	33.0	24.5	1713983	198	29.15	4.52	86	3.0	19.0
DSHX	20.8	15.5	1684516	194	28.65	4.44	75	2.6	16.9
IN-SERIES OPERATION:									
	43.5	32.0	3473758	401	59.08	9.15	161	2.7	17.6

TABLE 16 **Theoretical Performance Results of the Heat Exchangers in an Average Calgary Residence**

SCENARIO C: SHOWER

Heat Exchanger Configuration	Temperature Efficiencies (%)	Hot Water Heating Contribution (%)	Annual Energy Saved kJ/a	100 W Bulb Constant Use # days	Water Heating Savings Electric $/a	Water Heating Savings Natural Gas $/a	D-I-Y Cost of Materials $	Simple Payback Electric years	Simple Payback Natural Gas years
INDEPENDENT OPERATION:									
CCHX	33	27	4955094	572	84.28	13.06	86	1.0	6.6
DSHX	20.8	17	4822270	557	82.02	12.71	75	0.9	5.9
IN-SERIES OPERATION									
	43.5	35.5	10009562	1155	170.24	26.38	161	0.9	6.1

Note: The Hot Water Heating Contribution (%) is determined by dividing the actual temperature gain across the heat exchanger by the temperature gain required to satisfy hot reuse water demands. This calculation takes into account only the hot water demands that flow through the heat exchangers. This represents 98% of the hot reuse water demands for the SHWS at the ASH home/ office. Both the solar storage tank reuse water temperature and domestic hot water heater temperature are assumed to be 49^{0}C. Inlet reuse water temperature is assumed to be 18^{0}C and the inlet potable water temperature is assumed to be 5^{0}C.

5.6 Greywater Heat Exchanger Discussion

The indicators used to evaluate the heat exchangers at the ASH home/ office result in performances significantly less than expected. There are many reasons that contribute to these poor results and can be categorized within design decisions (i.e. retrofit location constraints), system commissioning errors (i.e. incorrect plumbing configurations), and monitoring problems (i.e. instrumentation, human errors).

The nature of the design for the Sustainable Home Water System limits the potential for the heat exchangers. This is partially due to the use of water conserving fixtures and appliances which results in low total daily water volumes used. Higher water savings potential is associated with higher hot water use. The reuse water supply is maintained at ambient temperatures (eg. 18 ^{0}C) which lowers the temperature gain potential of the reuse water compared with municipally supplied potable water (eg. 5 ^{0}C). However, these results are slightly misleading since the net annual expense of water heating for a conventional house is higher than that of a house installed with the Sustainable Home water system design. The indicator that takes all of these points into account and puts the potential savings in a proper context is the hot water heating contribution (%). The fact that there are monetary savings is significant and even though the payback periods at the ASH home/ office using the SHWS design seem inappropriate, the capital investment of either heat exchanger is small. Extrapolating the results to a conventional house show attractive payback periods and significant annual savings. Therefore installation of greywater heat exchangers are worthy of consideration.

The design and installation of the counter current and drum storage heat exchanger in-series affects the ability to determine the operation of either heat exchanger independently. The theoretical results for each heat exchanger operating independently show higher temperature gains across each of the heat exchangers compared with theoretical in-series operation of both heat exchangers (Table 11). This is because of the relatively warmer inlet reuse water temperatures (T3) to the counter current heat exchanger (prewarmed by the drum) and relatively cooler inlet greywater temperatures (T7) to the drum storage heat exchanger due to the heat loss through the counter current heat exchanger (fig.7). Therefore the experimental results appear less favourable due to individual performance analysis through in-series operating conditions.

There are benefits to in-series operation of the heat exchangers as part of the SHWS design when hot water demands can be met in concentrated amounts of time and coincide with the peak daily water temperature of the solar storage tank. Higher supply temperatures and concentrated water demands (i.e. both continuous and non-continuous types of water use) over short periods of time optimize the amount of reclaimed heat from both types of heat exchangers. Even when hot water demands are not coincident and the heat exchanger temperatures approach ambient conditions through conduction the transfer of heat to the surroundings contributes to space heating of the house which is beneficial during cooler months. The heat exchangers and associated plumbing were not yet insulated during the monitoring stage so losses to ambient surroundings may have lowered the experimental performance results. Theoretical results were based on the assumption that losses were negligible.

During the commissioning of the Sustainable Home Water System there were several complications that adversely affect the performance of the heat exchangers. The supply of greywater and reuse water to the greywater heat exchangers were plumbed differently to that of the initial design. The cold reuse supply currently branches off and supplies the ASH home/ office cold water demands, the inlet to the greywater drum storage heat exchanger, and the solar storage tank. According to the original design the cold reuse water supply should not enter the solar storage tank directly. Instead it should be preheated through the heat exchangers first then enter the solar storage tank. Current plumbing allows the prewarmed reuse water from the heat exchangers to supply the cold supply line of the shower/ bath tub only and does not supply the solar storage tank. This design reduces the overall heat reclamation potential of the SHWS. Greywater currently is collected from the shower/bath tub and clothes washer which represent 98% of the SHWS hot water demands. The sink basins and dishwasher are other hot greywater sources that could be utilized in the future for heat recovery through the drum storage heat exchanger.

The solar storage tank (SST) reuse water temperature varies during the day and with local weather conditions. This affects the performances of the greywater heat exchangers since the hot reuse water inlet supply temperature varies. During the monitoring sessions of the greywater heat exchangers the SST water temperature was taken and any changes were noted. Each monitoring session emulated shower or bath scenarios and there was an attempt to standardize the water temperature mix of 80:20 (hot:cold) at the shower/tub although it proved arbitrary. The SST temperature ranged from 41 to 54^{0}C whereas the shower drain temperatures were only between 30 and 36^{0}C (based on T5 data). This large discrepancy between the water temperature in the solar storage tank and the reuse water supply at the shower/ tub was due to a stripped anti-scalding control valve at the outlet of the SST. The valve appeared to be set at 100% hot, however, in reality it was set much lower, thus diluting the hot reuse water supply. Therefore smaller than expected heat gains were observed while monitoring the heat exchangers since the potential temperature differential between the greywater and the inlet reuse water supply was relatively small.

Instrumentation limitations lowered the experimental results for both the counter current (CCHX) and drum storage (DSHX) heat exchangers. The thermocouple type chosen (type K instead of type J) may not have been appropriate for the temperature ranges experienced in this monitoring application. The thermocouples were also homemade and were soldered instead of arc welded which may have an effect on their performance. During static water flow conditions, the thermocouple readings were variable. The DSHX reuse temperature differential varied from -2.8 to +0.1 ^{0}C. The CCHX reuse temperature differential ranged from -0.1 to +0.8 ^{0}C. In a static scenario one could expect a reasonable temperature variation of +/- 0.1 ^{0}C. Thermocouple T3 situated at the reuse water inlet to the counter current heat exchanger occasionally misbehaved by rapidly oscillating +/- 3.0 ^{0}C instead of stabilizing. Therefore analysis of data was conducted by comparing results derived from both T3 and T2 to determine the actual reuse water temperature gains across the counter current heat exchanger. A new battery was installed in the thermocouple meter at the start of the monitoring sessions and the other thermocouple readings stabilized quickly with high precision during flow events. Therefore the accuracy of the thermocouples were suspect, not the operation of the meter.

Location of the thermocouples also plays a part in their accuracy. The thermocouples were placed on the bottom and outside of the pipes on either side of the heat exchangers instead of directly inside the pipes which would give a much more accurate water temperature reading. The inlet and outlet pipes to and from the heat exchangers were made of different materials such as copper, ABS and polybutylene which affects heat transfer rates and potential (i.e. for recovery and heat losses). The laundry room in which the heat exchangers are situated is quite small and the ambient air temperature could potentially heat up quickly when there are occupants in the room. This may adversely affect the monitoring results. There is also a 100 W bulb that is in close proximity to the CCHX. When the light was on during some of the testing sessions it may have increased the temperature of the greywater pipe thus interfering with results for the actual heat transfer between the greywater and the reuse water.

Due to the reasons explained above, the experimental results of the greywater heat exchangers as part of the SHWS are unreliable and the actual performances have not yet been determined with confidence.

5.7 Greywater Heat Exchanger Recommendations

- The thermocouples used for the greywater heat exchanger monitoring should be recalibrated to determine the accuracy of each one and indicate the validity of the results obtained.

- The heat exchangers and all associated supply pipes should be insulated to limit the heat loss potential to the surroundings.

- A bypass should be plumbed in order to monitor each GWHX independently.

- To determine the actual performances of the heat exchanger system further monitoring should be completed with appropriate and well calibrated instrumentation. Each thermocouple readings should be taken at the same time at a more frequent rate (eg. one second intervals) during flow events then the data could be averaged at regular intervals and stored. This can be accomplished through the use of a multi-channel data logger in conjunction with appropriate computer hardware and data processing software. Long term monitoring to match the water use patterns of the occupants at the ASH home/ office will give more realistic performance results. This is in contrast to the previous monitoring events where the whole SHWS was stressed to peak capacity and created an imbalance in the ASH home/ office water supply and demand. Actual water temperatures should be measured directly within the water flow, and accurate water flow rates are required. Data collected during the stabilization scenario after flow activity could be used to determine the length of time that both the greywater and reuse water in either heat exchanger remain above ambient air temperature and thus have heat transfer potential. This information would be useful for determining the appropriate frequency and priority of fulfilling water use demands in order to maximize heat reclamation benefits.

6.0 PERFORMANCE ANALYSIS OF THE SUSTAINABLE HOME WATER SYSTEM

6.1 Actual Water Demand for the Sustainable Home Water System

Before the SHWS was commissioned, the ASH home/ office was plumbed with municipal water and sewer connections. The average monthly water consumption was 2400 litres per month for an annual total of 29 000 litres. These figures reflect water use by the two primary residents of the ASH home/ office who practice conserver lifestyles, as well as regular day use by employees, and occasional use by guests.

There are several water volume meters installed in the ASH home/ office to monitor the water use in the various components of the SHWS system (Table 17).

Table17 Water Volume Meter Locations for the SHWS

WATER METER	LOCATION	DETERMINES:
1	Mechanical Room: between pressure tank and potable supply to house	total potable water consumption
2	Greenhouse: between sump and greywater storage	greywater collection
3	Greenhouse: between reuse water storage tank and reuse supply to house	total reuse water demand
4	Mechanical Room: between house reuse supply and outside demands (i.e. hose bibs, subirrigation)	outdoor reuse water demand
5	Laundry Room: between drum storage heat exchanger and solar storage tank	cold reuse water prewarmed by the heat exchangers
6	Kitchen: between the passive solar breadbox preheater and the kitchen potable water supply	hot potable demand

Using the data recorded from the water volume meters, a water balance can be determined for the SHWS system as a whole as well as validate the theoretical water demand and supply figures generated in the SHWS design.

