Energy Impacts of Heat Island Reduction Strategies in Toronto, Canada

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Abstract

The effect of heat-island reduction (HIR) strategies on annual energy savings and peak-power avoidance of the building sector of the Greater Toronto Area is calculated. The analysis is focused on three major building types that offer highest saving potentials: residence, office, and retail store. Using the DOE-2 building energy simulation model, we quantified the energy saving potentials of (1) using reflective roofs on individual buildings, (2) planting deciduous shade trees near the south and west walls of building, (3) planting coniferous wind-shielding vegetation near a building, (4) ambient cooling by a large-scale program of urban reforestation with reflective building roofs and pavements, and (5) the combined effects of 1-4.

Results show potential annual energy savings of over CAD$11M (with uniform residential and commercial electricity and gas prices of $0.084/kWh and $5.54/GJ) could be realized by ratepayers from the combined effects of HIR strategies. Of that total, about 88% was from the direct effects [1-3] and the remainder (12%) from the effects of the cooler ambient air temperature. The residential sector accounts for over half (59%) of the total savings; offices, 13%; and retail stores, 28%. Savings from reflective roofs were about 20%; shade trees, 30%; wind shielding of trees, 37%; and ambient cooling effect, 12%. These results are highly sensitive to the price of gas. Assuming a residential gas price of $10.84/GJ (gas price during December 2001), the net annual savings are reduced to about $10M; about 78% resulted from wind-shielding, 16% from shading by trees, and 5% from cool roofs.

Potential annual electricity savings were estimated at about 150GWh and potential peak-power avoidance was estimated at 250MW.

1. Introduction

During the summer, solar-reflective roofs (also known as "high-albedo[†]" or "cool" roofs) reflect most of the incoming sunlight and reduce the amount of heat conduction into a building. Similarly, strategically placed trees that shade windows and walls of a building reduce the amount of direct heat gain. The reduction in summer heat gains yielded by cool roofs and deciduous shade trees reduces the air-conditioning load of a building, improves thermal comfort, saves peak-demand electricity, and saves money. During the winter, cool roofs and the shading effects of trees may add to the heating load of a building. However, the heating-energy penalties are typically small, since (1) most of the heating is required during the dark evening hours, (2) winter days are shorter and cloudier than summer days, and (3) buildings may have snow on the roofs. Furthermore, trees can actually reduce heating-energy bills by shielding a building from cold winter wind (Akbari and Taha, 1992).

Cool surfaces (roofs and pavements) together with urban vegetation (shade trees, park trees, lawn, etc.) can potentially cool the city by a few degrees Celsius. Lowered urban air temperatures can further reduce cooling-energy demand. More importantly, cooler ambient conditions can slow the rate of smog (O_3) formation and significantly improve the ambient air quality (Akbari *et al.,* 2001).

Energy savings from the use of solar-reflective roofs and shade trees have been predicted through computer simulations and verified with measured data in both residential and commercial buildings.

[†]When sunlight hits an opaque surface some energy is reflected (albedo = â) and the remainder (1 - â) is absorbed.

Konopacki and Akbari (2001) provide a summary of many studies that have measured and/or simulated the energy savings of the Heat Island Reduction (HIR) measures.

The objective of this study was to assess the impacts of the HIR measures on building cooling-energy use, building heating-energy use, and on ambient air quality in the Greater Toronto Area (GTA). This paper summarizes our efforts to calculate the annual energy savings and peak-power avoidance resulting from the implementation of HIR strategies in the GTA. We focused on the effect of various HIR strategies on three major building types that offer most savings potential: residence, office, and retail store. The HIR strategies included: (1) use of solar-reflective roofing material on buildings [*direct effect*], (2) placement of deciduous shade trees near south and west walls of buildings [*direct effect*], (3) placement of coniferous wind-shielding vegetation near buildings [*direct effect*], (4) effect of ambient cooling by a large-scale program of urban reforestation with reflective building roofs and pavements [*indirect effect*], and (5) combination of strategies 1-4 [*direct and indirect effects*].

2. Methodology

HIR measures can reduce cooling energy use of low-rise residential and commercial buildings; they do not significantly affect the energy use of large multistory commercial or apartment buildings typically located in the downtown area (Konopacki *et al.,* 1997). Hence, we focused our efforts mostly on single-family residential and low-rise commercial buildings (office and retail store).

