Title

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Final Report

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Streamlined Energy-Savings Calculations for Heat-Island Reduction Strategies

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Abstract

We have developed summary tables (sorted by heating- and cooling-degree-days) to estimate the potential of Heat-Island Reduction (HIR) strategies (i.e., solar-reflective roofs, shade trees, reflective pavements, and urban vegetation) to reduce cooling-energy use in buildings. The tables provide estimates of savings for both direct effect (reducing heat gain through the building shell) and indirect effect (reducing the ambient air temperature).

In this analysis, we considered three building types that offer the most savings potential: residences, offices, and retail stores. Each building type was characterized in detail by Pre-1980 (old) or 1980^+ (new) construction vintage and with natural gas or electricity as heating fuel. We defined prototypical-building characteristics for each building type and simulated the effects of HIR strategies on building cooling and heating energy use and peak power demand using the DOE-2.1E model and weather data for about 240 locations in the U.S. A statistical analysis of previously completed simulations for five cities was used to estimate the indirect savings. Our simulations included the effect of (1) solar-reflective roofing material on building [*direct effect*], (2) placement of deciduous shade trees near south and west walls of building [*direct effect*], and (3) ambient cooling achieved by urban reforestation and reflective building surfaces and pavements *[indirect effect*].

Upon completion of estimating the direct and indirect energy savings for all the selected locations, we integrated the results in tables arranged by heating- and cooling-degree-days. We considered 15 bins for heating-degree-days, and 11 bins for cooling-degree-days. Energy use and savings are presented per 1000 ft^2 of roof area.

In residences heated with gas and in climates with greater than 1000 cooling-degree-days, the annual electricity savings in Pre-1980 stock ranged from 650 to 1300 kWh/1000ft^2; for 1980^+ stock savings ranged 300 to 600 kWh/1000ft^2. For residences heated with electricity, the savings ranged from 350 to 1300 kWh/1000ft^2 for Pre-1980 stock and 190–600 kWh/1000ft^2 for 1980^+ stocks. In climates with less than 1000 cooling-degree-days, the electricity savings were not significantly higher than winter heating penalties. For gas-heated office buildings, simulations indicated electricity savings in the range of 1100–1500 kWh/1000ft^2 and 360–700 kWh/1000ft^2, for Pre-1980 and 1980^+ stocks, respectively. For electrically heated office buildings, simulations indicated electricity savings in the range of 700–1400 kWh/1000ft^2 and 100–700 kWh/1000ft^2, for Pre-1980 and 1980^+ stocks, respectively. Similarly, for gas-heated retail store buildings, simulations indicated electricity savings in the range of 1300–1700 kWh/1000ft^2 and 370–750 kWh/1000ft^2, for Pre-1980 and 1980^+ stocks, respectively. For electrically heated retail store buildings, simulations indicated electricity savings in the range of 1200–1700 kWh/1000ft^2 and 250–750 kWh/1000ft^2, for Pre-1980 and 1980^+ stocks, respectively.

Executive Summary

Urban areas tend to have higher air temperatures than their rural surroundings as a result of gradual surface modifications that include replacing the natural vegetation with buildings and roads. The term "Urban Heat Island" describes this phenomenon. The surfaces of buildings and pavements absorb solar radiation and become hot, which in turn warm the surrounding air. Cities that have been "paved over" do not receive the benefit of the natural cooling effect of vegetation.[1] As the air temperature rises, so does the demand for air-conditioning (a/c). This leads to higher emissions by power plants, as well as increased smog formation as a result of warmer temperatures. Strategies to reverse the heat-island effect include planting shade trees and other vegetation and incorporating high-albedo[2] roofs and pavements into the urban landscape.

In 1997, the U.S. Environmental Protection Agency (EPA) embarked on an initiative to quantify the potential benefits of Heat Island Reduction (HIR) strategies (i.e., shade trees, urban vegetation, reflective roofs, and reflective pavements) to reduce cooling-energy use in cities, improve urban air quality and reduce CO_2 emissions from power plants. Under this effort, entitled the "Heat Island Reduction Initiative," EPA has been engaged in research and implementation activities that include a comprehensive technical effort called the Urban Heat Island Pilot Project (UHIPP).

The objective of the UHIPP was to investigate the effect of HIR strategies to reduce cooling-energy use in buildings and to reduce ambient air temperature. Cooling ambient air temperature has the additional benefit of reducing the rate of urban smog formation, hence, improving urban air quality.

Five cities were selected for the UHIPP: Baton Rouge, LA; Chicago, IL; Houston, TX; Sacramento, CA; and Salt Lake City, UT. Since the inception of the project, Lawrence Berkeley National Laboratory (LBNL) has conducted detailed studies to investigate the effect of HIR strategies on heating- and cooling-energy use of the five selected pilot cities. In addition, LBNL has collected urban surface characteristic data and conducted preliminary meteorology and urban smog simulations for the pilot cities.

In two earlier reports, we summarized our efforts to calculate the annual energy savings, peak power avoidance and annual CO_2 reduction of HIR strategies in the five UHIPP metropolitan areas (Konopacki and Akbari, 2000 and 2002). In this report, we extend those earlier analyses to all other cities in the U.S.

In this study, we followed the same methodology used for analysis of the five UHIPP cities. The methodology consists of (1) defining prototypical buildings; for 240 U.S. climates (2) simulating the basecase heating- and cooling-energy use for each prototype; (3) simulating the energy effects of shade trees and reflective roofs for each prototype; (4) estimating the effect of ambient cooling on heating- and cooling-energy use of each prototype; and (5) integrating and tabulating the total energy savings by ranges of heating- and cooling-degree-days.

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[1] Evaporation of liquid water occurs at the leaf surface and lowers the local air temperature.

[2] When sunlight hits a surface some fraction of its energy is reflected (albedo = â) and the remainder is absorbed (α= 1–â). High-a surfaces become cooler than low-â surfaces and consequently lower the cooling load of a building.

Project Objective

The objective of this project was to develop a streamlining approach to estimate the effect of Heat Island Reduction (HIR) measures on building cooling- and heating-energy use. The results are presented in tabular formats for easy interpolation. In this analysis, we focused on three major building types that offer most savings potential:[1] residence, office, and retail store. For each prototype, we calculated the effects of HIR strategies A–D on heating- and cooling-energy use:

A. Use of solar-reflective roofing material on building ['cool roofs', *direct effect*],
B. Placement of deciduous shade trees near south and west walls of building ['shade trees', *direct effect*],
C. Urban reforestation with reflective building surfaces and pavements [*indirect effect*],
D. Combination of strategies A through C [*direct and indirect effects*].

Methodology

A five-step methodology was developed to assess the potential impact of HIR measures on buildings and metropolitan-wide energy use.

1. Define detailed prototypical building characteristics for Pre-1980 and 1980^+ construction.
2. Simulate annual energy use and peak demand using the DOE-2.1E model.
3. Determine direct energy and demand savings from each HIR strategy.
4. Determine total indirect energy and demand savings from all HIR strategies.

Results

The results of this analysis are summarized in three tables and three figures. **Tables 6–8** give the results for residential, office, and retail store buildings. Each table provides estimates of savings arranged by (**a**) heating-degree-days and (**b**) cooling-degree-days. The values in these tables are also plotted in **Figures 3–5** for residential, office, and retails store buildings, respectively. Each figure is plotted by (**a**) heating-degree-days, (**b**) cooling-degree-days, (i) basecase energy and demand use, (**ii**) direct savings (penalties) from cool roofs, (**iii**) direct savings (penalties) from shade trees, (**iv**) the indirect savings from cool surfaces (roofs and pavements) and increased urban vegetation, and (**v**) the combined direct and indirect savings.

We also calculated the total carbon emissions from heating and cooling the buildings (**Tables 6c, 6d, 7c, 7d, 8c, and 8d**). To generate these tables we used data provided by DOE's office of Energy Information Administration (EIA, 1997, 2002).

Table EX-1 summarizes these results of all U. S. climates. **Figures EX-1** through **EX-5** depict sample results for residential buildings. These figures (and the associated tables) can be used to read the estimated savings for each HIR measure. The report concludes the analysis by

[1] These building types were selected based on an earlier detailed study of the direct energy savings potential of highly-reflective roofs in eleven U.S. metropolitan areas, in which they were determined to account for over 90% of the national energy savings (Konopacki et al. 1997).

providing an example for estimating citywide savings by implementing measures to install cool roofs and programs to plant shade trees.

Table EX-1. Estimated ranges of annual basecase (electricity use, gas use, peak demand, and carbon emissions) and savings from heat-island reduction measures across all climate regions.

Prototype Building	Electricity (kWh/1000ft^2)		Gas (Therm/1000ft^2)		Peak Power (kW/1000ft^2)		Carbon (kgC/1000ft^2)	
	Basecase	Savings		Penalties	Basecase	Savings	Basecase	Savings
Residential								
Pre-1980 Gas Heated	1600–11000	400–1200	0–1000	0–50	3.1–4.0	0.4–0.6	1100–2200	60–220
Pre-1980 Electrically Heated	8500–20000	100–1200			3.1–4.0	0.4–0.6	900–4800	60–220
1980$^+$ Gas Heated	700–7000	150–700	0–500	0–20	1.7 –3.3	0.2–0.4	400–1200	30–100
1980$^+$ Electrically Heated	5000–9000	50–600			1.7–3.3	0.2–0.4	430–2300	30–100
Office								
Pre-1980 Gas Heated	7000–18700	1200–1400	0–500	0–20	6.3–8.4	0.5–1.0	1800–3100	200–260
Pre-1980 Electrically Heated	12600–18700	1100–1300			6.3–8.4	0.5–1.0	2000–2100	190–260
1980$^+$ Gas Heated	3500–10800	500–600	0–300	0–10	3.5–4.6	0.2–0.5	800–1800	70–120
1980$^+$ Electrically Heated	5700–10800	300–600			3.5–4.6	0.2–0.5	900–1800	50–100
Retail Store								
Pre-1980 Gas Heated	8200–15700	1400–1500	0–200	0–10	4.5–5.7	0.4–0.7	1400–2900	210–290
Pre-1980 Electrically Heated	10700–17200	1300–1700			4.1–5.7	0.4–0.7	1800–2900	200–290
1980$^+$ Gas Heated	3100–8900	500–700	0–60	0–6	2.2–2.8	0.2–0.3	520–1500	70–120
1980$^+$ Electrically Heated	4000–8900	300–700			2.2–2.8	0.2–0.3	650–1500	50–120

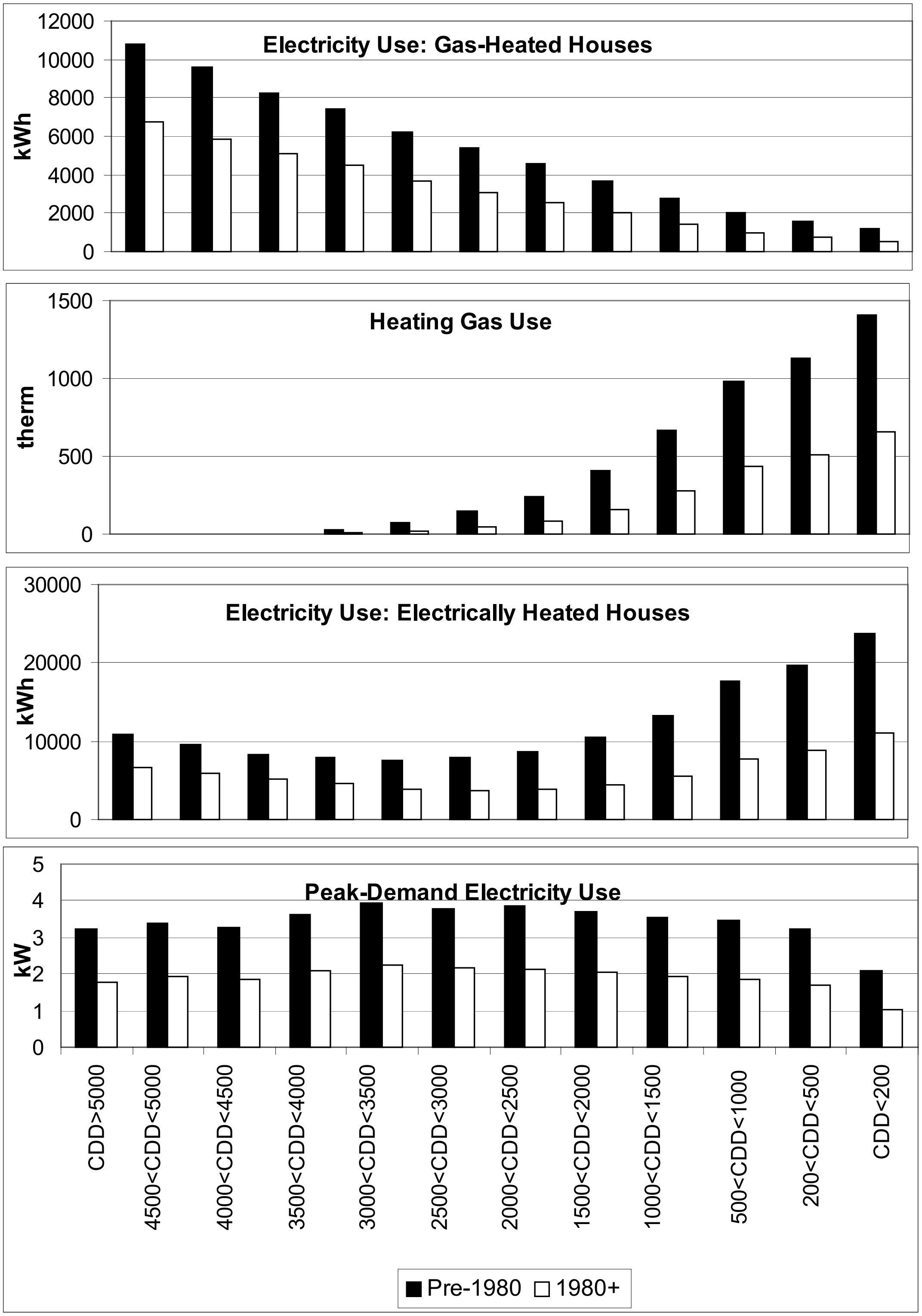

Figure EX-1. Residential Buildings. Basecase Energy Use as a function of cooling-degree-days: Annual basecase cooling-electricity use and heating-gas use for gas-heated houses, combined cooling- and heating-electricity use for electrically heated houses, and peak-electricity demand. All estimates are normalized per 1000 ft^2 of roof area.

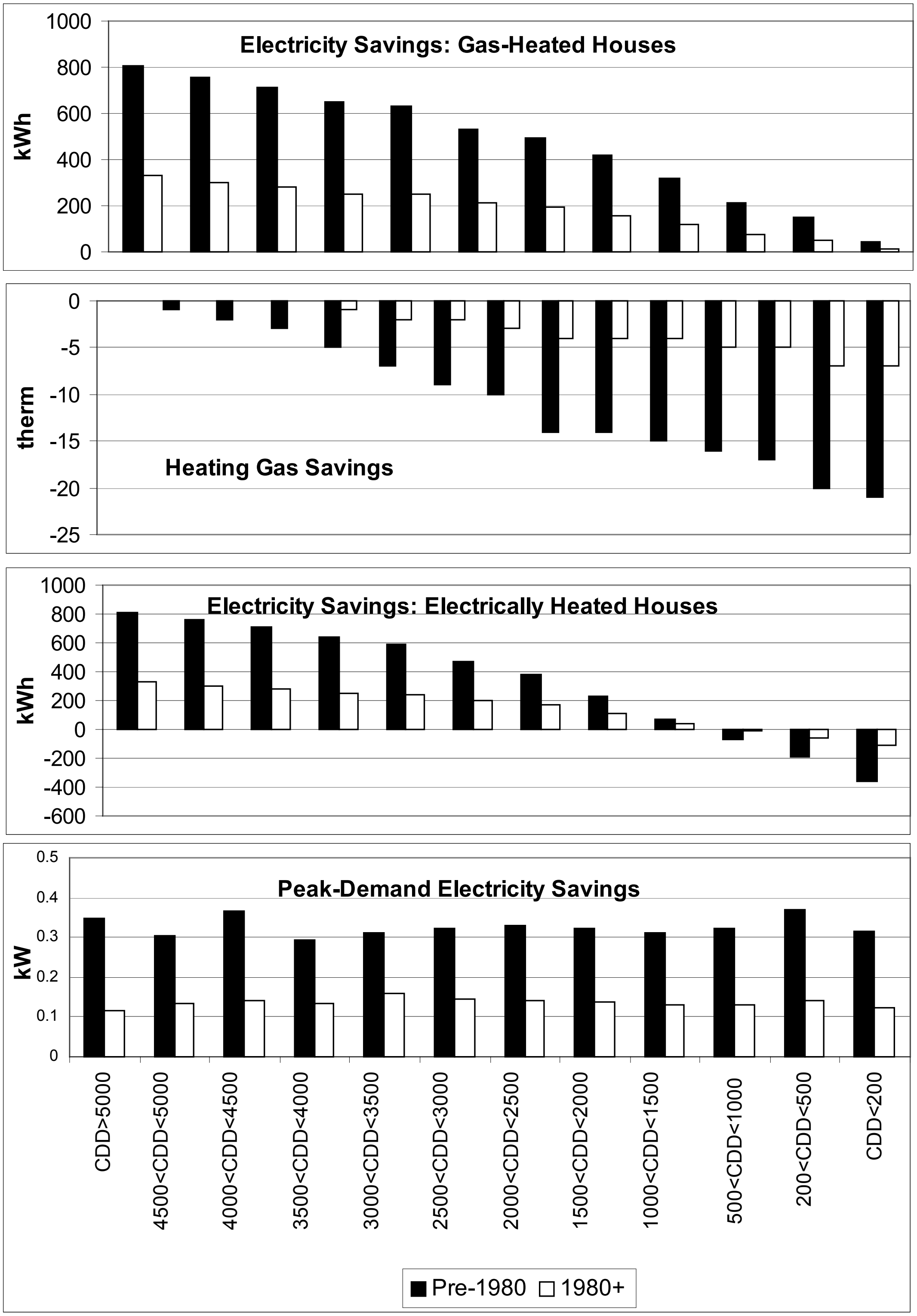

Figure EX-2. Residential Buildings. Savings from Cool Roofs as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

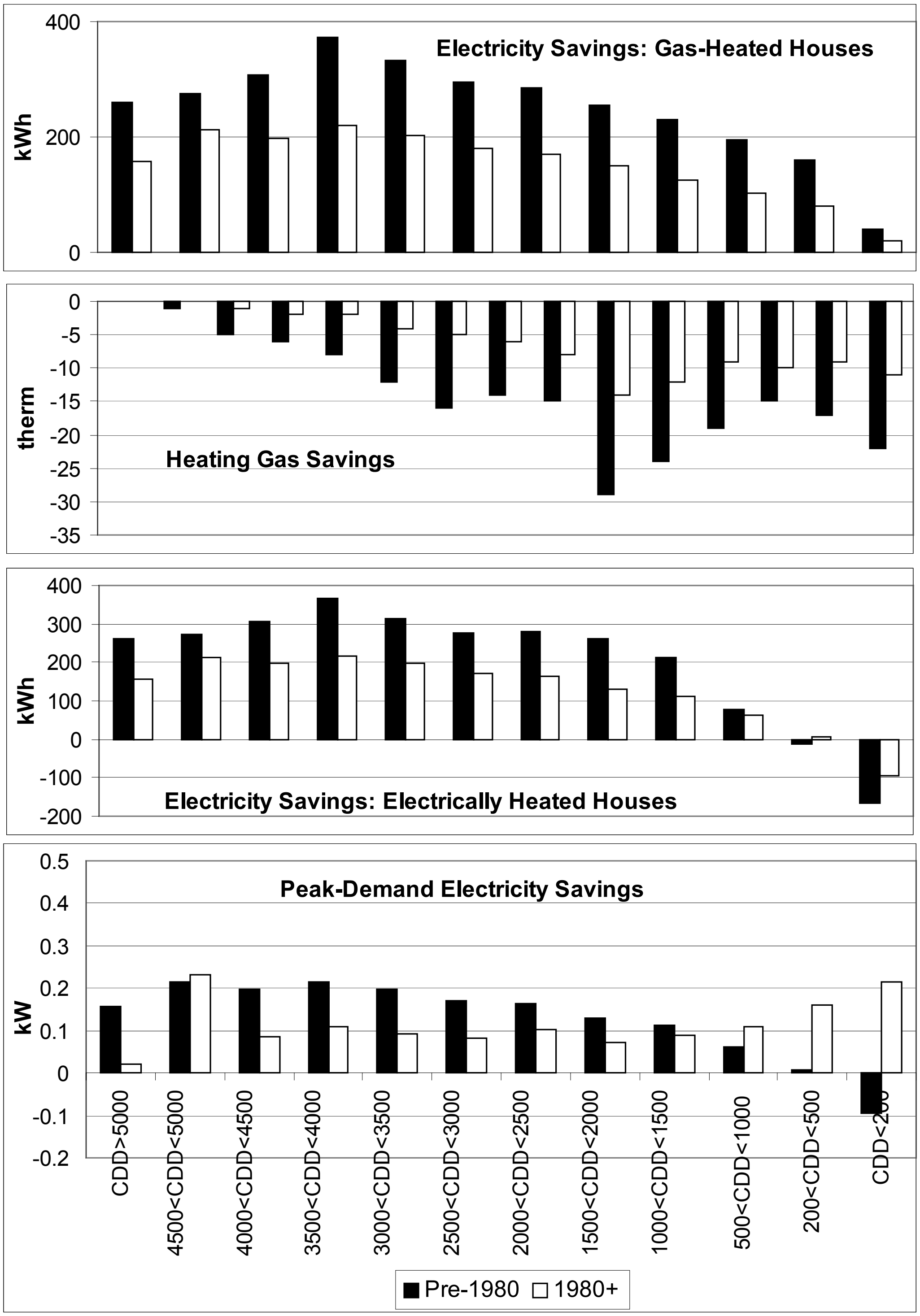

Figure EX-3. Residential Buildings. Savings from Shade Trees as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

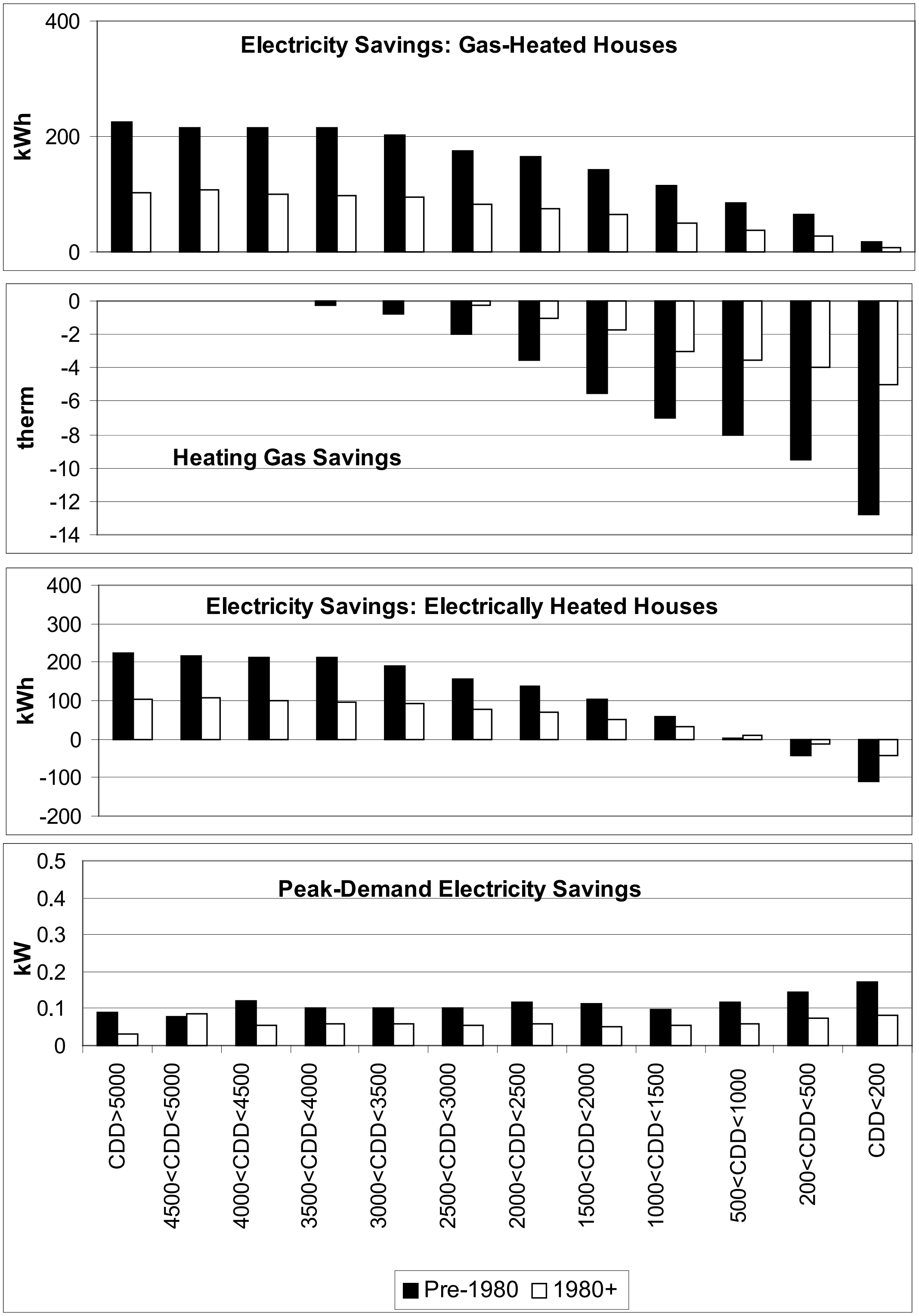

Figure EX-4. Residential Buildings. Indirect Savings as a function of cooling degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

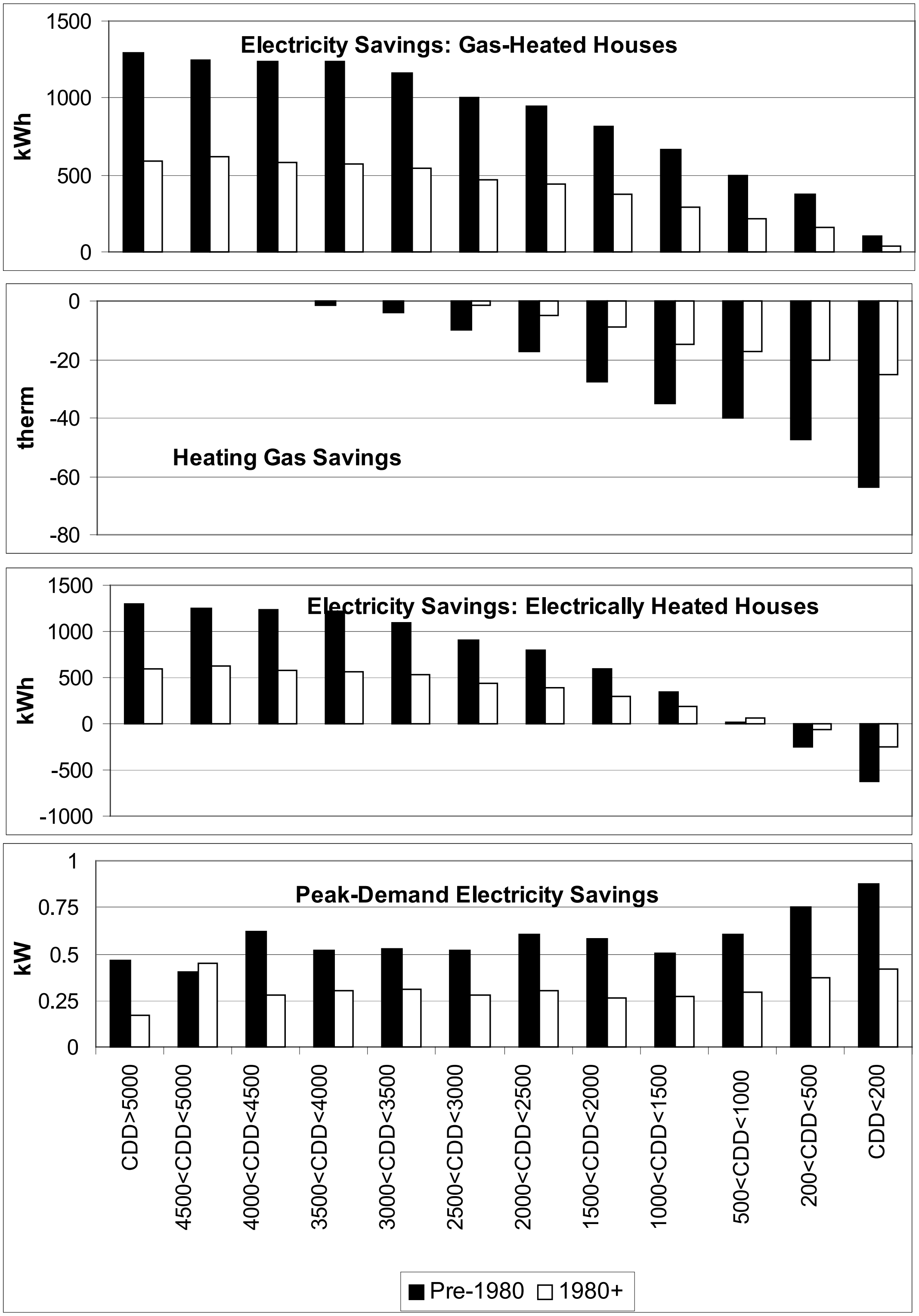

Figure EX-5. Residential Buildings. Combined Direct and Indirect Savings as a function of cooling-degree-days: Annual cooling electricity savings and heating gas savings for gas heated houses, combined heating and cooling electricity savings for electricity-heated houses, and peak electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

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1. Introduction

Urban areas tend to have higher air temperatures than their rural surroundings, as a result of gradual surface modifications that include replacing the natural vegetation with buildings and roads. The term "Urban Heat Island" describes this phenomenon. The surfaces of buildings and pavements absorb solar radiation and become hot, which in turn warm the surrounding air. Cities that have been "paved over" do not receive the benefit of the natural cooling effect of vegetation.[1] As the air temperature rises, so does the demand for air-conditioning (a/c). This leads to higher emissions by power plants, as well as increased smog formation as a result of warmer temperatures. Strategies to reverse the heat-island effect include planting shade trees and other vegetation and incorporating high-albedo[2] roofs and pavements into the urban landscape.

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Methodology

A five-step methodology was developed to assess the potential effects of HIR measures on buildings and metropolitan-wide energy use.

1. Define detailed prototypical building characteristics for Pre-1980 and 1980$^+$ construction. 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 prototypes were developed for both Pre-1980 and 1980$^+$ construction vintages and with both gas and electricity as heating fuels. The use of existing and reflective roofs and the placement of deciduous shade trees near the south and west sides of the building were considered. These data then defined the characteristics of the Building Description Language used by the DOE-2.1E energy simulation computer program (Winklemann et al., 1993; BESG, 1990).

2. Simulate annual energy use and peak demand using the DOE-2.1E model. The DOE-2 building-energy model was used to simulate the *direct* effects of reflective roofs and shade trees and on cooling- and heating-energy use for the selected prototypical buildings. The DOE-2 model simulates energy use of a building for 8760 hours of a year, using typical hourly weather data. Simulations were performed for basecase and the modified cases (as defined by HIR strategies).

3. Determine direct energy and demand savings from each HIR strategy. Simulated annual cooling- and heating-energy savings and avoided peak power were calculated by comparing the basecase energy use and demand to those of the HIR strategies. All results were normalized per 1000 ft^2 of roof area.

4. Determine total indirect energy and demand savings from all HIR strategies. To estimate the indirect effect, we developed simple algorithms to estimate indirect savings from detailed analysis previously completed for Baton Rouge LA, Chicago IL, Houston TX, Sacramento CA, and Salt Lake City UT. The algorithms are based on the regression of the estimated indirect savings vs. (1) cooling-electricity savings for gas-heated buildings, (2) gas heating-energy

[1] These building types were selected based on an earlier detailed study of the direct energy savings potential of highly-reflective roofs in eleven U.S. metropolitan areas, in which they were determined to account for over 90% of the national energy savings (Konopacki et al. 1997).

penalties for gas-heated buildings, (3) cooling- and heating-electricity savings for electrically heated buildings, and (4) peak electricity demand, for the five pilot cities.

