GLOBAL WARMING IMPACTS OF GROUND-SOURCE HEAT PUMPS COMPARED TO OTHER HEATING AND COOLING SYSTEMS

A Background Paper for the Buildings Table

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Introduction

Heat pumps can significantly reduce primary energy use for building heating and cooling. Heat pumps utilize renewable or solar energy stored in the ground near the surface (ground-source) or in the outdoor air (air-source). The renewable component, anywhere from as low as 33 (air-source) to 66 percent (ground-source) depending on location (climate), displaces the need for primary fuels, which when burned, produce greenhouse gases and contribute to global warming.

This analysis was undertaken on behalf of the Renewable and Electrical Energy Division to estimate the Total Equivalent (Global) Warming Impact (TEWI) of ground-source heat pumps compared to other heating and cooling systems in residential, commercial and institutional buildings. The modelling results show significant emission reductions in major cities in all regions of Canada. Heating impacts are examined in residential buildings, whereas both heating and cooling impacts are examined in commercial and institutional buildings.

TEWI Analysis

TEWI analysis can determine the overall contribution to global warming from energy using equipment over its operating lifetime. The electrical energy required by the equipment can result in releases of carbon dioxide and nitrogen oxides at the power plant. Fossil fuels, burned for heating purposes, release carbon monoxide, carbon dioxide and NO_x which also contribute to global warming. The leakage of refrigerants, greenhouse gases in themselves, used in both chillers and all heat pumps, contributes to global warming, as well.

The greenhouse gases released from fossil-fuel electricity production and combustion are referred to as the **indirect** TEWI effect. The leakage of refrigerants into the atmosphere is referred to as the **direct** effect. The global warming potential of released or leaked refrigerants is much greater than that of carbon dioxide.

The fuel used for electricity generation determines whether the electricity production results in large emissions of CO_2. In Canada, hydro power plants produced 64 percent of the total electricity generated in 1996 with another 16 percent from nuclear. Generation from combustion and fossil-fuel steam plants accounted for only 20 percent of the total electricity generated in the same year. The latter are large producers of CO_2, while the former produce none.

The electricity generation mix varies widely across Canada. In British Columbia and Quebec, 90 percent of the electricity is produced by hydro power plants. In Ontario, over 50 percent of the power is produced in nuclear plants with the remaining 50 percent is almost equally split between fossil-fuel and hydro power plants. In Alberta, Saskatchewan and Nova Scotia over 80 percent of the power is produced in fossil-fuel steam plants.

TEWI Analysis Data/Assumptions

The atmospheric emission factors and percent fossil-fuel electricity generation were obtained from the provincial utilities and Statistics Canada, respectively. The electric utility transmission and distribution losses were from the National Energy Board. The emission factors for natural gas combustion and oil combustion were from Natural Resources Canada. A natural gas transmission loss of 0.33 percent has been assumed. Refrigerant charges (R-22), for calculating the direct TEWI effect, reflect those of currently available equipment. Refrigerant leakage rates were from the Residential and Commercial reports of Environment Canada's Expert Panel on Alternative Refrigerants.

Energy Modelling

The **residential** house model had 230 m^2 of floor area above grade with a window area of 23 m^2. The insulation levels were R-20 in the walls, R-30 in the roof, with a basement wall insulation of R-10 applied to .6 meters below grade. The windows were double-glazed. The energy consumption of the competing **heating systems** was determined using the HVAC Advisor computer program for the cities of Vancouver, Toronto, Montreal and Halifax. The ground-source heat pump was closed-loop and was modelled using similar seasonal energy calculation procedures as those in HVAC Advisor for air-source heat pumps.

A small multi-unit residential building (MURB) and primary school building were two **commercial/ institutional building** models that were analyzed here. The **MURB** model is a 4-storey, 44 suite building, with an underground parking garage. The primary school is a 2-storey building with 4260 m^2 of floor space. The total energy use of these **buildings** was determined using the DOE 2.1E energy analysis program.

The energy efficiency characteristics of the residential heating equipment, ground-source heat pump, chiller and boiler used in the models are summarized in Table 1. The residential heating equipment, with the exception of the oil furnace, is high efficiency. The commercial/institutional **base case** building and equipment meets the energy requirements of the 1997 Model National Energy Code for Buildings. The ground-source heat pumps used in both the MURBs and primary school models are high efficiency commercial units, available in the market place.

