

# Energy Impacts of Heat Island Reduction Strategies in Toronto, Canada

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# Mitigation Measures: Light-Colored Surfaces and Trees

- **Direct Effect**

- ❖ **Light-colored roofs** reflect solar radiation, reducing air-conditioning use
- ❖ **Trees** that shade buildings reduce air-conditioning use

- **Indirect Effect**

- ❖ Cool (light-colored) surfaces in a neighborhood lower ambient air temperature
- ❖ Vegetation in a neighborhood reduces ambient air temperature by **evapotranspiration**



# Methodology: Energy and Air-Quality Analysis



# White Roofs and Trees: Measured Cooling Energy Savings

## ❖ Roofs

- *Sacramento*: 80% in a house; 35% in two school bungalows
- *Florida*: 10%-43% in several houses, average 19%
- *Recent Demonstrations*: 5%–20% in several commercial buildings in California and Florida

## ❖ Trees

- *Sacramento*: 30% in two houses
- *Florida*: 45% in a trailer office



# Heat-Island Reduction (HIR) Strategies

- High-albedo roofs [*direct effect*]
- Shade trees [*direct effect*],
- Wind-shielding trees [*direct effect*]
- Ambient air cooling by urban vegetation, reflective roofs, and reflective pavements [*indirect effect*]
- Combined strategies 1-4 [*direct and indirect effects*]



# Building Prototypes

- Residential (single-family, row houses)
- Offices
- Retail stores
- Pre-1980 (1980<sup>-</sup>) and post-1980 (1980<sup>+</sup>) vintage
- Electric cooling systems
- Both gas and heat pump heating system



# Methodology

- Define detailed prototypical building characteristics for 1980<sup>-</sup> and 1980<sup>+</sup> construction
- Simulate annual energy use and peak demand using the DOE-2.1E and determine direct and indirect energy and demand savings for each HIR strategy
- Estimate the total roof area of air-conditioned buildings in the Greater Toronto Area (GTA)
- Calculate the metropolitan-wide impact of HIR strategies



# Saving Potentials for Single-Family Residences (gas heated)

Mitigation strategy	elect. (kWh/100m <sup>2</sup> )		gas (GJ/100m <sup>2</sup> )		peak (kW/100m <sup>2</sup> )	
	1980-	1980+	1980-	1980+	1980-	1980+
Energy use & demand	1057	629	75	49.3	2.7	1.71
Savings						
reflective roof	94	52	-0.9	-0.5	0.12	0.08
shade tree	133	74	-1.1	-0.7	0.32	0.18
wind shield	-32	-25	2.5	1.2	0	-0.02
indirect	88	51	-0.8	-0.5	0.13	0.09
combined	283	152	-0.2	-0.6	0.57	0.33



# Saving Potentials for Row House (gas heated)

Mitigation strategy	elect. (kWh/100m <sup>2</sup> )		gas (GJ/100m <sup>2</sup> )		peak (kW/100m <sup>2</sup> )	
	1980-	1980+	1980-	1980+	1980-	1980+
Energy use & demand	1277	643	70.6	32.8	3.01	1.87
Savings						
reflective roof	113	52	-1.1	-0.4	0.16	0.09
shade tree	127	75	-0.8	-0.5	0.29	0.22
wind shield	-18	-13	1.1	0.3	-0.02	-0.01
indirect	82	49	-0.7	-0.3	0.18	0.1
combined	305	164	-1.6	-0.8	0.61	0.4



# Saving Potentials for Office (gas heated)

Mitigation strategy	elect. (kWh/100m <sup>2</sup> )		gas (GJ/100m <sup>2</sup> )		peak (kW/100m <sup>2</sup> )	
	1980-	1980+	1980-	1980+	1980-	1980+
Energy use & demand	7276	3842	57.3	27.5	7.12	4.2
Savings						
reflective roof	388	160	-0.5	-0.5	0.26	0.14
shade tree	637	260	-0.9	-0.8	0.43	0.23
wind shield	-36	-1	0.6	0.5	0.02	0.01
indirect	271	164	-0.3	-0.4	0.42	0.23
combined	1260	583	-1.2	-1.3	1.13	0.6



# Saving Potentials for Retail Store (gas heated)

Mitigation strategy	elect. (kWh/100m <sup>2</sup> )		gas (GJ/100m <sup>2</sup> )		peak (kW/100m <sup>2</sup> )	
	1980-	1980+	1980-	1980+	1980-	1980+
Energy use & demand	7493	3356	31.1	10.1	4.9	2.63
Savings						
reflective roof	522	200	-0.5	-0.6	0.26	0.14
shade tree	439	172	-0.2	-0.2	0.19	0.1
wind shield	-42	-13	1.1	0.8	0.02	0.01
indirect	258	133	-0.3	-0.3	0.24	0.11
combined	1177	492	0	-0.3	0.71	0.36