5. Group energy-saving potentials in tables ordered by annual Cooling- and Heating Degree-Days. After estimating the direct and indirect energy savings, and hence, total energy saving potentials, we averaged the saving estimates for climate zones in a range of heating- and cooling-degree-days (HDD and CDD). The final results were then tabulated by ranges of CDD and HDD.

2. Building Descriptions, Reflective Roofs, and Shade Trees

Three major building prototypes were selected for investigation: (1) residence (2) office (3) retail store. Konopacki *et al*. (1997), in a detailed study to quantify the effects of reflective roofs in 11 Metropolitan Statistical Areas (MSAs), showed that these three building types accounted for 93% of the residential and commercial air-conditioned roof area. The buildings were characterized for old (those built prior to 1980) and new (built 1980 or later) construction vintages. Two heating systems were available for each prototype, natural gas furnace and air-source electric heat pump. The prototype characteristics were written into Building Description Language (BDL) for DOE-2 modeling.

Residence

The residence was modeled as a single-story single-family detached structure. Changing the reflectance of the roof, primarily affects the heat transfer through the roof structure. Therefore, to minimize the variations in the number of prototypes for simulations, we focused on prototypical simulations of the upper floor capturing the effects of changes in roof reflectance and the addition of shade trees in the building as a whole. The average roof area selected for these prototypical simulations was $1600ft^2$. We presented the simulated data by normalizing the energy use savings per $1000ft^2$ of roof area. Then, in the example provided for calculating the savings for a metropolitan area, we accounted for the number of stories of the building stock.

The roof was constructed with asphalt shingles on a 20° sloped plywood deck, over a naturally ventilated and unconditioned attic, above a studded ceiling frame with fiberglass insulation (varying by vintage), and with a sheet of drywall beneath. The fractional-leakage-area of the attic and living quarters was dependent on vintage. Variable air infiltration was modeled by the Sherman-Grimsrud algorithm (Sherman 1986). The existing solar reflectance of the roof was 0.2, typical for a white asphalt shingles, and the albedo of the reflective roof was taken to be 0.5, typical for aged white roof coatings. The thermal emittance of both roofs was 0.9.

The residence was cooled and heated by a central air-conditioning system with ducts located in the attic space, a constant volume fan, and without an economizer. Cooling by natural ventilation was available by window operation. The systems were sized based on peak cooling and heating loads as determined by DOE-2, allowing for peak loads to be met. System component efficiencies were selected for each vintage. A Seasonal Energy Efficiency Ratio (SEER) of 8.5 and 10 was assumed for the central air-conditioner of the Pre-1980 and 1980^+ buildings, respectively. Also a Heating Season Performance Factor (HSPF) of 5 and 7 was assumed for the stock of old and new residential central electric heat pumps.

Modified part-load-ratio curves for a typical air-conditioner, heat pump, and gas furnace were used in place of the standard DOE-2 curves, as they have been shown to model low-energy use more accurately (Henderson 1998). Duct loads were simulated with a validated residential duct function (Parker *et al*. 1998) implemented into DOE-2 to better estimate the thermal interactions between the ducts and space. The function was designed for the residential central system type (RESYS) in DOE-2 and for a single air-conditioned living space with an attic and basement, and it greatly improves cooling- and heating-energy use estimates.

Building data for residences are shown in **Table 1** and were obtained from several sources. We used existing data to characterize the existing stock of Pre-1980 buildings (Konopacki *et al*., 1997). Characteristics for 1980^+ construction homes were identified from DOE national appliance energy standards (NAECA 1987), California Energy Commission prototypes (CEC 1994), and Energy Star® (USDOE 2001).

Office

The office was modeled as a non-directional building with four perimeter zones and a core zone, also in two construction vintages, those built prior to 1980, those built 1980 and after. The floor plan was a 70 feet by 70 feet layout with a total conditioned floor area of 4900ft^2, and the perimeter zone depth was 15 feet. The building operated from 6am to 7pm on weekdays only.

The roof was constructed with built-up materials on a flat plywood deck, over an unventilated and unconditioned plenum, above a studded ceiling frame with fiberglass insulation (varying by vintage), and with a sheet of drywall beneath. The existing solar reflectance of the roof was 0.2, typical for gray or tan built-up, and the albedo of the reflective roof was taken to be 0.6, typical for aged white roof coatings. The thermal emittance of both roofs was 0.9.

The building was cooled and heated by five rooftop, constant volume, packaged-single-zone systems, each one servicing a single zone. The systems were sized based on peak cooling and heating loads as determined by DOE-2, which allowed for peak loads to be met. Duct loads were simulated by specifying air leakage and temperature drop. An economizer was also implemented. An EER of 10 was used to model the new office air-conditioner.

Office characteristics were taken from previous research focusing on the impact of reflective roofs in 11 US metropolitan areas (Konopacki *et al*. 1997), California Energy Commission prototypes (CEC 1994), and Energy Star® (USDOE 2001). These are displayed in **Table 2**.

Retail Store

The retail store was modeled as a non-directional building with a single zone, also in two construction vintages, those built prior to 1980, those built 1980 and after. The floor plan was a 90 feet by 90 feet layout with 8100 ft^2 of total conditioned floor area. The building operated from 8am to 9pm on weekdays and from 10am to 5pm on weekends and holidays.

The roof was constructed with built-up materials on a flat plywood deck, over an unventilated and unconditioned plenum, above a studded ceiling frame with fiberglass insulation, and with a sheet of drywall beneath. The existing solar reflectance of the roof was 0.2, typical for gray or tan built-up, and the albedo of the reflective roof was taken to be 0.6, typical for aged white roof coatings. The thermal emittance of both roofs was 0.9.

The building was cooled and heated by a single rooftop, constant volume packaged-single-zone system. The system was sized based on peak cooling and heating loads as determined by DOE-2. Duct loads were simulated by specifying air leakage and temperature drop. An economizer was also implemented. An EER of 10 was used to model the new retail store air-conditioner.

Retail store characteristics were taken from previous research focusing on the impact of reflective roofs in 11 US metropolitan areas (Konopacki *et al*. 1997), California Energy Commission prototypes (CEC 1994), and Energy Star® (USDOE 2001). These are displayed in **Table 3**.

Solar-Reflective Roofs

A solar-reflective roof is typically light in color and absorbs less sunlight than a conventional dark-colored roof. Less absorbed sunlight means a lower surface temperature, directly reducing heat gain from the roof and air-conditioning demand. Typical albedo values for low- and high-albedo roofs were selected that cover the wide range of commercially available roofing materials (shingles, tiles, membranes and coatings). We also accounted for the effects of weathering and aging. These values were obtained primarily from the Cool Roofing Materials Database (CRMD 2001) developed at LBNL, which contains measured values of roof absorptance across the solar spectrum.

For the sloped-roof[1] residential sector, available highly reflective materials are scarce. White asphalt shingles are available, but have a relatively low albedo of about 0.25. Although it can be argued that white coatings can be applied to shingles or tiles to obtain an aged albedo of about 0.5, this practice is not followed in the field. Some highly reflective white shingles are being developed, but are only in the prototype stage. Some reflective tiles and metal roofing products with greater than 50% reflectivity are also available. Conversely, highly reflective materials for the low-slope commercial sector are on the market. White acrylic, elastomeric and cementatious coatings, as well as white thermoplastic membranes, can now be applied to built-up roofs to achieve an aged solar reflectance of 0.6.

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. The long-wave thermal emittance of these materials was a uniform 0.9. In DOE-2 the *ABSORPTANCE* keyword for roof construction was 0.8 (reflectivity of 0.2) for the basecase and was changed to 0.5 (o.5 reflectivity) and 0.4 (0.6 reflectivity) for residential and commercial reflective roofs, respectively.

Bretz and Akbari (1997) have reported that the albedo of white-coated roof surfaces can degrade up to 20% over a period of several years as a result of weathering and accumulation of dirt and debris (microbial growth can contribute to degradation in humid climates). By washing the roof, the albedo can be restored to 90–100% of the initial value. Note that rainfall can cleanse a roof and have the same effect as a thorough washing.

A "generic white" asphalt shingle has a laboratory-tested initial albedo of 0.25 (CRMD 2001). A "generic grey" asphalt shingle has a laboratory-tested initial albedo of 0.22, and the albedo of a green or brown shingle is about 0.12–0.15 (CRMD 2001). The roofs—built-up asphalt capsheet with light-grey granules—of three commercial buildings in California were

[1] A roof with higher than 9.5º slope is defined as a sloped roof. The roofing industry has widely accepted a slope of 2:12 or more as a definition of sloped roofs. This corresponds to a slope of approximately 9.5º (16.7%).

coated with a white-elastomeric material, where the measured pre-coated albedo ranged from 0.16 to 0.24, the initial post-coated albedo was 0.6, the unwashed albedo ranged from 0.47 to 0.56, and the washed albedo was 0.59 (Konopacki and Akbari 1998, Konopacki et. al. 1998).

Shade Trees

Shade trees block incoming sunlight to the windows and walls of a building and effectively lower cooling demand. Deciduous shade trees shed their leaves in the winter to allow sunlight to warm the building. Mature deciduous shade trees were modeled in DOE-2 with the *BUILDING-SHADE* keyword as a box-shaped building shade with seasonal transmittance. The summertime transmittance was 0.1 for 1 April through 31 October and wintertime was 0.9 for the remainder of the year (the fraction of light that passes through the tree is the transmittance). The geometry of the modeled tree consisted of a square cross-sectional area of 225 ft^2, 15 feet by 15 feet, a depth of 10 feet, and a canopy height of 15 feet. They were placed outside the south and west walls near the windows (with 2 feet of clearance from the building) in order to maximize the impact on the building-cooling load. The fully-grown trees shade a portion of the roof during low sun hours, but do not cover any of it. The number of shade trees modeled were 4, 8 and 10 for the residence, office, and retail store, respectively.

Table 1. Prototypical building description for single-family residence.

Single-Family Residence	**Pre-1980**	**1980+**
single-story, non-directional		
roof & floor area (ft^2)	1,600	
Zones		
living (conditioned)		
attic (unconditioned)		
basement (unconditioned)		
Roof Construction		
20^o slope		
¼" asphalt shingle		
¾" plywood deck w/ 2" x 6" rafters		
naturally ventilated attic		
¾" plywood deck w/ 2" x 6" rafters (15%)		
fiberglass insulation (85%)	R-11	R-30
½" drywall		
Roof Solar Reflectance		
pre	0.2	
post	0.5	
Roof Thermal Emittance	0.9	
Wall Construction		
brick exterior		
wood frame (15%)		
fiberglass insulation (85%)	R-5	R-13
½" drywall interior		
Windows		
clear with operable shades		
number of panes	1	2
window to wall ratio	0.18	
Fractional Leakage Area (in^2/100 ft^2)		
living	4	2
attic	8	4
Air-conditioning equipment		
central a/c, direct expansion, air-cooled		
seasonal energy efficiency ratio (SEER)	8.5	10
coefficient of performance (COP)	2.5	2.9
cooling setpoint (^oF)	78	
natural ventilation available		
Heating Equipment		
1) central forced air gas furnace		
efficiency (%)	70	78
heating setpoint (^oF)	70	
11pm–7am setback (^oF)	60	
2) central electric heat pump		
heating season performance factor (HSFP)	5	7
Duct Air Leakage (%)	20	10

Table 2. Prototypical building description for office.

Single-Story Office	**Pre-1980**	**1980+**
non-directional		
5 zones (conditioned)		
roof & floor area (ft^2)	4900	
Roof Construction		
built-up roofing		
3/4" plywood decking (0^o slope)		
plenum (unconditioned)		
Roof Solar Reflectance		
pre	0.2	
post	0.6	
Roof Thermal Emittance	0.9	
Ceiling Construction		
2"x 6" studded frame (15%)		
fiberglass insulation (85%)	R-11	R-30
1/2" drywall		
Wall Construction		
brick exterior		
wood frame (15%)		
fiberglass insulation (85%)	R-6	R-13
1/2" drywall		
Foundation		
slab-on-grade with carpet and pad		
Windows		
clear with operable shades		
number of panes	1	2
window to wall ratio	0.5	
Air-Conditioning Equipment		
packaged a/c, direct expansion, air-cooled		
seasonal energy efficiency ration (SEER)	8	10
coefficient of performance (COP)	2.3	2.9
Heating Equipment		
(1) gas furnace		
efficiency (%)	70	74
(2) electric heat pump		
heating season performance factor (HSPF)	5	7
Distribution		
constant-volume forced air system		
economizer	fixed	temperature
duct leakage (%)	20	10
duct temperature drop (^oF)	2	1
Thermostat		
weekday operation (6am–7pm)		
cooling setpoint (^oF)	78	
heating setpoint (^oF)	70	
Interior load		
infiltration (air-change/hour)	0.5	
lighting (W/ft^2)	1.9	1.4
equipment (W/ft^2)	1.7	1.5
Occupants	25	

Table 3. Prototypical building description for retail store.

Single-Story Retail Store	**Pre-1980**	**1980+**
non-directional		
single zone (conditioned)		
roof & floor area (ft^2)	8100	
Roof Construction		
built-up roofing		
3/4" plywood decking (0^o slope)		
plenum (unconditioned)		
Roof Solar Reflectance		
pre	0.2	
post	0.6	
Roof Thermal Emittance	0.9	
Ceiling Construction		
2"x 6" studded frame (15%)		
Fiberglass insulation (85%)	R-11	R-30
1/2" drywall		
Wall Construction		
brick exterior		
wood frame (15%)		
Fiberglass insulation (85%)	R-4	R-13
1/2" drywall		
Foundation		
slab-on-grade with carpet and pad		
Windows		
clear without operable shades		
number of panes	1	2
window to wall ratio	0.17	
Air-Conditioning Equipment		
packaged a/c, direct expansion, air-cooled		
seasonal energy efficiency ration (SEER)	8	10
coefficient of performance (COP)	2.3	2.9
Heating Equipment		
(1) gas furnace		
Efficiency (%)	70	74
(2) electric heat pump		
heating season performance factor (HSPF)	5	7
Distribution		
constant-volume forced air system		
Economizer	fixed	temperature
duct leakage (%)	20	10
duct temperature drop (^oF)	3	1
Thermostat		
weekday operation (8am–9pm)		
weekend operation (10am–5pm)		
cooling setpoint (^oF)	78	
heating setpoint (^oF)	70	
Interior Load		
infiltration (air-change/hour)	0.5	
lighting (W/ft^2)	2.4	1.7
equipment (W/ft^2)	0.7	0.6
occupants	16	

3. Energy Simulations

Cooling- and heating-energy use were simulated on an hourly time-step with the DOE-2.1E building energy simulation program (BESG 1990) using TMY2 weather data for residential, office and retail store building prototypes (Pre-1980 and 1980^{+} construction, natural gas furnace and electric heat pump) and for each Heat-Island Reduction (HIR) strategy (solar-reflective roofs, shade trees and indirect effect).

Direct vs. Indirect Effect

Strategies to cool cities and mitigate urban heat islands include planting shade trees around buildings, planting other urban vegetation in parks and along roadways, and using solar-reflective roofs and pavements. Trees shade buildings and reflective roofs reflect solar energy from buildings, *directly* reducing demand for air-conditioning (a/c). Urban vegetation and reflective surfaces (roofs and pavements) alter the surface energy balance of an area through evapotranspiration of vegetation and by reflecting incident solar energy, lowering the ambient temperature, and hence *indirectly* reducing a/c use.

Direct Energy Savings. The direct energy-savings potentials were simulated using DOE-2. To calculate the direct energy savings, we perform three sets of simulations for each location (climate). The first set of simulations was performed to establish a *basecase* energy use condition (heating- and cooling-energy use, and peak electricity cooling demand). The basecase scenario included no external shade and a roof albedo of 0.2 for both the residential and commercial buildings. The second set of simulations (*high-albedo roof*) was performed to calculate the heating- and cooling-energy use, and peak electricity cooling demand for buildings when they have reflective roofs. For the residence, office and retail store, we assumed a roof solar reflectance of 0.50, 0.60, and 0.60, respectively. The third set of simulations (*shade trees*) was performed to calculate the heating- and cooling-energy use, and peak electricity cooling demand for building when trees shade them. For the residence, office and retail store, we assumed 4, 8 and 10 shade trees, respectively. The difference between the *basecase* and *high-albedo roof* provided an estimate of energy savings and peak demand reduction by reflective roofs. The difference between the *basecase* and *shade trees* provided an estimate of energy savings and peak demand reduction by shade trees.

Indirect Energy Savings. In our previous work, we have used a detailed methodology to calculate the indirect energy and peak-demand saving potentials for the pilot cities investigated. We applied the detailed methodology to calculate the effect for the five selected pilot cities of Baton Rouge LA, Chicago IL, Houston TX, Sacramento CA, and Salt Lake City UT (Konopacki and Akbari 2000, 2002). The calculations for estimating indirect energy effects were carried out in a two-step process. First, a modified TMY2 weather tape was created to represent the effects of HIR strategies on ambient air temperature. Second, the prototypes were simulated with the modified weather tape to calculate the impact of ambient cooling on heating- and cooling-energy use.

To quantify the ambient cooling from the indirect effect for each pilot city, a modified urban fabric was first created from the present fabric with increased urban vegetation, the planting of shade trees, and the use of high-albedo roofs and pavements. Second, the effect of the modified urban fabric on climate was simulated using a meteorological simulation model, from which a modified average drybulb air temperature was obtained from several locations within the boundaries of the model over the 48 hour episode (discussed in detail by Taha and Chang, 1999a). Then, the modified temperature was calculated for each hour of the year using an algorithm developed by Taha (1999b) based on a statistical analysis of temperature change as a function of solar intensity; because ΔT is solely a function of solar, ΔT is zero during hours without sunlight. Finally ΔT was used to modify the standard TMY2 weather data to create modified temperature data for the building energy simulations.

It is important to notice that in all our previous calculations we assumed that all urban surfaces would be modified to the levels discussed above. This provided an upper boundary for estimates of indirect saving potentials. For the streamlining calculations, we continued to use the same global implementation throughout the cities.

Our objective in this study was to develop a simple method to estimate the indirect effects on energy use and peak demand for many locations in the U.S. For this, we used a statistical approach with data from the detailed analyses of five pilot cities. For these five cities (metropolitan areas) we regressed the indirect saving potential against the total energy savings. We normalized the data by several different methods, and we eventually determined that the direct energy-savings potentials normalized by heating- and cooling-degree-days are fairly well correlated with the total energy-savings potentials (see **Figure 1**). Using the results of these regressions, we estimated the total indirect electricity savings to be about 17% of total electricity savings, 20% for gas penalties, and 19% for peak demand savings.

Figure 2 compares the percentage of the indirect savings (relative to total savings) for the five pilot cities. The indirect electricity savings range from 11% (Chicago) to 21% (Salt Lake City); excluding Chicago the range is 15% to 20%. The typically short cooling season is a factor to account for Chicago's lower percentage of electricity savings. The indirect penalties from gas heating range from 1% (Chicago) to 25% (Houston); excluding Chicago the range is 17% to 25%. This is very interesting, as it underlines our intuitions that in most cold climates the percentage of winter heating penalties is fairly small (the absolute heating penalties may be higher). In cold climates, there is not much sun during the times when heating is required, hence the effect of a reflective roof on heating energy use is small. The indirect contribution to peak demand savings ranges from 9% (Chicago) to 30% (Houston). In this case, in addition to Chicago, the percentage of indirect savings for Baton Rouge is also small (10%). Although we can provide the same reasoning to explain the difference for Chicago, we do not have such a strong justification for the Baton Rouge savings percentages. The indirect savings for the other three cities range from 24% to 30%.

It should also be noted that these savings estimates are based on the assumption that all heat-island reduction measure have been fully implemented. Although we have not performed any analysis of partial or gradual implementation of the HIR measures, we assume that the savings, once normalized per square foot of roof area, can be linearly scaled.

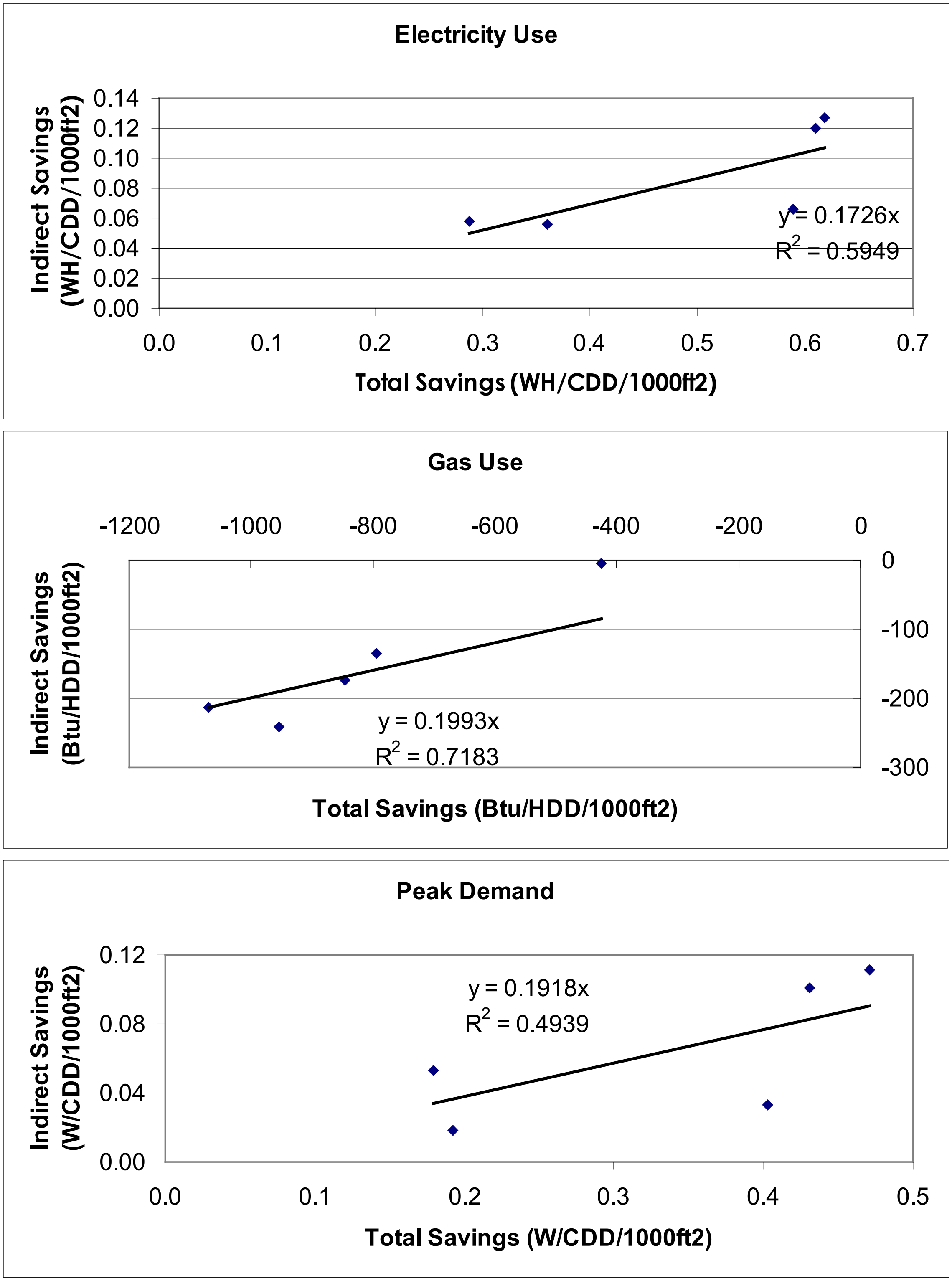

Figure 1. Indirect savings vs. total savings for metropolitan Baton Rouge LA, Chicago IL, Houston TX, Sacramento CA, and Salt Lake City UT. All saving potentials are normalized by cooling- and heating-degree-days, and by total square feet of roof area.

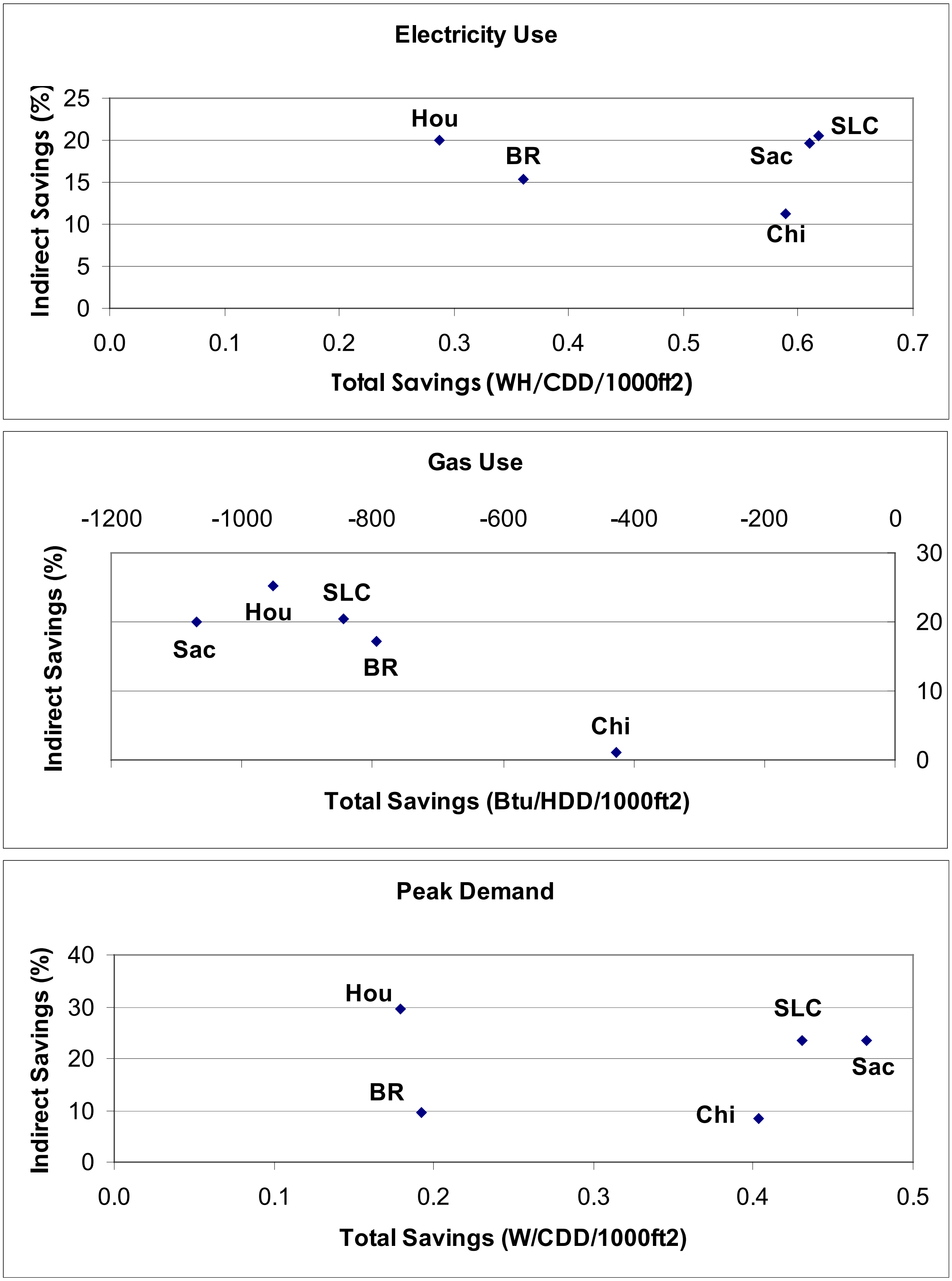

Figure 2. Percent indirect savings vs. total savings for metropolitan Baton Rouge LA, Chicago IL, Houston TX, Sacramento CA, and Salt Lake City UT. All saving potentials are normalized by cooling- and heating-degree-days, and by total square feet of roof area.

Weather Data

Local full-year hourly weather data are required as input to the DOE-2 building energy simulation program. Those data used were derived from the 1961–1990 National Solar Radiation Data Base (NREL 1995) and are in the Typical Meteorological Year (TMY2) format. There are 239 weather tapes and they represent conditions from all over the United States. It is important to note that the TMY2 format represents typical rather than extreme climate conditions. Of the 239 tapes, 17 are for Alaska (3 of those are unusable) and 6 are for tropical islands (4 in Hawaii, Guam, and San Juan). Some on the west coast are located at coastal airports and have moderate climates, which do not represent inland conditions (these include Los Angeles, Long Beach, San Diego, San Francisco and Seattle). The location, latitude, annual average temperature, heating-degree-days (base 65^oF), and cooling-degree-days (base 65^oF) for the simulated climates are shown in **Table 4**.

The direct energy effects are simulated with the building energy software DOE-2 and standard climate data. The indirect energy impacts are estimated from simple algorithms developed from the detailed analysis previously completed for Baton Rouge LA, Chicago IL, Houston TX, Sacramento CA, and Salt Lake City UT. The algorithms are based on the regression of the estimated indirect savings vs. (1) cooling-electricity savings for gas-heated buildings, (2) gas-heating energy penalties for gas-heated buildings, (3) cooling- and heating-electricity savings for electrically heated buildings, and (4) peak electricity demand, for the five pilot cities.

Tabulation of Results

Upon completion of estimating the direct and indirect energy savings for all the locations, we integrated the results in tables arranged by heating- and cooling-degree-days. We considered 15 bins for heating-degree-days, and 11 bins for cooling-degree-days. **Table 5** lists the ranges of heating- and cooling-degree-days. Note that the numbers of simulated climates for cooling-degree-days greater than 3000 are small. We would recommend that for these cooling-degree-days bins, the savings be calculated by averaging estimates using both heating- and cooling-degrees tables.

Results

Tables 6-8 give the results for residential, office, and retail store buildings. Each table provides estimates of savings arranged by (**a**) heating-degree-days and (**b**) cooling-degree-days. The values in these tables are also plotted in **Figures 3-5** for residential, office, and retails store buildings, respectively. Each figure is plotted by (**a**) heating-degree-days, (**b**) cooling-degree-days, (i) basecase energy and demand use, (**ii**) direct savings (penalties) from cool roofs, (**iii**) direct savings (penalties) from shade trees, (**iv**) the indirect savings from cool surfaces (roofs and pavements) and increased urban vegetation, and (**v**) the combined direct and indirect savings (penalties). It is easier to use Tables 6-8 for estimating energy savings. These figures are used to illustrate the magnitude of the savings and penalties.

Table 4. Summary weather data. The bin ranges for heating- and cooling-degree-days are listed in Table 5.