Table 1: Equipment Energy Efficiency Characteristics

Residential Heating Equipment	Energy Efficiency Rating/Value
electric furnace	AFUE – 100%
oil furnace	AFUE – 78%
high efficiency air-source heat pump	HSPF (Region V) – 6.8
ground-source heat pump	COP @ 0 C – 3.3
high efficiency natural gas furnace	AFUE – 90%

Commercial/Institutional Equipment

MURB	Cooling	Heating
reciprocating chiller	COP – 3.8	–
boiler	–	Ec – 80%
ground-source heat pumps	EER – 15.5	COP – 3.4

Primary School

reciprocating chiller	COP – 4.2	–
boiler	–	Ec – 80%
ground-source heat pumps	EER – 15.5	COP – 3.4

Results of TEWI Analysis

Residential Heating Systems

The results of the residential TEWI analysis are presented in Table 2 and Figure 1.

The **ground-source heat pump** has the lowest TEWI or total equivalent mass of CO_2 over the twenty year lifetime, in all the cities examined. The natural gas furnace case shown italicized in Table 2 for Halifax is only shown for comparison. It will be a few years before off-shore gas is available to this market. Even then, electricity generation will be gradually converted to natural gas steam plants from coal and oil with the effect that the ground-source heat pump will likely remain the lowest TEWI system.

The **high efficiency air-source** heat pump has the second lowest TEWI in Vancouver and Toronto. In Montreal, because of the very large fraction of hydro power electricity generation, the electric furnace has the second lowest TEWI because of the direct effect of refrigerant leakage from the air-source heat pump. The use of refrigerants which are not greenhouse gases would change this ranking to that observed in the other cities. In Halifax, the oil furnace has a slightly smaller TEWI than the high efficiency air-source heat pump.

The **electric furnace** has a lower TEWI than the oil furnace and high efficiency natural gas furnace in Vancouver, Toronto and Montreal. This is due to the relatively small fraction of fossil fuel electricity generation in these areas. In Halifax, where over 80 percent of electricity production is from fossil fuel, the oil furnace has the second lowest TEWI, just below the high efficiency air-source heat pump, but still higher than the ground-source heat pump.

In Vancouver, the **oil furnace**, which currently meets the cross-Canada regulated minimum AFUE of 78%, will produce over 13 times the equivalent CO_2 emissions of the ground-source heat pump. In Toronto, this is reduced to six times.

In Vancouver, the **high efficiency natural gas furnace** produces over eight times the lifetime greenhouse gas emissions of the high efficiency ground-source heat pump. In Toronto, this is reduced to 3.5 times.

Only in Halifax, and other areas (such as Edmonton and Calgary) where significant electrical generation is by fossil-fuel plants, do conventional furnaces have comparable TEWIs to ground-source heat pumps.

Commercial/Institutional Buildings

The results of the commercial/institutional building TEWI analysis are presented in Table 3 and Figures 2 and 3. Here, **total** building energy use is included in the indirect TEWI effect.

The **GSHP** system building has the lowest total equivalent mass of CO_2 or TEWI impact, in both the MURB and primary school building, in all cities.

The magnitude of the reduction depends on the base case system efficiency and the electrical generation mix. It varies from a high of 77% in the primary school in Montreal to only 15% in Regina, where electricity is largely produced by fossil-fuel steam plants. The direct effect shown in Table 3, due to an assumed higher refrigerant leakage rate, is **higher** for the GSHP packaged system than for the modern central reciprocating chillers in the base case. The direct effect varies from city to city due to variations in equipment size and hence the refrigerant charge.

Conclusions

Significant emission reductions are available through the application of ground-source heat pumps in both residential and commercial buildings. For the examples presented here, residential fossil-fuel heating systems produced anywhere from 1.2 to 36 times the equivalent CO_2 emissions of ground-source heat pumps. In the two commercial/institutional segments examined, CO_2 emission reductions from 15% to 77% were achieved through the use of ground-source heat pumps. The conventional buildings and HVAC systems in the base cases were in accord with the 1997 Model National Energy Code for Buildings.

Ground-source heat pump equipment is widely available throughout Canada. The equipment is competitive on a life-cycle cost basis with those systems examined here, particularly in those markets where air-conditioning is desired.

There is unlikely to be a potentially larger mitigating effect on greenhouse gas emissions and the resulting global warming impact of buildings from any other current, market-available single technology, than from ground-source heat pumps.

Definitions

AFUE – annual fuel utilization efficiency, defined as the ratio of annual output energy to annual input energy, which includes any off-cycle loss and cycling effects.

COP – coefficient of performance, defined as the ratio of the rate of heat or cooling delivered to the rate of energy input, for a complete system, including the compressor, fans, pumps and auxiliary heat, if any, at a given operating condition.

E_c – combustion efficiency, defined as 100% less flue losses.

EER – energy efficiency ratio, defined as the ratio of net cooling capacity (in Btu/h) divided by the electric input in watts under standard rating conditions.