We modeled a total of 20 prototypes, including ten residential buildings [pre-1980 (1980^-: built prior to 1980) singles-family houses, post 1980 (1980^+: built in 1980 or later) single-family houses, R-2000 single-family houses, 1980^- row-houses, 1980^+ row-houses; all modeled with both gas and electric heating systems], four office buildings [1980^- offices, 1980^+ offices; both modeled with gas and electric heating systems], and four retail store buildings [1980^- retail store buildings, 1980^+ retail store buildings; both modeled with gas and electric heating systems].

The calculation methodology included:

i. defining detailed prototypical building characteristics for 1980^- and 1980^+ construction;
ii. simulating annual energy use and peak demand using the DOE-2.1E model and determining direct and indirect energy and demand savings for each HIR strategy;
iii. estimating the total roof area of air-conditioned buildings in the GTA, using existing data sources; and
iv. calculating the metropolitan-wide impact of HIR strategies.

3. Building and Measure Descriptions

Prototypical building data were identified and used to define construction, internal load, and cooling and heating equipment characteristics for residential, office, and retail buildings. The buildings were characterized for 1980^- and 1980^+ construction vintages; an R-2000 residence was also modeled. The prototypes were developed with both gas and electricity heating systems. The use of existing and reflective roofs, the placement of deciduous shade trees about the south and west sides the building, and the placement of coniferous trees to shield the building from cold winter wind were considered. These data then defined the characteristics of the prototype building used by the DOE-2.1E energy simulation computer program. Building data were obtained primarily from NRCAN (2001a and 2001b) and Akbari and Taha (1992), and Konopacki *et al.* (1997).

A solar-reflective roof absorbs less sunlight than a conventional dark-colored roof. Less absorbed sunlight means a lower surface temperature, which directly reduces heat gain through the roof and air-conditioning demand. Typical values of albedo for low- and high-albedo roofs were selected to cover the wide range of commercially available roofing materials (shingles, tiles, membranes and coatings) and the effects of weathering and aging. These were obtained primarily from the Cool Roofing Materials Database (CRMD, 2001), containing measured values of roof absorptance across the solar spectrum. For this analysis, the values of roof albedo were chosen to be 0.2 and 0.5 for residential roofs and 0.2 and 0.6 for commercial roofs, which represent low and high albedo materials.

Shade trees were modeled in DOE-2 as a box-shaped building shade with seasonal transmittance*. The summertime transmittance was 0.1 for 1 April through 31 October and wintertime transmittance was 0.9 for the remainder of the year. The geometry of the modeled tree consisted of a square cross-sectional area of 21m^2, 4.6m by 4.6m, a depth of 3m, and a canopy height of 4.6m. They were placed outside the south and west walls near the windows (with 0.6m of clearance from the building) in order to maximize the impact on the building-cooling load. The number of shade trees modeled were 4, 8 and 10 for the residence, office, and retail store, respectively.

Trees shield a building from wind, directly reducing wind speed, and thus reducing outside air film conductance and wind-speed dependent infiltration. The tree-planting strategy consists of placing coniferous vegetation on the north side of a building to shield cold northerly winds, and locating deciduous foliage on the south and west sides. The wind-shielding effect was modeled using the internal functions of DOE-2.

4. Energy Simulations

The DOE-2 model simulates energy use of a building for 8,760 hours of a year, using typical hourly weather data. Using Toronto Weather Year for Energy Consumption (WYEC2) data, annual cooling-energy use, heating-energy use, and peak-power demand were simulated, and savings for each HIR strategy were calculated. The MM5 mesoscale meteorological model was used to simulate the impact of urban surface modifications on the cooling of the regional ambient air. Following that step, the WYEC2 data were modified to account for this ambient cooling. The rerun of the DOE-2 simulations with the modified weather data quantified the *indirect* impact of HIR measures on building-energy use.

To quantify the ambient cooling from the indirect effect, the combined effect of the cool roofs, cool pavements, and urban vegetation on temperature was simulated using the PSU/NCAR MM5 model (Grell *et al.*, 1994). From the meteorological simulations, we calculated a modified average dry-bulb air temperature using hourly temperature data from 15 locations within the boundaries of the model over 72-hour winter (Jan 15-17) and summer (July 15-17) episodes. The drybulb temperature of the WYEC2 was then calculated for each hour of the year, using an algorithm based on a statistical analysis of temperature change (ΔT) as a function of solar intensity.