Location	Latitude	Annual Average Temperature (°F)	Cooling-Degree-Days (base 65°F)	Cooling-Degree-Days Bin #	Heating-Degree-Days (base 65°F)	Heating-Degree-Days Bin #
Abilene, TX	32.43	69.7	2284	7	2597	6
Akron, OH	40.92	55.2	614	10	6201	13
Alamosa, CO	37.45	50.0	53	12	8760	15
Albany, NY	42.75	53.4	543	10	7079	14
Albuquerque, NM	35.05	62.7	1211	9	4361	9
Allentown, PA	40.65	56.5	722	10	5858	12
Alpena, MI	45.07	49.5	214	11	8458	15
Amarillo, TX	35.23	62.6	1294	9	4655	10
Anchorage, AK	61.17	44.4	2	12	10386	15
Annette, AK	55.03	48.5	3	12	7215	14
Arcata, CA	40.98	54.5	4	12	5196	11
Asheville, NC	35.43	60.0	748	10	4512	10
Astoria, OR	46.15	54.2	14	12	5291	11
Athens, GA	33.95	66.8	1640	8	2850	6
Atlanta, GA	33.65	65.7	1611	8	3090	7
Atlantic City, NJ	39.45	59.1	907	10	5264	11
Augusta, GA	33.37	68.0	1778	8	2887	6
Austin, TX	30.3	73.1	2965	6	1630	4
Bakersfield, CA	35.42	70.9	2367	7	2100	5
Baltimore, MD	39.18	60.5	1133	9	4912	10
Baton Rouge, LA	30.53	71.9	2444	7	1653	4
Bethel, AK	60.78	38.1	2	12	13094	15
Big Delta, AK	64	40.8	14	12	13399	15
Billings, MT	45.8	53.6	618	10	7083	14
Binghamton, NY	42.22	50.0	318	11	7535	14
Birmingham, AL	33.57	67.4	1671	8	2825	6
Bismarck, ND	46.77	51.3	408	11	8666	15
Boise, ID	43.57	57.5	692	10	6000	12
Boston, MA	42.37	54.9	646	10	5841	12
Boulder, CO	40.02	57.6	623	10	6007	13
Bradford, PA	41.8	48.9	143	12	8245	15
Bridgeport, CT	41.17	56.3	798	10	5664	12
Bristol, TN	36.48	60.8	929	10	4346	9
Brownsville, TX	25.9	77.2	3563	4	659	2
Buffalo, NY	42.93	53.3	511	10	6719	13
Burlington, VT	44.47	50.7	407	11	7892	14
Burns, OR	43.58	52.6	285	11	7072	14
Cape Hatteras, NC	35.27	65.5	1474	9	2640	6
Caribou, ME	46.87	45.1	114	12	9518	15
Casper, WY	42.92	52.6	328	11	7705	14
Cedar City, UT	37.7	58.3	651	10	6051	13
Charleston, SC	32.9	69.7	2010	7	2209	5
Charleston, WV	38.37	60.1	903	10	4632	10
Charlotte, NC	35.22	65.1	1513	8	3416	7
Chattanooga, TN	35.03	65.1	1585	8	3535	8
Cheyenne, WY	41.15	52.6	258	11	7317	14
Chicago, IL	41.78	55.4	749	10	6447	13

Location	Latitude	Annual Average Temperature (^oF)	Cooling-Degree-Days (base 65^oF)	Cooling-Degree-Days Bin #	Heating-Degree-Days (base 65^oF)	Heating-Degree-Days Bin #
Cleveland, OH	41.4	55.8	617	10	6108	13
Cold Bay, AK	55.2	42.2	0	12	9550	15
Colorado Springs, CO	38.82	55.4	409	11	6517	13
Columbia, MO	38.82	60.2	1228	8	5129	6
Columbia, SC	33.95	68.8	1898	9	2765	11
Columbus, GA	32.52	69.2	2118	7	2312	5
Columbus, OH	40	57.7	779	10	5551	12
Concord, NH	43.2	52.4	402	11	7665	14
Corpus Christi, TX	27.77	76.2	3267	5	884	2
Covington, KY	39.07	59.3	1007	9	5184	11
Cut Bank, MT	48.6	49.0	67	12	8660	15
Daggett, CA	34.87	74.3	2983	6	1740	4
Dayton, OH	39.9	56.5	715	10	5927	12
Daytona Beach, FL	29.18	74.8	2735	6	871	2
Des Moines, IA	41.53	56.1	908	10	6503	13
Detroit, MI	42.42	54.4	567	10	6726	13
Dodge City, KS	37.77	61.1	1371	9	5353	11
Duluth, MN	46.83	44.3	140	12	10186	15
Eagle, CO	39.65	50.7	71	12	8355	15
Eau Claire, WI	44.87	50.1	513	10	8484	15
El Paso, TX	31.8	70.8	2046	7	2597	6
Elkins, WV	38.88	54.8	345	11	6289	13
Elko, NV	40.83	54.3	289	11	7234	14
Ely, NV	39.28	51.6	145	12	8045	15
Erie, PA	42.08	52.9	454	11	6757	13
Eugene, OR	44.12	57.9	228	11	4627	10
Evansville, IN	38.05	61.4	1298	9	4803	10
Fairbanks, AK	64.82	41.3	29	12	14095	15
Fargo, ND	46.9	49.6	547	10	9069	15
Flagstaff, AZ	35.13	53.8	106	12	7430	14
Flint, MI	42.97	53.6	444	11	6981	13
Fort Smith, AR	35.33	67.1	1895	8	3351	7
Fort Wayne, IN	41	55.3	657	10	6391	13
Fort Worth, TX	32.83	70.5	2415	7	2304	5
Fresno, CA	36.77	69.4	1884	8	2602	6
Glasgow, MT	48.22	50.2	469	11	8659	15
Goodland, KS	39.37	57.4	842	10	6270	13
Grand Island, NE	40.97	57.3	925	10	6420	13
Grand Junction, CO	39.12	59.6	1145	9	5676	12
Grand Rapids, MI	42.88	53.4	508	10	7148	14
Great Falls, MT	47.48	52.1	362	11	7735	14
Green Bay, WI	44.48	50.0	414	11	8286	15
Greensboro, NC	36.08	62.9	1223	9	4091	9
Greenville, SC	34.9	65.3	1483	9	3408	7
Guam, PI	13.55	80.9	5184	1	0	1
Gulkana, AK	62.15	38.6	0	12	13880	15
Harrisburg, PA	40.22	58.2	987	10	5479	11
Hartford, CT	41.93	55.9	745	10	6264	13
Helena, MT	46.60	51.4	328	11	7802	14
Hilo, HI	19.72	76.4	3087	5	0	1

Location	Latitude	Annual Average Temperature (^oF)	Cooling-Degree-Days (base 65^oF)	Cooling-Degree-Days Bin #	Heating-Degree-Days (base 65^oF)	Heating-Degree-Days Bin #
Honolulu, HI	21.33	79.7	4329	3	0	1
Houghton, MI	47.17	49.6	234	11	8541	15
Houston, TX	29.98	73.4	2810	6	1552	4
Huntington, WV	38.37	60.6	998	10	4496	9
Huntsville, AL	34.65	65.1	1632	8	3542	8
Huron, SD	44.38	52.6	530	10	8235	15
Indianapolis, IN	39.73	57.7	910	10	5689	12
International Falls, MN	48.57	44.6	125	12	10435	15
Jackson, MS	32.32	69.9	2233	7	2501	6
Jacksonville, FL	30.50	73.4	2657	6	1437	3
Kahului, HI	20.90	79.2	3851	4	3	1
Kalispell, MT	48.30	49.9	105	12	8314	15
Kansas City, MO	39.30	60.5	1445	9	5155	11
Key West, FL	24.55	79.9	4757	2	62	1
King Salmon, AK	58.68	41.5	1	12	11446	15
Knoxville, TN	35.82	63.5	1366	9	3662	8
Kodiak, AK	57.75	45.1	2	12	8944	15
La Crosse, WI	43.87	52.4	617	10	7658	14
Lake Charles, LA	30.12	72.1	2624	6	1683	4
Lander, WY	42.82	51.7	371	11	7754	14
Lansing, MI	42.78	53.9	550	10	7122	14
Las Vegas, NV	36.08	73.8	3067	5	2293	5
Lewistown, MT	47.05	50.3	209	11	8338	15
Lexington, KY	38.03	59.7	1005	9	4994	10
Lihue, HI	21.98	77.8	3847	4	0	1
Little Rock, AR	34.73	67.3	1929	8	3181	7
Long Beach, CA	33.82	67.4	943	10	1309	3
Los Angeles, CA	33.93	65.2	470	11	1291	3
Louisville, KY	38.18	62.0	1300	9	4441	9
Lubbock, TX	33.65	65.7	1569	8	3451	7
Lufkin, TX	31.23	72.2	2493	7	1911	4
Lynchburg, VA	37.33	61.3	1070	9	4448	9
Macon, GA	32.70	69.5	2090	7	2353	5
Madison, WI	43.13	52.8	521	10	7495	14
Mansfield, OH	40.82	55.6	688	10	6245	13
Mason City, IA	43.15	51.3	505	10	8167	15
Massena, NY	44.93	49.5	351	11	8466	15
Mcgrath, AK	62.97	39.5	14	12	14206	15
Medford, OR	42.37	59.6	672	10	4829	10
Memphis, TN	35.05	67.3	1999	8	3108	7
Meridian, MS	32.33	69.5	1990	8	2585	6
Miami, FL	25.80	78.7	4127	3	141	1
Midland, TX	31.93	69.7	2032	7	2772	6
Miles City, MT	46.43	52.7	598	10	7783	14
Milwaukee, WI	42.95	51.2	473	11	7512	14
Minneapolis, MN	44.88	52.0	634	10	7986	14
Minot, ND	48.27	49.2	309	11	9092	15
Missoula, MT	46.92	51.2	274	11	7888	14
Mobile, AL	30.68	71.7	2508	6	1710	4

Location	Latitude	Annual Average Temperature (^{o}F)	Cooling-Degree-Days (base 65^{o}F)	Cooling-Degree-Days Bin #	Heating-Degree-Days (base 65^{o}F)	Heating-Degree-Days Bin #
Moline, IL	41.45	56.8	882	10	6302	13
Montgomery, AL	32.30	70.3	2104	7	2096	5
Muskegon, MI	43.17	52.9	494	11	7037	14
Nashville, TN	36.12	64.4	1672	8	4031	9
New Orleans, LA	29.98	72.6	2539	6	1464	3
New York City, NY	40.78	57.8	1002	9	5090	11
Newark, NJ	40.70	58.5	1062	9	5123	11
Nome, AK	64.50	39.5	0	12	13955	15
Norfolk, NE	41.98	56.0	998	9	6875	7
Norfolk, VA	36.90	64.0	1439	10	3489	13
North Bend, OR	43.42	55.4	1	12	4633	10
North Platte, NE	41.13	56.9	773	10	6798	13
Oklahoma City, OK	35.40	65.5	1810	8	3800	8
Olympia, WA	46.97	55.8	140	12	5495	11
Omaha, NE	41.37	57.6	1051	9	6047	13
Pendleton, OR	45.68	58.3	687	10	5311	11
Peoria, IL	40.67	56.4	882	10	6327	13
Philadelphia, PA	39.88	59.0	1053	9	5181	11
Phoenix, AZ	33.43	79.3	3815	4	1154	3
Pierre, SD	44.38	55.2	795	10	7224	14
Pittsburgh, PA	40.50	56.3	684	10	5986	12
Pocatello, ID	42.92	53.7	346	11	7275	14
Port Arthur, TX	29.95	73.0	2693	6	1543	4
Portland, ME	43.65	51.6	315	11	7442	14
Portland, OR	45.60	57.7	279	11	4461	9
Prescott, AZ	34.65	63.6	898	10	4404	9
Providence, RI	41.73	55.6	609	10	5986	12
Pueblo, CO	38.28	61.2	916	10	5241	11
Quillayute, WA	47.95	53.1	8	12	5899	12
Raleigh, NC	35.87	64.7	1313	9	3547	8
Rapid City, SD	44.05	53.6	517	10	7302	14
Redmond, OR	44.27	55.1	194	12	6732	13
Reno, NV	39.50	58.8	384	11	5768	12
Richmond, VA	37.50	63.2	1297	9	4097	9
Roanoke, VA	37.32	62.0	1035	9	4215	9
Rochester, MN	43.92	50.4	500	10	8244	13
Rochester, NY	43.12	54.0	620	10	6733	15
Rock Springs, IL	41.60	49.7	185	12	8371	15
Rockford, WY	42.20	54.0	628	10	6934	13
Sacramento, CA	38.52	65.9	1144	9	2794	6
Saint Cloud, MN	45.55	49.6	414	11	8971	15
Salem, OR	44.92	57.5	200	11	4969	10
Salt Lake City, UT	40.77	60.0	1054	9	5636	12
San Angelo, TX	31.37	69.4	2180	7	2662	6
San Antonio, TX	29.53	73.3	2863	6	1679	4
San Diego, CA	32.73	66.6	766	10	1076	3
San Francisco, CA	37.62	59.3	69	12	3239	7
San Juan, PR	18.43	81.9	5332	1	0	1
Santa Maria, CA	34.90	61.0	59	12	3159	7
Sault Ste Marie, MI	46.47	46.9	83	12	9141	15

Location	Latitude	Annual Average Temperature (^oF)	Cooling-Degree-Days (base 65^oF)	Cooling-Degree-Days Bin #	Heating-Degree-Days (base 65^oF)	Heating-Degree-Days Bin #
Savannah, GA	32.13	71.0	2292	7	1951	4
Scottsbluff, NE	41.87	57.0	714	10	6448	13
Seattle, WA	47.45	55.6	127	12	4867	10
Sheridan, WY	44.77	53.0	382	11	7685	14
Shreveport, LA	32.47	70.4	2287	7	2216	5
Sioux City, IA	42.40	56.1	842	10	6692	13
Sioux Falls, SD	43.57	53.5	794	10	7844	14
South Bend, IN	41.70	55.7	778	10	6292	13
Spokane, WA	47.63	53.3	405	11	6886	13
Springfield, IL	39.83	58.1	1171	9	5887	10
Springfield, MO	37.23	62.0	1346	9	4690	12
St Louis, MO	38.75	60.8	1437	9	5021	11
St Paul Is, AK	57.15	37.6	0	12	11126	15
Sterling, VA	38.95	59.9	1044	9	5233	11
Syracuse, NY	43.12	52.9	483	11	7038	14
Talkeetna, AK	62.30	43.5	2	12	11569	15
Tallahassee, FL	30.38	72.5	2361	7	1755	4
Tampa, FL	27.97	76.6	3311	5	697	2
Toledo, OH	41.60	54.9	610	10	6753	13
Tonopah, NV	38.07	60.1	695	10	5372	11
Topeka, KS	39.07	60.6	1281	9	5323	11
Traverse City, MI	44.73	51.8	458	11	7789	14
Tucson, AZ	32.12	75.0	2763	6	1554	4
Tucumcari, NM	35.18	64.7	1451	9	3958	8
Tulsa, OK	36.20	65.6	1870	8	3816	8
Victoria, TX	28.85	74.6	2966	6	1127	3
Waco, TX	31.62	71.6	2547	6	2088	5
Waterloo, IA	42.55	53.4	587	10	7245	14
West Palm Beach, FL	26.68	78.2	3802	4	236	1
Wichita Falls, TX	33.97	69.5	2385	8	3055	10
Wichita, KS	37.65	62.5	1585	7	4900	7
Wilkes-Barre, PA	41.33	53.5	547	10	6683	13
Williamsport, PA	41.27	55.5	672	10	6088	13
Wilmington, DE	39.67	59.5	1085	8	5087	6
Wilmington, NC	34.27	68.1	1868	9	2658	11
Winnemucca, NV	40.90	58.4	604	10	6444	13
Worchester, MA	42.27	52.2	389	11	6949	13
Yakima, WA	46.57	57.6	417	11	6060	13
Yakutat, AK	59.52	43.8	0	12	9797	15
Youngstown, OH	41.27	53.9	518	10	6695	13

Table 5. Bins of heating- and cooling-degree-days.

Bin #	Heating-degree-day range	No. of Simulations
1	0<HDD<500	9
2	500<HDD<1000	4
3	1000<HDD<1500	7
4	1500<HDD<2000	12
5	2000<HDD<2500	8
6	2500<HDD<3000	14
7	3000<HDD<3500	11
8	3500<HDD<4000	8
9	4000<HDD<4500	11
10	4500<HDD<5000	13
11	5000<HDD<5500	19
12	5500<HDD<6000	14
13	6000<HDD<7000	36
14	7000<HDD<8000	32
15	8000<HDD	38

Bin #	Cooling-degree-day range	No. of Simulations
1	5000<CDD	2
2	4500<CDD<5000	1
3	4000<CDD<4500	2
4	3500<CDD<4000	5
5	3000<CDD<3500	4
6	2500<CDD<3000	13
7	2000<CDD<2500	17
8	1500<CDD<2000	19
9	1000<CDD<1500	33
10	500<CDD<1000	66
11	200<CDD<500	39
12	0<CDD<200	35

Table 6a. Estimated annual basecase energy use and peak demand, and savings from heat-island reduction measures for *residential buildings*, ordered by ranges of *heating-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

HDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2)		Gas Heat Gas (Therm/1000ft^2)		Electric Heat Electricity (kWh/1000ft^2)		Gas & Electric Heat Peak Power (W/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group < 500 (bin #1)								
Energy use & demand	8387	5193	2	0	8426	5199	3151	1788
Savings								
reflective roof savings	732	291	0	0	732	291	320	132
shade tree savings	298	192	0	0	297	191	79	91
indirect savings	216	101	0	0	216	101	96	54
combined savings	1246	584	0	0	1245	583	495	277
Heating-degree-days group < 1000, > 500 (bin #2)								
Energy use & demand	6201	3748	58	15	7177	3956	3658	2124
Savings								
reflective roof savings	534	208	-1	0	510	203	290	148
shade tree savings	291	175	-1	0	279	171	72	56
indirect savings	173	80	-1	0	166	79	87	49
combined savings	998	463	-3	0	955	453	449	253
Heating-degree-days group <1500, >1000 (bin #3)								
Energy use & demand	3911	2172	102	31	5589	2589	3514	1972
Savings								
reflective roof savings	447	167	-2	0	397	159	322	140
shade tree savings	249	147	-5	-1	209	135	123	107
indirect savings	146	66	-2	0	127	62	107	59
combined savings	842	380	-9	-1	733	356	552	306
Heating-degree-days group <2000, >1500 (bin #4)								
Energy use & demand	5236	2968	163	53	7998	3728	3804	2118
Savings								
reflective roof savings	542	213	-3	0	463	198	333	145
shade tree savings	293	177	-6	-2	279	168	145	90
indirect savings	175	82	-2	-1	156	77	115	56
combined savings	1010	472	-11	-3	898	443	593	291
Heating-degree-days group <2500, >2000 (bin #5)								
Energy use & demand	4674	2583	219	75	8510	3690	4056	2272
Savings								
reflective roof savings	494	188	-5	-1	379	165	328	143
shade tree savings	307	182	-8	-2	287	170	171	113
indirect savings	168	78	-3	-1	140	70	120	61
combined savings	969	448	-16	-4	806	405	619	317
Heating-degree-days group <3000, >2500 (bin #6)								
Energy use & demand	3907	2099	298	107	8912	3669	3698	2031
Savings								
reflective roof savings	466	176	-7	-2	313	141	333	139
shade tree savings	282	165	-12	-4	263	148	145	84
indirect savings	157	72	-5	-2	121	61	115	54
combined savings	905	413	-24	-8	697	350	593	277

HDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2) Pre-1980	Gas Heat Electricity (kWh/1000ft^2) 1980$^+$	Gas Heat Gas (Therm/1000ft^2) Pre-1980	Gas Heat Gas (Therm/1000ft^2) 1980$^+$	Electric Heat Electricity (kWh/1000ft^2) Pre-1980	Electric Heat Electricity (kWh/1000ft^2) 1980$^+$	Gas & Electric Heat Peak Power (W/1000ft^2) Pre-1980	Gas & Electric Heat Peak Power (W/1000ft^2) 1980$^+$
Heating-degree-days group <3500, >3000 (bin #7)								
Energy use & demand	3037	1640	396	149	9439	3808	3513	1936
Savings								
reflective roof savings	333	126	-9	-2	138	82	329	151
shade tree savings	211	125	-16	-5	192	109	154	121
indirect savings	114	53	-6	-2	69	40	116	65
combined savings	658	304	-31	-9	399	231	599	337
Heating-degree-days group <4000, >3500 (bin #8)								
Energy use & demand	3343	1777	472	185	11225	4612	3705	2020
Savings								
reflective roof savings	374	144	-10	-3	154	81	329	136
shade tree savings	250	141	-14	-6	271	121	202	85
indirect savings	131	60	-6	-2	89	42	127	53
combined savings	755	345	-30	-11	514	244	658	274
Heating-degree-days group <4500, >4000 (bin #9)								
Energy use & demand	2567	1274	579	231	11580	4678	3315	1804
Savings								
reflective roof savings	343	125	-14	-4	81	51	326	131
shade tree savings	223	117	-15	-8	221	110	106	103
indirect savings	119	51	-7	-3	63	34	104	56
combined savings	685	293	-36	-15	365	195	536	290
Heating-degree-days group <5000, >4500 (bin #10)								
Energy use & demand	2073	1018	680	281	12642	5139	3308	1797
Savings								
reflective roof savings	236	84	-14	-4	-20	10	296	143
shade tree savings	181	97	-29	-14	231	94	237	161
indirect savings	88	38	-11	-5	44	22	128	73
combined savings	505	219	-54	-23	255	126	661	377
Heating-degree-days group <5500, >5000 (bin #11)								
Energy use & demand	2270	1134	770	321	14037	5916	3381	1837
Savings								
reflective roof savings	234	84	-15	-4	-43	0	315	132
shade tree savings	183	101	-24	-12	252	101	192	161
indirect savings	88	39	-10	-4	44	21	122	70
combined savings	505	224	-49	-20	253	122	629	363
Heating-degree-days group <6000, >5500 (bin #12)								
Energy use & demand	2020	968	876	379	15217	6516	3262	1713
Savings								
reflective roof savings	222	80	-16	-5	-69	-13	321	134
shade tree savings	185	98	-19	-9	150	61	140	82
indirect savings	85	37	-9	-4	17	10	111	52
combined savings	492	215	-44	-18	98	58	572	268
Heating-degree-days group <7000, >6000 (bin #13)								
Energy use & demand	1990	945	1025	456	18006	7952	3444	1829
Savings								
reflective roof savings	198	71	-17	-5	-97	-25	325	130
shade tree savings	190	97	-15	-10	37	57	135	95
indirect savings	81	35	-8	-4	-13	7	110	54
combined savings	469	203	-40	-19	-73	39	570	279

HDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2)		Gas Heat Gas (Therm/1000ft^2)		Electric Heat Electricity (kWh/1000ft^2)		Gas & Electric Heat Peak Power (W/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group <8000, >7000 (bin #14)								
Energy use & demand	1747	802	1169	529	20424	9102	3310	1724
Savings								
reflective roof savings	153	54	-20	-7	-193	-64	338	132
shade tree savings	168	87	-17	-9	-13	17	207	130
indirect savings	67	30	-9	-4	-43	-10	131	63
combined savings	388	171	-46	-20	-249	-57	676	325
Heating-degree-days group >8000 (bin #15)								
Energy use & demand	1551	713	1614	765	28511	13549	2421	1223
Savings								
reflective roof savings	67	22	-21	-7	-330	-109	344	124
shade tree savings	82	41	-22	-11	-227	-103	357	197
indirect savings	31	13	-11	-5	-117	-45	168	77
combined savings	180	76	-54	-23	-674	-257	869	398

Table 6b. Estimated annual basecase energy use and peak demand and savings from heat-island reduction measures for *residential buildings*, ordered by ranges of *cooling-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

CDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2)		Gas Heat Gas (Therm/1000ft^2)		Electric Heat Electricity (kWh/1000ft^2)		Gas & Electric Heat Peak Power (W/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Cooling-degree-days group > 5000 (bin #1)								
Energy use & demand	10770	6715	0	0	10770	6715	3235	1776
Savings								
reflective roof savings	807	333	0	0	807	333	347	115
shade tree savings	260	158	0	0	260	158	30	21
indirect savings	224	103	0	0	224	103	90	33
combined savings	1291	594	0	0	1291	594	467	169
Cooling-degree-days group > 4500, <5000 (bin #2)								
Energy use & demand	9603	5846	1	0	9623	5847	3391	1939
Savings								
reflective roof savings	755	297	0	0	756	298	305	133
shade tree savings	274	212	0	0	274	213	21	231
indirect savings	216	107	0	0	216	107	78	87
combined savings	1245	616	0	0	1246	618	404	451
Cooling-degree-days group > 4000, < 4500 (bin #3)								
Energy use & demand	8225	5084	3	0	8274	5090	3270	1840
Savings								
reflective roof savings	712	282	0	0	712	282	367	140
shade tree savings	308	198	0	0	306	198	136	87
indirect savings	214	101	0	0	214	101	121	54
combined savings	1234	581	0	0	1232	581	624	281
Cooling-degree-days group > 3500, < 4000 (bin #4)								
Energy use & demand	7454	4498	30	8	7979	4610	3631	2085
Savings								
reflective roof savings	649	250	0	0	638	247	292	134
shade tree savings	372	220	-1	0	365	216	129	110
indirect savings	214	99	0	0	211	97	101	59
combined savings	1235	569	-1	0	1214	560	522	303
Cooling-degree-days group > 3000, < 3500 (bin #5)								
Energy use & demand	6254	3647	71	20	7559	3946	3953	2242
Savings								
reflective roof savings	630	247	-1	0	593	241	313	159
shade tree savings	332	203	-2	0	315	198	112	91
indirect savings	202	95	-1	0	191	92	102	60
combined savings	1164	545	-4	0	1099	531	527	310
Cooling-degree-days group > 2500, < 3000 (bin #6)								
Energy use & demand	5381	3085	145	46	7840	3753	3797	2146
Savings								
reflective roof savings	534	210	-3	0	466	197	321	146
shade tree savings	294	179	-5	-1	278	171	98	82
indirect savings	174	82	-2	0	156	77	101	55
combined savings	1002	471	-10	-1	900	445	520	283
Cooling-degree-days group > 2000, < 2500 (bin #7)								
Energy use & demand	4541	2518	243	85	8703	3788	3851	2143

CDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2) Pre-1980	Gas Heat Electricity (kWh/1000ft^2) 1980$^+$	Gas Heat Gas (Therm/1000ft^2) Pre-1980	Gas Heat Gas (Therm/1000ft^2) 1980$^+$	Electric Heat Electricity (kWh/1000ft^2) Pre-1980	Electric Heat Electricity (kWh/1000ft^2) 1980$^+$	Gas & Electric Heat Peak Power (W/1000ft^2) Pre-1980	Gas & Electric Heat Peak Power (W/1000ft^2) 1980$^+$
Savings								
reflective roof savings	495	191	-5	-1	377	167	331	141
shade tree savings	286	171	-9	-3	280	162	159	102
indirect savings	164	76	-4	-1	138	69	118	58
combined savings	945	438	-18	-5	795	398	608	301
Cooling-degree-days group > 1500, < 2000 (bin #8)								
Energy use & demand	3689	1994	407	156	10480	4377	3693	2050
Savings								
reflective roof savings	418	159	-9	-2	227	111	321	139
shade tree savings	256	149	-13	-5	261	131	145	73
indirect savings	142	65	-6	-2	102	51	112	51
combined savings	816	373	-28	-9	590	293	578	263
Cooling-degree-days group > 1000, < 1500 (bin #9)								
Energy use & demand	2757	1411	665	275	13235	5607	3525	1939
Savings								
reflective roof savings	317	116	-13	-4	75	44	311	130
shade tree savings	231	126	-15	-8	213	113	95	90
indirect savings	115	51	-7	-3	60	33	97	53
combined savings	663	293	-35	-15	348	190	503	273
Cooling-degree-days group > 500, < 1000 (bin #10)								
Energy use & demand	2045	978	978	436	17665	7819	3454	1844
Savings								
reflective roof savings	213	77	-16	-5	-67	-14	322	130
shade tree savings	195	103	-16	-9	79	63	163	108
indirect savings	86	38	-8	-4	3	10	116	57
combined savings	494	218	-40	-18	15	59	601	295
Cooling-degree-days group >200, < 500 (bin #11)								
Energy use & demand	1606	719	1130	511	19768	8779	3235	1681
Savings								
reflective roof savings	150	51	-19	-6	-191	-63	368	142
shade tree savings	159	79	-19	-10	-14	7	236	160
indirect savings	65	27	-10	-4	-43	-12	145	72
combined savings	374	157	-48	-20	-248	-68	749	374
Cooling-degree-days group < 200 (bin #12)								
Energy use & demand	1208	536	1408	655	23814	11063	2084	1013
Savings								
reflective roof savings	43	13	-21	-7	-355	-112	317	125
shade tree savings	40	20	-30	-13	-165	-96	392	215
indirect savings	17	7	-13	-5	-109	-44	170	82
combined savings	100	40	-64	-25	-629	-252	879	422

Table 6c. Estimated annual basecase carbon emissions and savings from heat-island reduction measures for *residential buildings*, ordered by ranges of *heating-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group < 500 (bin #1)				
Carbon emissions	1404	867	1407	868
Savings				
reflective roof savings	122	49	122	49
shade tree savings	50	32	50	32
indirect savings	36	17	36	17
combined savings	208	98	208	97
Heating-degree-days group < 1000, > 500 (bin #2)				
Carbon emissions	1119	648	1199	661
Savings				
reflective roof savings	88	35	85	34
shade tree savings	47	29	47	29
indirect savings	28	13	28	13
combined savings	163	77	159	76
Heating-degree-days group <1500, >1000 (bin #3)				
Carbon emissions	801	408	933	432
Savings				
reflective roof savings	72	28	66	27
shade tree savings	34	23	35	23
indirect savings	22	11	21	10
combined savings	128	62	122	59
Heating-degree-days group <2000, >1500 (bin #4)				
Carbon emissions	1110	572	1336	623
Savings				
reflective roof savings	86	36	77	33
shade tree savings	40	27	47	28
indirect savings	26	13	26	13
combined savings	152	75	150	74
Heating-degree-days group <2500, >2000 (bin #5)				
Carbon emissions	1097	540	1421	616
Savings				
reflective roof savings	75	30	63	28
shade tree savings	40	28	48	28
indirect savings	23	12	23	12
combined savings	138	69	135	68
Heating-degree-days group <3000, >2500 (bin #6)				
Carbon emissions	1084	505	1488	613
Savings				
reflective roof savings	68	26	52	24
shade tree savings	30	22	44	25
indirect savings	19	10	20	10
combined savings	117	58	116	58

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group <3500, >3000 (bin #7)				
Carbon emissions	1080	489	1576	636
Savings				
reflective roof savings	43	18	23	14
shade tree savings	12	14	32	18
indirect savings	10	6	12	7
combined savings	65	38	67	39
Heating-degree-days group <4000, >3500 (bin #8)				
Carbon emissions	1241	564	1875	770
Savings				
reflective roof savings	48	20	26	14
shade tree savings	21	15	45	20
indirect savings	13	7	15	7
combined savings	83	41	86	41
Heating-degree-days group <4500, >4000 (bin #9)				
Carbon emissions	1267	547	1934	781
Savings				
reflective roof savings	37	15	14	9
shade tree savings	16	8	37	18
indirect savings	9	4	11	6
combined savings	62	27	61	33
Heating-degree-days group <5000, >4500 (bin #10)				
Carbon emissions	1330	577	2111	858
Savings				
reflective roof savings	19	8	-3	2
shade tree savings	-12	-4	39	16
indirect savings	-1	0	7	4
combined savings	6	4	43	21
Heating-degree-days group <5500, >5000 (bin #11)				
Carbon emissions	1493	654	2344	988
Savings				
reflective roof savings	17	8	-7	0
shade tree savings	-4	0	42	17
indirect savings	1	1	7	4
combined savings	14	8	42	20
Heating-degree-days group <6000, >5500 (bin #12)				
Carbon emissions	1605	710	2541	1088
Savings				
reflective roof savings	14	6	-12	-2
shade tree savings	3	3	25	10
indirect savings	2	1	3	2
combined savings	19	11	16	10
Heating-degree-days group <7000, >6000 (bin #13)				
Carbon emissions	1816	818	3007	1328
Savings				
reflective roof savings	8	5	-16	-4
shade tree savings	10	2	6	10
indirect savings	2	0	-2	1
combined savings	21	7	-12	6

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group <8000, >7000 (bin #14)				
Carbon emissions	1983	899	3411	1520
Savings				
reflective roof savings	-3	-1	-32	-11
shade tree savings	3	2	-2	3
indirect savings	-2	-1	-7	-2
combined savings	-2	0	-42	-9
Heating-degree-days group >8000 (bin #15)				
Carbon emissions	2594	1226	4761	2263
Savings				
reflective roof savings	-19	-6	-55	-18
shade tree savings	-18	-9	-38	-17
indirect savings	-10	-4	-20	-7
combined savings	-48	-20	-113	-43