The SHWS was fully commissioned in August 1998 with municipal water and sewer services physically disconnected from the SHWS to prevent cross-contamination. During the monitoring phase of the greywater heat exchangers water consumption was greater than actual realistic use patterns would have been during that period of time.

Consequently water meter monitoring has been conducted for only a brief period of time but will be continued on an ongoing basis to generate more complete data.

The ratio of theoretical water demands to the actual values should be 2:1 due to the current discrepancy between the number of occupants. Currently 7 L of potable water per day is being consumed by two people. The theoretical value is 30 L per day for a family of four. The total reuse water use is averaging 14 L/day compared with the theoretical value of 176 L per day. Average greywater generation is 14 L/ day. Theoretical values are estimated at 206 L/ day.

Therefore significant water savings have been realized with the SHWS due to the occupants commitment to water conservation, installation of water saving devices currently on the market, elimination of blackwater generation, and the adoption of a two tiered system of water use. This includes a small amount of potable water treated to high standards, and reclamation, treatment and reuse of greywater for secondary non-potable demands.

6.2 Capital Costs for the Sustainable Home Water System

A detailed inventory of material and labour costs determine a total value of about $33 500 for all associated SHWS systems including: 3 greywater treatment systems, two cisterns, 2 hot water heating systems, 2 toilet systems and 2 greywater heat exchangers. The potable water system cost $8 600 in materials and $2 600 for labour, amounting to $11 200. Common plumbing and components for the reuse system include $4 600 in materials and $1 600 for installation costs. Material and installation costs for each of the greywater treatment systems were totaled: $ 800 for two slow sand filters, $2 550 for the Greywater Garden Wall, and $1 250 for the Soil Box Subirrigation. The solar system for hot reuse water supply cost approximately $3 500 (including material and labour costs). The fireplace hydrocoil and associated components totaled $1 350. Both toilet systems cost a total of $6 650.

Costs were added for fair representation even if components were donated for the SHWS system at the ASH home/ office (i.e. pumps, or float controls). These costs are based on current 1998 list or retail prices representing replacement costs. If current contractor prices were used, a price of about $27 000 could be realized. An hourly rate of $42 per hour was used for the plumber. Monitoring costs were not included.

Two items that were not included in the above, but were part of the water systems while connected to city services include: 1) salt-free water softener ($700) and 2) fluoride and chlorine filters ($500). They are not an essential part of the autonomous water system, but are still being utilized in the SHWS as backup treatments. Two items which will be added in the future include: two electric instantaneous hot water heaters and a breadbox solar preheater (estimated at $120).

Another possible technology that is being investigated at this time is a water purification system which would replace UV or ozone treatment that uses significantly less power, is maintenance free and kills pathogens, viruses, parasites, and bacteria. A smaller hot water tank (i.e. 90 litres vs. 180 litres) could be used for quick response heat from renewable heat sources with adequate water supply for specific water demands (i.e. shower, washing machine).

Potential Cost Reductions

Estimated reductions to the actual costs that could be made at a house of similar design, if redundancy, experimentation/prototypes, duplication and unnecessary features or quality (i.e. water level indicator, stainless steel hot water tank) were eliminated, could be about $10 000. Savings would chiefly accrue from:

1) one cistern only, (smaller with few manholes)	$ 1 600
2) greater use of reused materials: (i.e. rain barrels, piping leftovers)	$ 300
3) one greywater treatment system (i.e. planter boxes)	$ 3 400
4) one heat exchanger	$ 200
5) greater optimization of mechanical components	$ 1 000
6) alternative waterless toilet	$ 1 000
7) system simplification & optimization (i.e. fireplace hydrocoils)	$ 500
8) smaller hot water tank (i.e. 40 gal vs. 80 gal)	$ 300
9) better cost control, more competitive pricing, better specifications	$ 1 000
10) avoiding toilet conversion (i.e. base kit for ultra low flush toilet)	$ 330
11) one planter box vs. two	$ 370
TOTAL:	**$10 000**

If a basement was used, further savings of $4,300 could be realized:

1) an integrated wood/polyethylene basement cistern	$ 2 500
2) an integrated wood/polyethylene basement cistern	$ 2 500
3) gravity feed ultra low flush toilet without vacuum pump and tank	$ 1 300
4) simplified systems (i.e. no sump, direct feed)	$ 500
TOTAL:	**$ 4 300**

Therefore this would bring the actual costs down to about $19 200 for a sustainable (single family) home water system.

If an eco-village or small sustainable community (i.e. 50-60 housing units) was planned to take advantage of the experience of this project and the Toronto Healthy House, further price reductions of perhaps another $5 000 could be realized per housing unit due to economies of scale, competitive bidding, better initial design and specification, closer coordination with suppliers and manufacturers and better cost control and the use of neighborhood collection/treatment. At that point, a sustainable community water system could show very attractive total costs (capital and operational costs), especially over the life-cycle of the system (i.e. 25 years) to the true costs of traditional centralized water, including subdivision infrastructure costs. This is worthy of further investigation, when such a project is realized.

6.3 "INTEGRATED SAVINGS ACCOUNT: Energy, Green House Gas (GHG), Environmental Credits, Externalities and Societal Savings"

Table 19 is a summation of environmental advantages of the Sustainable Home Water System beyond the water consumption reductions addressed previously in this report. Extensive research was conducted to determine the details of the environmental cost savings including approximately 40 different publications, articles, documents and websites. In addition, a file of personal e-mail correspondence with major players in the field (i.e. Lawrence Berkeley National Labs, California Energy Commission, Natural Resources Defense Council, Environmental Protection Agency in the U.S.) was also compiled.

Table 19 reviews energy savings (in GJ and kWh), operational savings (in $), greenhouse gas (GHG) avoidance (in grams, kilograms and tonnes), environmental credits (in grams and kilograms), externalities (in $), societal cost savings (in $) and potential results achievable for a small housing development of 50 sustainable housing units.

The findings are as expected with significant environmental improvements made, but cost savings are not large for a single family house. Cost savings become more attractive if they are extended into a future time frame and to a larger sustainable development (i.e. an Eco-Village of 50 units or larger). It should be remembered that all environmental credits achieved will be small but still important when considered together with the much larger numbers achieved in tradable permits through saving electrical energy (i.e. coal), space heating and hot water heating energy (i.e. natural gas) in a self-sufficient home/office and sustainable community.

The greenhouse gas emissions and externalities were first calculated for the ASH home/ office. If the environmental credits as audited were to be sold, they would not warrant the paperwork involved in such a contract. However, if they were combined with externalities for avoided greenhouse gas emissions from drastic reductions in electrical and natural gas consumption, the sale of externalities would be more attractive. If a small sustainable community (i.e. 50 housing units) based on similar performance was to sell their accumulated environmental credits, a contract would be much more attractive and substantial, as discussed below. It is on the community level that will make such autonomous water systems cost-effective and cost competitive.

6.3.1 Operational Costs

Electrical consumption requirements associated with the Sustainable Home Water System (SHWS) were determined through 100 hour energy consumption monitoring and rated consumption values for each pump, fan, air compressor, and U.V.

TABLE 18 Sustainable Home Water System Electrical Consumption

#	Device	Rating (Watts)	Purpose	R/P	Location	kWh/year	A/E
1	Pump # 1	48 W continuous	Fish tank to gravel filters	R	Greenhouse	415.28	A
	Pump # 2	63 W intermittent	Planter box #1 to #2	R	Greenhouse	0.81	A
	Pump # 3	(pumps combined)	Planter box # 2 to Reuse Tank	R	Greenhouse		
2	Pump # 4	380 W intermittent	Sump to Greenhouse	R	Living Room Floor	1.84	A
3	Pump # 5	380 W intermittent	Cistern to Slow Sand Filter	P	Mechanical Room	17.01	A
4	Pump # 6	34 W intermittent	Solar Collector to SST[6]	R	Greenhouse	103.00	A
5	Pressure Pump # 1	890 W intermittent	Pressurize Reuse Water	R	Greenhouse	40.00	E
6	Pressure Pump # 2	890 W intermittent	Pressurize Potable Water	P	Mechanical Room	6.22	E
7	Air Compressor # 1	4 W continuous	Aerate marsh # 2	R	Greenhouse	30.66	A
	Air Compressor # 2	5 W continuous	Aerate marsh # 1	R	Greenhouse	20.71	A
	Air Compressor # 3	6 W continuous	Aerate gravel filters	R	Greenhouse	45.11	A
8	Compost Toilet Fan	9 W continuous	Ventilate utility room	R	Utility Room	79.15	A
9	U.V. disinfection # 1	27 W continuous	Sterilization of potable water	P	Mechanical Room	236.52	E
10	U.V. disinfection # 2	27 W continuous	Sterilization of reuse water	R	Greenhouse	236.52	E
COMPARISON OF THE ENERGY REQUIREMENTS FOR WATER SERVICE							
ASH SHWS		Annual Energy Requirements for potable water [1] (kWh/a)				259.75	
		Annual Energy Requirements for reuse water [2] (kWh/a)				973.08	[7]
		Annual SHWS Energy Requirements for total water use [3] (kWh/a)				**1232.83**	
AVERAGE CALGARY RESIDENCE		Annual Energy Requirements for potable water service [4] (kWh/a)				115.0	
		Annual Energy Requirements for wastewater service [5] (kWh/a)				60.2	
		Annual Energy Requirements for municipal water service (kWh/a)				**175.2**	

Notes: R = reuse water system; P = potable water system;
A = actual 100 hour monitoring by an Energy Consumption Monitor (ECM)
E = estimated/ calculated kWh/year based on ECM monitoring or rated consumption
Rating is based on 120 volts AC (or as specified) and includes an adapter where appropriate
1 Total of above energy requirement figures (kWh/a) for potable water system
2 Total of above energy requirement figures (kWh/a) for reuse water system
3 Annual total water consumption is 75.239 m^3
4 Based on 0.342 kWh/m^3 (required energy for treatment and pumping) x 336 m^3 annual potable water consumption
5 Based on 0.263 kWh/m^3 (required energy for pumping and treatment) x 229 m^3 annual wastewater generation
6 Energy consumption for the SHWS solar water heating component is included, but for the average Calgary residence, the embodied energy of natural gas delivery (i.e. from well site to consumer) is not reflected in the total energy requirements.
7 This value reflects the current use of three greywater treatment systems, representing 72% of the total electrical requirements of the ASH home/ office (average of 1719.15 kWh/a from 1994-1998).