Local residential and commercial electricity and natural gas rates were applied to the simulation results to obtain total annual energy use in dollars. Average commercial rates for electricity and natural gas consumption were available from a 1998 City of Toronto facility analysis (ICLEI, 2001) and were CAD$0.084 per kilo watt-hour (kWh) and $5.54 per giga Joule (GJ) ($0.206/m^3). Specific residential rates were obtained by inspecting the monthly utility bill for a typical house (Ligeti, 2002). The electricity rate was essentially the same as the commercial rates based on a comparison of Toronto Hydro Electric System rate schedules (THES, 2001). The gas rate was $10.84/GJ. To perform a preliminary analysis of the impact of the gas price on potential savings, we also calculated the net savings with a uniform price of $5.54/GJ for both residential and commercial buildings.

The simulated base energy use, peak demand, and savings are presented in **Tables 1 and 2**†. Table 1 shows the energy and demand savings in absolute terms [kWh/100m^2, GJ/100m^2 & kW/100m^2], and Table 2 shows the dollar saving in with two prices for residential gas. The simulations predicted net

* The fraction of light that passes through the tree is the transmittance.

† Linear interpolation can be used to estimate savings or penalties for other net changes in roof reflectance ($\Delta\hat{a}_2$) than presented in the tables ($\Delta\hat{a}_1$) (Konopacki *et al.*, 1997). Therefore, these results can be simply adjusted by the ratio $\Delta\hat{a}_2/\Delta\hat{a}_1$ to obtain estimates for other reflective roof scenarios.

annual energy savings of about 3-5% from combined direct and indirect effects [17-22$/100m^2 for old and 9$/100m^2 for new] in gas-heated single-family and row-house residences. This number increased to 10% for offices [40$/100m^2 for new and 100$/100m^2 for old] and 12% for retail buildings [40$/100m^2 for new and 100$/100m^2 for old]. Electric-heated units did not fare so well, where savings of 0-2% were simulated for residences and 5-9% for the office and retail buildings because the higher cost of heating with electricity than heating with natural gas.

An annual natural gas deficit was found for all building types and in each HIR mitigation strategy with the exception of wind-shielding; wind-shielding reduced the heating requirements of the buildings. The annual gas deficit for combined direct and indirect effects was 2-6$/100m^2 for residences, 11-12$/100m^2 for offices and only 0-3$/100m^2 for retail stores.

Simulated peak power reduction was significant for all building types and strategies (wind-shielding was the exception). Combined direct and indirect peak-demand reduction in cooling electricity was 21-23% in residences and 13-16% in offices and retail stores. This translates into 0.57-0.61kW/100m^2 for 1980- residences, 0.33-0.40kW/100m^2 for 1980$^+$ residences, 0.60-1.13kW/100m^2 for all offices, and 0.36-0.71kW/100m^2 for all retail stores.

5. Air-Conditioned Roof Area for the GTA

The stock of air-conditioned (a/c) residential, office and retail buildings in the GTA were estimated for 1980$^-$ and 1980$^+$ construction vintages and both natural gas and electricity heating systems. The 1996 population for the GTA was 4,218,465 persons residing in 1,488,370 households (STATCAN, 1996).

The total roof area for the stock of residences with a/c was calculated from integrating data from Statistics Canada (STATCAN, 1996), ICLEI Energy Services (ICLEI, 1997), and NRCAN (2001a). The residential stock was disaggregated into single-family, row-house (multi-family) and apartment structure types for 1980- and 1980$^+$ construction vintages. The total residential air-conditioned roof area for the GTA was estimated to be 39.8Mm^2 (77% single-family, 20% row-house and 3% apartment) (Konopacki and Akbari, 2001).

The total roof area for the stock of office buildings and retail stores with a/c was calculated for 1980$^-$ and 1980$^+$ construction vintages from integrating data from the above residential sector estimates and from Konopacki *et al.* (1997). Office and retail store air-conditioned roof area for the GTA was estimated to be 5.3Mm^2 (1.9Mm^2 for offices and 3.4Mm^2 for retail stores) (Konopacki and Akbari, 2001).