Table 6d. Estimated annual basecase carbon emissions and savings from heat-island reduction measures for *residential buildings*, ordered by ranges of *cooling-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Cooling-degree-days group > 5000 (bin #1)				
Carbon emissions	1799	1121	1799	1121
Savings				
reflective roof savings	135	56	135	56
shade tree savings	43	26	43	26
indirect savings	37	17	37	17
combined savings	216	99	216	99
Cooling-degree-days group > 4500, <5000 (bin #2)				
Carbon emissions	1605	976	1607	976
Savings				
reflective roof savings	126	50	126	50
shade tree savings	46	35	46	36
indirect savings	36	18	36	18
combined savings	208	103	208	103
Cooling-degree-days group > 4000, < 4500 (bin #3)				
Carbon emissions	1378	849	1382	850
Savings				
reflective roof savings	119	47	119	47
shade tree savings	51	33	51	33
indirect savings	36	17	36	17
combined savings	206	97	206	97
Cooling-degree-days group > 3500, < 4000 (bin #4)				
Carbon emissions	1288	763	1332	770
Savings				
reflective roof savings	108	42	107	41
shade tree savings	61	37	61	36
indirect savings	35	16	35	16
combined savings	205	95	203	94
Cooling-degree-days group > 3000, < 3500 (bin #5)				
Carbon emissions	1147	638	1262	659
Savings				
reflective roof savings	104	41	99	40
shade tree savings	53	34	53	33
indirect savings	33	16	32	15
combined savings	189	91	183	89
Cooling-degree-days group > 2500, < 3000 (bin #6)				
Carbon emissions	1108	582	1309	627
Savings				
reflective roof savings	85	35	78	33
shade tree savings	42	28	46	29
indirect savings	26	13	26	13
combined savings	153	77	150	74

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Cooling-degree-days group > 2000, < 2500 (bin #7)				
Carbon emissions	1110	544	1453	633
Savings				
reflective roof savings	75	30	63	28
shade tree savings	35	24	47	27
indirect savings	22	11	23	12
combined savings	132	66	133	66
Cooling-degree-days group > 1500, < 2000 (bin #8)				
Carbon emissions	1205	559	1750	731
Savings				
reflective roof savings	57	24	38	19
shade tree savings	24	18	44	22
indirect savings	16	8	17	8
combined savings	96	50	99	49
Cooling-degree-days group > 1000, < 1500 (bin #9)				
Carbon emissions	1423	634	2210	936
Savings				
reflective roof savings	34	14	13	7
shade tree savings	17	9	36	19
indirect savings	9	4	10	6
combined savings	60	27	58	32
Cooling-degree-days group > 500, < 1000 (bin #10)				
Carbon emissions	1757	794	2950	1306
Savings				
reflective roof savings	12	6	-11	-2
shade tree savings	9	4	13	11
indirect savings	3	1	0	2
combined savings	25	11	2	10
Cooling-degree-days group >200, < 500 (bin #11)				
Carbon emissions	1903	859	3301	1466
Savings				
reflective roof savings	-2	0	-32	-11
shade tree savings	-1	-1	-2	1
indirect savings	-3	-1	-7	-2
combined savings	-6	-3	-41	-11
Cooling-degree-days group < 200 (bin #12)				
Carbon emissions	2239	1037	3977	1848
Savings				
reflective roof savings	-23	-8	-59	-19
shade tree savings	-37	-15	-28	-16
indirect savings	-16	-6	-18	-7
combined savings	-75	-30	-105	-42

Table 7a. Estimated annual basecase energy use and peak demand and savings from heat-island reduction measures for *office buildings*, ordered by ranges of *heating-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

HDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2)		Gas Heat Gas (Therm/1000ft^2)		Electric Heat Electricity (kWh/1000ft^2)		Gas & Electric Heat Peak Power (W/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group < 500 (bin #1)								
Energy use & demand	16839	9606	2	0	16863	9606	6674	3834
Savings								
reflective roof savings	694	242	0	0	693	242	263	95
shade tree savings	317	202	0	0	317	202	118	63
indirect savings	212	93	0	0	212	93	91	38
combined savings	1,223	537	0	0	1222	537	472	196
Heating-degree-days group < 1000, > 500 (bin #2)								
Energy use & demand	15222	8252	34	3	15601	8289	7723	4364
Savings								
reflective roof savings	662	212	-1	0	652	210	306	102
shade tree savings	368	279	0	0	364	278	117	192
indirect savings	216	103	0	0	213	102	102	71
combined savings	1,246	594	-1	0	1,229	590	525	365
Heating-degree-days group <1500, >1000 (bin #3)								
Energy use & demand	13213	6587	50	5	13747	6636	7553	4035
Savings								
reflective roof savings	776	234	-1	0	761	231	370	119
shade tree savings	525	266	-1	0	520	263	484	181
indirect savings	273	105	-1	0	269	104	205	72
combined savings	1,574	605	-3	0	1,550	598	1,059	372
Heating-degree-days group <2000, >1500 (bin #4)								
Energy use & demand	13684	7057	76	12	14565	7191	7890	4129
Savings								
reflective roof savings	739	214	-2	0	718	205	359	92
shade tree savings	501	259	-2	0	494	256	323	138
indirect savings	260	99	-1	0	255	97	164	55
combined savings	1,500	572	-5	0	1,467	558	846	285
Heating-degree-days group <2500, >2000 (bin #5)								
Energy use & demand	13196	6739	102	17	14394	6941	8428	4631
Savings								
reflective roof savings	771	227	-3	-1	743	216	406	145
shade tree savings	544	281	-2	0	523	278	247	155
indirect savings	276	107	-1	0	266	104	157	72
combined savings	1,591	615	-6	-1	1532	598	810	372
Heating-degree-days group <3000, >2500 (bin #6)								
Energy use & demand	11875	6028	127	26	13385	6334	7735	4152
Savings								
reflective roof savings	733	213	-3	-1	706	197	421	120
shade tree savings	493	247	-3	0	456	241	190	94
indirect savings	257	97	-2	0	244	92	147	51
combined savings	1,483	557	-8	-1	1,406	530	758	265
Heating-degree-days group <3500, >3000 (bin #7)								
Energy use & demand	10725	5346	167	41	12717	5828	7494	4134
Savings								

HDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2) Pre-1980	Gas Heat Electricity (kWh/1000ft^2) 1980$^+$	Gas Heat Gas (Therm/1000ft^2) Pre-1980	Gas Heat Gas (Therm/1000ft^2) 1980$^+$	Electric Heat Electricity (kWh/1000ft^2) Pre-1980	Electric Heat Electricity (kWh/1000ft^2) 1980$^+$	Gas & Electric Heat Peak Power (W/1000ft^2) Pre-1980	Gas & Electric Heat Peak Power (W/1000ft^2) 1980$^+$
reflective roof savings	662	191	-4	-2	623	169	363	128
shade tree savings	535	237	-5	-1	495	225	311	139
indirect savings	251	90	-2	-1	235	83	162	64
combined savings	1,448	518	-11	-4	1,353	477	836	331
Heating-degree-days group <4000, >3500 (bin #8)								
Energy use & demand	10794	5489	199	56	13329	6211	7648	4192
Savings								
reflective roof savings	640	186	-5	-2	580	158	334	117
shade tree savings	579	249	-3	-1	566	233	361	125
indirect savings	256	91	-2	-1	241	82	167	58
combined savings	1,475	526	-10	-4	1,387	473	862	300
Heating-degree-days group <4500, >4000 (bin #9)								
Energy use & demand	9482	4759	226	70	12311	5618	7006	3886
Savings								
reflective roof savings	659	198	-5	-2	599	167	381	180
shade tree savings	526	241	-4	-1	485	225	304	255
indirect savings	249	92	-2	-1	228	82	164	104
combined savings	1,434	531	-11	-4	1,312	474	849	539
Heating-degree-days group <5000, >4500 (bin #10)								
Energy use & demand	8540	4198	277	89	11980	5295	6827	3764
Savings								
reflective roof savings	602	164	-5	-3	547	128	375	123
shade tree savings	616	242	-4	-2	582	213	384	185
indirect savings	256	85	-2	-1	237	72	182	74
combined savings	1,474	491	-11	-6	1,366	413	941	382
Heating-degree-days group <5500, >5000 (bin #11)								
Energy use & demand	8571	4287	315	112	12585	5697	7071	3923
Savings								
reflective roof savings	576	155	-6	-3	503	112	347	108
shade tree savings	600	246	-4	-3	567	209	381	185
indirect savings	247	84	-3	-2	225	67	175	70
combined savings	1,423	485	-13	-8	1,295	388	903	363
Heating-degree-days group <6000, >5500 (bin #12)								
Energy use & demand	7966	4009	354	135	12577	5738	6570	3662
Savings								
reflective roof savings	557	155	-7	-4	463	105	315	119
shade tree savings	594	244	-6	-4	539	196	338	215
indirect savings	242	84	-3	-2	210	63	157	80
combined savings	1,393	483	-16	-10	1,212	364	810	414
Heating-degree-days group <7000, >6000 (bin #13)								
Energy use & demand	7796	3963	434	181	13832	6455	6878	3800
Savings								
reflective roof savings	532	149	-8	-4	418	91	337	115
shade tree savings	622	265	-5	-5	559	198	377	199
indirect savings	242	87	-3	-2	205	61	171	75
combined savings	1,396	501	-16	-11	1,182	350	885	389
Heating-degree-days group <8000, >7000 (bin #14)								
Energy use & demand	7096	3586	485	207	14022	6548	6468	3569
Savings								
reflective roof savings	499	141	-10	-5	353	70	315	113
shade tree savings	668	283	-7	-6	576	196	437	239
indirect savings	245	89	-4	-3	195	56	180	84

HDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft²)		Gas Heat Gas (Therm/1000ft²)		Electric Heat Electricity (kWh/1000ft²)		Gas & Electric Heat Peak Power (W/1000ft²)	
	Pre-1980	1980+	Pre-1980	1980+	Pre-1980	1980+	Pre-1980	1980+
combined savings	1,412	513	-21	-14	1,124	322	932	436
Heating-degree-days group >8000 (bin #15)								
Energy use & demand	5597	2838	711	341	16799	8321	5265	2919
Savings								
reflective roof savings	395	107	-13	-5	196	18	286	101
shade tree savings	510	220	-14	-10	307	64	404	241
indirect savings	190	69	-7	-4	106	17	166	82
combined savings	1,095	396	-34	-19	609	99	856	424

Table 7b. Estimated annual basecase energy use and peak demand and savings from heat-island reduction measures for *office buildings*, ordered by ranges of *cooling-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

CDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2)		Gas Heat Gas (Therm/1000ft^2)		Electric Heat Electricity (kWh/1000ft^2)		Gas & Electric Heat Peak Power (W/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Cooling-degree-days group > 5000 (bin #1)								
Energy use & demand	18699	10794	0	0	18699	10794	6946	4010
Savings								
reflective roof savings	759	261	0	0	758	261	297	96
shade tree savings	315	198	0	0	315	198	94	41
indirect savings	226	96	0	0	225	96	94	33
combined savings	1,300	555	0	0	1,298	555	485	170
Cooling-degree-days group > 4500, <5000 (bin #2)								
Energy use & demand	17553	9951	3	0	17585	9951	7075	4022
Savings								
reflective roof savings	774	225	0	0	773	225	349	86
shade tree savings	333	210	0	0	333	210	90	58
indirect savings	232	91	0	0	232	91	105	35
combined savings	1,339	526	0	0	1,338	526	544	179
Cooling-degree-days group > 4000, < 4500 (bin #3)								
Energy use & demand	16669	9431	3	0	16701	9432	6819	3861
Savings								
reflective roof savings	720	248	0	0	719	247	298	101
shade tree savings	333	207	0	0	333	207	132	34
indirect savings	221	96	0	0	221	95	103	32
combined savings	1,274	551	0	0	1,273	549	533	167
Cooling-degree-days group > 3500, < 4000 (bin #4)								
Energy use & demand	16321	9057	19	1	16530	9074	7549	4295
Savings								
reflective roof savings	664	235	-1	0	655	235	237	102
shade tree savings	441	251	0	0	438	252	185	96
indirect savings	232	102	0	0	230	102	101	48
combined savings	1,337	588	-1	0	1,323	589	523	246
Cooling-degree-days group > 3000, < 3500 (bin #5)								
Energy use & demand	15271	8198	42	5	15735	8250	7861	4376
Savings								
reflective roof savings	729	238	-1	0	712	234	337	117
shade tree savings	494	345	0	0	486	344	193	243
indirect savings	257	122	0	0	252	121	127	86
combined savings	1,480	705	-1	0	1,450	699	657	446
Cooling-degree-days group > 2500, < 3000 (bin #6)								
Energy use & demand	14003	7283	71	11	14822	7404	8010	4244
Savings								
reflective roof savings	728	211	-2	0	709	203	356	91
shade tree savings	492	252	-2	0	487	249	355	130
indirect savings	256	97	-1	0	251	95	171	53
combined savings	1,476	560	-5	0	1,447	547	882	274
Cooling-degree-days group > 2000, < 2500 (bin #7)								

CDD Range, Basecase, and Savings by Strategy	Gas Heat				Electric Heat		Gas & Electric Heat	
	Electricity (kWh/1000ft^2)		Gas (Therm/1000ft^2)		Electricity (kWh/1000ft^2)		Peak Power (W/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Energy use & demand	12812	6568	109	22	14115	6828	8030	4334
Savings								
reflective roof savings	746	220	-3	-1	721	208	405	133
shade tree savings	493	247	-2	0	470	242	200	113
indirect savings	260	98	-1	0	250	95	145	59
combined savings	1,499	565	-6	-1	1,441	545	750	305
Cooling-degree-days group > 1500, < 2000 (bin #8)								
Energy use & demand	11348	5787	175	47	13537	6378	7835	4283
Savings								
reflective roof savings	677	200	-4	-2	632	176	361	117
shade tree savings	512	244	-3	0	483	233	229	115
indirect savings	250	93	-2	-1	234	86	142	56
combined savings	1,439	537	-9	-3	1,349	495	732	288
Cooling-degree-days group > 1000, < 1500 (bin #9)								
Energy use & demand	9589	4874	277	97	13200	6131	7381	4075
Savings								
reflective roof savings	615	175	-6	-3	543	137	359	113
shade tree savings	576	248	-4	-2	542	221	314	130
indirect savings	250	89	-3	-1	228	75	162	58
combined savings	1,441	512	-13	-6	1,313	433	835	301
Cooling-degree-days group > 500, < 1000 (bin #10)								
Energy use & demand	8069	4075	418	174	13963	6532	6966	3839
Savings								
reflective roof savings	535	154	-8	-4	423	97	326	121
shade tree savings	619	266	-5	-4	557	206	392	203
indirect savings	242	88	-3	-2	206	64	172	78
combined savings	1,396	508	-16	-10	1,186	367	890	402
Cooling-degree-days group > 200, < 500 (bin #11)								
Energy use & demand	7042	3532	471	200	13790	6416	6269	3468
Savings								
reflective roof savings	517	145	-10	-4	375	76	327	117
shade tree savings	658	282	-7	-6	564	191	448	265
indirect savings	247	90	-4	-3	197	56	186	92
combined savings	1,422	517	-21	-13	1,136	323	961	474
Cooling-degree-days group < 200 (bin #12)								
Energy use & demand	5439	2612	597	274	14496	6917	4757	2653
Savings								
reflective roof savings	443	109	-10	-5	292	38	314	110
shade tree savings	478	190	-14	-9	290	56	415	272
indirect savings	193	63	-6	-4	122	20	175	92
combined savings	1,114	362	-30	-18	704	114	904	474

Table 7c. Estimated annual basecase carbon emissions and savings from heat-island reduction measures for *office buildings*, ordered by ranges of *heating-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group < 500 (bin #1)				
Carbon emissions	2815	1604	2816	1604
Savings				
reflective roof savings	116	40	116	40
shade tree savings	53	34	53	34
indirect savings	35	16	35	16
combined savings	204	90	204	90
Heating-degree-days group < 1000, > 500 (bin #2)				
Carbon emissions	2591	1382	2605	1384
Savings				
reflective roof savings	109	35	109	35
shade tree savings	61	47	61	46
indirect savings	36	17	36	17
combined savings	206	99	205	99
Heating-degree-days group <1500, >1000 (bin #3)				
Carbon emissions	2279	1107	2296	1108
Savings				
reflective roof savings	128	39	127	39
shade tree savings	86	44	87	44
indirect savings	45	18	45	17
combined savings	259	101	259	100
Heating-degree-days group <2000, >1500 (bin #4)				
Carbon emissions	2395	1196	2432	1201
Savings				
reflective roof savings	121	36	120	34
shade tree savings	81	43	82	43
indirect savings	42	17	43	16
combined savings	243	96	245	93
Heating-degree-days group <2500, >2000 (bin #5)				
Carbon emissions	2351	1150	2404	1159
Savings				
reflective roof savings	124	36	124	36
shade tree savings	88	47	87	46
indirect savings	44	17	44	17
combined savings	257	101	256	100
Heating-degree-days group <3000, >2500 (bin #6)				
Carbon emissions	2167	1044	2235	1058
Savings				
reflective roof savings	118	34	118	33
shade tree savings	78	41	76	40
indirect savings	41	16	41	15
combined savings	237	91	235	89

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group <3500, >3000 (bin #7)				
Carbon emissions	2033	952	2124	973
Savings				
reflective roof savings	105	29	104	28
shade tree savings	82	38	83	38
indirect savings	39	14	39	14
combined savings	226	81	226	80
Heating-degree-days group <4000, >3500 (bin #8)				
Carbon emissions	2091	998	2226	1037
Savings				
reflective roof savings	100	28	97	26
shade tree savings	92	40	95	39
indirect savings	40	14	40	14
combined savings	232	82	232	79
Heating-degree-days group <4500, >4000 (bin #9)				
Carbon emissions	1911	896	2056	938
Savings				
reflective roof savings	103	30	100	28
shade tree savings	82	39	81	38
indirect savings	38	14	38	14
combined savings	223	83	219	79
Heating-degree-days group <5000, >4500 (bin #10)				
Carbon emissions	1827	830	2001	884
Savings				
reflective roof savings	93	23	91	21
shade tree savings	97	38	97	36
indirect savings	39	12	40	12
combined savings	230	73	228	69
Heating-degree-days group <5500, >5000 (bin #11)				
Carbon emissions	1887	878	2102	951
Savings				
reflective roof savings	88	22	84	19
shade tree savings	94	37	95	35
indirect savings	38	12	38	11
combined savings	220	70	216	65
Heating-degree-days group <6000, >5500 (bin #12)				
Carbon emissions	1843	865	2100	958
Savings				
reflective roof savings	83	20	77	18
shade tree savings	91	35	90	33
indirect savings	36	11	35	11
combined savings	209	66	202	61
Heating-degree-days group <7000, >6000 (bin #13)				
Carbon emissions	1930	924	2310	1078
Savings				
reflective roof savings	77	19	70	15
shade tree savings	97	37	93	33
indirect savings	36	11	34	10
combined savings	210	67	197	58

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group <8000, >7000 (bin #14)				
Carbon emissions	1887	898	2342	1094
Savings				
reflective roof savings	69	16	59	12
shade tree savings	101	39	96	33
indirect savings	35	11	33	9
combined savings	205	66	188	54
Heating-degree-days group >8000 (bin #15)				
Carbon emissions	1964	967	2805	1390
Savings				
reflective roof savings	47	11	33	3
shade tree savings	65	22	51	11
indirect savings	22	6	18	3
combined savings	134	39	102	17

Table 7d. Estimated annual basecase carbon emissions and savings from heat-island reduction measures for *office buildings*, ordered by ranges of *cooling-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Cooling-degree-days group > 5000 (bin #1)				
Carbon emissions	3123	1803	3123	1803
Savings				
reflective roof savings	127	44	127	44
shade tree savings	53	33	53	33
indirect savings	38	16	38	16
combined savings	217	93	217	93
Cooling-degree-days group > 4500, <5000 (bin #2)				
Carbon emissions	2936	1662	2937	1662
Savings				
reflective roof savings	129	38	129	38
shade tree savings	56	35	56	35
indirect savings	39	15	39	15
combined savings	224	88	223	88
Cooling-degree-days group > 4000, < 4500 (bin #3)				
Carbon emissions	2788	1575	2789	1575
Savings				
reflective roof savings	120	41	120	41
shade tree savings	56	35	56	35
indirect savings	37	16	37	16
combined savings	213	92	213	92
Cooling-degree-days group > 3500, < 4000 (bin #4)				
Carbon emissions	2753	1514	2761	1515
Savings				
reflective roof savings	109	39	109	39
shade tree savings	74	42	73	42
indirect savings	38	17	38	17
combined savings	221	98	221	98
Cooling-degree-days group > 3000, < 3500 (bin #5)				
Carbon emissions	2611	1376	2628	1378
Savings				
reflective roof savings	120	40	119	39
shade tree savings	82	58	81	57
indirect savings	43	20	42	20
combined savings	245	118	242	117
Cooling-degree-days group > 2500, < 3000 (bin #6)				
Carbon emissions	2441	1232	2475	1236
Savings				
reflective roof savings	119	35	118	34
shade tree savings	79	42	81	42
indirect savings	41	16	42	16
combined savings	239	94	242	91

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Cooling-degree-days group > 2000, < 2500 (bin #7)				
Carbon emissions	2297	1129	2357	1140
Savings				
reflective roof savings	120	35	120	35
shade tree savings	79	41	78	40
indirect savings	42	16	42	16
combined savings	241	93	241	91
Cooling-degree-days group > 1500, < 2000 (bin #8)				
Carbon emissions	2148	1034	2261	1065
Savings				
reflective roof savings	107	31	106	29
shade tree savings	81	41	81	39
indirect savings	39	15	39	14
combined savings	228	86	225	83
Cooling-degree-days group > 1000, < 1500 (bin #9)				
Carbon emissions	2002	954	2204	1024
Savings				
reflective roof savings	94	25	91	23
shade tree savings	90	39	91	37
indirect savings	38	13	38	13
combined savings	223	76	219	72
Cooling-degree-days group > 500, < 1000 (bin #10)				
Carbon emissions	1952	932	2332	1091
Savings				
reflective roof savings	78	20	71	16
shade tree savings	96	39	93	34
indirect savings	36	12	34	11
combined savings	210	70	198	61
Cooling-degree-days group >200, < 500 (bin #11)				
Carbon emissions	1858	879	2303	1071
Savings				
reflective roof savings	72	18	63	13
shade tree savings	100	38	94	32
indirect savings	35	11	33	9
combined savings	207	68	190	54
Cooling-degree-days group < 200 (bin #12)				
Carbon emissions	1772	833	2421	1155
Savings				
reflective roof savings	60	11	49	6
shade tree savings	60	19	48	9
indirect savings	24	5	20	3
combined savings	143	35	118	19

Table 8a. Estimated annual basecase energy use and peak demand and savings from heat-island reduction measures for *retail store buildings*, ordered by ranges of *heating-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

HDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity ($kWh/1000ft^2$)		Gas Heat Gas ($Therm/1000ft^2$)		Electric Heat Electricity ($kWh/1000ft^2$)		Gas & Electric Heat Peak Power ($W/1000ft^2$)	
	Pre-1980	1980^+	Pre-1980	1980^+	Pre-1980	1980^+	Pre-1980	1980^+
Heating-degree-days group < 500 (bin #1)								
Energy use & demand	15712	8013	0	0	15717	8013	4546	2328
Savings								
reflective roof savings	923	309	0	0	923	309	283	90
shade tree savings	320	195	0	0	320	195	94	67
indirect savings	261	106	0	0	261	106	90	38
combined savings	1504	610	0	0	1504	610	467	195
Heating-degree-days group < 1000, > 500 (bin #2)								
Energy use & demand	14694	7098	12	0	14823	7102	5311	2736
Savings								
reflective roof savings	833	265	0	0	828	266	251	96
shade tree savings	269	147	0	0	270	147	76	47
indirect savings	231	87	0	0	231	87	78	34
combined savings	1333	499	0	0	1329	500	405	177
Heating-degree-days group <1500, >1000 (bin #3)								
Energy use & demand	12936	5759	16	0	13110	5763	5077	2500
Savings								
reflective roof savings	1014	289	0	0	1008	290	380	99
shade tree savings	415	186	0	0	417	186	134	77
indirect savings	300	100	0	0	299	100	123	42
combined savings	1729	575	0	0	1724	576	637	218
Heating-degree-days group <2000, >1500 (bin #4)								
Energy use & demand	13486	6168	30	0	13826	6177	5402	2672
Savings								
reflective roof savings	993	298	-1	0	981	298	349	124
shade tree savings	391	190	0	0	392	191	138	59
indirect savings	291	102	0	0	288	103	117	44
combined savings	1675	590	-1	0	1661	592	604	227
Heating-degree-days group <2500, >2000 (bin #5)								
Energy use & demand	13090	5792	40	0	13562	5801	5750	2835
Savings								
reflective roof savings	1010	283	-2	0	986	283	388	120
shade tree savings	396	197	0	0	392	197	150	81
indirect savings	295	101	-1	0	289	101	129	48
combined savings	1701	581	-3	0	1667	581	667	249
Heating-degree-days group <3000, >2500 (bin #6)								
Energy use & demand	11888	5217	51	1	12500	5239	5268	2573
Savings								
reflective roof savings	977	265	-3	0	944	263	349	112
shade tree savings	364	169	0	0	358	170	104	33
indirect savings	282	91	-1	0	273	91	109	35
combined savings	1623	525	-4	0	1575	524	562	180
Heating-degree-days group <3500, >3000 (bin #7)								
Energy use & demand	10787	4580	74	4	11699	4637	5153	2530
Savings								

HDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2)		Gas Heat Gas (Therm/1000ft^2)		Electric Heat Electricity (kWh/1000ft^2)		Gas & Electric Heat Peak Power (W/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$
reflective roof savings	902	248	-3	0	864	241	360	123
shade tree savings	393	178	0	0	389	177	130	56
indirect savings	272	89	-1	0	263	88	118	43
combined savings	1567	515	-4	0	1516	506	608	222
Heating-degree-days group <4000, >3500 (bin #8)								
Energy use & demand	10813	4764	94	7	12024	4883	5228	2617
Savings								
reflective roof savings	878	239	-5	0	815	227	305	93
shade tree savings	362	183	0	0	359	181	115	93
indirect savings	260	89	-1	0	247	86	101	45
combined savings	1500	511	-6	0	1421	494	521	231
Heating-degree-days group <4500, >4000 (bin #9)								
Energy use & demand	9662	4174	108	7	11059	4282	4830	2384
Savings								
reflective roof savings	893	245	-5	-1	842	230	365	126
shade tree savings	404	179	0	0	404	176	140	70
indirect savings	272	89	-1	0	262	85	121	47
combined savings	1569	513	-6	-1	1508	491	626	243
Heating-degree-days group <5000, >4500 (bin #10)								
Energy use & demand	8910	3716	138	14	10659	3916	4825	2375
Savings								
reflective roof savings	813	211	-5	-1	755	192	338	124
shade tree savings	485	202	0	0	491	199	200	116
indirect savings	273	87	-1	0	262	82	129	58
combined savings	1571	500	-6	-1	1508	473	667	298
Heating-degree-days group <5500, >5000 (bin #11)								
Energy use & demand	8805	3754	169	22	11026	4071	4959	2440
Savings								
reflective roof savings	793	203	-6	-2	732	172	350	107
shade tree savings	438	183	0	0	441	175	180	87
indirect savings	259	81	-2	-1	246	73	127	47
combined savings	1490	467	-8	-3	1419	420	657	241
Heating-degree-days group <6000, >5500 (bin #12)								
Energy use & demand	8152	3509	196	34	10737	3974	4583	2257
Savings								
reflective roof savings	754	199	-7	-3	676	159	313	106
shade tree savings	423	174	-1	0	423	163	172	78
indirect savings	247	78	-2	-1	231	68	116	44
combined savings	1424	451	-10	-4	1330	390	601	228
Heating-degree-days group <7000, >6000 (bin #13)								
Energy use & demand	7918	3492	255	58	11493	4353	4836	2395
Savings								
reflective roof savings	704	189	-7	-4	628	132	321	98
shade tree savings	414	178	0	-1	407	159	156	77
indirect savings	235	77	-2	-1	217	61	114	42
combined savings	1353	444	-9	-6	1252	352	591	217
Heating-degree-days group <8000, >7000 (bin #14)								
Energy use & demand	7191	3135	285	69	11296	4184	4553	2248
Savings								
reflective roof savings	674	181	-9	-5	566	109	304	100
shade tree savings	443	186	0	-1	441	163	187	95
indirect savings	235	77	-2	-2	211	57	118	47

HDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2)		Gas Heat Gas (Therm/1000ft^2)		Electric Heat Electricity (kWh/1000ft^2)		Gas & Electric Heat Peak Power (W/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$
combined savings	1352	444	-11	-8	1218	329	609	242
Heating-degree-days group >8000 (bin #15)								
Energy use & demand	5619	2413	435	148	12410	4859	3768	1854
Savings								
reflective roof savings	567	143	-9	-6	438	48	295	94
shade tree savings	427	162	-2	-3	402	109	213	99
indirect savings	209	64	-3	-2	176	33	122	46
combined savings	1203	369	-14	-11	1016	190	630	239

Table 8b. Estimated annual basecase energy use and peak demand and savings from heat-island reduction measures for *retail store buildings*, ordered by ranges of *cooling-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

CDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2)		Gas Heat Gas (Therm/1000ft^2)		Electric Heat Electricity (kWh/1000ft^2)		Gas & Electric Heat Peak Power (W/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Cooling-degree-days group > 5000 (bin #1)								
Energy use & demand	17209	8919	0	0	17209	8919	4642	2454
Savings								
reflective roof savings	1016	349	0	0	1016	349	329	111
shade tree savings	372	272	0	0	372	272	112	113
indirect savings	291	130	0	0	291	130	106	54
combined savings	1679	751	0	0	1679	751	547	278
Cooling-degree-days group > 4500, <5000 (bin #2)								
Energy use & demand	16490	8338	1	0	16496	8338	5046	2589
Savings								
reflective roof savings	955	331	0	0	955	331	305	112
shade tree savings	473	148	0	0	474	148	362	42
indirect savings	300	101	0	0	300	101	160	37
combined savings	1728	580	0	0	1729	580	827	191
Cooling-degree-days group > 4000, < 4500 (bin #3)								
Energy use & demand	15645	7900	0	0	15651	7900	4613	2314
Savings								
reflective roof savings	878	279	0	0	877	279	240	59
shade tree savings	271	161	0	0	272	161	-3	3
indirect savings	241	92	0	0	241	92	57	15
combined savings	1390	532	0	0	1390	532	294	77
Cooling-degree-days group > 3500, < 4000 (bin #4)								
Energy use & demand	15494	7665	6	0	15559	7666	5106	2600
Savings								
reflective roof savings	880	297	0	0	878	297	259	97
shade tree savings	349	179	0	0	350	179	105	56
indirect savings	258	100	0	0	258	100	87	37
combined savings	1487	576	0	0	1486	576	451	190
Cooling-degree-days group > 3000, < 3500 (bin #5)								
Energy use & demand	14639	6971	15	0	14797	6978	5373	2709
Savings								
reflective roof savings	932	288	0	0	926	289	303	100
shade tree savings	321	211	0	0	319	211	72	96
indirect savings	263	105	0	0	261	105	90	47
combined savings	1516	604	0	0	1506	605	465	243
Cooling-degree-days group > 2500, < 3000 (bin #6)								
Energy use & demand	13695	6305	28	0	14016	6314	5445	2706
Savings								
reflective roof savings	983	288	-1	0	970	288	369	106
shade tree savings	364	189	0	0	364	189	126	69
indirect savings	283	100	0	0	280	100	119	42
combined savings	1630	577	-1	0	1614	577	614	217
Cooling-degree-days group > 2000, < 2500 (bin #7)								

CDD Range, Basecase, and Savings by Strategy	Gas Heat Electricity (kWh/1000ft^2)		Gas Heat Gas (Therm/1000ft^2)		Electric Heat Electricity (kWh/1000ft^2)		Gas & Electric Heat Peak Power (W/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Energy use & demand	12724	5696	46	1	13277	5721	5485	2693
Savings								
reflective roof savings	989	283	-2	0	965	281	365	120
shade tree savings	380	176	0	0	378	176	137	60
indirect savings	287	96	-1	0	282	96	120	43
combined savings	1656	555	-3	0	1625	553	622	223
Cooling-degree-days group > 1500, < 2000 (bin #8)								
Energy use & demand	11390	5028	82	6	12439	5128	5388	2659
Savings								
reflective roof savings	919	253	-4	0	872	244	342	105
shade tree savings	348	167	0	0	344	166	102	35
indirect savings	266	88	-1	0	255	86	107	34
combined savings	1533	508	-5	0	1471	496	551	174
Cooling-degree-days group > 1000, < 1500 (bin #9)								
Energy use & demand	9687	4264	150	21	11690	4573	5106	2530
Savings								
reflective roof savings	825	225	-6	-2	758	198	337	117
shade tree savings	394	182	0	0	397	176	146	80
indirect savings	256	85	-2	-1	243	79	116	47
combined savings	1475	492	-8	-3	1398	453	599	244
Cooling-degree-days group > 500, < 1000 (bin #10)								
Energy use & demand	8192	3601	247	59	11716	4500	4861	2401
Savings								
reflective roof savings	719	195	-7	-4	641	138	319	101
shade tree savings	416	181	0	-1	411	163	162	80
indirect savings	238	79	-2	-1	221	63	115	43
combined savings	1373	455	-9	-6	1273	364	596	224
Cooling-degree-days group > 200, < 500 (bin #11)								
Energy use & demand	7184	3090	272	66	11121	4116	4421	2172
Savings								
reflective roof savings	703	187	-8	-4	599	119	319	100
shade tree savings	469	191	0	-1	468	167	201	95
indirect savings	246	79	-2	-1	224	60	125	47
combined savings	1418	457	-10	-6	1291	346	645	242
Cooling-degree-days group < 200 (bin #12)								
Energy use & demand	5613	2177	345	109	10850	3975	3463	1697
Savings								
reflective roof savings	631	146	-7	-4	531	83	306	104
shade tree savings	457	160	-1	-2	432	117	222	111
indirect savings	228	64	-2	-2	202	42	127	52
combined savings	1316	370	-10	-8	1165	242	655	267