TABLE 19 Annual Integrated Savings Account: Energy, Greenhouse Gases (GHG), Environmental and Social

A.

		Operating			Greenhouse Gases (Anthropogenic) (grams)						Total GHG (kg)			
		Resource	Energy		Kyoto[1]			Precursors[2]			Normal	Weighted	Others (g)	
System	**Details**	**Offset**	**kWh**	**$**	**CO_2**	**CH_4**	**N_2O**	**CO**	**NO_x**	**VOC**			**SO_2**	**Particulates**
Solar	Collector to Solar Storage Tank (9.71GJ)	Gas [5]	2700.0	26.03	485500	19.42	5.8	67.97	271.88	11.65	485.88	488.06	1.94	58.26
Potable Water (336 m^3)	Electrical Processing	Coal [4]	115.0	7.06	116955	69.00	N/A	104.65	292.10	2.07	117.42	118.80	370.76	2.30
	Service Charge (Basic Rate)			103.20										
	Consumption Charge			258.59										
	Upgrade Costs			6.90										
	Municipal Tax (Estimate)			12.00										
Sewage (229 m^3)	Electrical Processing	Coal [4]	60.3	3.70	61325	36.18	N/A	54.87	153.16	1.09	61.57	62.29	194.41	1.21
	Service Charge			70.33										
	Consumption Charge			176.23										
	Upgrade Costs			6.90										
	Municipal Tax			12.00										
	Methane Produced (13.12 m3)					8830.00								
Totals	**$ Savings to City (100%)**			**114.66**										
	$ Savings to Homeowner			**646.15**										
	Emissions (grams)				**663780**	**8954.60**	**5.8**	**227.49**	**717.14**	**14.81**	**664.87**	**669.15**	**567.10**	**61.77**

B.

	Environmental Credits (g)							Totals	Externalities [9]				Social[7]	Eco-Village [8]			
									CO_2 ($)		SO_2 ($)			CO_2	Credits	CO_2 Income[9] ($)	
System	**HC**	**Hg**	**Cr**	**Cd**	**Pb**	**Ni**	**As**	**(g)**	**Now**	**Future**	**Now**	**Future**	**$**	**tonnes**	**kg**	**Now**	**Future**
Solar	77.68	/	N/A	N/A	N/A	N/A	N/A	77.68	26.70	89.00	0.00	0.00	51.38	24.28	3.88	1335.12	4450.42
Potable Water	3.34	/	0.0002	0.0005	0.002	0.004	0.0010	3.35	6.43	21.44	0.08	0.27	12.38	5.85	0.17	321.63	1072.09
Sewage	1.75	/	0.0001	0.0003	0.001	0.002	0.0005	1.75	3.37	11.24	0.04	0.14	6.49	3.07	0.09	168.64	562.15
Totals	**82.77**	**/**	**0.0003**	**0.0008**	**0.003**	**0.006**	**0.0015**	**82.78**	**36.50**	**121.68**	**0.12**	**0.41**	**70.25**	**33.20**	**4.14**	**1825.39**	**6084.66**

Notes:

1. Kyoto Protocol, December 1997
2. 'Criteria Pollutants' for urban smog or 'Contributing Greenhouse Gases' (includes CO_2, NO_x, NM VOC (non-methane Volatile Organic Compounds), and ROG (reactive organic gases) (Personal Communications, Nancy Powers (CEC), Stephen Wiel (LBL))
3. Radiative Forcing Functions for 'Global Warming Potential' using 100 years: CO_2 = 1; CH_4 = 21; N_2O = 310; SO_2 = N/A; NO_x = N/A
4. Coal Generated Electric Power Emissions in g/kWh: CO_2 = 1017; CH_4 = 0.6; N_2O = N/A; CO = 0.91; NO_x = 2.54; VOC = 0.018; SO_2 = 3.224; HC = 0.029; Particulates = 0.02; Hg = N/A; Cr = 1.66×10^{-6}; Cd = 4.33×10^{-6}; Pb = 1.73×10^{-5}; Ni = 3.29×10^{-5}; As = 9.08×10^{-6}; SO_x = 2.1
   Sources: 'Full Fuel Cycle Emissions Analysis of Existing and Future Electric Power Generation Options in Alberta, Canada'
   ENMAX table: ' Emission Factors for Emission Reduction Credits Quantification'
5. Natural Gas Emissions (Combustion only not 'full fuel cycle emission analysis') in g/GJ : CO_2 = 50000; CH_4 = 2; N_2O = 0.6; CO = 7; NO_x = 28; VOC = 1.2; SO_2 = 0.2; HC = 8; Particulates = 6; Natural Gas Cost ($2.68/GJ)
6. Conversion of Methane (specific gravity or density) = 0.042017 lbs./CF or 673 g/m^3)
7. Social (Societal) of $105.82/tonne ($96/ton) CO_2 (Howard, Bion, 1993. 'Simplified Pollution Avoidance Calculation for Builders', North East Sun, NESEA)
8. Eco-Village of 50 housing units similar to the performance of the ASH home/office
9. Greenhouse Gas Permit Trading (Externalities): Now: $15/tC, Future: $50/tC; 1 t CO_2 = 3.67 tC (Carbon); Now: 1t SO_2 = $220.46 (Clean Air Conservancy), Future: 1t SO_2 = $734.87; Now: 1t NOx = $2204.64 (CAC), Future: 1t NOx = $7348.73; Total weighted Greenhouse Gas Emissions used as basis of calculations. No environmental credits accounted for.

disinfection unit. The monitoring results are shown on Table 18. The total annual energy requirements for the potable water system is 259.75 kWh/year and 973.08 kWh/year for the reuse water system. These figures are quite high and represent 72% of the total average (1994 -1998) electrical consumption for the ASH home/ office. Several factors contribute to these high figures such as pump inefficiency, excess number of pumps installed, and duplicate systems. Several of the pumps installed satisfy appropriate head requirements but are oversized and throttled back with respect to flow rates. Therefore, pump efficiency is compromised. These inefficient pumps will be replaced once further investigation reveals appropriately sized pumps for each pump application that is currently consuming too much energy for operation. There are triplicate greywater treatment systems within the SHWS so there is redundancy and excessive energy consumption associated with showcasing and monitoring the performance of several greywater treatment options.

The energy consumption costs associated solely with treatment and pumping of both potable water supply and sewage collection have been determined by the City of Calgary as 0.342 kWh/m^3 and 0.263 kWh/m^3 respectively. However, this cost only takes into account the associated electrical costs but does not reflect the total capital and operation costs for the municipal water and wastewater service. Comparison of the annual electrical consumption between the SHWS (1233 kWh) and an average Calgary residence's water and wastewater service (175 kWh) shows an order of magnitude difference, however, the SHWS is both a prototype system and does not benefit from the economy of scale in which a residence supplied by municipal water service does.

Despite the excessive current electrical consumption of the SHWS, the sustainable home water system will save the city about $115 year per house in operational costs of the water and sewage treatment plants, including electrical costs. In addition, it will save the homeowner about $650 a year in utility bills. Due to the artificially low prices (i.e. subsidies) for water and sewage services, these numbers do not represent viable amounts to discuss payback. However, homeowners should realize that they are paying for municipal water two times, once when it comes into the house and another time when its leaves as sewage.

6.3.2 Environmental Savings

The SHWS avoids the production of 8.8 kg of methane per year, as would be produced by the (anaerobic) digestors at the central sewage plant when treating the sewage of an average single family home (229,000 litres/year). However, the release of further methane from finished sludge was not included in these calculations. This is important since methane is one of six greenhouse gases identified under the Kyoto protocol. Its potency for atmospheric disruption is 21 times that of CO_2 ("radiative forcing function").

CO_2 Externalities for the SHWS

The potable water system saves about 116.96 kg of CO_2 emissions per year. At a current price of $15/tC (tonne of carbon), this could earn $6.43 annually. At a future cost of $50/tC , this could earn $21.44. A small community of 50 housing units could earn $321.63 now or $1072.09 in the future per year.

The avoided sewage saves about 61.33 kg of CO_2 emissions per year. At a current price of $15 (US)/t carbon, this could earn $3.37 annually. At a future cost of $50 (US)/tc, this could earn $11.24. A small community of 50 housing units could earn $168.64 now or $562.15 in the future, per year.

SO_2 Externalities for the SHWS

The potable water system saves about 370.76 grams of SO_2 emissions per year. At a current price of $220.46/t (tonne of SO_2), this could earn $0.08 annually. At a future cost of $734.87/t , this could earn $0.27. A small community of 50 housing units could earn $4.00 now or $13.62 in the future, per year.

The avoided sewage saves about 194.41 grams of SO_2 emissions per year. At a current price of $220.46/t (tonne of SO_2), this could earn $0.04 annually. At a future cost of $734.87/t, this could earn $0.14 per year for the Alberta Sustainable Home/ Office. A small community of 50 housing units could earn $2.14 now or $7.13 in the future, per year.

NO_x Externalities for the SHWS

The potable water system saves about 292.10 grams of NO_x emissions per year. At a current price of $2204.64/t (tonne of NO_x), this could earn the ASH Home/Office $0.64 annually. At a future cost of $7348.73/t,.this.could earn $2.15. A small community (50 housing units) could earn $32.00 now or $107.50 in the future, per year.

The avoided sewage saves about 153.16 kg of NO_x emissions per year. At a current price of $2204.64/t (tonne of NO_x), this could earn $0.34 annually. At a future cost of $7348.73/t , this could earn $1.13. A small community of 50 housing units could earn $17.00 now or $56.50 in the future, per year.

CO_2 Externalities for the solar hot water heating system

The evacuated solar collector heating system saves about 9.71 GJ of natural gas per year. This saves about 486 kg of CO_2 emissions per year. If these credits were sold as part of a trading permit, $26.70 could be earned now or $89.00 could be earned later on. When combined with the utility saving of $26.00, this small 20 tube solar collector could earn $52.70 now or $115.70 in the future, per year in 1998 costs. A small community could earn $1335 now or $4450 in the future, per year for CO_2 credits alone.

SO_2 Externalities for the solar hot water heating system

Since the evacuated solar collector heating system saves about 9.71 GJ of natural gas per year, this saves about 1.94 grams of SO_2 emissions per year. The value is of no significance since it is offsetting natural gas.