6. Metropolitan-Area Estimates

Metropolitan-wide potential annual electricity savings [giga watt-hour, GWh], annual natural gas deficit [peta Joule, PJ=10^{15} Joule], and peak power avoided [mega watt, MW] are presented in **Table 3.** Metropolitan-wide estimates of annual energy-use expenditure and savings [million Canadian dollar, M$] are presented in **Table 4** with two prices for residential gas. With uniform gas prices for commercial and residential buildings, annual electricity savings of $12.6M less a 10% natural gas deficit combine for a potential rate-payer benefit of over $11M. Of that total, about 88% was from the direct impact (roughly divided equally among reflective roofs, shade trees and wind-shielding) and the remainder (12%) from the indirect impact of the cooler ambient air temperature. The residential sector accounts for over half (about 59%) of the total savings, offices 13% and retail stores 27%. Savings from cool roofs were about 20%; shade trees, 30%; wind-shielding by trees, 37%; and the indirect effect, 12%. These results are highly sensitive to the price of gas. Assuming a residential gas price of $10.84/GJ (gas price during December 2001), the net annual savings are reduced to $10M; about 78% resulted from wind-shielding, 16% from shading by trees, and 5% from cool roofs.

Potential annual electricity savings were estimated at about 150GWh or over $12M, of which about 75% accrued from roofs and shade trees and only 2% from wind-shielding. The indirect effect from a modified urban fabric was 23%. The potential annual natural gas deficit was estimated to be over 0.232 PJ (about $1-2M), with actual savings of over $4-8M from wind-shielding and a combined penalty of under $3-7M. Residences accounted for about 94% of the gas deficit. Potential peak-power avoidance was estimated at about 250MW with about 74% attributed to the direct impacts (roofs about 24%, shade trees 51% and wind-shielding a small negative %) and the remainder (26%) to the indirect impact. About 83% of the avoided peak power resulted from the effects of the residences. The remainder was yielded by offices (7%) and retail stores (9%).

7. Discussion

In this study, we focused on three building types (residential, office, and retail store) that offer the highest potential savings for the GTA. However, HIR technologies are also very effective on other building types such as hospitals, schools, restaurants, grocery stores, etc. The potential savings from these other buildings only contribute a few percent additional savings for the entire GTA.

In reviewing the results of this analysis, the following should be considered:

- Reflective roofs and shade trees reduce summer cooling-energy use and also potentially increase winter heating-energy use. The net savings ($ savings in cooling energy use minus $ penalties in heating-energy use) is highly sensitive to prices of cooling- and heating-energy fuels.
- Our capabilities to simulate the shading effects of trees are typically more refined than our ability to simulate the wind-shielding effects. Future studies to investigate further the wind-shielding effects of trees on heating-energy use would improve the current estimates.
- DOE-2 can underestimate the cooling-energy saving potentials of reflective roofs by as much as a factor of two. Hence, the saving potentials shown for reflective roofs should be considered conservative.
- Although the simulations were performed for office, retail store, and residential prototypes, the results can be used to estimate savings potentials in other similar building types.
- The total roof area for commercial buildings in the GTA was estimated using an approach based on the population and the residential roof area. A more direct estimate of the actual roof area for commercial buildings can improve the accuracy of the estimates.
- The indirect saving potentials were only a small fraction of total potential savings. Hence, for energy saving potentials consideration, reflective roofs and shade trees that save energy both directly and indirectly should be given a higher priority than reflective pavements that only save energy indirectly.

8. Conclusion

We simulated the potential of Heat Island Reduction (HIR) strategies (i.e., solar-reflective roofs, shade trees, wind-shielding, reflective pavements and urban vegetation) to reduce cooling energy use in buildings in the Greater Toronto Area, Canada. For gas heated residential prototypes, the simulations predicted annual total energy savings of about 3-5% from combined direct and indirect effects. This number increased to 10% for offices and 12% for retail stores. Electric-heated units did not fare so well: savings of 0-2% were calculated for residences and 5-9% for offices and retail stores. For the entire GTA, potential annual energy savings of over $11M (with uniform residential and commercial electricity and gas prices of $0.084/kWh and $5.54/GJ) could be realized by rate-payers from the combined direct and indirect effects of HIR strategies. These results were highly sensitive to the price of gas. Assuming a residential gas price of $10.84/GJ (gas price during December 2001), the net annual savings are reduced to $10M.

Combined direct and indirect peak-demand reduction in cooling electricity was 21-23% in residences and 13-16% in offices and retail stores. This translates into 0.57-0.61kW/100m^2 for 1980$^-$ residences, 0.33-0.40kW/100m^2 for 1980$^+$ residences, 0.60-1.13kW/100m^2 for old and new offices, and 0.36-0.71kW/100m^2 for old and new retails. For the GTA, the potential avoided peak-power was estimated at about 250MW. About 83% of the avoided peak power was because of the effects of the residences and the rest yielded by offices (7%) and retail stores (9%).