Table 8c. Estimated annual basecase carbon emissions and savings from heat-island reduction measures for *retail store buildings*, ordered by ranges of *heating-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group < 500 (bin #1)				
Carbon emissions	2624	1338	2625	1338
Savings				
reflective roof savings	154	52	154	52
shade tree savings	53	33	53	33
indirect savings	44	18	44	18
combined savings	251	102	251	102
Heating-degree-days group < 1000, > 500 (bin #2)				
Carbon emissions	2471	1185	2475	1186
Savings				
reflective roof savings	139	44	138	44
shade tree savings	45	25	45	25
indirect savings	39	14	39	14
combined savings	223	83	222	83
Heating-degree-days group <1500, >1000 (bin #3)				
Carbon emissions	2183	962	2189	962
Savings				
reflective roof savings	169	48	168	48
shade tree savings	69	31	70	31
indirect savings	50	17	50	17
combined savings	289	96	288	96
Heating-degree-days group <2000, >1500 (bin #4)				
Carbon emissions	2296	1030	2309	1032
Savings				
reflective roof savings	164	50	164	50
shade tree savings	65	32	65	32
indirect savings	48	17	48	17
combined savings	278	99	277	99
Heating-degree-days group <2500, >2000 (bin #5)				
Carbon emissions	2244	967	2265	969
Savings				
reflective roof savings	166	47	165	47
shade tree savings	66	33	65	33
indirect savings	49	17	48	17
combined savings	280	97	278	97
Heating-degree-days group <3000, >2500 (bin #6)				
Carbon emissions	2059	873	2088	875
Savings				
reflective roof savings	159	44	158	44
shade tree savings	61	28	60	28
indirect savings	46	15	46	15
combined savings	266	88	263	87

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group <3500, >3000 (bin #7)				
Carbon emissions	1909	771	1954	774
Savings				
reflective roof savings	146	41	144	40
shade tree savings	66	30	65	30
indirect savings	44	15	44	15
combined savings	256	86	253	84
Heating-degree-days group <4000, >3500 (bin #8)				
Carbon emissions	1942	806	2008	815
Savings				
reflective roof savings	139	40	136	38
shade tree savings	60	31	60	30
indirect savings	42	15	41	14
combined savings	242	85	237	82
Heating-degree-days group <4500, >4000 (bin #9)				
Carbon emissions	1770	707	1847	715
Savings				
reflective roof savings	142	39	141	38
shade tree savings	67	30	67	29
indirect savings	44	15	44	14
combined savings	253	84	252	82
Heating-degree-days group <5000, >4500 (bin #10)				
Carbon emissions	1688	641	1780	654
Savings				
reflective roof savings	129	34	126	32
shade tree savings	81	34	82	33
indirect savings	44	14	44	14
combined savings	253	82	252	79
Heating-degree-days group <5500, >5000 (bin #11)				
Carbon emissions	1715	659	1841	680
Savings				
reflective roof savings	124	31	122	29
shade tree savings	73	31	74	29
indirect savings	41	13	41	12
combined savings	238	74	237	70
Heating-degree-days group <6000, >5500 (bin #12)				
Carbon emissions	1645	635	1793	664
Savings				
reflective roof savings	116	29	113	27
shade tree savings	69	29	71	27
indirect savings	38	12	39	11
combined savings	223	70	222	65
Heating-degree-days group <7000, >6000 (bin #13)				
Carbon emissions	1691	667	1919	727
Savings				
reflective roof savings	107	26	105	22
shade tree savings	69	28	68	27
indirect savings	37	11	36	10
combined savings	213	65	209	59

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Heating-degree-days group <8000, >7000 (bin #14)				
Carbon emissions	1613	623	1886	699
Savings				
reflective roof savings	100	23	95	18
shade tree savings	74	30	74	27
indirect savings	36	11	35	10
combined savings	209	63	203	55
Heating-degree-days group >8000 (bin #15)				
Carbon emissions	1568	617	2072	811
Savings				
reflective roof savings	82	15	73	8
shade tree savings	68	23	67	18
indirect savings	31	7	29	6
combined savings	181	45	170	32

Table 8d. Estimated annual basecase carbon emissions and savings from heat-island reduction measures for *retail store buildings*, ordered by ranges of *cooling-degree-days*. Direct savings include the effect of roof reflectivity and shading by trees. The indirect savings include the effects of increasing the albedo of urban surfaces (roofs and pavements) and increasing urban vegetation. Gas Heat: Gas-heated buildings; Electric Heat: Electrically heated buildings.

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980$^+$	Pre-1980	1980$^+$
Cooling-degree-days group > 5000 (bin #1)				
Carbon emissions	2874	1489	2874	1489
Savings				
reflective roof savings	170	58	170	58
shade tree savings	62	45	62	45
indirect savings	49	22	49	22
combined savings	280	125	280	125
Cooling-degree-days group > 4500, <5000 (bin #2)				
Carbon emissions	2755	1392	2755	1392
Savings				
reflective roof savings	159	55	159	55
shade tree savings	79	25	79	25
indirect savings	50	17	50	17
combined savings	289	97	289	97
Cooling-degree-days group > 4000, < 4500 (bin #3)				
Carbon emissions	2613	1319	2614	1319
Savings				
reflective roof savings	147	47	146	47
shade tree savings	45	27	45	27
indirect savings	40	15	40	15
combined savings	232	89	232	89
Cooling-degree-days group > 3500, < 4000 (bin #4)				
Carbon emissions	2596	1280	2598	1280
Savings				
reflective roof savings	147	50	147	50
shade tree savings	58	30	58	30
indirect savings	43	17	43	17
combined savings	248	96	248	96
Cooling-degree-days group > 3000, < 3500 (bin #5)				
Carbon emissions	2466	1164	2471	1165
Savings				
reflective roof savings	156	48	155	48
shade tree savings	54	35	53	35
indirect savings	44	17	44	18
combined savings	253	101	252	101
Cooling-degree-days group > 2500, < 3000 (bin #6)				
Carbon emissions	2328	1053	2341	1054
Savings				
reflective roof savings	163	48	162	48
shade tree savings	61	32	61	32
indirect savings	47	17	47	17
combined savings	270	96	270	96

HDD Range, Basecase, and Savings by Strategy	Gas Heat Carbon (kgC/1000ft^2)		Electric Heat Carbon (kgC/1000ft^2)	
	Pre-1980	1980+	Pre-1980	1980+
Cooling-degree-days group > 2000, < 2500 (bin #7)				
Carbon emissions	2191	953	2217	955
Savings				
reflective roof savings	162	47	161	47
shade tree savings	63	29	63	29
indirect savings	47	16	47	16
combined savings	273	93	271	92
Cooling-degree-days group > 1500, < 2000 (bin #8)				
Carbon emissions	2021	848	2077	856
Savings				
reflective roof savings	148	42	146	41
shade tree savings	58	28	57	28
indirect savings	43	15	43	14
combined savings	249	85	246	83
Cooling-degree-days group > 1000, < 1500 (bin #9)				
Carbon emissions	1835	742	1952	764
Savings				
reflective roof savings	129	35	127	33
shade tree savings	66	30	66	29
indirect savings	41	14	41	13
combined savings	235	79	233	76
Cooling-degree-days group > 500, < 1000 (bin #10)				
Carbon emissions	1725	687	1957	752
Savings				
reflective roof savings	110	27	107	23
shade tree savings	69	29	69	27
indirect savings	37	11	37	11
combined savings	217	67	213	61
Cooling-degree-days group >200, < 500 (bin #11)				
Carbon emissions	1593	612	1857	687
Savings				
reflective roof savings	106	25	100	20
shade tree savings	78	30	78	28
indirect savings	38	11	37	10
combined savings	222	67	216	58
Cooling-degree-days group < 200 (bin #12)				
Carbon emissions	1437	521	1812	664
Savings				
reflective roof savings	95	19	89	14
shade tree savings	75	24	72	20
indirect savings	35	9	34	7
combined savings	205	51	195	40

We also calculated the total carbon emissions from heating and cooling the buildings (**Tables 6c, 6d, 7c, 7d, 8c, and 8d**). To generate these tables we used data provided by DOE's office of Energy Information Administration (EIA, 1997). [The corresponding conversion factor for 2001 is 0.173 kgC/kWh (EIA, 2003)]. In 1995, the U.S. mix of electricity generation emitted 0.167 kgC/kWh. The estimated carbon emission from combustion of natural gas was 1.447 kgC/therm.

To estimate direct savings from increased roof reflectance (Δρ) other than the differential specified in the tables, multiply the savings by the ratio Δρ/0.3 for residences and Δρ/0.4 for commercial buildings[1]. Linear interpolation can also be applied to direct shade-tree savings. Savings will increase for buildings with less roof insulation than that specified in these prototypes (R-11 for old construction; R-30 for new). Conversely, savings will decrease for those with more roof insulation. Savings in peak power demand make it clear that an air-conditioner can be downsized when HIR strategies are considered.

Snow cover will negate some of the heating-energy penalties from a reflective roof depending on what fraction of the roof is covered and for what duration. To account for snow cover in the annual natural gas deficit (heating penalties) a reduction of 50% for the reflective roof and 25% in the indirect effect can be assumed.

The estimated savings may be questionable for cases where the HDD is very high (over 6000) or CDD is very low (under 200). In very cold climates, the energy-savings potentials of HIR are expected to be minimal.

Residential Buildings by Heating-Degree-Days. (Tables 6a and 6c) (All numbers are normalized per 1000ft^2 of roof area). For stock of Pre-1980 gas-heated residential buildings, the annual basecase electricity use ranges from about 8500 kWh (for HDD< 500) to 2000 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 1200 kWh (15%) (HDD<500) to about 500 kWh (25%) (5500<HDD< 6000). The heating-energy use ranges from 0 to 900 therms and penalties range from 0 to 45 therms (0–5%). For 1980$^+$ stock of residential buildings, the annual basecase electricity use ranges from about 5000 kWh (for HDD< 500) to 1000 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 600 kWh (12%) (HDD<500) to about 200 kWh (20%) (5500<HDD< 6000). The heating-energy use ranges from 0 to 400 therms and penalties range from 0 to 20 therms (0–5%). These results are summarized in **Table 9**.

For stock of Pre-1980 electrically heated residential buildings, the annual basecase electricity use (heating and cooling) ranges from about 8500 kWh (for HDD< 500) to 15,000 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 1200 kWh (15%) (HDD<500) to about 100 kWh (0%) (5500<HDD< 6000). For 1980$^+$ stock of residential buildings, the annual basecase electricity use ranges from about 5000 kWh (for HDD< 500) to 6500 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 600 kWh

[1] Linear interpolation can be used to estimate savings or penalties for other net changes in roof reflectance ($\Delta\rho_2$) than presented in the tables ($\Delta\rho_1$) (Konopacki *et al*. 1997). Therefore, these results can be simply adjusted by the ratio $\Delta\rho_2/\Delta\rho_1$ to obtain estimates for other reflective roof scenarios.

(12%) (HDD<500) to about 50 kWh (1%) (5500<HDD< 6000). Over 75% of the total savings are from direct effects of cool roofs and shade trees.

The peak demand electricity use is about 3.1 to 4.0 kW/1000ft^2 of roof area for Pre-1980 residential stock and 1.7–3.3 kW/1000ft^2 for 1980$^+$ stock. The total savings range from 0.4–0.6 kW/1000ft^2 for Pre-1980 stock and 0.2–0.4 kW/1000ft^2 for 1980$^+$ stock.

For stock of Pre-1980 gas-heated residential buildings, the annual rate of carbon emissions ranges from 1100–2600 kgC. The total carbon savings for climates with less than 4500 heating-degree-days ranged from 60–210 kgC. For 1980$^+$ stock of gas-heated residential buildings, the annual rate of carbon emissions ranges from 400–1200 kgC. The total carbon savings for climates with less than 4500 heating-degree-days ranged from 30–100 kgC. For stock of Pre-1980 electrically heated residential buildings, the annual rate of carbon emissions ranges from 900–4800 kgC. The total carbon savings for climates with less than 4500 heating-degree-days range from 60–210 kgC. For 1980$^+$ stock of electrically heated residential buildings, the annual rate of carbon emissions ranges from 430–2300 kgC. The total carbon savings for climates with less than 4500 heating-degree-days range from 30–100 kgC.

Residential Buildings by Cooling-degree-days. (Table 6b and 6d) (All numbers are normalized per 1000ft^2 of roof area). For stock of Pre-1980 gas-heated residential buildings, the annual basecase electricity use ranges from about 11,000 kWh (for CDD>5000) to 1600 kWh (for 200<CDD<500). The total HIR savings potential range from about 1200 kWh (10%) (CDD>5000) to about 400 kWh (25%) (200<CDD< 500). The heating-energy use ranges from 0 to 1000 therms and penalties range from 0 to 50 therms (0–5%). For 1980$^+$ stock of residential buildings, the annual basecase electricity use ranges from about 7000 kWh (for CDD>5000) to 700 kWh (for 200<CDD<500). The total HIR savings potentials for range from about 600 kWh (8%) (CDD>5000) to about 150 kWh (20%) (200<CDD< 500). The heating-energy use ranges from 0 to 500 therms and penalties range from 0 to 20 therms (0–4%). These results are summarized in Table 9.

For stock of Pre-1980 electrically heated residential buildings, the annual basecase electricity use (heating and cooling) ranges from about 11,000 kWh (for CDD>5000) to 20,000 kWh (for 200<CDD<500). The total HIR savings potentials range from about 1300 kWh (15%) (HDD<500) to about -250 kWh (-1%) (200<CDD< 500). For 1980$^+$ stock of residential buildings, the annual basecase electricity use ranges from about 700 kWh (for CDD>5000) to 9000 kWh (for 200<CDD<500). The total HIR savings potentials range from about 600 kWh (8%) (CDD>5000) to about -50 kWh (-1%) (200<CDD< 500). Over 75% of the total savings are from direct effects of cool roofs and shade trees.

The peak demand electricity use is about 3.2 to 4.0 kW/1000ft^2 of roof area for Pre-1980 residential stock and 1.7–2.2 kW/1000ft^2 for 1980$^+$ stock. The total savings range from 0.4–0.6 kW/1000ft^2 for Pre-1980 stock and 0.2–0.4 kW/1000ft^2 for 1980$^+$ stock.

For stock of Pre-1980 gas-heated residential buildings, the annual rate of carbon emissions ranges from 1100–2200 kgC. The total carbon savings for climates with more than 1000 cooling-degree-days range from 60–220 kgC. For 1980$^+$ stock of gas-heated residential buildings, the annual rate of carbon emissions ranges from 560–1040 kgC. The total carbon savings for climates with less than 4500 heating-degree-days range from 30–100 kgC. For stock of Pre-1980 electrically heated residential buildings, the annual rate of carbon emissions ranges from 1300–4000 kgC. The total carbon savings for climates with less than 4500 heating-degree-days range from 60–220 kgC. For 1980$^+$ stock of electrically heated residential buildings, the annual rate of carbon emissions ranges from 630–1800 kgC. The total carbon savings for climates with less than 4500 heating-degree-days ranged from 30–100 kgC.

Office Buildings by Heating-degree-days. (Table 7a and 7c) (All numbers are normalized per 1000ft^2 of roof area). For stock of Pre-1980 gas-heated office buildings, the annual basecase electricity use ranges from about 16,800 kWh (for HDD< 500) to 8,000 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 1200 kWh (7%) (HDD<500) to about 1,400 kWh (18%) (5500<HDD< 6000). The heating energy use ranges from 0 to 300 therms and penalties range from 0 to 15 therms (0–5%). For 1980$^+$ stock of office buildings, the annual basecase electricity use ranges from about 9600 kWh (for HDD< 500) to 4000 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 500 kWh (5%) (HDD<500) to about 500 kWh (12%) (5500<HDD< 6000). The heating-energy use ranges from 0 to 140 therms and penalties range from 0 to 10 therms (0–7%). These results are summarized in Table 9.

For stock of Pre-1980 electrically heated office buildings, the annual basecase electricity use (heating and cooling) ranges from about 16,900 kWh (for HDD< 500) to 12,600 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 1200 kWh (7%) (HDD<500) to about 1200 kWh (10%) (5500<HDD< 6000). For 1980$^+$ stock of office buildings, the annual basecase electricity use ranges from about 9600 kWh (for HDD< 500) to 5700 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 500 kWh (5%) (HDD<500) to about 400 kWh (7%) (5500<HDD< 6000). Over 75% of the total savings are from direct effects of cool roofs and shade trees.

The peak demand electricity use is about 6.7 to 8.4 kW/1000ft^2 of roof area for Pre-1980 office stock and 3.7–4.6 kW/1000ft^2 for 1980$^+$ stock. The total savings range from 0.5–1.0 kW/1000ft^2 for Pre-1980 stock and 0.2–0.4 kW/1000ft^2 for 1980$^+$ stock.

For stock of Pre-1980 gas-heated office buildings, the annual rate of carbon emissions ranges from 1800–2800 kgC. The total carbon savings for climates with less than 8000 heating-degree-days range from 200–260 kgC. For 1980$^+$ stock of gas-heated residential buildings, the annual rate of carbon emissions ranges from 800–1600 kgC. The total carbon savings for climates with less than 8000 heating-degree-days range from 70–90 kgC. For stock of Pre-1980 electrically heated residential buildings, the annual rate of carbon emissions ranges from 2000–2800 kgC. The total carbon savings for climates with less than 8000 heating-degree-days range from 200–260 kgC. For 1980$^+$ stock of electrically heated residential buildings, the annual rate of carbon emissions ranges from 900–1600 kgC. The total carbon savings for climates with less than 4500 heating-degree-days ranged from 50–100 kgC.

Office Buildings by Cooling-degree-days. (Table 7b and 7d) (All numbers are normalized per 1000ft^2 of roof area). For stock of Pre-1980 gas-heated office buildings, the annual basecase electricity use ranges from about 18,700 kWh (for CDD>5000) to 7,000 kWh (for 200<CDD<500). The total HIR savings potentials range from about 1300 kWh (7%) (CDD>5000) to about 1400 kWh (20%) (200<CDD< 500). The heating energy use ranges from 0 to 500 therms and penalties range from 0 to 20 therms (0–4%). For 1980$^+$ stock of office buildings, the annual basecase electricity use ranges from about 10,800 kWh (for CDD>5000) to 3,500 kWh (for 200<CDD<500). The total HIR savings potentials range from about 600 kWh (5%) (CDD>5000) to about 500 kWh (14%) (200<CDD< 500). The heating energy use ranges from 0 to 300 therms and penalties range from 0 to 10 therms (0–3%). These results are summarized in Table 9.

For stock of Pre-1980 electrically heated office buildings, the annual basecase electricity use (heating and cooling) ranges from about 18,700 kWh (for CDD>5000) to 13,800 kWh (for 200<CDD<500). The total HIR savings potentials range from about 1300 kWh (7%) (HDD<500) to about 1100 kWh (8%) (200<CDD< 500). For 1980$^+$ stock of office buildings, the annual basecase electricity use ranges from about 10,800 kWh (for CDD>5000) to 6,400 kWh (for 200<CDD<500). The total HIR savings potentials range from about 600 kWh (5%) (CDD>5000) to about 300 kWh (5%) (200<CDD< 500). Over 75% of the total savings are from direct effects of cool roofs and shade trees.

The peak demand electricity use is about 6.3 to 8.0 kW/1000ft^2 of roof area for Pre-1980 office stock and 3.5–4.4 kW/1000ft^2 for 1980$^+$ stock. The total savings range from 0.5–1.0 kW/1000ft^2 for Pre-1980 stock and 0.2–0.5 kW/1000ft^2 for 1980$^+$ stock.

For stock of Pre-1980 gas-heated office buildings, the annual rate of carbon emissions ranges from 1900–3100 kgC. The total carbon savings for climates with more than 200 cooling-degree-days range from 210–250 kgC. For 1980$^+$ stock of gas-heated residential buildings, the annual rate of carbon emissions ranges from 830–1800 kgC. The total carbon savings for climates with more than 200 cooling-degree-days ranges from 70–120 kgC. For stock of Pre-1980 electrically heated residential buildings, the annual rate of carbon emissions ranges from 2200–3100 kgC. The total carbon savings for climates with more than 200 cooling-degree-days range from 190–240 kgC. For 1980$^+$ stock of electrically heated residential buildings, the annual rate of carbon emissions ranges from 1100–1800 kgC. The total carbon savings for climates with more than 200 heating-degree-days ranges from 50–100 kgC.

Retail Store Buildings by Heating-degree-days. (Table 8a) (All numbers are normalized per 1000ft^2 of roof area). For stock of Pre-1980 gas-heated retail store buildings, the annual basecase electricity use ranges from about 15,700 kWh (for HDD< 500) to 8,200 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 1,500 kWh (10%) (HDD<500) to about 1,400 kWh (17%) (5500<HDD< 6000). The heating-energy use ranges from 0 to 200 therms and penalties range from 0 to 10 therms (0–5%). For 1980$^+$ stock of retail store buildings, the annual basecase electricity use ranges from about 8,000 kWh (for HDD< 500) to 3,500 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 600 kWh (7%) (HDD<500) to about 500 kWh (14%) (5500<HDD< 6000). The heating-energy use ranges from 0 to 30 therms and penalties range from 0 to 4 therms (0–13%). These results are summarized in Table 9.

For stock of Pre-1980 electrically heated retail store buildings, the annual basecase electricity use (heating and cooling) ranges from about 15,700 kWh (for HDD< 500) to 10,700 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 1500 kWh (10%) (HDD<500) to about 1300 kWh (12%) (5500<HDD< 6000). For 1980$^+$ stock of retail store buildings, the annual basecase electricity use ranges from about 8,000 kWh (for HDD< 500) to 4,000 kWh (for 5500<HDD<6000). The total HIR savings potentials range from about 600 kWh (7%) (HDD<500) to about 400 kWh (10%) (5500<HDD< 6000). Over 75% of the total savings are from direct effects of cool roofs and shade trees.

The peak demand electricity use is about 4.5 to 5.7 kW/1000ft^2 of roof area for Pre-1980 retail store stock and 2.3–2.8 kW/1000ft^2 for 1980$^+$ stock. The total savings range from 0.4–0.7 kW/1000ft^2 for Pre-1980 stock and 0.2–0.3 kW/1000ft^2 for 1980$^+$ stock.

For stock of Pre-1980 gas-heated retail store buildings, the annual rate of carbon emissions ranges from 1600–1900 kgC. The total carbon savings for climates with less than 8000 heating-degree-days range from 210–260 kgC. For 1980$^+$ stock of gas-heated residential buildings, the annual rate of carbon emissions ranges from 600–800 kgC. The total carbon savings for climates with less than 8000 heating-degree-days range from 60–90 kgC. For stock of Pre-1980 electrically heated residential buildings, the annual rate of carbon emissions ranges from 1800–2100 kgC. The total carbon savings for climates with less than 8000 heating-degree-days range from 200–250 kgC. For 1980$^+$ stock of electrically heated residential buildings, the annual rate of carbon emissions ranges from 650–810 kgC. The total carbon savings for climates with less than 4500 heating-degree-days range from 50–800 kgC.

Retail Store Buildings by Cooling-degree-days. (Table 8b) (All numbers are normalized per 1000ft^2 of roof area). For stock of Pre-1980 gas-heated retail store buildings, the annual basecase electricity use ranges from about 17,200 kWh (for CDD>5000) to 7,200 kWh (for 200<CDD<500). The total HIR savings potentials range from about 1800 kWh (10%) (CDD>5000) to about 1400 kWh (20%) (200<CDD< 500). The heating-energy use ranges from 0 to 300 therms and penalties range from 0 to 10 therms (0–3%). For 1980$^+$ stock of retail store buildings, the annual basecase electricity use ranges from about 8,900 kWh (for CDD>5000) to 3,100 kWh (for 200<CDD<500). The total HIR savings potentials range from about 700 kWh (8%) (CDD>5000) to about 500 kWh (16%) (200<CDD< 500). The heating-energy use ranges from 0 to 60 therms and penalties range from 0 to 6 therms (0–10%). These results are summarized in Table 9.

For stock of Pre-1980 electrically heated retail store buildings, the annual basecase electricity use (heating and cooling) ranges from about 17,200 kWh (for CDD>5000) to 11,100 kWh (for 200<CDD<500). The total HIR savings potentials range from about 1700 kWh (10%) (HDD<500) to about 1300 kWh (12%) (200<CDD< 500). For 1980$^+$ stock of retail store buildings, the annual basecase electricity use ranges from about 8,900 kWh (for CDD>5000) to 4,100 kWh (for 200<CDD<500). The total HIR savings potentials range from about 700 kWh (8%) (CDD>5000) to about 300 kWh (7%) (200<CDD< 500). Over 75% of the total savings are from direct effects of cool roofs and shade trees.

The peak demand electricity use is about 4.1 to 5.5 kW/1000ft^2 of roof area for Pre-1980 retail store stock and 2.2–2.7 kW/1000ft^2 for 1980$^+$ stock. The total savings range from 0.5–0.6 kW/1000ft^2 for Pre-1980 stock and 0.2–0.3 kW/1000ft^2 for 1980$^+$ stock.

For stock of Pre-1980 gas-heated retail store buildings, the annual rate of carbon emissions ranges from 1400–2900 kgC. The total carbon savings for climates with more than 200 cooling-degree-days range from 220–290 kgC. For 1980$^+$ stock of gas-heated residential buildings, the annual rate of carbon emissions ranges from 520–1500 kgC. The total carbon savings for climates with more than 200 cooling-degree-days range from 70–120 kgC. For stock of Pre-1980 electrically heated residential buildings, the annual rate of carbon emissions ranges from 1800–2900 kgC. The total carbon savings for climates with more than 200 cooling-degree-days range from 220–290 kgC. For 1980$^+$ stock of electrically heated residential buildings, the annual rate of carbon emissions ranges from 660–1500 kgC. The total carbon savings for climates with more than 200 heating-degree-days range from 60–120 kgC.

4. Using Tables 6–8 to Estimate the Heat-Island Reduction Potential for a City

The information summarized in Table 6–8 and Figures 3–5 can be used in many ways to estimate energy-saving potentials from the application of reflective roofs and shade trees.

Estimating Savings for Individual buildings

A building owner, a contractor, a policy manager, an energy engineer can obtain an estimate of the direct saving potentials directly from the Tables or Figures. For example, to estimate the savings from the application of a reflective roof on an old (Pre-1980) gas-heated office building with a 10,000-ft^2 roof area in Phoenix Arizona, the following steps are taken:

1. From Table 4, the HDD is read at 1154 and the CDD is read at 3815.
2. From Table 7a (based on HDD), the annual cooling-energy savings (for an increase in roof albdeo from 0.2 to 0.6; a change in albedo of 0.4) are read at 776 kWh/1000ft^2 of roof area, the peak-demand savings are read at 370 W/1000ft^2, and the heating penalty is read at 1 therm/1000ft^2. (The same information can be extracted from Figure 4a.) Alternatively from Table 7b (based on CDD), the annual cooling-energy savings are read at 664 kWh/1000ft^2 of roof area, the peak-demand savings are read at 237 W/1000ft^2, and the heating penalty is read at 1 therm/1000ft^2. (The same information can be extracted from Figure 4b.) Hence the total annual cooling-energy savings are estimated at 6640–7390 kWh, the peak-demand reduction is 2.4–3.7 kW, and the annual heating penalty is 1–3 therms.
3. For other changes in roof reflectivity, simply scale the savings by the ratio Δalbedo/0.4.

The same table can be used to estimate the saving potentials from shade trees.

Estimating Savings for an Urban Area

Data in Tables 6–8 and Figures 3–5 can also be used to estimate the potential savings from reflective roofs and shade trees at an urban scale. For demonstration, we present an example of how the data generated in this report can be used to estimate the heat-island reduction saving potential for Houston. The choice of Houston as an example would allow us to compare the results from this report with previous detailed analysis presented in Konopacki and Akbari (2002). This demonstration example is summarized in **Table 10**. Let us also assume that we would plant 4, 8 and 10 shade trees for the residence, office, and retail store, respectively. Also, the albedo of the residences is increased from 0.2 to 0.5, and for offices and retail stores it is increased from 0.2 to 0.6.

Table 9. Estimated ranges of annual basecase (electricity use, gas use, peak demand, and carbon emissions) and savings from heat-island reduction measures across all climate regions.

Prototype Building	Electricity (kWh/1000ft^2)		Gas (Therm/1000ft^2)		Peak Power (kW/1000ft^2)		Carbon (kgC/1000ft^2)	
	Basecase	Savings	Basecase	Penalties	Basecase	Savings	Basecase	Savings
Residential								
Pre-1980 Gas-Heated	1600–11000	400–1200	0–1000	0–50	3.1–4.0	0.4–0.6	1100–2200	60–220
Pre-1980 Electrically heated	8500–20000	100–1200			3.1–4.0	0.4–0.6	900–4800	60–220
1980$^+$ Gas-Heated	700–7000	150–700	0–500	0–20	1.7 –3.3	0.2–0.4	400–1200	30–100
1980$^+$ Electrically heated	5000–9000	50–600			1.7–3.3	0.2–0.4	430–2300	30–100
Office								
Pre-1980 Gas-Heated	7000–18700	1200–1400	0–500	0–20	6.3–8.4	0.5–1.0	1800–3100	200–260
Pre-1980 Electrically heated	12600–18700	1100–1300			6.3–8.4	0.5–1.0	2000–2100	190–260
1980$^+$ Gas-Heated	3500–10800	500–600	0–300	0–10	3.5–4.6	0.2–0.5	800–1800	70–120
1980$^+$ Electrically heated	5700–10800	300–600			3.5–4.6	0.2–0.5	900–1800	50–100
Retail Store								
Pre-1980 Gas-Heated	8200–15700	1400–1500	0–200	0–10	4.5–5.7	0.4–0.7	1400–2900	210–290
Pre-1980 Electrically heated	10700–17200	1300–1700			4.1–5.7	0.4–0.7	1800–2900	200–290
1980$^+$ Gas-Heated	3100–8900	500–700	0–60	0–6	2.2–2.8	0.2–0.3	520–1500	70–120
1980$^+$ Electrically heated	4000–8900	300–700			2.2–2.8	0.2–0.3	650–1500	50–120

1. Row 1a shows the stock of conditioned roof area for buildings heated with gas: Pre-1980 Residences: 789 Mft^2; 1980^+ Residences: 310 Mft^2; Pre-1980 Offices: 48 Mft^2; 1980^+ Offices: 27 Mft^2; and Pre-1980 Retail Stores: 90 Mft^2; 1980^+ Retail Stores: 19 Mft^2.
   Row 1b shows the stock of conditioned roof area for buildings heated with electric heat pump: Pre-1980 Residences: 78 Mft^2; 1980^+ Residences: 51 Mft^2; Pre-1980 Offices: 2.5 Mft^2; 1980^+ Offices: 4.8 Mft^2; and Pre-1980 Retail Stores: 4.8 Mft^2; 1980^+ Retail Stores: 0 Mft^2.
2. Row 2 shows the heating-degree-days (base 65F) read from Table 4.
3. Row 3 shows the cooling-degree-days (base 65F) read from Table 4.
4. Row 4a shows the normalized estimated basecase annual air-conditioning electricity use for a building heated with gas, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
   Row 4b shows the normalized estimated basecase annual air-conditioning electricity use for a building heated with heat pumps, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
   Row 4c shows the normalized estimated basecase annual air-conditioning electricity peak power demand for a building heated with wither gas or heat pumps, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
   Row 4d shows the normalized estimated basecase annual heating energy use for a building heated with gas, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
5. Row 5a shows the normalized estimated annual reflective roofs air-conditioning electricity savings for a building heated with gas, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
   Row 5b shows the normalized estimated annual reflective roofs air-conditioning electricity savings for a building heated with heat pumps, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
   Row 5c shows the normalized estimated annual reflective roofs air-conditioning electricity peak power demand reduction for a building heated with wither gas or heat pumps, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
   Row 5d shows the normalized estimated annual reflective roofs heating energy penalties for a building heated with gas, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
6. Row 6a shows the normalized estimated annual shade trees air-conditioning electricity savings for a building heated with gas, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
   Row 6b shows the normalized estimated annual shade trees air-conditioning electricity savings for a building heated with heat pumps, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
   Row 6c shows the normalized estimated annual shade trees air-conditioning electricity peak power demand reduction for a building heated with wither gas or heat pumps, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)
   Row 6d shows the normalized estimated annual shade trees heating energy penalties for a building heated with gas, using the HDD Tables 6a, 7a, and 8a. (Alternatively, CDD Tables 6b, 7b, and 8b can be used.)