HSPF – (Region V) – heating seasonal performance factor, the total heating output of a air-source heat pump during its normal annual usage period for heating (in Btu) divided by the total electric energy input during the same period (in watt-hrs), for a given climate.

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Table 3: Environmental Analysis - GSHP vs Base Case (Primary Schools and Small MURBs - Total building energy)

					INDIRECT EFFECT				DIRECT EFFECT		
City	**System**	**Lifetime [yrs]**	**Electrical Energy [kWh]**	**Oil or Gas Consumed [L/yr] or [m^3/yr]**	**Electricity Gen./Trans. [kg equiv. CO_2]**	**Natural Gas Burner [kg equiv. CO_2]**	**Natural Gas Transmission [kg equiv. CO_2]**	**Total Indirect [kg equiv. CO_2]**	**Refrigerant Mass of CO_2 [kg]**	**Total Direct [kg equiv. CO_2]**	**Total Equiv. Mass of CO_2 [kg]**
Vancouver	**Primary Schools**										
	Base Case1: Central VAV	20	412001	46386	442270	1806710	47700	2296680	37485	37485	2334165
	GSHP	20	379140	8097	406990	315370	8330	730690	53295	53295	783985
Regina	**Primary Schools**										
	Base Case1: Central VAV	20	463602	81453	8818240	3172570	83770	12074580	40545	40545	12115125
	GSHP	20	513219	9408	9762010	366450	9680	10138140	53295	53295	10191435
Toronto	**MURBs**										
	Base Case1: 4-pipe/chiller/boiler	20	517944	40484	1635750	1576850	41630	3254230	18164	18164	3272394
	GSHP	20	568201	7498	1794470	292050	7710	2094230	46609	46609	2140839
	Primary Schools										
	Base Case1: Central VAV	20	467153	61838	1475340	2408580	63600	3947520	53550	53550	4001070
	GSHP	20	447894	8610	1414520	335360	8850	1758730	62985	62985	1821715
Montreal	**MURBs**										
	Base Case1: 4-pipe/chiller/boiler	20	508877	27968	144990	1089360	28760	1263110	18925	18925	1282035
	GSHP	20	537910	10235	153260	398650	10530	562440	41522	41522	603962
	Primary Schools										
	Base Case1: Central VAV	20	448463	54825	127780	2135410	56380	2319570	53550	53550	2373120
	GSHP	20	452335	8895	128880	346460	9150	484490	58140	58140	542630
Halifax	**MURBs**										
	Base Case1: 4-pipe/chiller/boiler	20	505135	32407	9777830	1894210	-	11672040	17018	17018	11689058
	GSHP	20	553088	6629	10706050	387450	-	11093500	46609	46609	11140109
	Primary Schools										
	Base Case1: Central VAV	20	421331	53794	8155650	3144260	-	11299900	43605	43605	11343505
	GSHP	20	410539	8293	7946750	484710	-	8431460	54910	54910	8486370

Table 2: Environmental Analysis - GSHP vs Other Systems (Residential - heating only)

City	System	Lifetime [yrs]	Electrical Energy [kWh/yr]	Oil or Gas Consumed [L/yr] or [m^3/yr]	INDIRECT EFFECT: Electricity Gen./Trans. [kg equiv. CO_2]	INDIRECT EFFECT: Oil or Gas Burner [kg equiv. CO_2]	INDIRECT EFFECT: Natural Gas Transmission [kg equiv. CO_2]	INDIRECT EFFECT: Total Indirect [kg equiv. CO_2]	DIRECT EFFECT: Refrigerant Mass of CO_2 [kg]	DIRECT EFFECT: Total Direct [kg equiv. CO_2]	Total Equiv. Mass of CO_2 [kg]
Vancouver	Electric Furnace	20	11481	-	12320	-	-	12324	0	0	12324
	Oil Furnace	20	715	1428	770	83470	-	84234	0	0	84234
	Hi. Eff. air-source HP	20	3838	-	4120	-	-	4120	4966	4966	9086
	GSHP	20	3926	-	4210	-	-	4215	2100	2100	6314
	Hi. Eff. Natural Gas Furnace	20	686	1344	740	52350	1382	54467	0	0	54467
Toronto	Electric Furnace	20	19431	-	61370	-	-	61366	0	0	61366
	Oil Furnace	20	817	2404	2580	140510	-	143094	0	0	143094
	Hi. Eff. air-source HP	20	8989	-	28390	-	-	28389	4966	4966	33355
	GSHP	20	6724	-	21230	-	-	21234	2100	2100	23333
	Hi. Eff. Natural Gas Furnace	20	766	2211	2420	86120	2274	90811	0	0	90811
Montreal	Electric Furnace	20	21561	-	6140	-	-	6143	0	0	6143
	Oil Furnace	20	865	2659	250	155420	-	155666	0	0	155666
	Hi. Eff. air-source HP	20	11938	-	3400	-	-	3401	4966	4966	8368
	GSHP	20	7829	-	2230	-	-	2231	2100	2100	4330
	Hi. Eff. Natural Gas Furnace	20	809	2435	230	94840	2504	97577	0	0	97577
Halifax	Electric Furnace	20	19366	-	374870	-	-	374865	0	0	374865
	Oil Furnace	20	885	2403	17130	140460	-	157587	0	0	157587
	Hi. Eff. air-source HP	20	8105	-	156890	-	-	156887	4966	4966	161854
	GSHP	20	6701	-	129710	-	-	129711	2100	2100	131811
	Hi. Eff. Natural Gas Furnace	*20*	*835*	*2222*	*16160*	*86550*	*2285*	*104994*	*0*	*0*	*104994*