# Effect of Gas Price on Savings: Single-Family Residence (CAD\$/100m<sup>2</sup>)

Mitigation strategy	Res. gas \$5.54/GJ		Res. gas \$10.84/GJ	
	1980-	1980+	1980-	1980+
Base energy expenditure	504	325	898	584
Savings				
reflective roof	2.5	1.5	-2.5	-1.1
shade tree	5.6	2	0.3	-2
wind shield	11.6	4.4	25.1	10.6
indirect	2.7	1.3	-1.7	-1.6
combined	22.5	9.3	21.2	5.9



# Effect of Gas Price on Savings: Row House (CAD\$/100m<sup>2</sup>)

Mitigation strategy	Res. gas \$5.54/GJ		Res. gas \$10.84/GJ	
	1980-	1980+	1980-	1980+
Base energy expenditure	498	236	868	408
Savings				
reflective roof	3.4	1.9	-2.3	-0.4
shade tree	5.8	3.6	1.2	1.1
wind shield	4.4	0.6	10	2.3
indirect	3	2.7	-0.8	1.3
combined	16.7	8.9	8.2	4.3

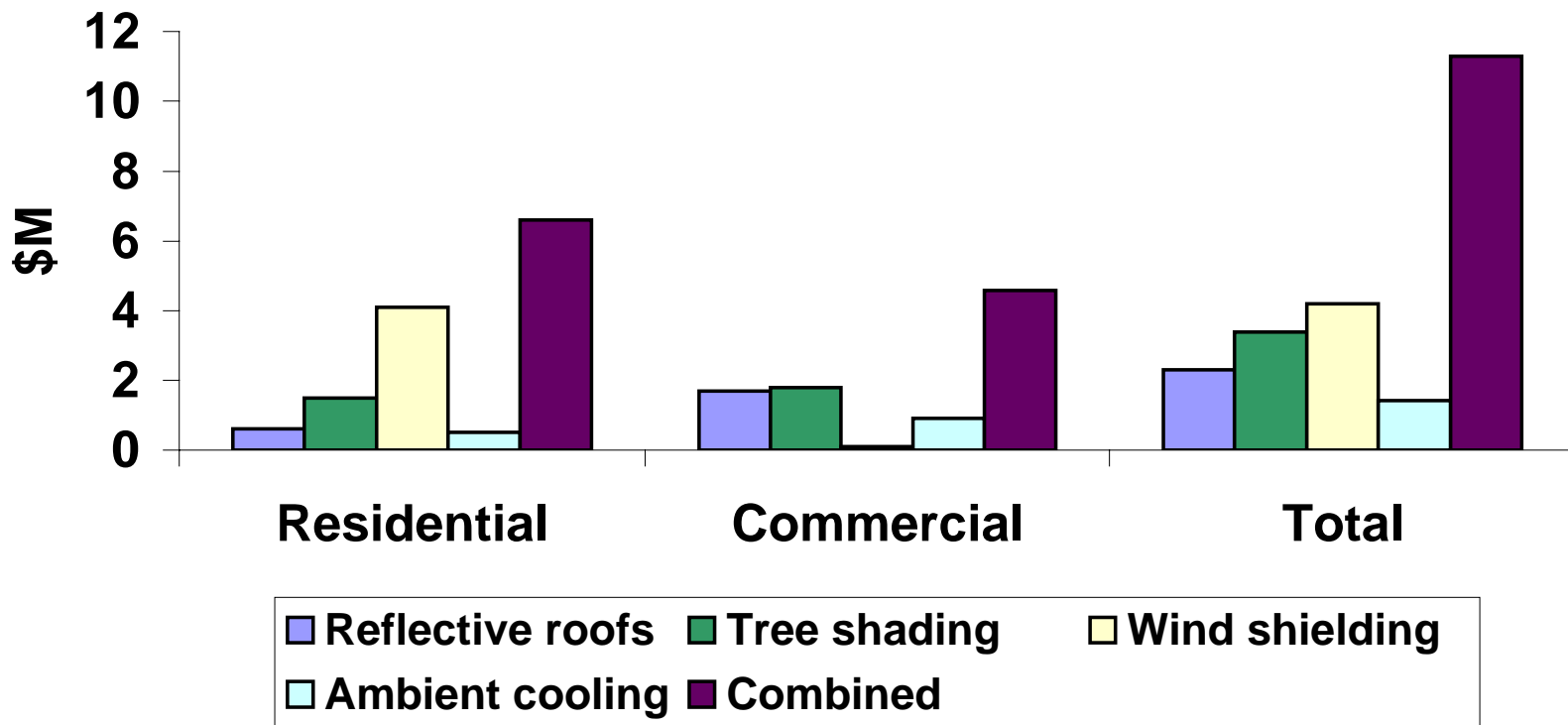


# Building Stock in the GTA

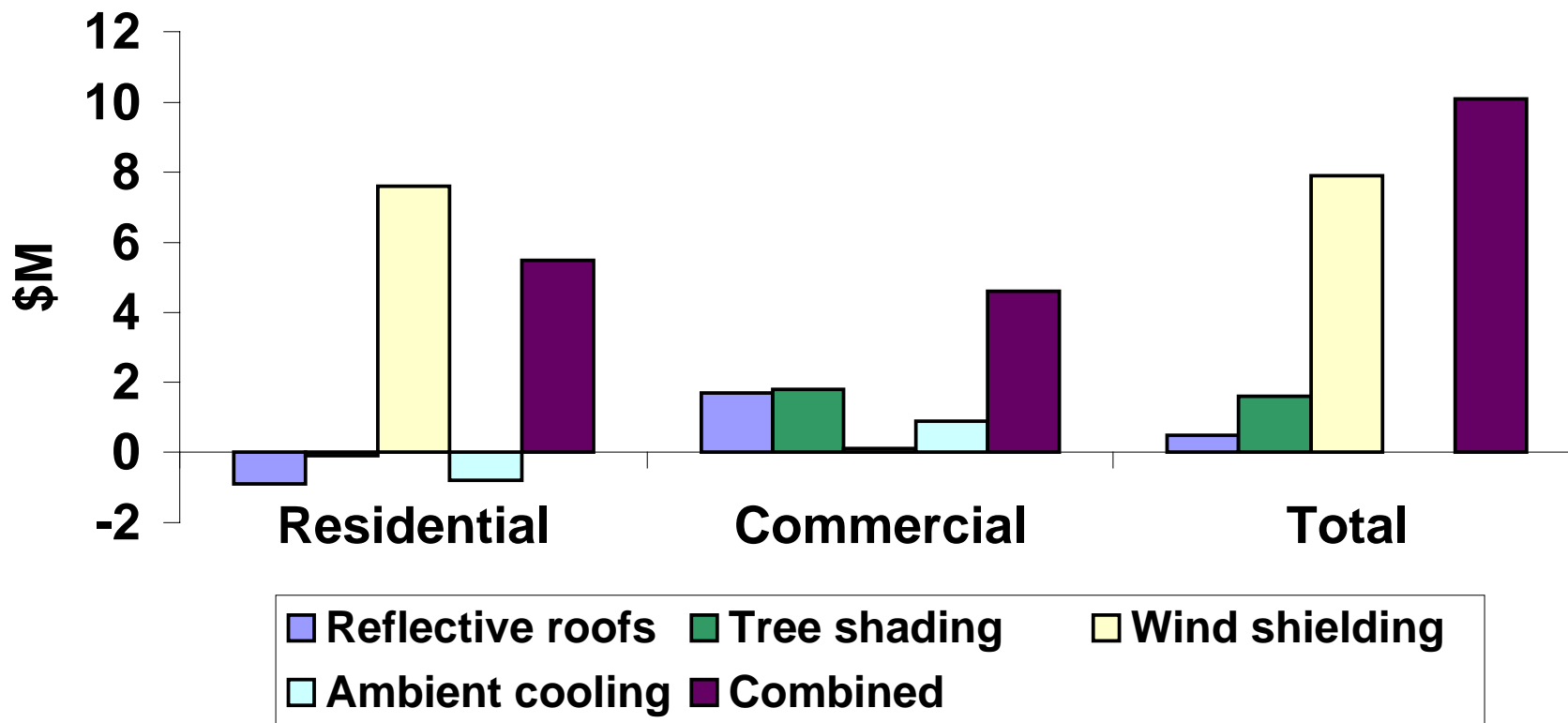
- 1996 data (STATCAN, 1996)
  - Population: 4,218,465
  - Households: 1,488,370
- Residential roof area (ICLEI, 1997; NRCAN, 2001)
  - Total roof area: 39.8Mm<sup>2</sup>
  - Single-family: 77%
  - Row-house: 20%
  - Apartment (multi-family): 3%
- Commercial roof area (Konopacki *et al.*, 1997)
  - Office: 1.9Mm<sup>2</sup>
  - Retail store: 3.4Mm<sup>2</sup>



# The GTA Annual Savings with a uniform electricity rate of \$0.084/kWh and gas rate of \$5.54/GJ



The GTA Annual Savings with a uniform electricity rate of \$0.084/kWh, commercial gas rate of \$5.54/GJ, and residential gas rate of \$10.84/GJ



# The GTA Peak Demand Savings: Total of 250 MW (~20%)

Mitigation strategy	1980 <sup>-</sup>	1980 <sup>+</sup>
Energy use & demand	1048	226
Savings		
reflective roof	48.4	10
shade tree	103.8	21.8
wind shield	-0.3	-1.4
indirect	53.5	11.5
combined	205	42



# Concluding Remarks

- The net savings of HIR strategies is highly sensitive to relative prices of electricity and natural gas
- Our simulation of the shading effects of trees is more refined than our simulation of wind-shielding effects
- DOE-2 can underestimate the cooling-energy saving potentials of reflective roofs by as much as a factor of two
- These results can be used to estimate savings in other building types
- Indirect saving potentials are a small fraction of total savings
- Reflective roofs and shade trees that save energy both directly and indirectly should be given higher priority than reflective pavements that only save energy indirectly