7. Row 7a shows the total estimated basecase annual air-conditioning electricity use for a building heated with gas by multiplying Row 1a by Row 4a.
   Row 7b shows the total estimated basecase annual air-conditioning electricity use for a building heated with heat pumps by multiplying Row 1b by Row 4b.
   Row 7c shows the total estimated basecase annual air-conditioning electricity peak power demand for a building heated with either gas or heat pumps by multiplying (Row 1a + Row 1b) by Row 4c.
   Row 7d shows the total estimated basecase annual heating-energy use for a building heated with gas by multiplying Row 1a by Row 4d.
8. Row 8a shows the estimated total direct reflective roofs annual air-conditioning electricity savings for a building heated with gas by multiplying Row 1a by Row 5a.
   Row 8b shows the estimated total direct reflective roofs annual air-conditioning electricity savings for a building heated with heat pumps by multiplying Row 1b by Row 5b.
   Row 8c shows the estimated total direct reflective roofs annual air-conditioning electricity peak power demand reduction for a building heated with either gas or heat pumps by multiplying (Row 1a + Row 1b) by Row 5c.
   Row 8d shows the estimated total direct reflective roofs annual heating energy penalties for a building heated with gas by multiplying Row 1a by Row 5d.
9. Row 9a shows the estimated total direct shade trees annual air-conditioning electricity savings for a building heated with gas by multiplying Row 1a by Row 6a.
   Row 9b shows the estimated total direct shade trees annual air-conditioning electricity savings for a building heated with heat pumps by multiplying Row 1b by Row 6b.
   Row 9c shows the estimated total direct shade trees annual air-conditioning electricity peak power demand reduction for a building heated with either gas or heat pumps by multiplying (Row 1a + Row 1b) by Row 6c.
   Row 9d shows the estimated total direct shade trees annual heating energy penalties for a building heated with gas by multiplying Row 1a by Row 6d.
10. Row 10a shows the estimated total direct reflective roofs and shade trees annual air-conditioning electricity savings for a building heated with gas by adding Row 8a and Row 9a.
    Row 10b shows the estimated total direct reflective roofs and shade trees annual air-conditioning electricity savings for a building heated with heat pumps by adding Row 8b and Row 9b.
    Row 10c shows the estimated total direct reflective roofs and shade trees annual air-conditioning electricity peak power demand reduction for a building heated with either gas or heat pumps by adding Row 8c and Row 9c.
    Row 10d shows the estimated total direct reflective roofs and shade trees annual heating energy penalties for a building heated with gas by adding Row 8d and Row 9d.
11. Row 11a shows the estimated total indirect reflective roofs and shade trees annual air-conditioning electricity savings for a building heated with gas by multiplying Row 10a by (0.17/0.83). (Note that we estimated that the indirect savings are 17% of the total direct and indirect savings; or 0.17/0.83 of the direct savings.
    Row 11b shows the estimated total indirect reflective roofs and shade trees annual air-conditioning electricity savings for a building heated with heat pumps by multiplying Row 10b by (0.17/0.83).

Row 11c shows the estimated total indirect reflective roofs and shade trees annual air-conditioning electricity peak power demand reduction for a building heated with either gas or heat pumps by multiplying Row 10c by (0.19/0.81).
Row 11d shows the estimated total indirect reflective roofs and shade trees annual heating energy penalties for a building heated with gas by multiplying Row 10d by (0.20/0.80).

12. Row 12a shows the estimated total direct and indirect reflective roofs and shade trees annual air-conditioning electricity savings for a building heated with gas by adding Row 10a and Row 11a.
Row 12b shows the estimated total direct and indirect reflective roofs and shade trees annual air-conditioning electricity savings for a building heated with heat pumps by adding Row 10b and Row 11b.
Row 12c shows the estimated total direct and indirect reflective roofs and shade trees annual air-conditioning electricity peak power demand reduction for a building heated with either gas or heat pumps by adding Row 10b and Row 11b.
Row 12d shows the estimated total direct and indirect reflective roofs and shade trees annual heating energy penalties for a building heated with gas by adding Row 10d and Row 11d.

The total annual electricity savings potential obtained by adding all columns of Row 12 a and Row 12b is estimated at 1294 GWh (compared to 1,181 GWh estimated by Konopacki and Akbari (2002)). The total electricity peak demand reduction potential is 729 MW (compared to 734 MW estimated by Konopacki and Akbari (2002)). Finally, the total annual heating-gas penalties are 10 Mtherm (compared to 18 Mtherm estimated by Konopacki and Akbari (2002)). Using the data from Cooling-Degree-Days Tables 6b, 7b, and 8b, the corresponding electricity savings, peak demand reduction, and heating-gas penalties are estimated at 1,281 GWh, 665 MW, and 9 Mtherm, respectively.

For other changes in roof reflectivity and number of trees, simply adjust the normalized savings (Row 4) as described earlier.

Table 10. Estimating citywide savings from the implementation of reflective roofs and shade trees: Example of Houston, TX.

Item	Residence		Office		Retail Store	
	Pre-1980	1980^+	Pre-1980	1980^+	Pre-1980	1980^+
1a. Building Roof Area Stock with Gas Heating System (Mft^2)	789	310	48	27	90	19
1b. Building Roof Area Stock with Heat Pump System (Mft^2)	78	51	2.5	4.8	4.8	0
2. Heating Degree-Days(base 65F)	1552	1552	1552	1552	1552	1552
3. Cooling Degree-Days (base 65F)	2810	2810	2810	2810	2810	2810
4a. Estimated basecase electricity use with gas heating system ($kWh/1000ft^2$) (Table 6–8a)	5236	2968	13684	7057	13486	6168
4b. Estimated basecase electricity use with heat pump system ($kWh/1000ft^2$) (Table 6–8a)	7998	3728	14565	7191	13826	6177
4c. Estimated basecase electricity peak power demand ($W/1000ft^2$) (Table 6–8a)	3804	2118	7890	4129	5402	2672
4d. Estimated basecase gas use with gas heating system ($Therm/1000ft^2$) (Table 6–8a)	163	53	76	12	30	0
5a. Estimated reflective roofs electricity saving with gas heating system ($kWh/1000ft^2$) (Table 6–8a)	542	213	739	214	993	298
5b. Estimated reflective roofs electricity savings with heat pump system ($kWh/1000ft^2$) (Table 6–8a)	463	198	718	205	981	298
5c. Estimated reflective roofs electricity peak power demand reduction ($W/1000ft^2$) (Table 6–8a)	333	145	359	92	349	124
5d. Estimated reflective roofs gas penalties with gas heating system ($Therm/1000ft^2$) (Table 6–8a)	-3	0	-2	0	-1	0
6a. Estimated shade trees electricity saving with gas heating system ($kWh/1000ft^2$) (Table 6–8a)	293	177	501	259	391	190
6b. Estimated shade trees electricity savings with heat pump system ($kWh/1000ft^2$) (Table 6–8a)	279	168	494	256	392	191
6c. Estimated shade trees electricity peak power demand reduction ($W/1000ft^2$) (Table 6–8a)	145	90	323	138	138	59
6d. Estimated shade trees gas penalties with gas heating system ($Therm/1000ft^2$) (Table 6–8a)	-6	-2	-2	0	0	0
7a. Estimated total electricity use with gas heating system (GWh) (1a*4a)	4131	920	657	191	1214	117
7b. Estimated total electricity use with heat pump system (GWh) (1b*4b)	624	190	36	35	66	0
7c. Estimated total electricity peak power demand (MW) ((1a+1b)*4c)	3298	765	398	131	512	51
7d. Estimated total gas use with gas heating system (MTherm) (1a*4d)	129	16	4	0	3	0
8a. Estimated total reflective roofs electricity savings with gas heating system (GWh) (1a*5a)	428	66	35	6	89	6

Item	Residence		Office		Retail Store	
	Pre-1980	1980^+	Pre-1980	1980^+	Pre-1980	1980^+
8b. Estimated total reflective roofs electricity savings with heat pump system (GWh) (1b*5b)	36	10	2	1	5	0
8c. Estimated total reflective electricity peak power demand reduction (MW) ((1a+1b)*5c)	289	52	18	3	33	2
8d. Estimated total reflective roofs gas penalties with gas heating system (MTherm) (1a*5d)	-2	0	0	0	0	0
9a. Estimated total shade trees electricity savings with gas heating system (GWh) (1a*6a)	231	55	24	7	35	4
9b. Estimated total shade trees electricity savings with heat pump system (GWh) (1b*6b)	22	9	1	1	2	0
9c. Estimated total shade trees electricity peak power demand reduction (MW) ((1a+1b)*6c)	126	32	16	4	13	1
9d. Estimated total shade trees gas penalties with gas heating system (MTherm) (1a*6d)	-5	-1	0	0	0	0
10a. Estimated total direct electricity savings with gas heating system (GWh) (8a+9a)	659	121	60	13	125	9
10b. Estimated total direct electricity savings with heat pump system (GWh) (8b+9b)	58	19	3	2	7	0
10c. Estimated total direct lectricity peak power demand reduction (MW) (8c+9c)	414	85	34	7	46	3
10d. Estimated total direct gas penalties with gas heating system (MTherm) (8a+9d)	-7	-1	0	0	0	0
11a. Estimated total indirect electricity savings with gas heating system (GWh) (10a*(0.17/0.83))	135	25	12	3	26	2
11b. Estimated total indirect electricity savings with heat pump system (GWh) (10b*0.17/0.83)	12	4	1	0	1	0
11c. Estimated total indirect lectricity peak power demand reduction (MW) (10c*0.19/0.81)	97	20	8	2	11	1
11d. Estimated total indirect gas penalties with gas heating system (MTherm) (10d*0.20/0.80)	-2	0	0	0	0	0
12a. Estimated total direct + indirect electricity savings with gas heating system (GWh) (10a+11a)	794	146	72	15	150	11
12b. Estimated total direct + indirect electricity savings with heat pump system (GWh) (10b+11b)	70	22	4	3	8	0
12c. Estimated total direct + indirect electricity peak power demand reduction (MW) (10c+11c)	512	105	43	9	57	4
12d. Estimated total direct + indirect gas penalties with gas heating system (MTherm) (10d+11d)	-9	-1	0	0	0	0

5. Summary and Conclusions

In this study, we have developed summary tables (sorted by heating- and cooling-degree-days) to estimate the potential of Heat Island Reduction (HIR) strategies (i.e., solar-reflective roofs, shade trees, reflective pavements and urban vegetation) to reduce cooling-energy use in buildings. The tables provide estimates of savings for both direct effect (reducing heat gain through the building shell) and indirect effect (reducing the ambient air temperature).

To perform this analysis, we focused on three building types that offer the most savings potential: residences, offices, and retail stores. Each building type was characterized in detail by Pre-1980 (old) or 1980^+ (new) construction vintage and with natural gas or electricity as heating fuel. We defined prototypical building characteristics for each building type and simulated the impact of HIR strategies on building cooling- and heating-energy use and peak power demand using the DOE-2.1E model and weather data for about 240 locations in the U.S. A statistical analysis of previously completed simulations for five cities was used to estimate the indirect savings. Our simulations included the impact of HIR strategies outlined below.

A. Use of solar-reflective roofing material on building [‘cool roofs’, *direct effect*].

B. Placement of deciduous shade trees near south and west walls of buildings [‘shade trees’, *direct effect*].

C. Urban reforestation with reflective building surfaces and pavements [*indirect effect*].

D. Combination of strategies A through C [*direct and indirect effects*].

Upon completion of estimating the direct and indirect energy savings for all the locations, we integrated the results in tables arranged by heating- and cooling-degree-days. We considered 15 bins for heating-degree-days, and 11 bins for cooling-degree-days. Energy use and savings were presented per 1000 ft^2 of roof area. The highlights of the results include:

- For all building types, over 75% of the total savings were from direct effects of cool roofs and shade trees.
- For Pre-1980 gas-heated residential buildings, the total HIR savings potentials ranged from about 1200 kWh/1000ft^2 (15%) (HDD<500) to about 500 kWh/1000ft^2 (25%) (5500<HDD< 6000). The heating-energy penalties ranged from 0 to 45 therms (0–5%). For 1980^+ stock of residential buildings, the total HIR savings potentials ranged from about 600 kWh (12%) (HDD<500) to about 200 kWh (20%) (5500<HDD< 6000). The heating-energy penalties ranged from 0 to 20 therms (0–5%). The peak demand electricity savings ranged from 0.4–0.6 kW/1000ft^2 for Pre-1980 stock and 0.2–0.4 kW/1000ft^2 for 1980^+ stock.
- For stock of Pre-1980 gas-heated office buildings, the total HIR savings potentials ranged from about 1200 kWh (7%) (HDD<500) to about 1,400 kWh (18%) (5500<HDD< 6000). The heating-energy penalties ranged from 0 to 15 therms (0–5%). For 1980^+ stock of office buildings, the total HIR savings potentials ranged from about 500 kWh (5%) (HDD<500) to about 500 kWh (12%) (5500<HDD< 6000). The heating-energy penalties ranged from 0 to 10 therms (0–7%). The peak demand electricity savings ranged from 0.5–1.0 kW/1000ft^2 for Pre-1980 stock and 0.2–0.4 kW/1000ft^2 for 1980^+ stock.
- For stock of Pre-1980 gas-heated retail store buildings, the total HIR savings potentials ranged from about 1,500 kWh (10%) (HDD<500) to about 1,400 kWh (17%)

(5500<HDD< 6000). The heating-energy penalties ranged from 0 to 10 therms (0–5%). For 1980^+ stock of retail store buildings, the total HIR savings potentials ranged from about 600 kWh (7%) (HDD<500) to about 500 kWh (14%) (5500<HDD< 6000). The heating-energy penalties ranged from 0 to 4 therms (0–13%). The peak demand electricity savings ranged from 0.4–0.7 kW/1000ft^2 for Pre-1980 stock and 0.2–0.3 kW/1000ft^2 for 1980^+ stock.

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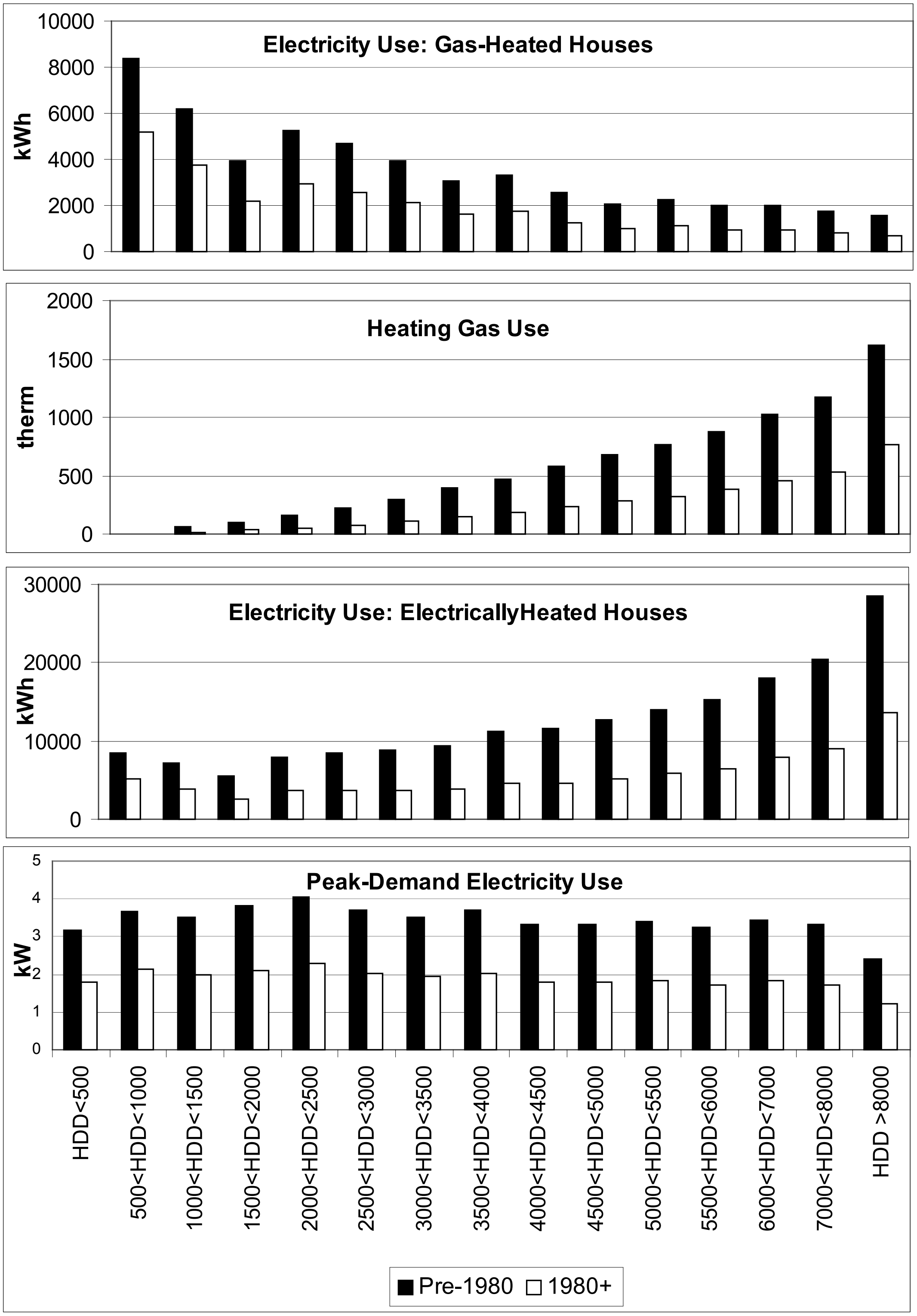

Figure 3a(i). Residential Buildings. Basecase Energy Use as a function of heating-degree-day: Annual basecase cooling-electricity use and heating-gas use for gas-heated houses, combined heating- and cooling-electricity use for electrically heated houses, and peak-electricity demand. All estimates are normalized per 1000 ft^2 of roof area.

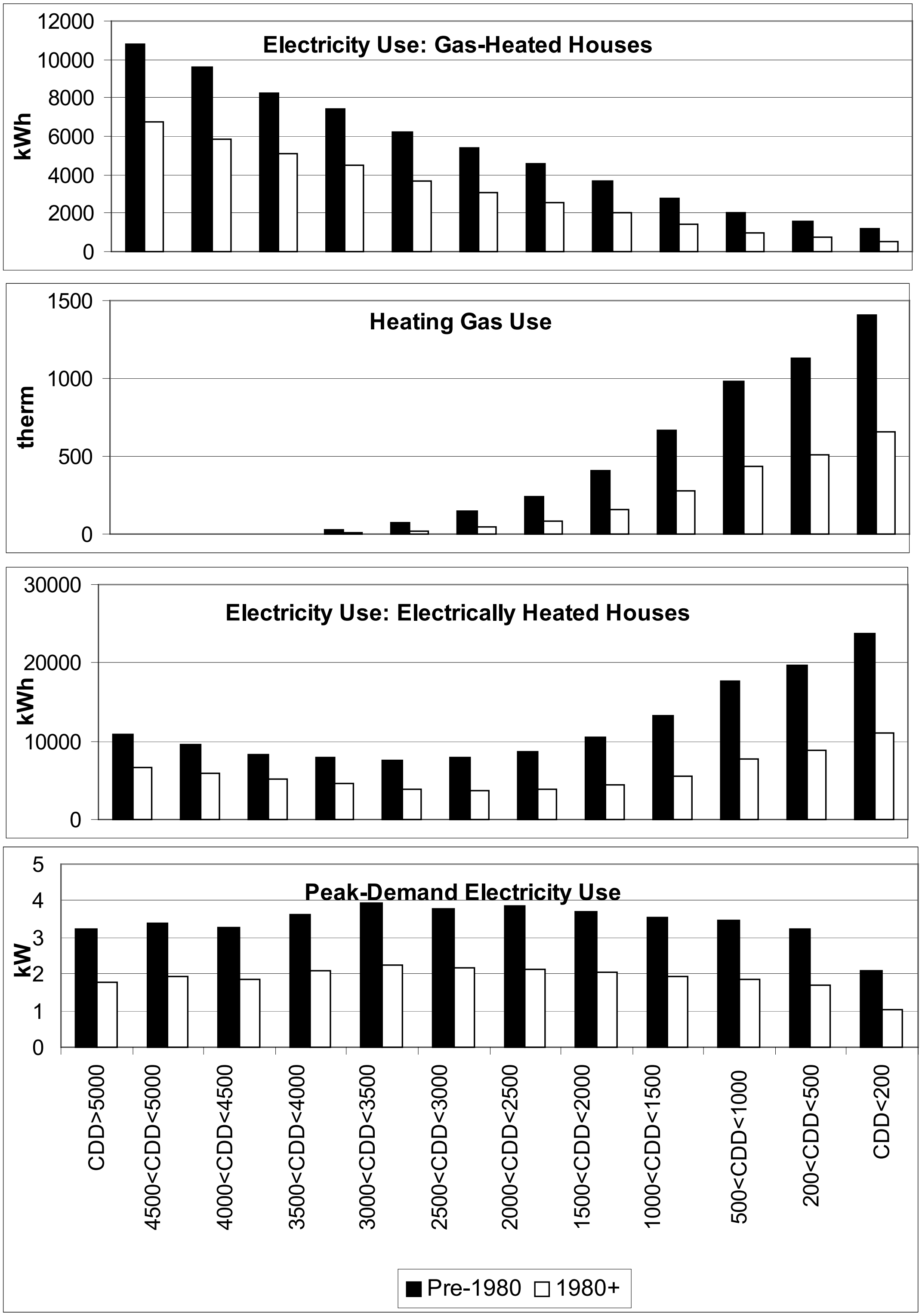

Figure 3b(i). Residential Buildings. Basecase Energy Use as a function of cooling-degree-days: Annual basecase cooling-electricity use and heating-gas use for gas-heated houses, combined cooling-and heating-electricity use for electrically heated houses, and peak-electricity demand. All estimates are normalized per 1000 ft^2 of roof area.

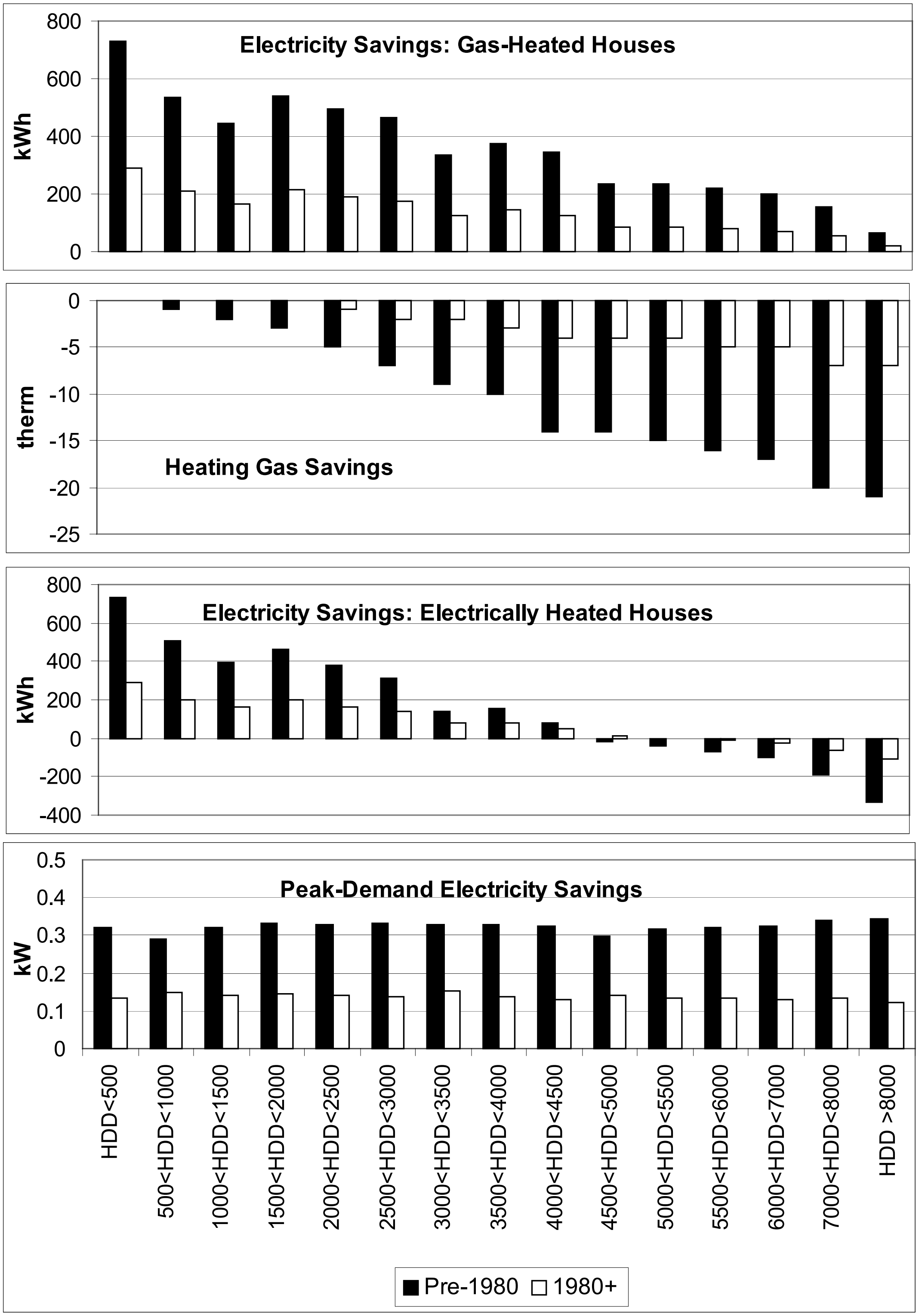

Figure 3a(ii). Residential Buildings. Effect of Cool Roofs, as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

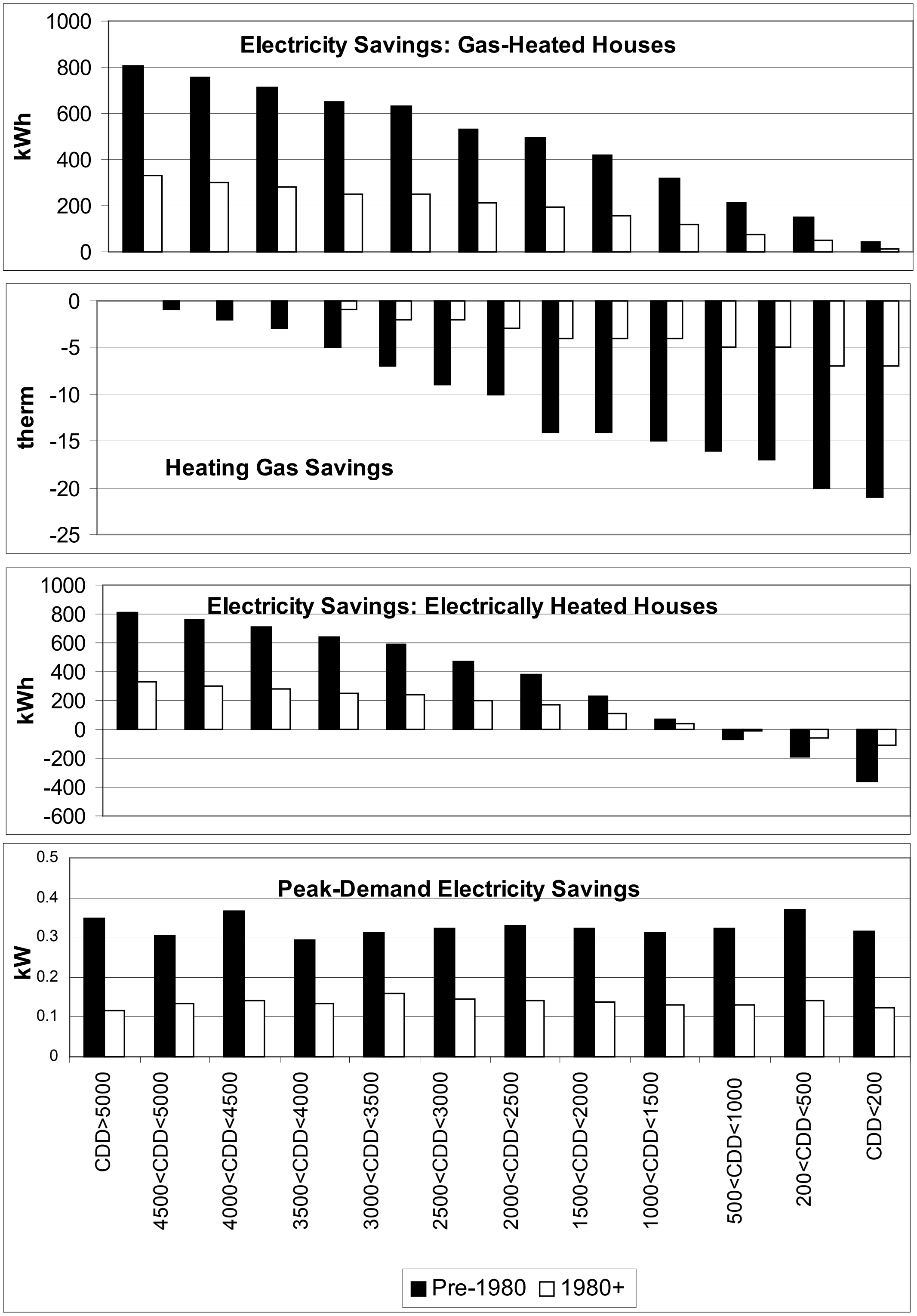

Figure 3b(ii): Residential Buildings. Savings from Cool Roofs as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