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Table 1. Simulated cooling and heating annual base energy use and savings [electricity: kWh/100m^2, gas: GJ/100m^2], and peak-power demand and savings [kW/100m^2] from Heat Island Reduction strategies for prototype residential and commercial buildings. Direct savings are from the use of solar-reflective roofs, strategic placement of deciduous shade trees and wind-shielding vegetation. Indirect savings include the impact of reduced ambient air temperature from a modified urban fabric. kWh: kilo watt-hour; GJ: giga Joule; kW: kilo watt.

building type	**gas heat**				**electric heat**		**gas & electric heat**	
&	**electricity (kWh/100m^2)**		**gas (GJ/100m^2)**		**electricity (kWh/100m^2)**		**peak power (kW/100m^2)**	
mitigation strategy	1980$^-$	1980$^+$	1980$^-$	1980$^+$	1980$^-$	1980$^+$	1980$^-$	1980$^+$
Residence: Single-Family								
Energy use & demand	1057	629	75.0	49.3	14785	8391	2.70	1.71
Savings								
reflective roof	94	52	-0.9	-0.5	-62	-20	0.12	0.08
shade tree	133	74	-1.1	-0.7	-24	-8	0.32	0.18
wind shield	-32	-25	2.5	1.2	379	134	0.00	-0.02
indirect	88	51	-0.8	-0.5	-100	-59	0.13	0.09
combined	283	152	-0.2	-0.6	193	47	0.57	0.33
Residence: Row-House								
Energy use & demand	1277	643	70.6	32.8	18509	8393	3.01	1.87
Savings								
reflective roof	113	52	-1.1	-0.4	-111	-60	0.16	0.09
shade tree	127	75	-0.8	-0.5	-34	-11	0.29	0.22
wind shield	-18	-13	1.1	0.3	194	45	-0.02	-0.01
indirect	82	49	-0.7	-0.3	-138	-49	0.18	0.10
combined	305	164	-1.6	-0.8	-90	-75	0.61	0.40
Office								
Energy use & demand	7276	3842	57.3	27.5	16934	8108	7.12	4.20
Savings								
reflective roof	388	160	-0.5	-0.5	273	60	0.26	0.14
shade tree	637	260	-0.9	-0.8	485	129	0.43	0.23
wind shield	-36	-1	0.6	0.5	88	96	0.02	0.01
indirect	271	164	-0.3	-0.4	160	64	0.42	0.23
combined	1260	583	-1.2	-1.3	1007	350	1.13	0.60
Retail Store								
Energy use & demand	7493	3356	31.1	10.1	12733	4944	4.90	2.63
Savings								
reflective roof	522	200	-0.5	-0.6	429	102	0.26	0.14
shade tree	439	172	-0.2	-0.2	423	146	0.19	0.10
wind shield	-42	-13	1.1	0.8	138	111	0.02	0.01
indirect	258	133	-0.3	-0.3	179	82	0.24	0.11
combined	1177	492	0.0	-0.3	1170	442	0.71	0.36

Table 2. Simulated cooling and heating annual base expenditures and savings [$/100m^2] from Heat Island Reduction strategies for prototype residential and commercial buildings. The numbers in parentheses show % savings. Direct savings are from the use of solar-reflective roofs, strategic placement of deciduous shade trees and wind-shielding vegetation. Indirect savings include the impact of reduced ambient air temperature from a modified urban fabric.