NO_x Externalities of the solar hot water heating system

The solar hot water heating system saves about 271.88 grams of NO_x emissions per year. If these credits were sold as part of trading permit, $0.60 could now be earned each year or $2.00 per year could be earned later on.

Societal Value

If societal cost savings were salable, and a present value of $105.82/t of CO_2, and a future value of $352.74 were used, societal costs could generate $18.87 now and $62.89 in the future per year for both the potable and sewage system. For an Eco-Village this would mean $943.50 now and $3,144.50 per year in the future.

Total Externalities

If the externalities from CO_2, SO_2, and NO_x, were salable today, the potable water and sewage system could now earn $10.90 per year for The Alberta Sustainable Home/ Office or $36.37 per year in the future. If the societal value was included to current costs, the SHWS could earn the Alberta Sustainable Home/ Office $29.77 on an annual basis. Future income could represent $99.26 in 1998 dollars.

Therefore, for a small Eco-Village of 50 housing units, annual sales could generate sales of $545.00 now or $1,818.50 in the future, just for CO_2, SO_2, and NO_x avoidance. If the societal value was included, this would bring the current annual income to $1,488.50 and $4,963.00 annually in the future.

Table 19 and those aspects not evaluated at this time (but discussed below) provide a good beginning for the construction of a generic all-encompassing environmental template with which to evaluate any new project from an integrated approach to energy, operating costs, greenhouse gases, environmental and societal savings.

Environmental Advantages not Accounted For

It should be noted that, due to the lack of adequate information at this time, the only externalities that have been calculated for income projections are the offsets for $C0_2$, SO_2, NO_x and societal values. A thorough detailed and wholistic "life cycle accounting" on environmental savings would generate an entire study in itself. This brief introduction is meant for consideration in any future work of this nature.

No financial credits have been calculated for other greenhouse gases (GHG) under the Kyoto protocol such as methane (CH_4) or nitrous oxides (N_20) or other "criteria pollutants" (i.e. precursors of GHGs) such as carbon monoxide (CO), and non-methane volatile organic compounds (NMVOC). Another serious pollutant not assigned monetary values at this time are particulates. In addition, no monetary value has been found for other serious pollutants such as: mercury (Hg), hexavalent chromium (Cr), inorganic cadmium (Cd), lead (Pb), nickel compounds (Ni), and inorganic arsenic (As). Reactive organic gases (ROGs), halogens and sulphur oxides (SO_X) (@ 2.1 g/kWh for coal generated electricity) were not included in these calculations. This applies to both coal-generated electricity and natural gas for residential heating purposes.

In Alberta, as in some other provinces and states in North America, coal is still a major resource for generating electricity. In Alberta about 80-90% of all electricity comes from coal generating plants. Therefore, it should also be recognized that such plants may also produce: acids and anhydrides, amines, inorganic salts, carbonyl compounds, hetercyclics, polycyclic aromatic hydrocarbons, sulphur compounds, organic metallics, cyanides, trace elements, toxic elements, radioactive elements, nitric acid, nitrosamines, chromium chloride, formaldehyde, pyridines, benzene, hydrogen sulphide, tetraethyl lead, hydrogen cyanide, and radium. These were also not addressed and no environmental cost associated with their avoidance was found.

Therefore, any reductions in coal generated electricity should account for and bring value to these avoided emissions, as appropriate. If dollar values were assigned to each of these potent emissions, the income generation potential of environmental savings would be very significant.

The greenhouse gas emissions and other pollutants for natural gas combustion are not "full cycle" emissions (from drilling through to combustion) since they were not available. The values used were at the combustion site (end user). No calculations were undertaken for the heavy metals and toxic chemicals (as listed above) that were kept out of the environment due to reduced gas consumption, since these also were not available at this time.

A detailed analysis of other environmental externalities are justifiable but outside the scope of this work. Such items as impacts in water quality and quantity, soils, land use, aesthetics, indoor air quality were not addressed. "Residual emission values" using "cost of control" methodology or "damage functions" were also not addressed at this time. In future "Integrated Savings Accounts", these factors should be considered as measurements, methodologies and values become known.

It should also be noted that advantages were not assigned to the composting toilet in helping to relieve household garbage. This would impact utility costs for the homeowner, municipal operating costs, demand for landfill and methane gas releases, especially when calculated on a sustainable community basis.

Notes, Assumptions and Limitations

Notes, assumptions, and limitations to the integrated savings analysis are summarized below:

1) Table 19 is as up-to-date as possible without making this chapter a study in itself.
2) improvements to the SHWS will be made in the future as resources permit, to reduce its energy and maintenance requirements, improve its performance and income generation capabilities
3) additional environmental criteria and credits will be added to this format as numbers become known
4) electrical energy requirements and water quality testing will be monitored over the long term, as resources allow.
5) all electrical requirements are provided on-site from renewable resources and are thus not subtracted from the gains (savings) accrued.
6) the numbers used are quite conservative. Where ranges of values existed, their average were used.
7) information from various sources was very inconsistent and in many cases very incomplete. In some cases, pollutants were identified, but emission rates not shown. In other cases, many pollutants were not even addressed, even if they do exist. Full cycle emission analysis was available for coal generated electricity, but not for natural gas combustion (i.e. drilling to residential furnace).
8) the price for avoided carbon is now about $10-15/tonne and is expected by conventional economists to rise to $100/tonne.

Two price regimes are discussed below one at a current price of $15/t, and one at a future price of $50/t. The $100/t price scenario has not been discussed.

6.3.3 A 10 and 20 Year Forecast

One aspect of a future "Integrated Savings Account" would be to include a life cycle costing projection over a 10 and 20 year period to calculate savings for both an individual house and sustainable community. For instance, an initial review would indicate that the combined operating cost savings and future income generation (externalities) for the ASH home/ office would be $883 per year. The present value of $883 per year (assuming a 5% inflation rate) is $7,159 and $11,554 for 10 and 20 years respectively (based on partial environmental credits i.e. CO_2 only). On the scale of a small sustainable community (50 housing units), this would represent savings of $357,950 in 10 years and $577,700 in 20 years. If one considers 10 years as a reasonable payback period then $357,950 (the ten year savings) could represent an initial budget for the capital costs for such systems.

From a water point of view 336,000 litres of water and about 229,000 litres of sewage are saved through the Sustainable Home Water System. Due to a conserver lifestyle, on-site rainwater collection and the recycling of greywater for reuse, no city water is being used and no sewage needs to be treated by one of two municipal sewage treatment plants. This is also accomplished in the Toronto Healthy House. If these savings were realized over 10 and 20 year periods, savings would be very substantial. In addition, if they were considered on a subdivision basis, this could avoid significant infrastructure costs of a normal subdivision for storm, sewer and water piping and associated costs (i.e. excavation, maintenance, etc.) and may even be able to avoid or delay the construction of new treatment plants at some future date, depending on the size of the new community.

The income generation of some aspects of the Sustainable Home Water System such as the Greywater Garden Wall could be harnessed with income generating greenhouse activities such as fish farms, food production, flower gardens, aviaries, etc. in which a community could rent out space to urban farmers. Maintenance would be a job creation for on-site live-in staff.

6.3.4 Security of Supply and Service, Trends, Precedents

Another important environmental advantage of a SHWS is its security in times of emergencies and climatic stress. No cost has been assigned to this advantage. A self-sufficient water system is very resilient against earthquakes, ice storms, power outages, computer failures (i.e. Y2K) and flooding. If an earthquake hit the general urban area (i.e. water, sewer and storm lines broken), or the central sewage treatment plants were flooded (as has happened in several Albertan centers), or another "Great Ice Storm" occurred, to render the central life support system inoperable, any building with a Sustainable Home Water System would be much more secure against external failures that may occur anywhere else in the urban region.

As our urban infrastructure becomes more aged and outdated, as cities cut back on operating costs, as urban centers want to continue development without providing the infrastructure, as municipalities make greater use of "development levies", as water and sewer systems reach saturation levels and maximum capacities, as taxes and operating costs spiral upwards, as "user fees" become more universally applied to all aspects of civic service, as codes require greater energy efficiency, as green taxes (i.e. carbon taxes, energy levies, "add-ons", "riders" etc.) become more widespread, as global warming becomes more threatening, as weather patterns become more damaging, as insurance companies reward projects with reduced environmental impact, as "emissions trading" gains momentum, as more buildings and communities are being developed in remote locations (urban and rural), as the age of plenty comes to an end and the fossil fuel era comes to closure, then self-sufficient water systems in homes, communities, subdivisions, factories, schools and office buildings will become much more attractive, driven by any single or combined effect of the aforementioned indicators and trends.

As has already been demonstrated in several other precedents such as the Boyne River School in Ontario, the Body Shop in Toronto and the C.K. Choi Building in Vancouver, on-site sustainable water systems are already entering the mainstream. In the long term, this is the only feasible, tenable, cost-effective, environmentally-sound and politically astute direction that will be possible.

It should also be noted that these calculations do not assume a "development levy", for new development, as is being implemented in some cities (i.e. Vancouver) to cover infrastructure costs. Such costs are as high as $11,000 per housing unit. A SHWS would have much merit in such applications and could justify certain aspects to avoid municipal interconnections.

No discussion was made of fuel taxes, green taxes, congestion fees, or add-on "riders" that are being contemplated and legislated in various localities in North America (i.e. New Jersey, California) and elsewhere. More stringent code requirements are another trend that will make SHWS more justified. One municipality in Scandinavia will be banning the use of all water-flushed toilets beginning in the year 2000 where approximately 70% of all toilets are already biological. These mechanisms will spur on the consideration (and in some cases), the implementation of self-sufficient water systems.

6.3.5 Water and Sewage as Precious Resources

If both water and sewage were treated as precious commodities and given due respect to reflect their inherent value, operational savings would be much greater. The higher the costs, the greater the savings, and the more cost-attractive a sustainable home water system would be. The authors classify water as a non-renewable resource, due to the fact that once treated, all heavy metals and toxic chemicals are not eliminated and some do enter the environment downstream, even with primary, secondary and partial tertiary treatment. Human waste should be seen as a renewable resource including all biodegradable refuse which should be recycled for reuse on the property instead of being flushed away for disposal elsewhere.

6.3.6 Politics of Water

There is also a political aspect of a sustainable home water system. Many residents in numerous cities in Canada no longer trust city water for personal consumption and would rather pay for water of superior quality sold as bottled water. As more residents reject city water injected with fluoride, chlorine and other harmful substances, water consumption will drop slowly due to other sources of supply. The health concern of water for internal consumption has already given rise to questioning the possible serious impact and health concerns in taking baths and showers where very significant intakes of these chemicals and pollutants is possible. This is yet another reason to make every effort to advance self-sufficient home water systems. They are safer from a personal health point of view and allow far greater control and satisfaction than that now provided by mass inoculation of city water contrary to established scientific evidence, serious health risks and lack of personal consent.