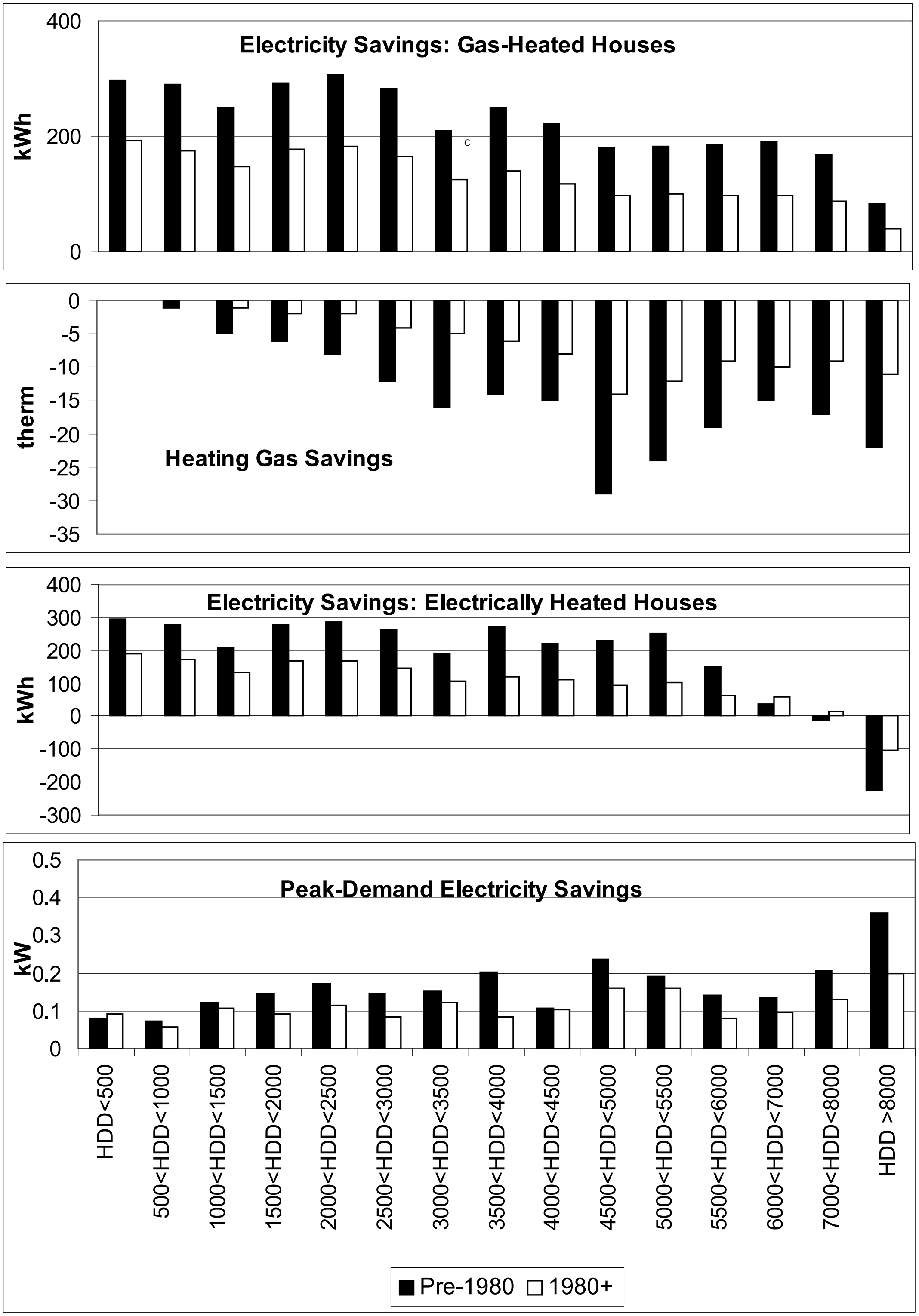

Figure 3a(iii). Residential Buildings. Savings from Shade Trees as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

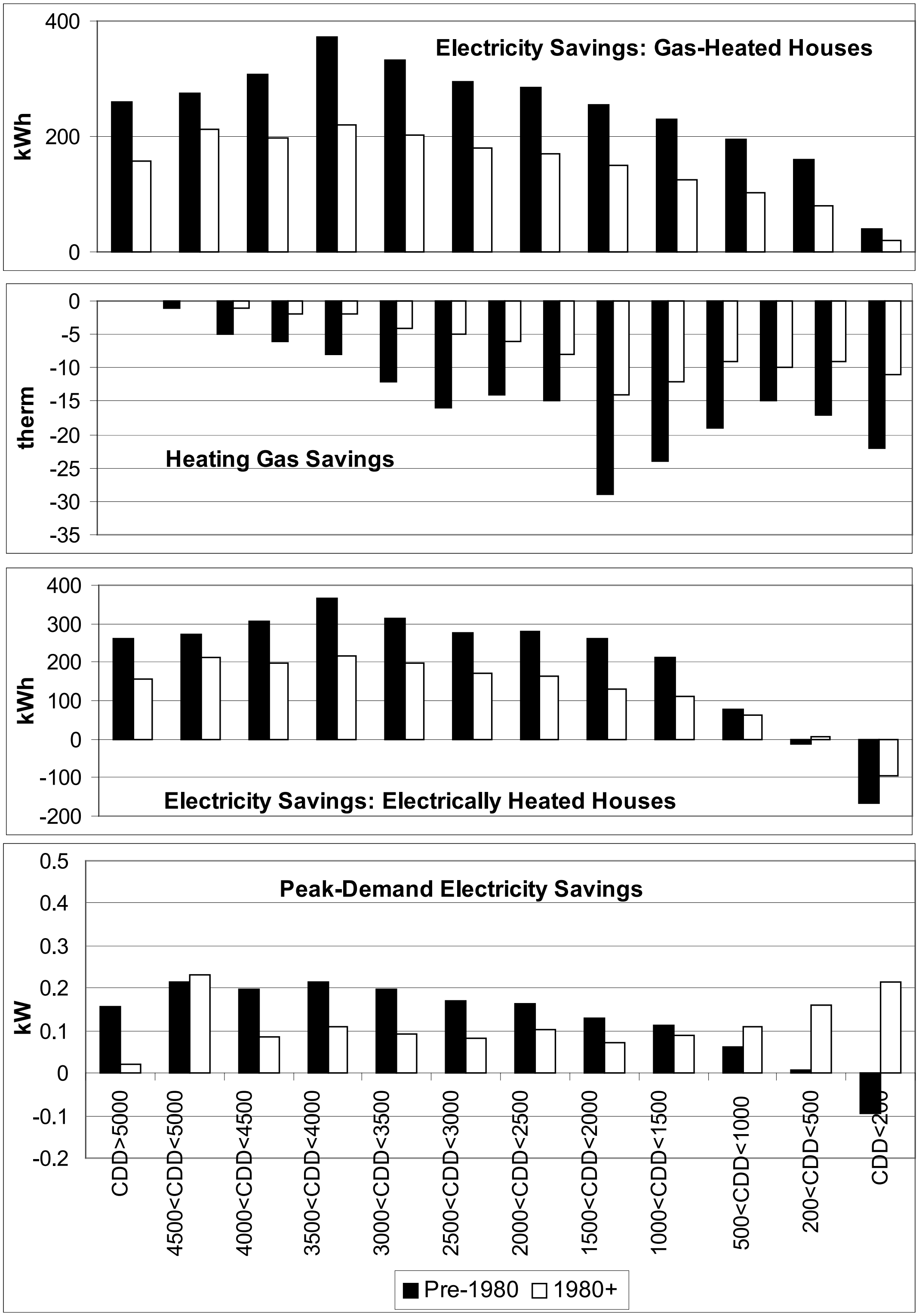

Figure 3b(iii). Residential Buildings. Savings from Shade Trees as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

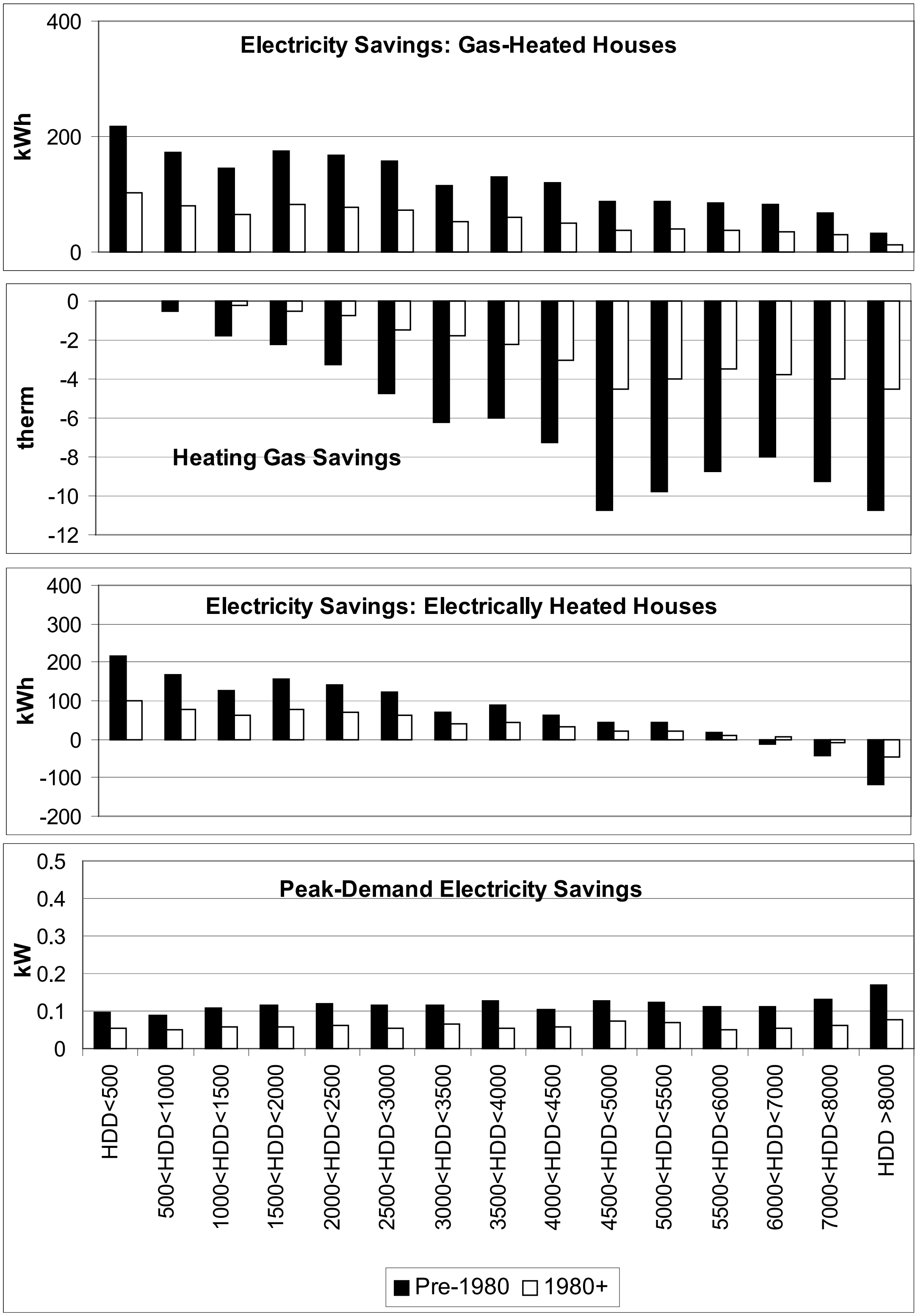

Figure 3a(iv). Residential Buildings. Indirect Savings as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

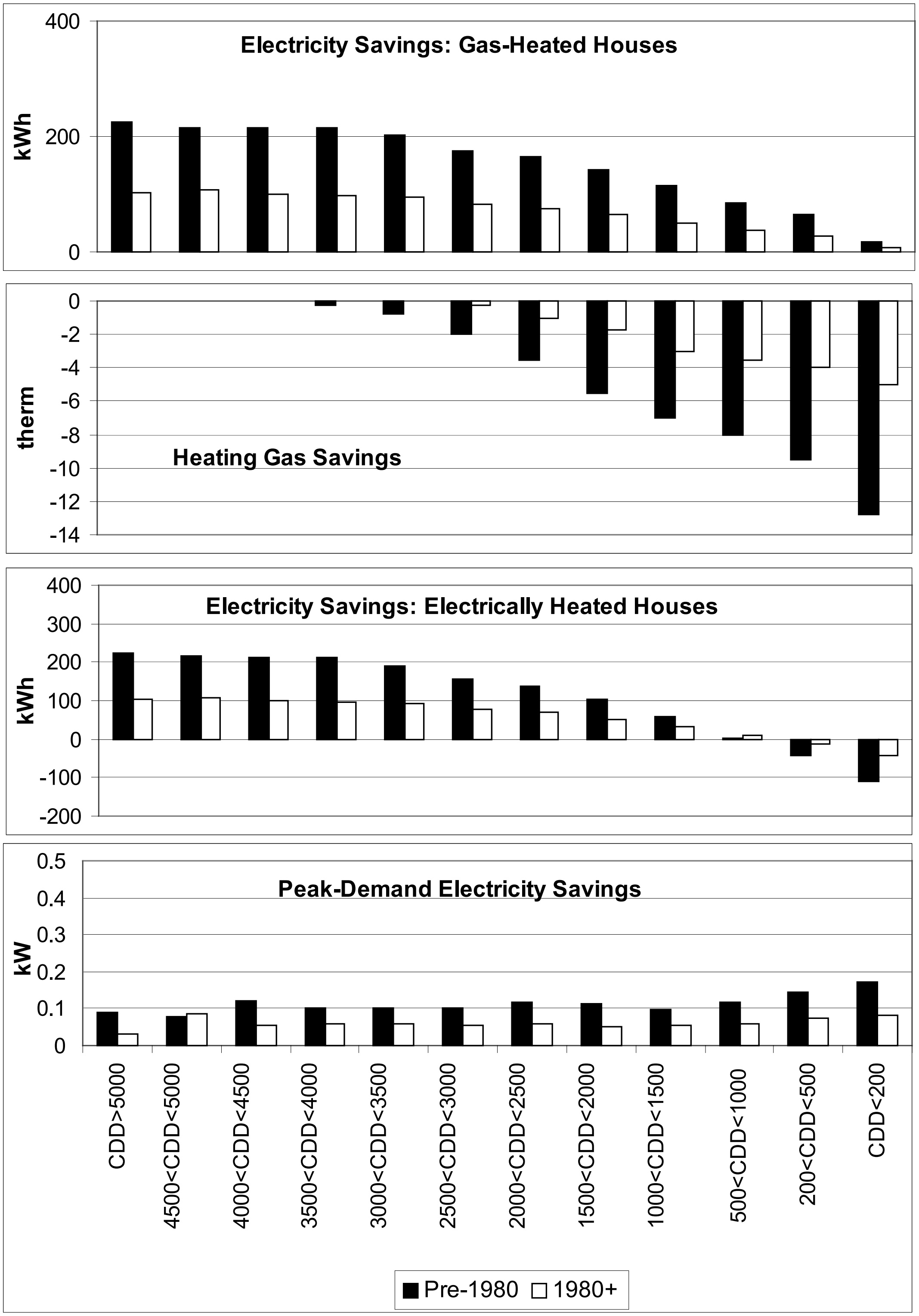

Figure 3b(iv). Residential Buildings. Indirect Savings as a function of cooling degree days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

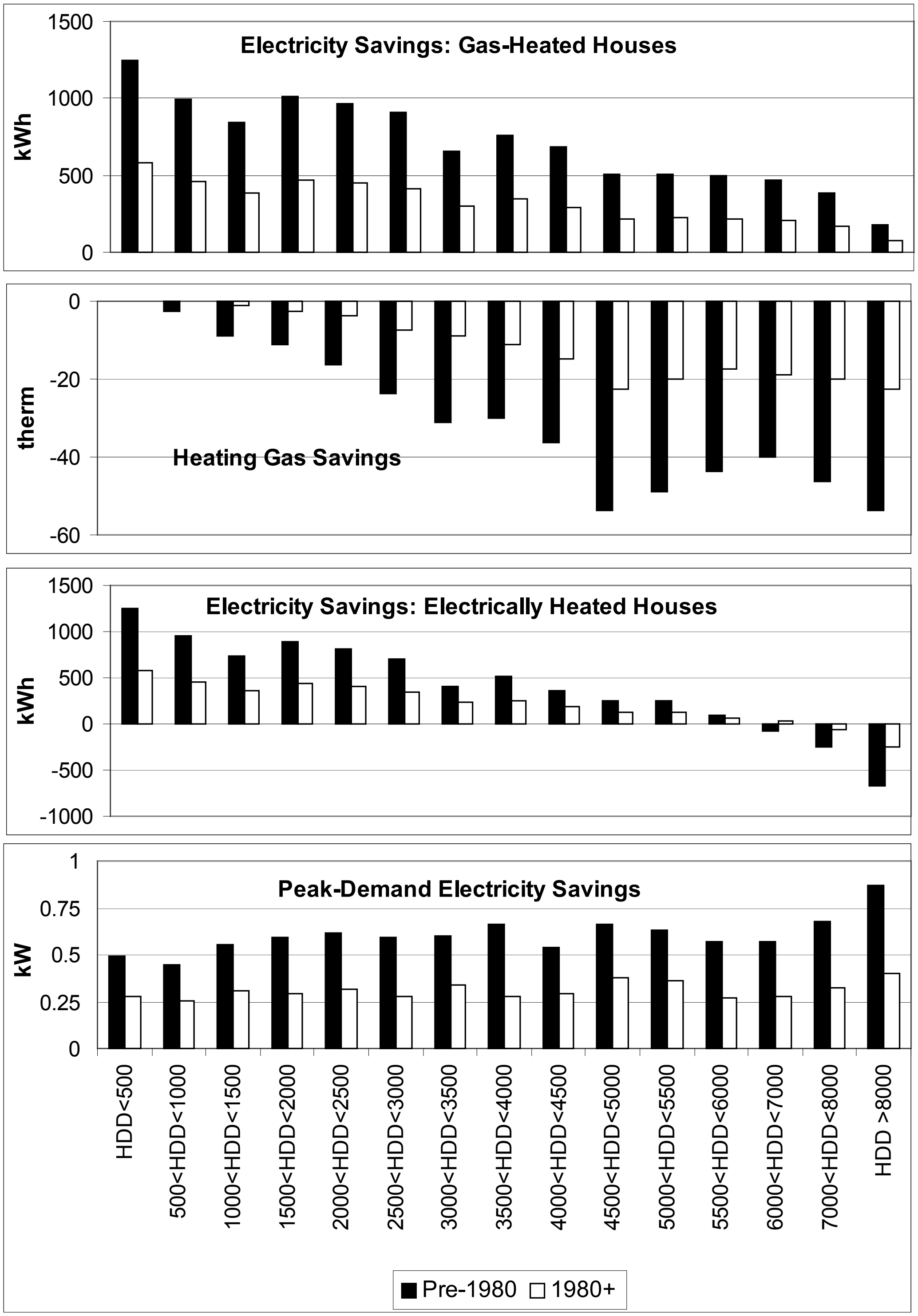

Figure 3a(v). Residential Buildings. Combined Direct and Indirect Savings as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

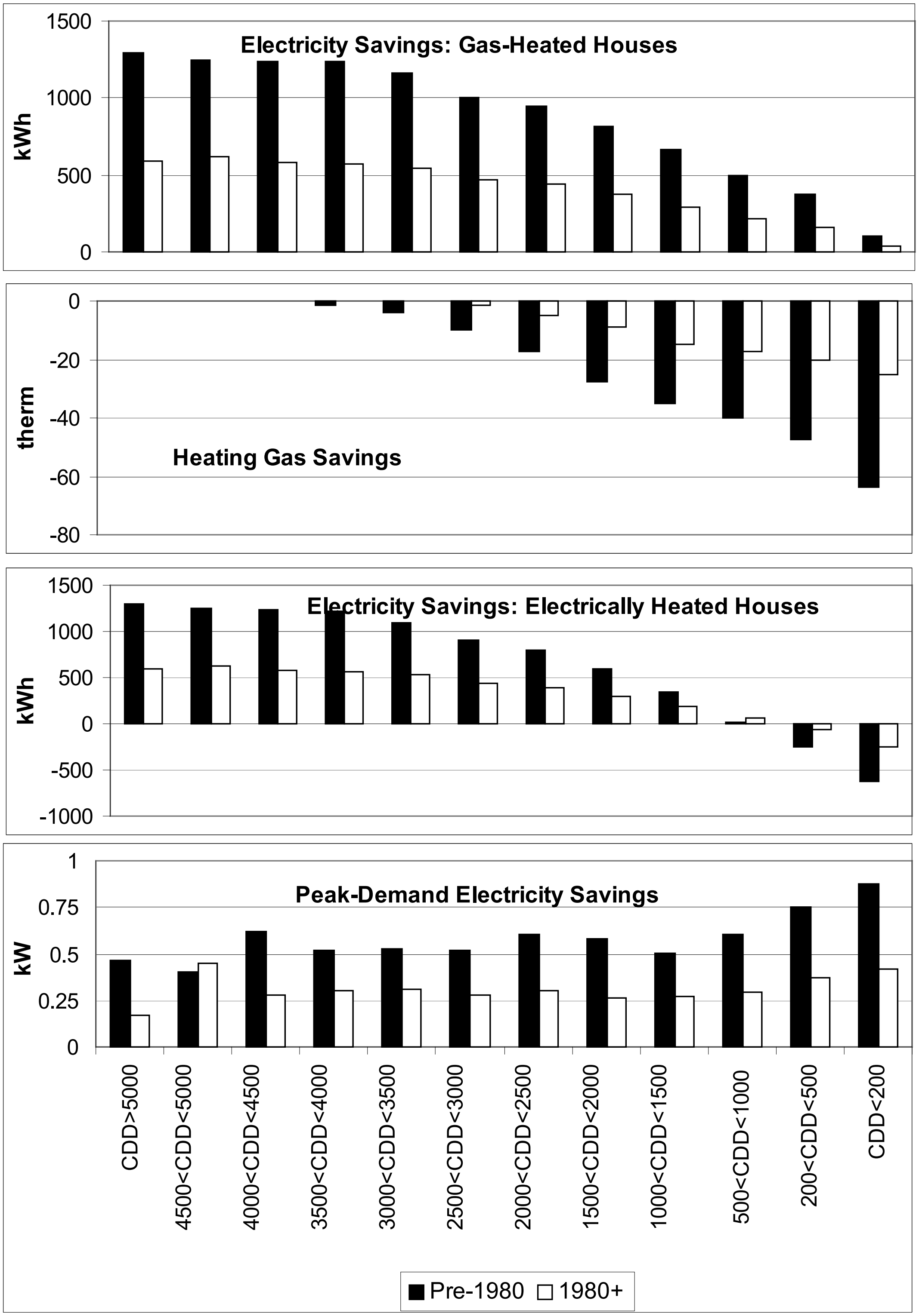

Figure 3b(v). Residential Buildings. Combined Direct and Indirect Savings as a function of cooling-degree-days: Annual cooling electricity savings and heating gas savings for gas heated houses, combined heating and cooling electricity savings for electricity heated houses, and peak electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

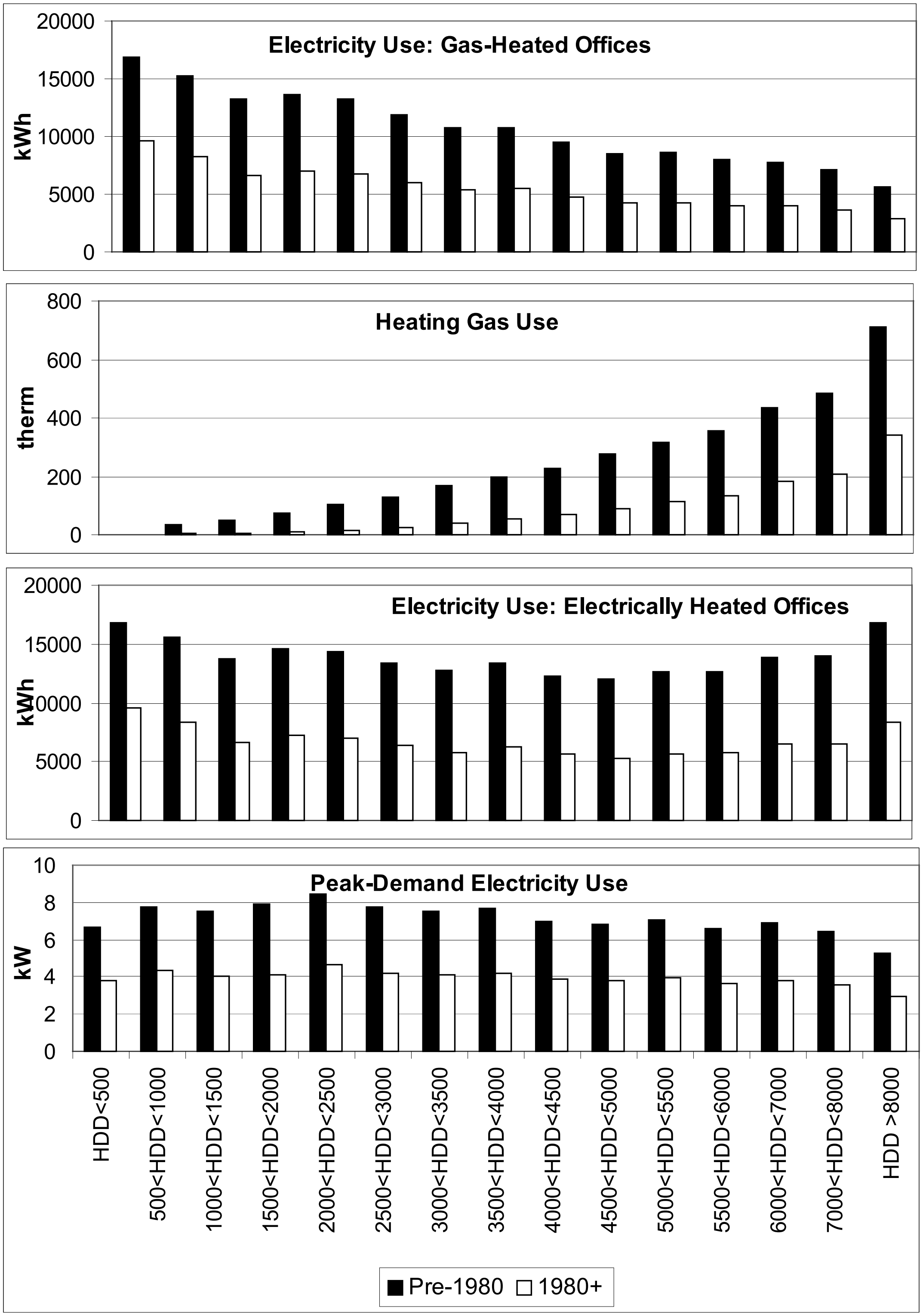

Figure 4a(i). Office Buildings. Basecase Energy Use as a function of heating-degree-days: Annual basecase cooling-electricity use and heating-gas use for gas-heated houses, combined heating- and cooling-electricity use for electrically heated houses, and peak-electricity demand. All estimates are normalized per 1000 ft^2 of roof area.

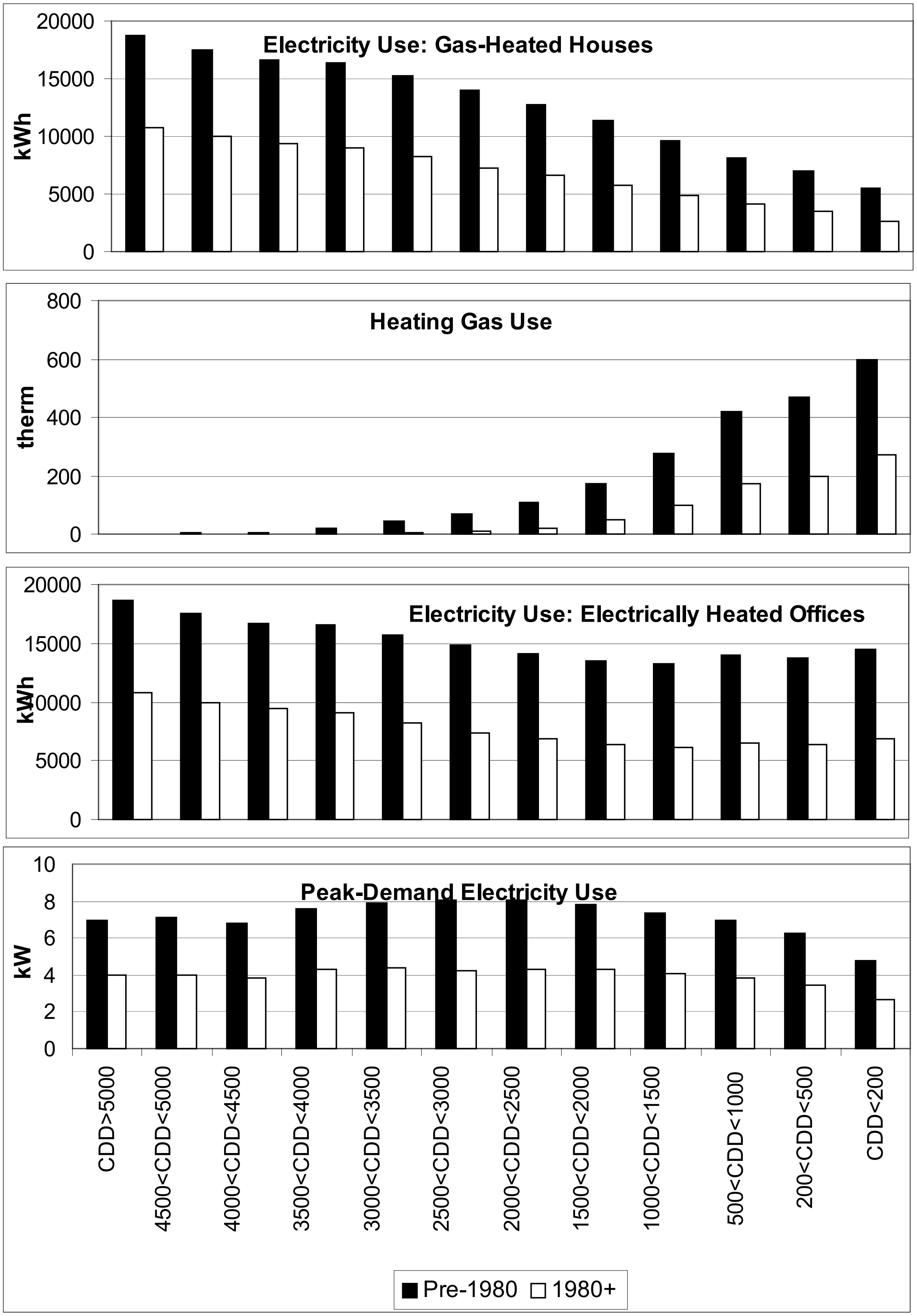

Figure 4b(i). Office Buildings. Basecase Energy Use as a function of cooling-degree-days: Annual basecase cooling-electricity use and heating-gas use for gas-heated houses, combined cooling- and heating-electricity use for electrically heated houses, and peak-electricity demand. All estimates are normalized per 1000 ft^2 of roof area.