building type & mitigation strategy	**Residential gas price of $5.54/GJ**				**Residential gas price of $10.84/GJ**			
	gas heat		electric heat		gas heat		electric heat	
	1980^-	1980^+	1980^-	1980^+	1980^-	1980^+	1980^-	1980^+
Residence: Single-Family								
Base energy expenditure	504	325	1242	705	898	584	1242	705
Savings								
reflective roof	2.5	1.5	-5.2	-1.7	-2.5	-1.1	-5.2	-1.7
shade tree	5.6	2.0	-2.0	-0.7	0.3	-2.0	-2.0	-0.7
wind shield	11.6	4.4	31.8	11.2	25.1	10.6	31.8	11.2
indirect	2.7	1.3	-8.4	-5.0	-1.7	-1.6	-8.4	-5.0
combined	22.5	9.3	16.2	3.9	21.2	5.9	16.2	3.9
Residence: Row-House								
Base energy expenditure	498	236	1555	705	868	408	1555	705
Savings								
reflective roof	3.4	1.9	-9.3	-5.1	-2.3	-0.4	-9.3	-5.1
shade tree	5.8	3.6	-2.9	-0.9	1.2	1.1	-2.9	-0.9
wind shield	4.4	0.6	16.3	3.8	10.0	2.3	16.3	3.8
indirect	3.0	2.7	-11.6	-4.2	-0.8	1.3	-11.6	-4.2
combined	16.7	8.9	-7.5	-6.3	8.2	4.3	-7.5	-6.3
Office								
Base energy expenditure	929	475	1422	681	929	475	1422	681
Savings								
reflective roof	29.5	10.3	22.9	5.1	29.5	10.3	22.9	5.1
shade tree	48.5	17.5	40.8	10.9	48.5	17.5	40.8	10.9
wind shield	0.8	3.1	7.4	8.1	0.8	3.1	7.4	8.1
indirect	20.9	11.2	13.5	5.4	20.9	11.2	13.5	5.4
combined	99.6	42.1	84.6	29.4	99.6	42.1	84.6	29.4
Retail Store								
Base energy expenditure	802	338	1070	415	802	338	1070	415
Savings								
reflective roof	40.7	13.0	36.0	8.6	40.7	13.0	36.0	8.6
shade tree	35.6	13.2	35.5	12.3	35.6	13.2	35.5	12.3
wind shield	2.1	3.3	11.6	9.4	2.1	3.3	11.6	9.4
indirect	19.8	9.3	15.1	6.9	19.8	9.3	15.1	6.9
combined	98.9	39.4	98.2	37.1	98.9	39.4	98.2	37.1

Table 3. Estimates of (a) annual cooling- and heating-energy savings and avoided peak power, and (b) savings in annual energy-use expenditures from Heat Island Reduction strategies for residential and commercial buildings in The Greater Toronto Area. Direct savings are from the use of solar-reflective roofs, strategic placement of deciduous shade trees and wind-shielding vegetation. Indirect savings include the effect of reduced ambient air temperature from a modified urban fabric. GWh: giga watt-hour; PJ: peta Joule; MW: mega watt; M$: million Canadian $.

a)

building type	**gas heat**				**electric heat**		**gas & electric heat**	
&	**electricity (GWh)**		**gas (PJ)**		**electricity (GWh)**		**peak power (MW)**	
mitigation strategy	1980^-	1980^+	1980^-	1980^+	1980^-	1980^+	1980^-	1980^+
Energy use & demand	596	103	20.7	4.4	570	125	1048	226
Savings								
reflective roof	45.5	6.9	-0.27	-0.05	-2.6	-0.8	48.4	10.0
shade tree	54.7	9.5	-0.27	-0.07	-0.9	-0.2	103.8	21.8
wind shield	-9.1	-2.2	0.61	0.11	13.0	0.8	-0.3	-1.4
indirect	33.3	6.5	-0.22	-0.05	-3.9	-0.8	53.5	11.5
combined	124.4	20.7	-0.16	-0.07	5.6	-0.9	205	42

b)

	Residential gas price of $5.54/GJ					**Residential gas price of $10.84/GJ**				
building type	**Annual energy and savings (M$)**				**Total**	**Annual energy and savings (M$)**				**Total**
&	gas heat		electric heat		**(M$)**	gas heat		electric heat		**(M$)**
mitigation strategy	1980^-	1980^+	1980^-	1980^+		1980^-	1980^+	1980^-	1980^+	
Base energy expenditure	164	33	48	10	256	273	57	48	10	388
Savings										
reflective roof	2.3	0.3	-0.2	-0.1	2.3	0.8	0.0	-0.2	-0.1	0.5
shade tree	3.1	0.4	-0.1	0.0	3.4	1.7	0.0	-0.1	0.0	1.6
wind shield	2.6	0.4	1.1	0.1	4.2	5.8	0.9	1.1	0.1	7.9
indirect	1.6	0.3	-0.3	-0.1	1.4	0.4	0.0	-0.3	-0.1	0.0
combined	9.6	1.3	0.5	-0.1	11.3	8.7	1.0	0.5	-0.1	10.1