Figure 1: Environmental Analysis – GSHP vs Other Residential Heating Systems (Heating energy only)

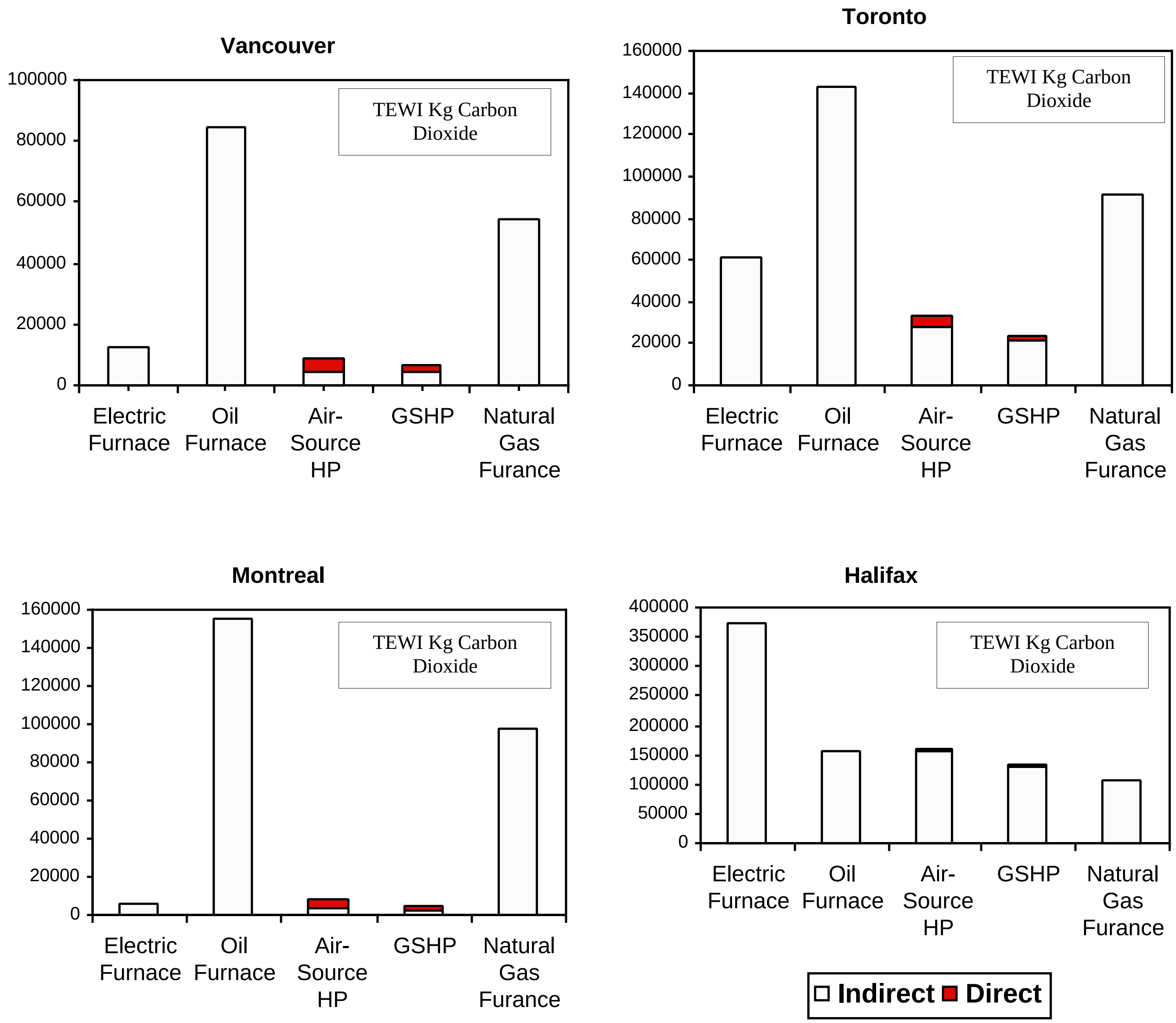

Figure 2: Environmental Analysis – GSHP vs Other Commercial/Institutional Systems (Primary Schools – Total building energy)