At a future date, discussions with the city should be held to discuss the impact of such independent systems and to reduce property taxes since independent water systems do not use city water infrastructure or require associated maintenance costs.

7.0 CONCLUSIONS

The Sustainable Home Water System (SHWS) at the Alberta Sustainable Home/ Office is operating autonomously as an independent system from municipal water and sewer services. The SHWS design significantly reduces the actual potable water consumption at the ASH home/ office by 98.5% compared with an average residence in Calgary, Alberta. This is achieved through the adoption of a two-tiered water supply system consisting of potable and reuse water. Other factors are water conservation practices and integration of water conserving fixtures and appliances currently available on the market to Canadian consumers.

Potable water demands are easily supplied, even in semiarid environments such as Calgary, through the collection and treatment of rainwater to Canadian Drinking Water Quality (CDWQ) Guidelines. The potable water supply at the ASH home/ office is acceptable for human consumption according to the parameters tested. Some of the water quality parameters tested are currently unregulated but have aesthetic objectives that were exceeded slightly, however, are unlikely to cause health risks. Non-potable demands are satisfied by reclaiming and treating greywater. Currently there are no Federal or Alberta water quality standards or guidelines for use of non-potable water.

The greywater heat exchangers installed as part of the SHWS reclaim heat from greywater and transfer it to the reuse water supply to contribute to hot reuse water heating. The contributions to hot reuse water heating for the counter current greywater heat exchanger and drum storage greywater heat exchanger are 7.4 % and 4.4 % of the total hot reuse water used respectively. More efficient In-series operation of the greywater heat recovery system accounts for 16.8% of the required hot water heating at the ASH home/ office. Temperature efficiencies are 33.0% for the counter current heat exchanger, 20.8% for the drum storage heat exchanger, and 47.5% for both heat exchangers operating in-series.

Maintenance, and operation requirements of the SHWS are inexpensive, and require limited time, however, a complete understanding of the system is required. Maintenance includes filter and component cleaning, regular observations to determine proper operations, occasional adjustments, repairs, or replacement of parts, and harvesting edible biomass (i.e. plants, produce, and fish).

The total capital costs of this prototype SHWS is $33 500 (1998 $ Cdn.); however, this figure includes multiple systems such as the three greywater treatment systems. The total capital costs figure applies to the retrofit market and includes retail material costs and professional installation. New home applications would cost less at an estimate of $19200. Several of the components within the SHWS could be assembled and installed by homeowners which would further reduce the costs. If the system was installed on a larger scale such as in a sustainable community development (i.e. 50 housing units) costs could be reduced to approximately $14 200.

The benefits of heat recovery, water volume savings, central water supply and disposal infrastructure and operating cost savings offset the total SHWS capital and operating costs and gives an indication of the overall performance of the SHWS.

The annual power consumption of the pumps within the SHWS is a total of 1233 kWh which represents 72% of the average total electrical requirements at the ASH home/ office. This total electrical consumption for water supply and treatment is quite high but is associated with duplication of subsystems for demonstration and experimentation purposes. Therefore SHWS systems installed in other residences would not consume nearly as much energy as the ASH home/ office SHWS.

Environmental cost savings were determined for the SHWS at the ASH home/ office based on an Integrated Saving Account which includes savings in Energy, Greenhouse gases, Environmental Credits, Externalities, and Societal savings. Although the savings seem small for the ASH home/ office, the values were extrapolated to a sustainable community (i.e. 50 housing units) for present and future savings. Significant environmental benefits can be accrued through widespread adoption of sustainable home water systems.

Public perceptions of the SHWS have been positive during the bimonthly tours of the ASH home/ office. The touring public have genuine interest and are receptive to the various components that comprise the SHWS.

Therefore the Sustainable Home Water System is marketable as a cost-effective, environmentally- friendly, safe home water system in which components can easily be installed in both retrofit applications and new home residential water systems. Many of these components are commercially viable or are currently available on the market with favourable payback periods and are affordable. Examples include Vaughn's GFX, Earthstar's Graywater Heat Reclaimer, and Drain Gain. The SHWS as a whole has many duplicate components to compare their relative performances and to determine their optimal applications. This offers an inventory of methods for further investigation and offers a choice to consumers. There are many parameters that affect the design of a sustainable or autonomous home water system and each installation would be unique due to the preferences of the occupants. Therefore, the SHWS is marketable as an adaptable set of components that can be co-ordinated together or used separately for a particular market application. The resulting custom design would be appropriate for successful operation and performance within the framework of the occupants' lifestyle demands and location specific environmental limitations.

Applications of the SHWS could be especially beneficial and adapted for use in remote or rural areas, acreages with septic systems, agricultural applications, environmental sensitive locations, various climatic zones with scarce fresh water resources, areas with contaminated water sources, autonomous or sustainable communities, and environmentally conscious individuals.

Large scale centralized water and wastewater treatment systems including distribution and collection infrastructure are expensive taking into account capital costs, and continuous operation and maintenance costs. These systems require large inputs of energy and chemicals to ensure a supply of potable water and proper treatment of wastewater while attempting to maintain acceptable levels of health and safety.

Centralized wastewater treatment is inefficient since wastewater is mixed sewage consisting of residential greywater and sewage, surface runoff, and industrial sewage. The combination of these waste streams produces toxic byproducts and large volumes of wastewater that could be treated more effectively separately. Excessive volumes of potable quality drinking water are used for non-consumption purposes which represents a waste of energy and money to treat the water in the first place. If SHWS design principles were incorporated into common practice in Calgary, residential potable water consumption could be reduced by 78% through the incorporation of conservation practices and common sense and up to 97% if reuse water is used for non-potable water demands.

Incorporating the SHWS into Canadian residences in both retrofit and new applications include the following benefits: improves conventional water and wastewater treatment systems, reduces infrastructure, operation and maintenance costs, fresh water resource conservation, environmental protection, enhances environmental awareness, and economics (i.e. utility bill reduction) as detailed below.

SHWS benefits include improvements to Conventional Water and Wastewater Treatments:

- collection of rainwater diverts runoff in cities and buffers the overflow into storm and wastewater sewer infrastructure (this results in a decreased load on waterways and treatment plants and improves water treatment effectiveness)
- decreases potable water demand and consumption for non-potable uses
- decreases load on wastewater treatment plants and septic systems which improves wastewater treatment performance
- improved treatment effectiveness reduces levels of pollutants entering surface water, groundwater, and contaminating soils
- extends life and capacity of treatment methods and facilities
- reduce capital costs by postponing the need for expanding infrastructure requirements due to growing populations
- lower energy requirements, operation costs, and chemical use for treatment

SHWS benefits include enhanced Environmental Protection:

- protects water quality of natural surface water and groundwater
- natural purification of greywater in biologically active layer of soil through greywater subsurface irrigation

- faster decomposition of greywater components which are easily assimilated into usable nutrients compared with combined residential and industrial wastewater
- promotes use of biocompatible cleaning and health care products (avoid toxic compounds, phosphates, salts, boron, chlorine since harmful to plants, soil structure and permeability)
- waste reduction

SHWS benefits include Resource Conservation:

- reduces total water use
- minimizes use of uncontaminated fresh water resources
- subsurface irrigation recharges local groundwater aquifers
- reclamation and reuse/recycling of nutrients
- reclamation and reuse of heat energy otherwise lost down the drain
- increase natural fertility of soil
- greywater subsurface irrigation increases plant productivity (especially in arid environments where water is a limiting factor)
- allows waste to be reused on-site (i.e. garden compost)

SHWS benefits include enhanced Environmental Consciousness:

- become more in tune or balanced with nature through awareness
- responsible use of the resources that we do consume
- demonstrate a successful alternative to water and wastewater management
- promote sustainable and environmentally responsible alternatives

SHWS benefits include improvements in Economics:

- lower utility costs (i.e. water, gas, electric)
- increase energy-efficiency
- improve home resale value
- integration of many products that are currently commercially viable
- flexible options allow customization of water systems to unique situations (i.e. choose appropriate treatment options: slow sand filtration, soil bed irrigation, or greywater garden wall; rainwater collection if viable and residential water demands match local climatic characteristics)
- increased market and need for such products due to water shortages, droughts, mistrust of water quality from current source, cost of bottled water, contaminated drinking water sources (i.e. surface water and groundwater), remote areas, failing septic systems, expanding communities' stress on current infrastructure

7.1 Government Involvement

Current legislation recognizes only two classes of water, potable and sewage. Even though greywater is a potential valuable resource, it is not addressed. The current lack of government regulations or guidelines addressing greywater reuse creates confusion and an overlap of responsibilities between multiple levels of government with respect to evaluating greywater reuse systems such as the Sustainable Home Water System at the ASH home/ office. The following list include some of the departments that potentially have jurisdiction over the operation of the SHWS. Related bylaws, guidelines, regulations, Acts, and Codes that are affected are also included.

Municipal: (City of Calgary)
Plumbing Bylaws
Water and Waste Management Regulations
Medical Officer of Health
Public Health Act - Nuisance Regulations
Plumbing and Gas Safety

Provincial: (Alberta)
Environmental Health
Alberta Environmental Protection - Clean Water Act
- Surface Water Regulations
Alberta Labour - Plumbing Branch - Plumbing and Drainage Act
Alberta Building Code

Federal: (Canada)
Canadian Drinking Water Quality Guidelines, 5th Edition, Health and Welfare Canada

7.2 Compliance Issues

The SHWS has adopted the following basic principles to prevent health and safety risks and address compliance within current standards and practices related to general water use.

- no direct human contact with the greywater
- prevent the contamination risk of cross connections between greywater and potable water supplies (eg. completely separate both water systems, potable water pressure greater than greywater or reuse water pressure, double wall linings with positive leak protection between water supplies when in close contact (i.e. greywater heat exchangers))
- install a backflow preventor or disconnect the municipal potable water supply from the SHWS completely
- avoid use of greywater from infected persons or soiled diaper wash water
- regular monitoring and maintenance of system operations
- use gloves when cleaning or maintaining greywater system (i.e. filters) since infectious organisms may be present
- label reuse water plumbing clearly (indoors and outdoors)
- avoid surface application (including sprinklers) of greywater to soil, foliage, and turf

- irrigate through subsurface dispersal methods only
- permit intermittent greywater applications to prevent saturation of soil and promote aeration
- divert water to municipal sewer system if toxic, harmful or questionable products enter the greywater system (option available but unlikely to occur)
- when applicable, use septic tank leach field guidelines for leach fields in order to prevent contamination of wells

The following basic health and safety issue is not being met with the current level of water use in the SHWS. Once the water system's supply and demand are balanced this issue will be resolved.