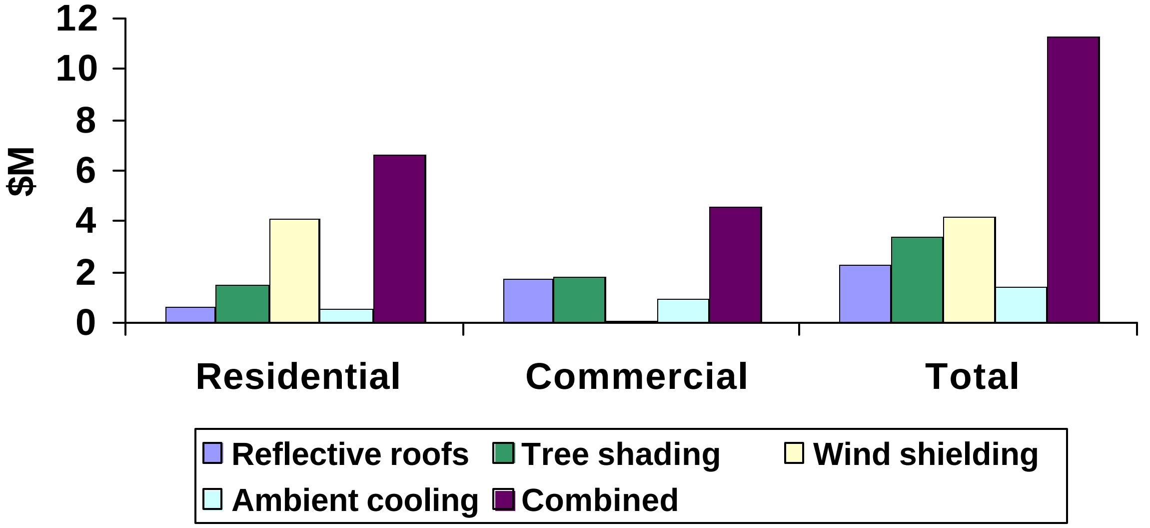

Figure 1. Savings in annual heating and cooling energy-use expenditure assuming a uniform electricity rate of CAD$0.084/kWh and gas rate of CAD$5.54/GJ.

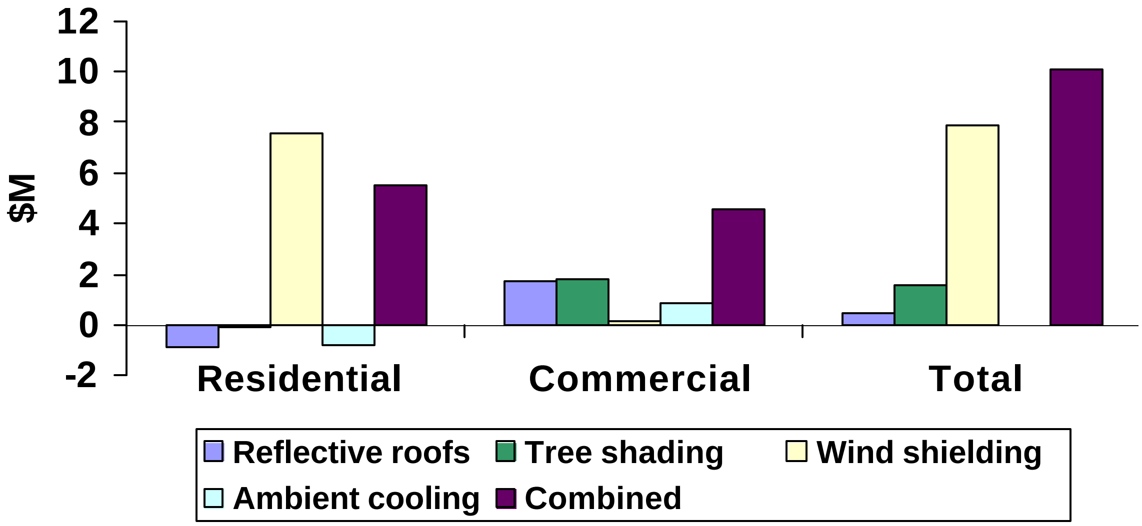

Figure 2. Savings in annual heating and cooling energy-use expenditure assuming a uniform electricity rate of CAD$0.084/kWh, commercial gas rate of CAD$5.54/GJ, and residential gas rate of CAD$10.84/GJ.