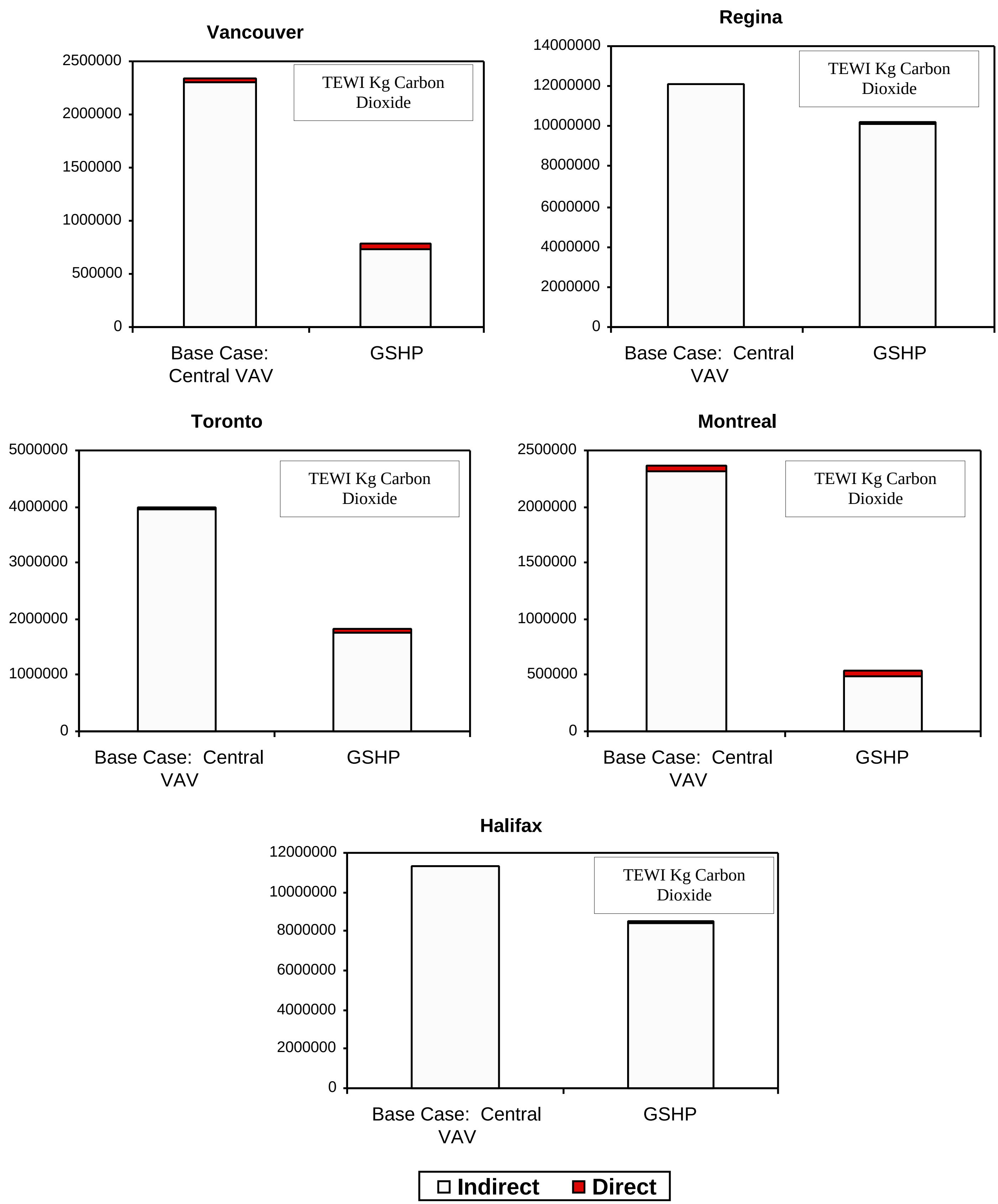

Figure 3: Environmental Analysis – GSHP vs Other Commercial/Institutional Systems (Small MURBs – Total building energy)