- greywater should not be stored or left to become stagnant

Due to its autonomous nature the SHWS is a relatively closed system. The only output of water from the system will be outdoor greywater subsurface irrigation when commissioned. According to the November 1992 study by the Office of Water Reclamation, City of Los Angeles, CA, titled Greywater Pilot Project: Final Report, there is no health threat from greywater subsurface irrigation since the background levels of pathogenic organisms in the soil is greater than the levels found in greywater. At the ASH home/ office there is no risk of cross contamination to the municipal potable water supply since the potable water connection has been physically disconnected from the entire SHWS system. The water main valve could also easily be turned off at the property line as an extra precaution. The wastewater sewer is not currently being used either. The greywater flows into a sump and is pumped to the greenhouse for treatment then cycles through the home/ office system again as the reuse water supply.

8.0 RECOMMENDATIONS

Recommendations for improvements to the Sustainable Home Water System (SHWS) include simplifying the system for future applications. There are multiple overlapping systems being tested as potential options within the SHWS design. For example, greywater is treated by slow sand filters, soil bed irrigation, and the Greywater Garden Wall. Two types of greywater heat exchangers were also analyzed: counter current and drum storage greywater heat exchangers. This flexibility allows for customization of the SHWS design so that it matches the water use patterns and preferences of the occupants, resulting in successful operation and acceptance of the SHWS.

Some aspects of the SHWS were designed as retrofits based on design limiting space restrictions, current plumbing locations and configurations and lack of a basement. Therefore the design, as a prototype and retrofit, is not as efficient as a SHWS designed specifically for new home applications. Future systems will be configured to take further advantage of gravity systems and the cascade approach to water use, and limit the use of pumping mechanisms thereby decreasing energy consumption and capital costs of the system.

Further monitoring over a longer time frame would enhance evaluation of the behaviour and performance of the SHWS as a complete system. Specific testing is required to adequately determine the efficiencies of the drum storage greywater heat exchangers. Regular water quality monitoring of the various water sources in the ASH home/ office will indicate the temporal improvement in the performance of the treatment systems installed as part of the SHWS.

The main barrier of current water related standards and guidelines as mentioned previously is that greywater is not addressed as a potential water source for reuse applications. The main concerns are health risks associated with human contact with the greywater or cross contamination of with potable water supplies. At the ASH home/ office we have addressed these concerns within the SHWS.

1) In order to benefit from this potential resource and maintain safety and health standards, greywater and reuse water guidelines need to be developed in Canada. In states such as California and Florida greywater regulations have been developed in response to repeated water shortages and droughts. The following regulations and standards addressing greywater reuse should be used as resources for developing guidelines in Canada.

- U.S. Stormwater Regulations
- Appendix W of California Uniform Plumbing Code
  The standards were approved by the California Water Commission and took effect at the end of 1994. Included are Guidelines for Graywater Systems to ensure safe use of greywater via subsurface irrigation.
- California Building Standards Commission developed standards for construction, alterations and repair of greywater systems.

2) Further research and monitoring need to be conducted to determine typical greywater characteristics and water quality. This information would be used to determine and ensure safe greywater handling procedures and appropriate, effective treatment options.

3) Reuse water quality characterization is required to determine appropriate guidelines and define acceptable water quality parameters for beneficial and safe application of reuse water for various reuse demands (i.e. subsurface irrigation, toilet flushing, clothes washing, bathing).

4) The value of greywater should be recognized by existing codes and waivers should be given for initial greywater system applications to gain further experience and knowledge.

5) Develop appropriate plumbing and building codes to ensure proper installation of greywater and reuse water applications.

6) Building officials should be educated and trained in inspecting greywater/reuse water systems.

7) Relevant trade associations should be informed and updated with current R & D

8) Plumbers and related trades should be educated and trained to install, maintain, and repair greywater and reuse water systems.

9) Provide public awareness of greywater reuse benefits through education and information dissemination. (eg. simple information brochures for homeowners)

10) Adopt incentive or rebate programs for retrofit greywater or reuse water system installations.

11) Require installation of greywater or reuse water systems in all new homes.

12) Extend existing federal programs to include or develop new programs to encourage and promote use of on-site greywater treatment systems and heat exchangers (i.e. R-2000, New Energy Code for Houses) in appropriate applications (i.e. schools, hotels, federal buildings) and to help Canadian manufacturers with initial market penetration.

13) CMHC should support larger community-based projects for further research and monitoring.

Proposing specific changes to existing codes, regulations, guidelines, standards, or Acts is beyond the scope of this report since it would require in depth research and the input from various government bodies, researchers and experts in related fields (i.e. health, safety, plumbing, water quality, water resources, environment, horticulture), and public feedback.

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Appendix A-1

Greywater Heat Exchange Monitoring at the Alberta Sustainable House

TC	Description	Location
TC1	Reuse Water In (Cold)	Inlet to Drum Heat Exchanger
TC2	Reuse Water Out (Warm)	Outlet from Drum Heat Exchanger
TC3	Reuse Water In (Warm)	Inlet to Counter Current Heat Exchanger
TC4	Reuse Water Out (Hot)	Outlet From Counter Current Heat Exchanger
TC5	Greywater In (Hot)	Inlet to Counter Current Heat Exchanger
TC6	Greywater Out (Warm)	Outlet From Counter Current Heat Exchanger
TC7	Greywater In (Warm)	Inlet to Drum Heat Exchanger
TC8	Greywater Out (Cold)	Outlet from Drum Heat Exchanger
TC9	Dryer Air In (Warm)	Inlet to Drum Heat Exchanger (optional)
TC10	Dryer Air Out (Cold)	Outlet from Drum Heat Exchanger (optional)

Test # 1cc: Counter-current Heat Exchanger (Scenario a)

		Thermocouple Temperature Readings (^{0}C)						
Date	Time	TC3	TC4	TC4-TC3	TC5	TC6	TC6-TC5	Comments
98/08/15	11:01:00							reuse meter reading 0.093 m^3
	11:02:00							9.0L/ 60.7 sec = 8.9L/min
	11:05:00				32.4	33.1	0.7	
	11:05:30	24.7	33.9	9.2				
	11:08:15	25.2	33.9	8.7				
	11:08:45				32.3	32.6	0.3	
	11:12:15	25.6	34.1	8.5				
	11:12:00				32.2	32.7	0.5	
	11:17:15	25.9	32.7	6.8				
	11:17:45				30.6	30.8	0.2	
	11:19:00							reuse meter reading 0.094 m^3
	11:20:00							6.0L/ 89.7 sec = 4.0L/min

Appendix A-2

Test # 2cc: Counter-current Heat Exchanger (Scenario c)

Date	Time	Thermocouple Temperature Readings (^{0}C)						Comments
		TC3	TC4	TC4-TC3	TC5	TC6	TC6-TC5	
98/08/15	12:00:00							6.75L/47.2 sec = 8.58L/min
	12:03:15	18.9	18.8	-0.1				
	12:03:45				27.0	27.4	0.4	
	12:04:30							reuse meter reading 0.330 m^3
								6.0L/66.7 sec = 5.4L/min
	12:05:30	17.9	18.7	0.8				
	12:06:00				26.0	26.0	0.0	
	12:07:00	17.5	18.5	1.0				
	12:07:30				25.8	25.7	-0.1	
	12:08:45	17.5	19	1.5				
	12:09:00				25.9	25.7	-0.2	
	12:12:00							reuse meter reading 0.365 m^3

Test # 3cc: Counter-current Heat Exchanger (Scenario c)

Date	Time	Thermocouple Temperature Readings (^{0}C)						Comments
		TC3	TC4	TC4-TC3	TC5	TC6	TC6-TC5	
98/09/01	20:15:30							gw:6.25L/1:05 min= 5.77 L/min
								gw:6.0L/ 0:55 min= 6.55 L/min
	20:18:30				25.7	26.0	0.3	
	20:18:45	21.7	22.7	1.0				
	20:19:15							reuse meter reading 0.4001 m^3
	20:20:30				25.5	25.8	0.3	
	20:21:00	21.1	22.3	1.2				
	20:22:30				25.5	25.7	0.2	
	20:22:45	20.9	22.3	1.4				
	20:23:15							reuse meter reading 0.4135 m^3
	21:02:00	24.3	23.8	-0.5	22.8	24.1	1.3	no flow conditions
98/09/04	16:30:00	25.2	25.7	0.5	25.4	25.1	-0.3	no flow conditions, static
98/09/09	17:00:00	22.4	22.7	0.3	22.8	22.2	-0.6	no flow conditions, static

Appendix A-3

Test # 4cc: Counter-current Heat Exchanger (Scenario c)

Date	Time	Thermocouple Temperature Readings (°C)						Comments
		TC3	TC4	TC4-TC3	TC5	TC6	TC6-TC5	
98/09/12		24.2	23.2	-1.0	22.9	24.1	1.2	
		24.2	23.3	-0.9	23.0	23.9	0.9	
								gw: 6.0L/1:54 min= 3.2 L/min
	13:09:30							reuse meter reading 0.4530 m^3
	13:14:15				26.1	26.4	0.3	
	13:14:30	22.9	24.4	1.5				
	13:16:00				26.0	26.2	0.2	
	13:16:15	21.8	23.7	1.9				
	13:17:00							reuse meter reading 0.4670 m^3
	13:17:30				26.3	26.3	0.0	
	13:18:00	21.8	23.6	1.8				
								gw: 6.0L/1:44 min= 3.5 L/min
	13:21:00				26.6	26.5	-0.1	
	13:21:15	21.9	23.4	1.5				
	13:21:40							reuse meter reading 0.4755 m^3

Test # 5cc: Counter-current Heat Exchanger (Scenario c)

Date	Time	Thermocouple Temperature Readings (°C)						Comments
		TC3	TC4	TC4-TC3	TC5	TC6	TC6-TC5	
98/09/12	13:34:00							gw: 6.25L/0:35 min= 10.7L/min
	13:35:45							reuse meter reading 0.4830 m^3
	13:37:15				26.5	26.9	0.4	
	13:37:30	22.4	23.5	1.1				
	13:38:30	21.8	23.2	1.4				
	13:38:45				27.2	27.4	0.2	
	13:39:00							reuse meter reading 0.4980 m^3
	13:39:30	21.8	22.8	1.0				
	13:40:00				27.0	27.4	0.4	
								gw: 6.0L/1:23 min= 4.3 L/min
	13:45:30	23.0	24.1	1.1				

Appendix A-4

Test # 6cc: Counter-current Heat Exchanger (Scenario c)

Date	Time	Thermocouple Temperature Readings (^oC)						Comments
		TC3	TC4	TC4-TC3	TC5	TC6	TC6-TC5	
98/09/12	15:10:45							reuse meter reading 0.5200 m^3
								gw: 9.0L/1:20 min= 6.75 L/min
	15:13:45				28.2	29.1	0.9	
	15:14:00	24.3	26.3	2.0				
	15:15:00							reuse meter reading 0.5300 m^3
	15:15:15				28.6	29.0	0.4	
	15:15:30	23.6	25.5	1.9				
	15:16:45				28.4	28.9	0.5	
	15:17:00	22.8	24.6	1.8				
	15:18:30				28.5	28.8	0.3	
	15:18:45	22.7	25.2	2.5				
								gw: 6.0L / 0:51 min =7.1 L/min
	15:21:15				28.5	28.9	0.4	
	15:22:00	22.7	24.9	2.2				
	15:22:20							reuse meter reading 0.5470 m^3

Test # 7cc: Counter-current Heat Exchanger (Scenario c) **(test run concurrently with test #2ds)**

Date	Time	Thermocouple Temperature Readings (^oC)						Comments
		TC3	TC4	TC4-TC3	TC5	TC6	TC6-TC5	
98/09/17	19:15:00							solar tank temperature 51.6^oC
	19:15:00	24.6	23.7	-0.9	23.7	24.8	1.1	initial readings
	19:21:45							reuse meter reading 0.5720 m^3
	19:22:00							gw: 6.0L /0:42 min = 8.6 L/min
	19:24:30	24.5	27.0	2.5				
	19:25:00				30.4	31.2	0.8	
	19:26:30	25.1	27.4	2.3				
	19:26:15				30.6	31.8	1.2	
	19:27:45							reuse meter reading 0.5850 m^3
	19:28:00							gw: 6.0L/ 0:42 min = 8.6 L/min
	19:30:30	25.1	28.1	3.0				
	19:30:45				32.1	32.6	0.5	
	19:32:00	25.7	32.9	7.2				
	19:32:15				33.0	33.8	0.8	
	19:35:00							reuse meter reading 0.5880 m^3

Appendix A-5

Test # 1ds: Drum Storage Heat Exchanger (Scenario c)

Date	Time	Thermocouple Temperature Readings (^0C)						
		TC1	TC2	TC2-TC1	TC7	TC8	TC8-TC7	Comments
98/09/12	15:54:00							solar tank temperature 46.1^{0}C
	15:54:00	23.8	22.8	-1.0				initial reading before water flow
	15:54:30				24.8	25.0	0.2	initial reading before water flow
	15:58:00							reuse water meter reading 0.5490 m^3
	16:00:00							gw flow: 9.0L/ 2:09 min= 4.2 L/min
	16:02:00	23.0	26.4	3.4				
	16:02:30				28.2	26.2	-2.0	
	16:04:30	23.0	25.0	2.0				
	16:04:45				30.2	26.7	-3.5	
	16:05:50							reuse water meter reading 0.5590 m^3
	16:06:30	23.4	24.6	1.2				
	16:06:45				30.1	27.4	-2.7	
	16:08:00	23.0	24.1	1.1				
	16:08:15				29.8	27.2	-2.6	
	16:09:00							gw flow: 9.0L/ 2:05 min= 4.3 L/min
	16:12:45	22.4	24.3	1.9				
	16:13:15				29.7	27.6	-2.1	

Test # 2ds: Drum Storage Heat Exchanger (Scenario c) (run concurrently with counter-current heat exchanger test #7cc)

Date	Time	Thermocouple Temperature Readings (^0C)						
		TC1	TC2	TC2-TC1	TC7	TC8	TC8-TC7	Comments
98/09/17	19:15:00							solar tank temperature 51.6^{0}C
	19:21:00	22.5	23.4	0.9	23.6	23.7	0.1	initial reading before water flow
	19:21:45							reuse water meter reading 0.5720 m^3
	19:22:00							gw flow: 6.0L/ 0:42 min= 8.6 L/min
	19:23:30	23.1	24.2	1.1				
	19:24:00				27.5	23.7	-3.8	
	19:25:15	22.3	24.3	2.0				
	19:25:30				30.2	24.2	-6.0	
	19:27:45							reuse water meter reading 0.5850 m^3
	19:28:00							gw flow: 6.0L/ 0:42 min= 8.6 L/min
	19:29:15	22.6	23.3	0.7				
	19:30:00				31.0	24.6	-6.4	
	19:31:15	22.6	23.5	0.9				
	19:31:45				32.5	24.7	-7.8	
	19:35:00							reuse water meter reading 0.5880 m^3

Appendix A-6

Test # 8cc/ # 3ds: Counter-current Heat Exchanger and Drum Storage Heat Exchanger
DATE: October 3, 1998

Note: Tn refers to thermocouple location (see fig.7)

TIME	T3	T4	T4-T3	TIME	T5	T6	T6-T5	TIME	T1	T2	T2-T1	TIME	T7	T8	T8-T7
SCENARIO B: DRAWING A BATH															
SOLAR STORAGE TANK TEMP = 50^0C (122^0F); METER READING: COLD REUSE WATER = 0.617 m^3															
6:00:02	21.2	21.0	-0.2	6:00:46	20.8	21.4	0.6	6:01:38	20.8	20.4	-0.4	6:02:09	20.9	20.6	-0.3
6:02:33	21.9	20.2	-1.7	6:02:57	20.7	21.4	0.7	6:03:49	19.7	21.0	1.3	6:04:27	20.9	20.6	-0.3
6:05:18	20.3	20.3	0	6:05:40	20.9	21.3	0.4	6:06:21	19.7	19.9	0.2	6:06:50	20.9	20.6	-0.3
6:07:38	20.3	19.8	-0.5	6:08:17	20.9	21.4	0.5	6:08:40	19.8	19.9	0.1	6:09:03	20.9	20.6	-0.3
6:09:35	21.9	19.8	-2.1	6:10:12	20.9	21.3	0.4	6:10:48	20.1	19.9	-0.2	6:11:18	20.9	20.8	-0.1
FILLING OF TUB WAS COMPLETED; COLD REUSE METER READING = 0.656 m^3; REUSE WATER FLOW RATE (V_{RW}) = 3.5 L/min															
SCENARIO A: DRAINING THE BATH															
SOLAR STORAGE TANK TEMP = 50^0C (122^0F); COLD REUSE WATER METER = 0.656 m^3															
6:23:41	STARTED DRAINING THE TUB														
6:23:41	22.6	20.0	-2.6	6:24:22	21.5	22.1	0.6	6:24:53	20.1	20.2	0.1	6:25:24	23.8	21.0	-2.8
6:25:57	22.0	22.1	0.1	6:26:30	25.2	26.5	1.3	6:27:21	20.0	20.0	0.0	6:27:49	26.0	23.8	-2.2
6:26:30	WATER FINISHED DRAINING; STABILIZATION TEMPERATURES FOLLOW **(IE. SCENARIO D)**														
6:28:34	22.5	23.8	1.3	6:29:06	25.2	25.9	0.7	6:29:48	19.9	20.0	0.1	6:30:18	25.3	23.4	-1.9
6:31:08	24.3	24.1	-0.2	6:31:37	24.6	25.2	0.6	6:32:08	19.9	20.1	0.2	6:32:40	24.6	23.0	-1.6
6:33:13	22.3	24.1	1.8	6:33:46	24.2	24.6	0.4	6:34:20	19.9	20.1	0.2	6:34:53	24.1	22.6	-1.5
6:35:40	24.7	24.0	-0.7	6:36:15	23.7	24.0	0.3	6:36:47	19.8	20.2	0.4	6:37:19	23.5	22.5	-1.0
6:37:45	22.3	24.1	1.8	6:38:20	23.5	23.5	0.0	6:39:02	19.9	20.3	0.4	6:39:24	23.2	22.3	-0.9
6:40:15	22.3	24.1	1.8	6:40:40	23.3	23.3	0.0	6:41:24	19.9	20.2	0.3	6:41:47	22.9	21.9	-1.0
6:43:22	22.2	24.0	1.8	6:43:55	22.9	22.6	-0.3	6:44:29	19.7	20.3	0.6	6:45:00	22.5	21.8	-0.7
6:45:30	24.7	23.8	-0.9	6:46:23	22.7	22.5	-0.2	6:47:03	19.8	20.2	0.4	6:47:35	22.4	21.6	-0.8
6:48:50	22.6	23.8	1.2	6:49:23	22.5	22.5	0.0	6:50:55	19.8	20.4	0.6	6:52:00	22.1	21.4	-0.7
SOLAR STORAGE TANK TEMP = 50^0C (122^0F)															

Appendix A-7

Test # 9cc/ # 4ds: Counter-current Heat Exchanger and Drum Storage Heat Exchanger
DATE: October 9, 1998

TIME	T3	T4	T4-T3	TIME	T5	T6	T6-T5	TIME	T1	T2	T2-T1	TIME	T7	T8	T8-T7
SCENARIO D: STATIC TEMPERATURE READINGS															
SOLAR STORAGE TANK TEMP = 41^{0}C (105^{0}F); METER READINGS: TOTAL REUSE WATER = 1.373 m^3; COLD REUSE WATER = 0.658 m^3															
7:45:00	21.5	21.5	0.0	7:44:50	21.5	21.8	0.3	7:45:45	20.2	20.9	0.7	7:46:45	21.2	21.2	0.0
7:47:48	21.8	21.7	-0.1	7:48:00	21.5	22.0	0.5	7:49:06	20.2	21.0	0.8	7:49:35	21.4	21.3	-0.1
7:50:59	21.7	21.8	0.1	7:51:20	21.8	22.0	0.2	7:51:45	20.4	21.1	0.7	7:52:20	21.6	21.3	-0.3
7:53:02	24.1	21.7	-2.4	7:53:40	21.8	22.0	0.2	7:54:18	20.5	21.2	0.7	7:55:02	21.7	21.5	-0.2
7:55:25	24.0	21.8	-2.2	7:56:08	22.0	22.3	0.3	7:57:03	21.3	21.2	-0.1	7:57:34	21.8	21.5	-0.3
7:58:04	24.0	21.8	-2.2	7:59:25	22.1	22.3	0.2	7:59:54	20.7	21.3	0.6	8:00:30	22.0	21.6	-0.4
8:01:02	24.7	21.9	-2.8	8:01:50	22.1	22.3	0.2	8:02:35	20.6	21.4	0.8	8:03:12	21.8	21.6	-0.2
SCENARIO C: SHOWER															
SOLAR STORAGE TANK TEMP = 41^{0}C (105^{0}F); METER READINGS: TOTAL REUSE WATER = 1.373 m^3; COLD REUSE WATER = 0.658 m^3															
8:45:15	23.2	23.7	0.5	8:45:45	28.6	29.3	0.7	8:46:00	20.2	20.9	0.7	8:46:30	28.9	21.0	-7.9
8:47:05	20.6	23.3	2.7	8:48:40	29.3	30.1	0.8	8:49:15	20.5	20.8	0.3	8:49:50	29.3	21.5	-7.8
8:50:30	21.1	23.6	2.5	8:51:10	29.5	30.3	0.8	8:51:45	20.7	21.3	0.6	8:51:55	29.5	22.9	-6.6
8:52:04	21.7	24.0	2.3	8:52:35	29.6	30.5	0.9	8:53:25	20.9	21.6	0.7	8:54:01	29.7	22.7	-7.0
8:54:01	RAN OUT OF REUSE WATER SUPPLY V_{RW}=43.5L/ 8.75 mins= 4.97L/min HOT REUSE WATER FROM SST = 67.5 L														
SCENARIO B: DRAWING A BATH															
SOLAR STORAGE TANK TEMP = 39^{0}C (103^{0}F); METER READINGS: TOTAL REUSE WATER = 1.484 m^3; COLD REUSE WATER = 0.7015 m^3															
10:12:25	22.8	24.5	1.7	10:13:15	24.5	24.4	-0.1	10:13:45	21.1	27.4	6.3	10:14:15	23.0	23.9	0.9
10:15:05	23.2	26.5	3.3	10:15:35	24.4	24.5	0.1	10:16:15	21.0	23.1	2.1	10:17:20	22.9	24.1	1.2
10:17:50	22.4	22.6	0.2	10:18:25	24.5	24.0	-0.5	10:19:00	22.3	22.3	0.0	10:19:35	22.8	24.2	1.4
10:20:20	22.3	22.4	0.1	10:20:45	24.1	23.3	-0.8	10:21:50	21.3	22.3	1.0	10:22:30	23.0	23.9	0.9
10:23:10	24.0	22.4	-1.6	10:23:50	23.4	22.9	-0.5	10:24:21	21.4	22.4	1.0	10:25:00	22.8	23.9	1.1
10:23:10	FILLING OF TUB WAS COMPLETED V_{RW}=40L/ 12.5 mins= 3.2L/min HOT REUSE WATER FROM SST = 63 L														
SCENARIO A: DRAINING THE BATH															
SOLAR STORAGE TANK TEMP = 39^{0}C(103^{0}F); METER READINGS: TOTAL REUSE WATER= 1.58675 m^3;COLD REUSE WATER =0.7415 m^3															
10:29:54	STARTED DRAINING THE TUB														
10:30:30	22.4	22.4	0.0	10:30:50	25.0	24.3	-0.7	10:31:20	21.5	22.4	0.9	10:31:45	26.6	27.3	0.7
10:31:45	WATER FINISHED DRAINING; STABILIZATION TEMPERATURES FOLLOW (IE. SCENARIO D)														
10:32:35	24.2	25.5	1.3	10:33:09	27.9	28.5	0.6	10:34:38	21.4	22.4	1.0	10:35:10	27.7	27.2	-0.5
10:35:45	24.8	26.2	1.4	10:36:20	26.9	28.2	1.3	10:37:00	21.2	22.4	1.2	10:37:40	26.7	26.3	-0.4
10:38:15	24.3	26.3	2.0	10:38:55	26.3	27.7	1.4	10:39:00	21.2	22.4	1.2	10:39:15	26.0	25.6	-0.4
10:40:55	24.2	26.1	1.9	10:42:00	25.6	27.3	1.7	10:42:30	21.1	22.5	1.4	10:43:00	25.4	25.0	-0.4
10:43:36	27.2	26.2	-1.0	10:43:15	25.2	27.1	1.9	10:43:45	21.1	22.4	1.3	10:44:25	24.9	24.6	-0.3
SOLAR STORAGE TANK TEMP= 38^{0}C(100^{0}F); METER READINGS: TOTAL REUSE WATER= 1.58675 m^3;COLD REUSE WATER = 0.7415 m^3															

Appendix A-8

Test # 10cc/ # 5ds: Counter-current Heat Exchanger and Drum Storage Heat Exchanger
DATE: October 23, 1998

TIME	T3	T4	T4-T3	TIME	T5	T6	T6-T5	TIME	T1	T2	T2-T1	TIME	T7	T8	T8-T7
SCENARIO D: STATIC TEMPERATURE READINGS															
SOLAR STORAGE TANK TEMP = 54°C (130°F); METER READINGS: TOTAL REUSE WATER = 1.8155 m^3; COLD REUSE WATER = 0.743 m^3															
8:08:22	22.8	22.9	0.1	8:11:23	23.0	23.0	0.0	8:13:29	19.5	21.6	2.1	8:15:40	22.5	22.0	-0.5
8:16:27	23.2	23.1	-0.1	8:19:27	23.0	23.0	0.0	8:18:20	19.5	21.5	2.0	8:20:41	22.5	21.9	-0.6
8:23:06	24.3	23.0	-1.3	8:24:45	23.2	23.1	-0.1	8:25:39	19.7	21.6	1.9	8:26:45	22.6	22.0	-0.6
8:28:43	23.7	23.0	-0.7	8:29:05	23.5	23.3	-0.2	8:29:40	19.9	21.8	1.9	8:30:20	22.7	22.0	-0.7
8:31:25	25.2	23.2	-2.0	8:32:55	23.3	23.1	-0.2	8:32:35	19.9	21.7	1.8	8:33:10	22.7	22.1	-0.6
SCENARIO C: SHOWER															
SOLAR STORAGE TANK TEMP = 54°C (130°F); METER READINGS: TOTAL REUSE WATER = 1.8155 m^3; COLD REUSE WATER = 0.743 m^3															
8:49:38	22.0	22.6	0.6	8:49:26	24.7	25.5	0.8	8:51:35	20.4	20.0	-0.4	8:51:05	30.3	20.1	-10.2
8:52:40	22.8	26.4	3.6	8:52:20	34.7	33.8	-0.9	8:53:06	19.9	21.2	1.3	8:54:30	34.2	20.0	-14.2
8:54:30	20.6	24.6	4.0	8:55:05	35.8	35.0	-0.8	8:56:40	20.0	20.9	0.9	8:57:32	34.9	20.6	-14.3
8:58:22	21.2	25.1	3.9	8:58:58	36.1	35.3	-0.8	8:59:35	19.9	21.4	1.5	8:59:45	35.0	26.2	-8.8
RAN OUT OF REUSE WATER SUPPLY;STABILIZATION TEMPERATURES FOLLOW (IE. SCENARIO D);V_{RW} = 44.1L/10.12mins = 4.36 L/min															
9:01:21	24.9	25.7	0.8	9:01:58	36.4	35.7	-0.7	9:02:20	19.9	21.9	2.0	9:02:45	34.9	31.6	-3.3
9:04:32	25.7	29.0	3.3	9:04:13	35.4	32.2	-3.2	8:56:40	20.2	22.0	1.8	9:06:11	32.3	29.2	-3.1
SCENARIO B: DRAWING A BATH															
SOLAR STORAGE TANK TEMP = 53°C (128°F); METER READINGS: TOTAL REUSE WATER = 1.93 m^3; COLD REUSE WATER = 0.7871 m^3															
10:04:29	23.3	25.5	2.2	10:05:36	23.7	25.8	2.1	10:05:15	20.3	31.2	10.9	10:06:50	23.3	23.3	0.0
10:07:27	25.1	26.2	1.1	10:09:00	23.6	25.6	2.0	10:09:50	20.2	22.6	2.4	10:10:26	23.3	23.3	0.0
10:10:25	24.3	22.2	-2.1	10:12:35	23.6	23.6	0.0	10:12:30	20.3	22.3	2.0	10:13:24	23.1	23.3	0.2
10:14:50	22.1	22.0	-0.1	10:15:58	23.5	22.9	-0.6	10:16:26	20.4	22.2	1.8	10:17:07	23.2	23.2	0.0
10:15:24	FILLING OF TUB WAS COMPLETED														
SCENARIO A: DRAINING THE BATH															
SOLAR STORAGE TANK TEMP = 52°C(126°F); METER READINGS: TOTAL REUSE WATER = 2.0355 m^3; COLD REUSE WATER = 0.8295 m^3															
10:21:40	23.5	22.2	-1.3	10:21:59	24.3	23.4	-0.9	10:22:25	20.5	22.4	1.9	10:22:50	27.6	27.6	0.0
10:22:10	25	25.5	0.5	10:23:40	31.6	31.5	-0.1	10:24:48	20.2	22.4	2.2	10:25:17	32.3	32.0	-0.3
10:23:45	WATER FINISHED DRAINING; STABILIZATION TEMPERATURES FOLLOW (IE. SCENARIO D)														
10:25:01	29.6	29.4	-0.2	10:26:38	31.2	32.7	1.5	10:26:12	20.2	22.5	2.3	10:27:48	30.8	30.2	-0.6
10:28:29	30.5	29.3	-1.2	10:29:55	29.6	31.5	1.9	10:30:25	20.1	22.6	2.5	10:30:50	29.0	28.6	-0.4
10:31:45	25.4	29.0	3.6	10:32:20	28.6	30.7	2.1	10:32:50	20.2	22.8	2.6	10:33:20	27.9	27.4	-0.5
10:33:50	30.6	29.1	-1.5	10:34:20	27.9	30.3	2.4	10:34:57	19.9	22.7	2.8	10:35:30	27.2	26.9	-0.3
10:35:10	24.9	28.8	3.9	10:36:45	27.2	30.1	2.9	10:37:25	20.2	22.9	2.7	10:37:55	26.5	26.5	0.0
10:38:25	30.4	28.7	-1.7	10:39:02	26.9	29.7	2.8	10:39:44	20.0	23.0	3.0	10:40:45	25.6	25.9	0.3
SOLAR STORAGE TANK TEMPERATURE = 51°C (123°F)															