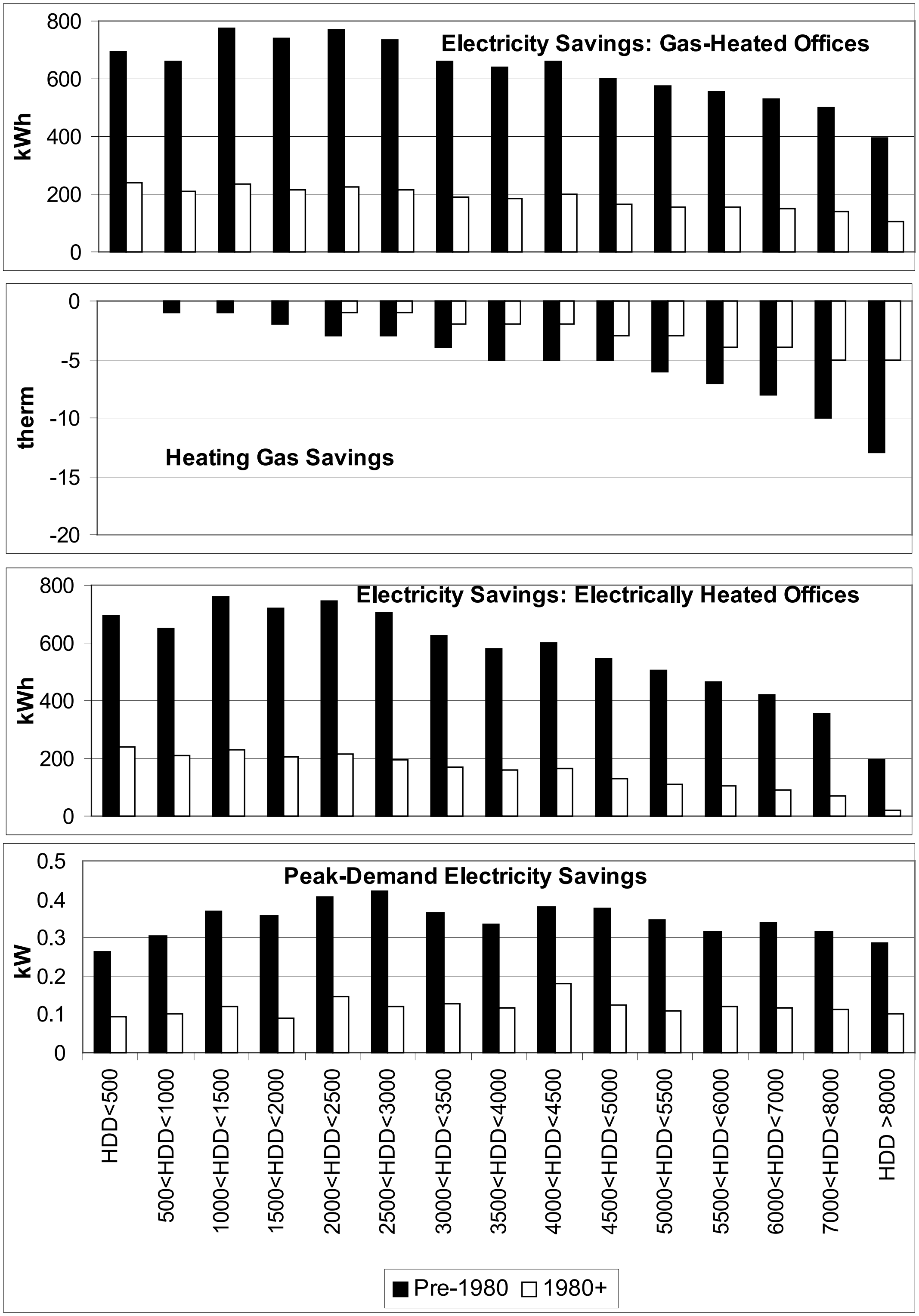

Figure 4a(ii). Office Buildings. Effect of Cool Roofs, as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

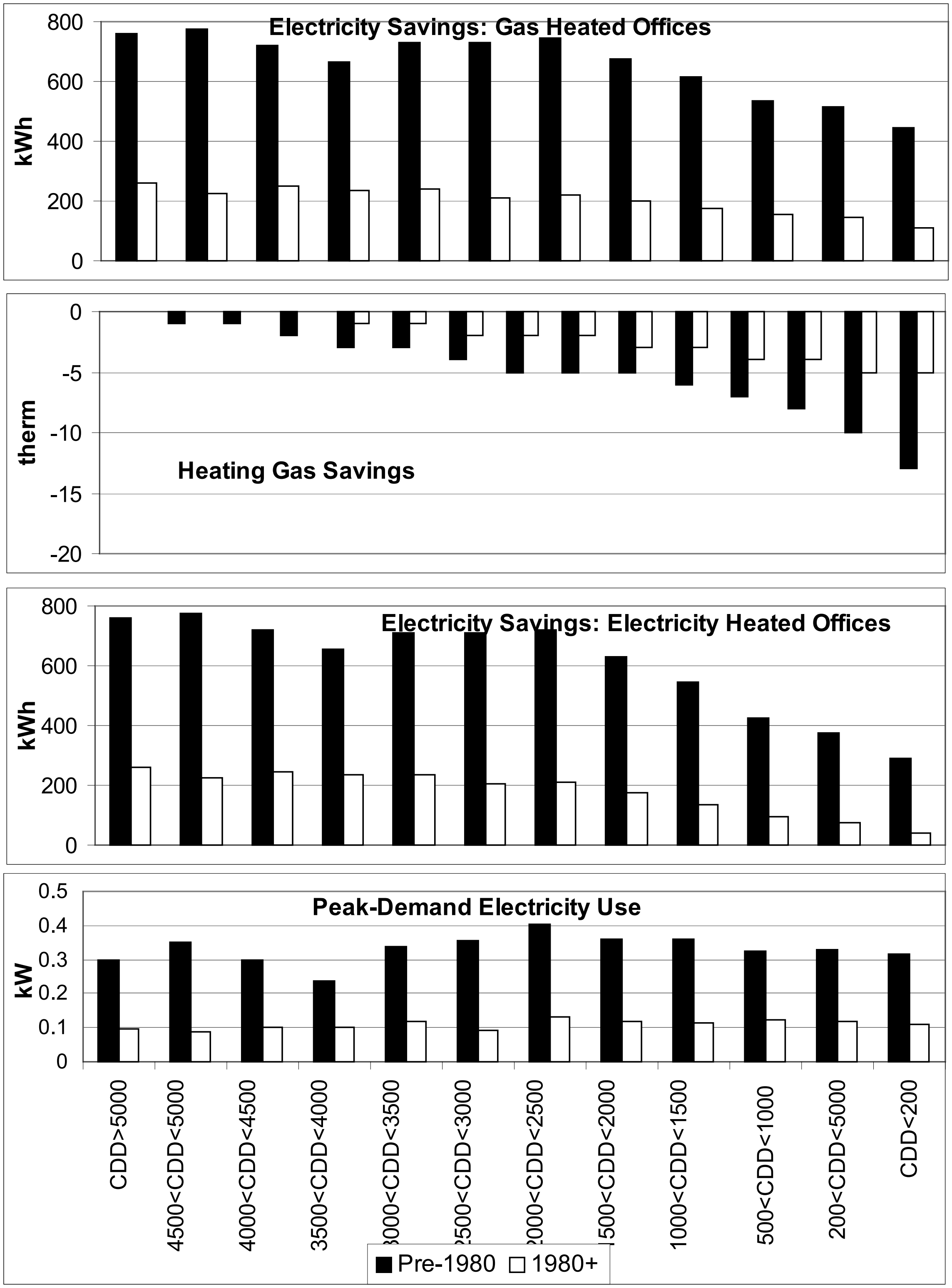

Figure 4b(ii). Office Buildings. Savings from Cool Roofs as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

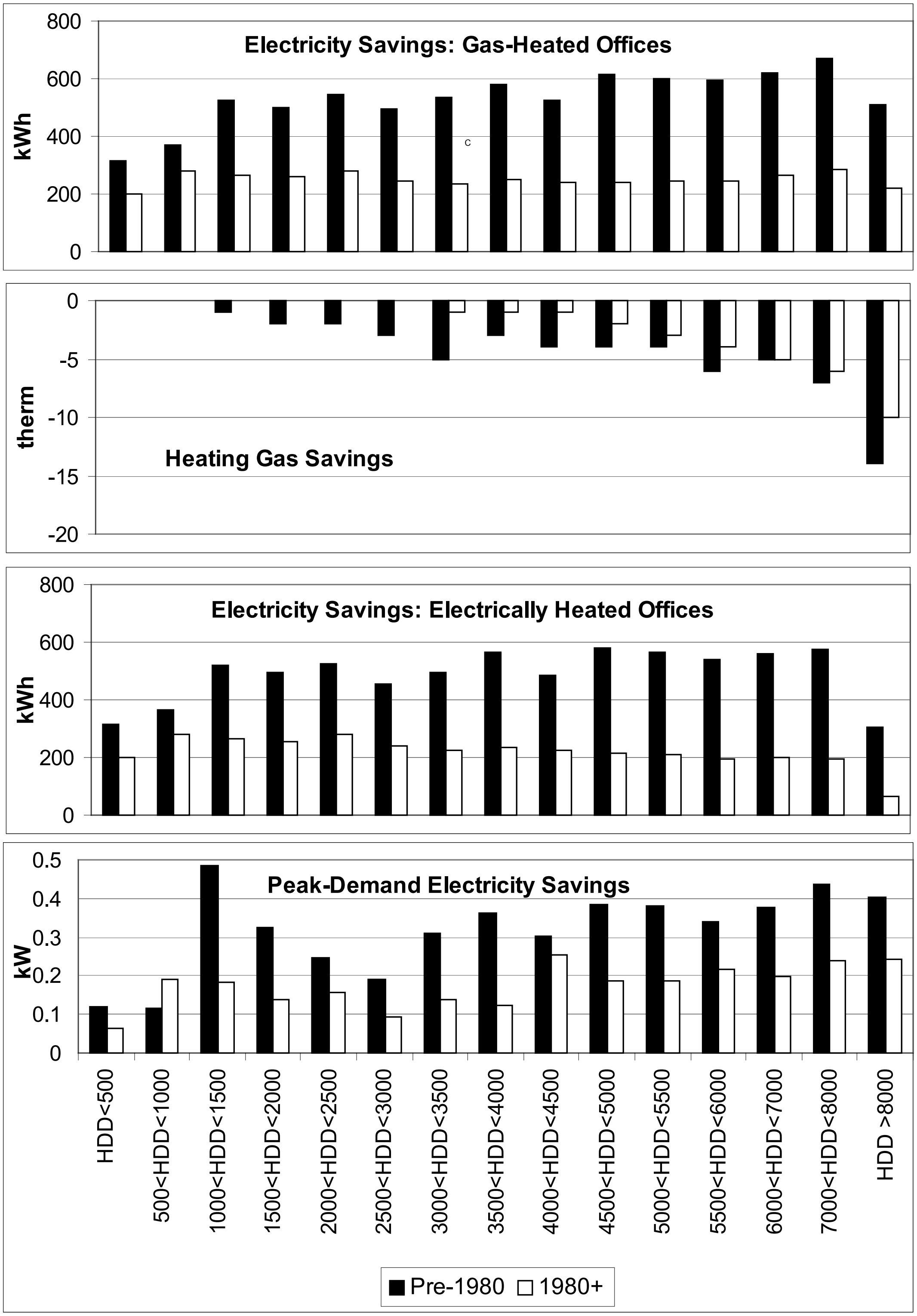

Figure 4a(iii). Office Buildings. Savings from Shade Trees as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

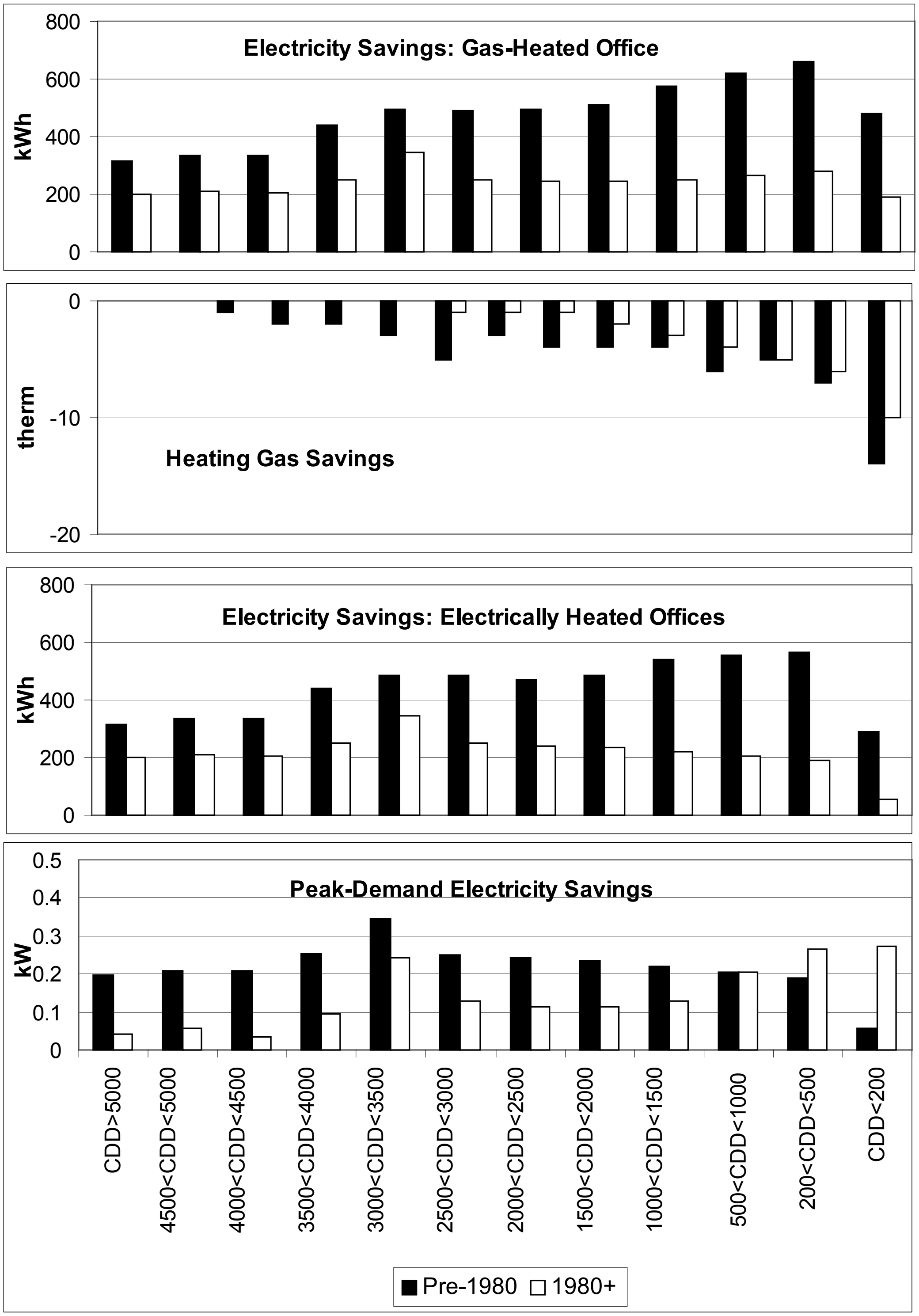

Figure 4b(iii). Office Buildings. Savings from Shade Trees as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

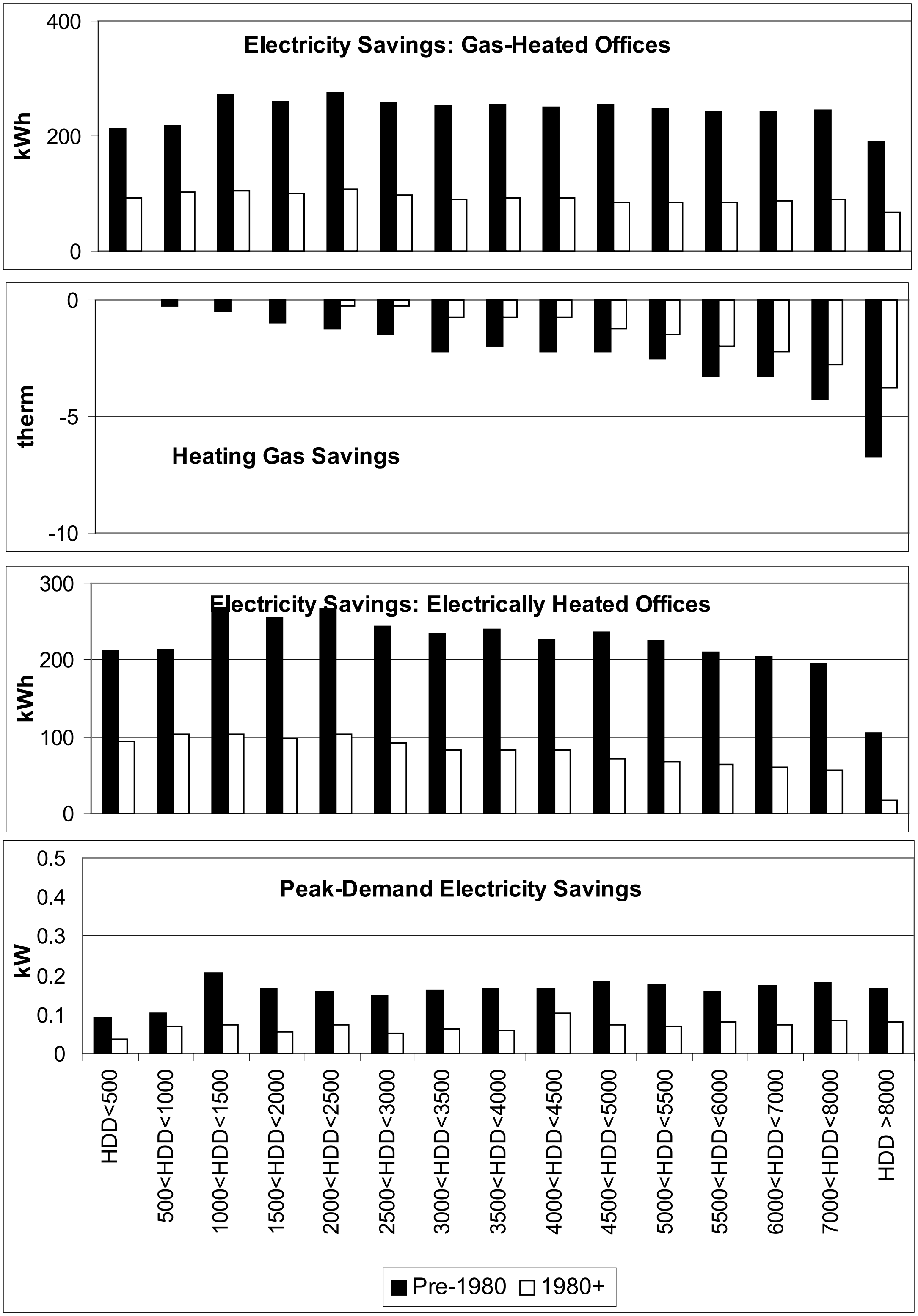

Figure 4a(iv). Office Buildings. Indirect Savings as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

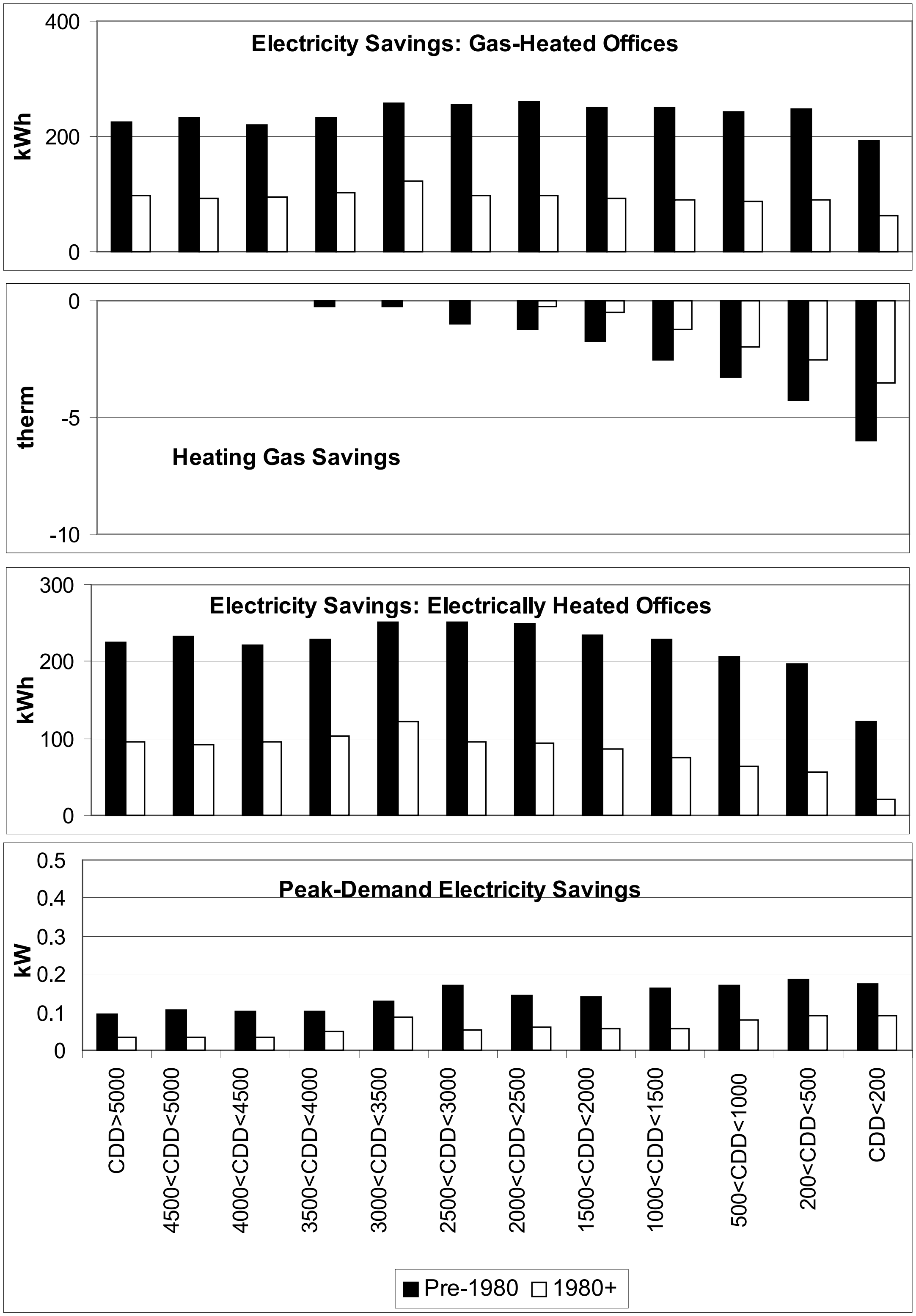

Figure 4b(iv). Office Buildings. Indirect Savings as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

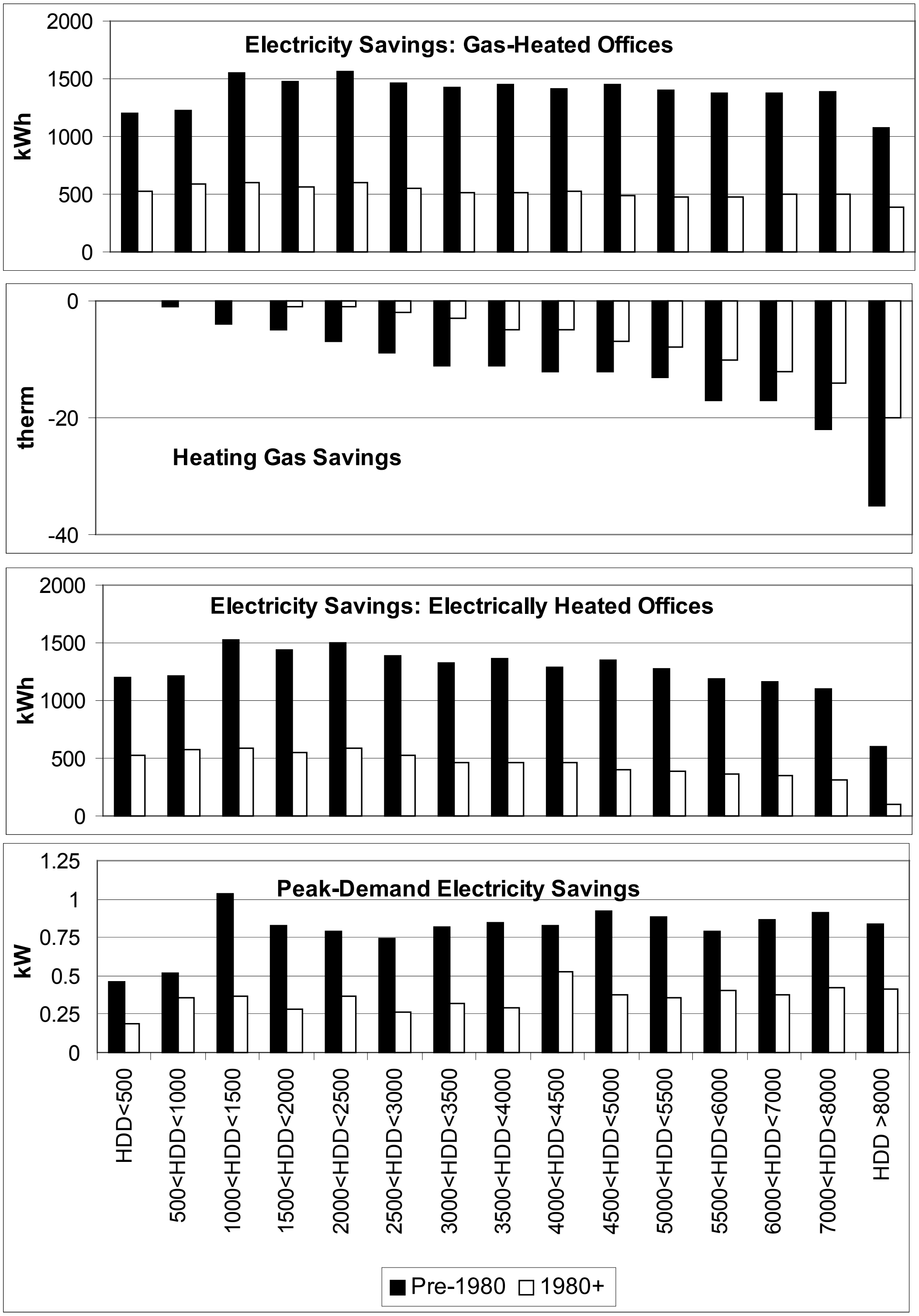

Figure 4a(v). Office Buildings. Combined Direct and Indirect Savings as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

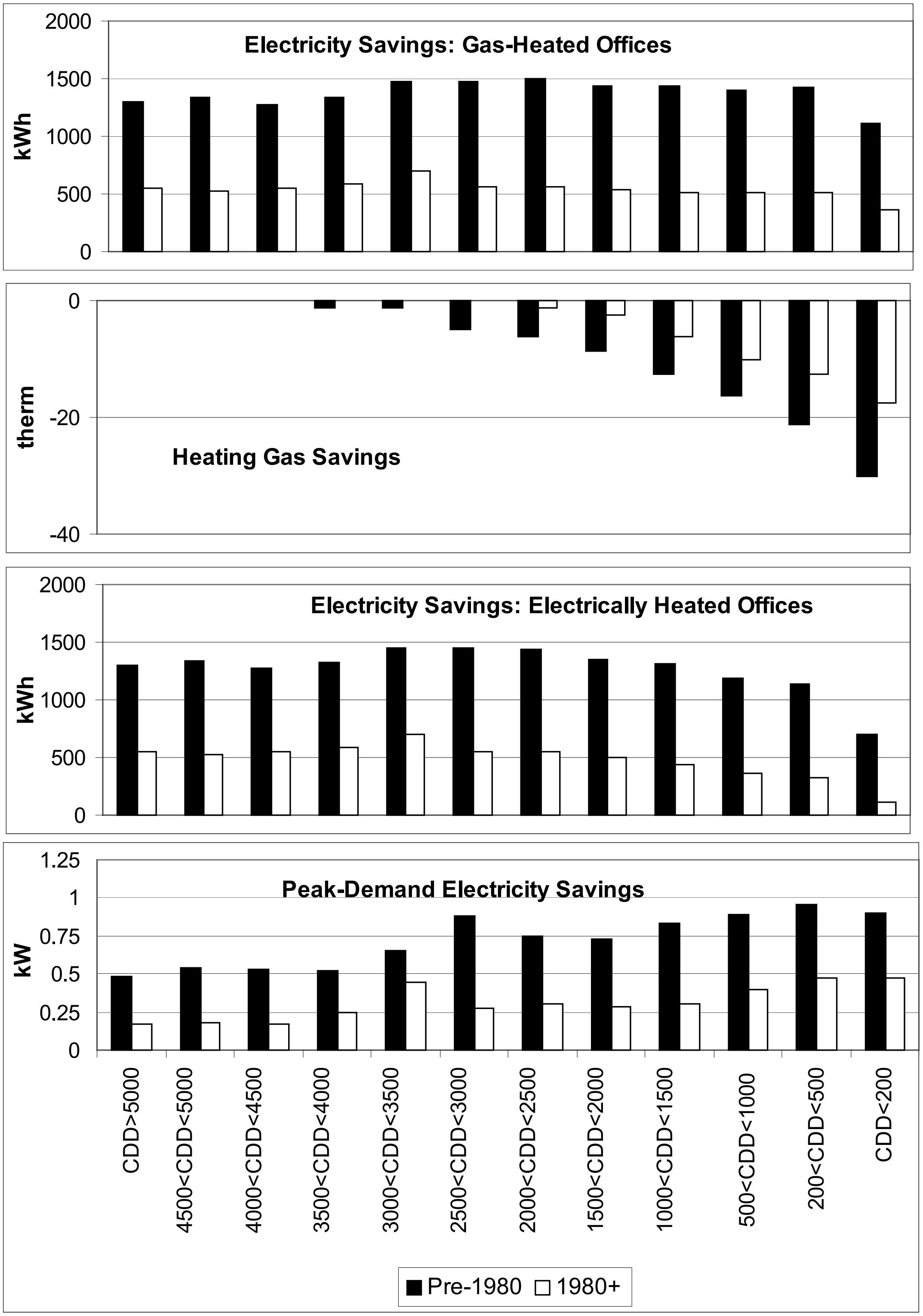

Figure 4b(v). Office Buildings. Combined Direct and Indirect Savings as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

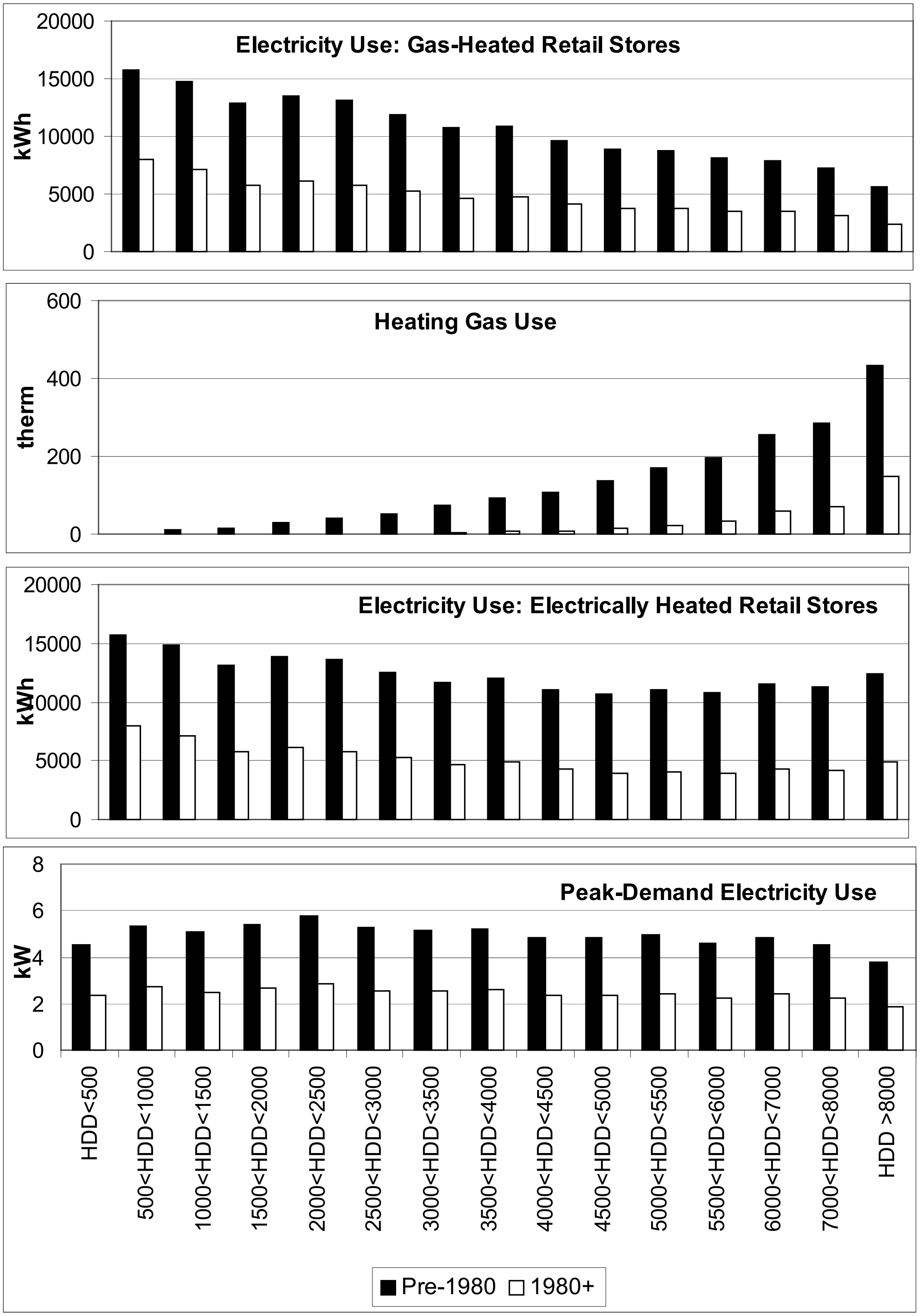

Figure 5a(i). Retail Store Buildings. Basecase Energy Use as a function of heating-degree-day: Annual basecase cooling-electricity use and heating-gas use for gas-heated houses, combined heating- and cooling-electricity use for electrically heated houses, and peak-electricity demand. All estimates are normalized per 1000 ft^2 of roof area.

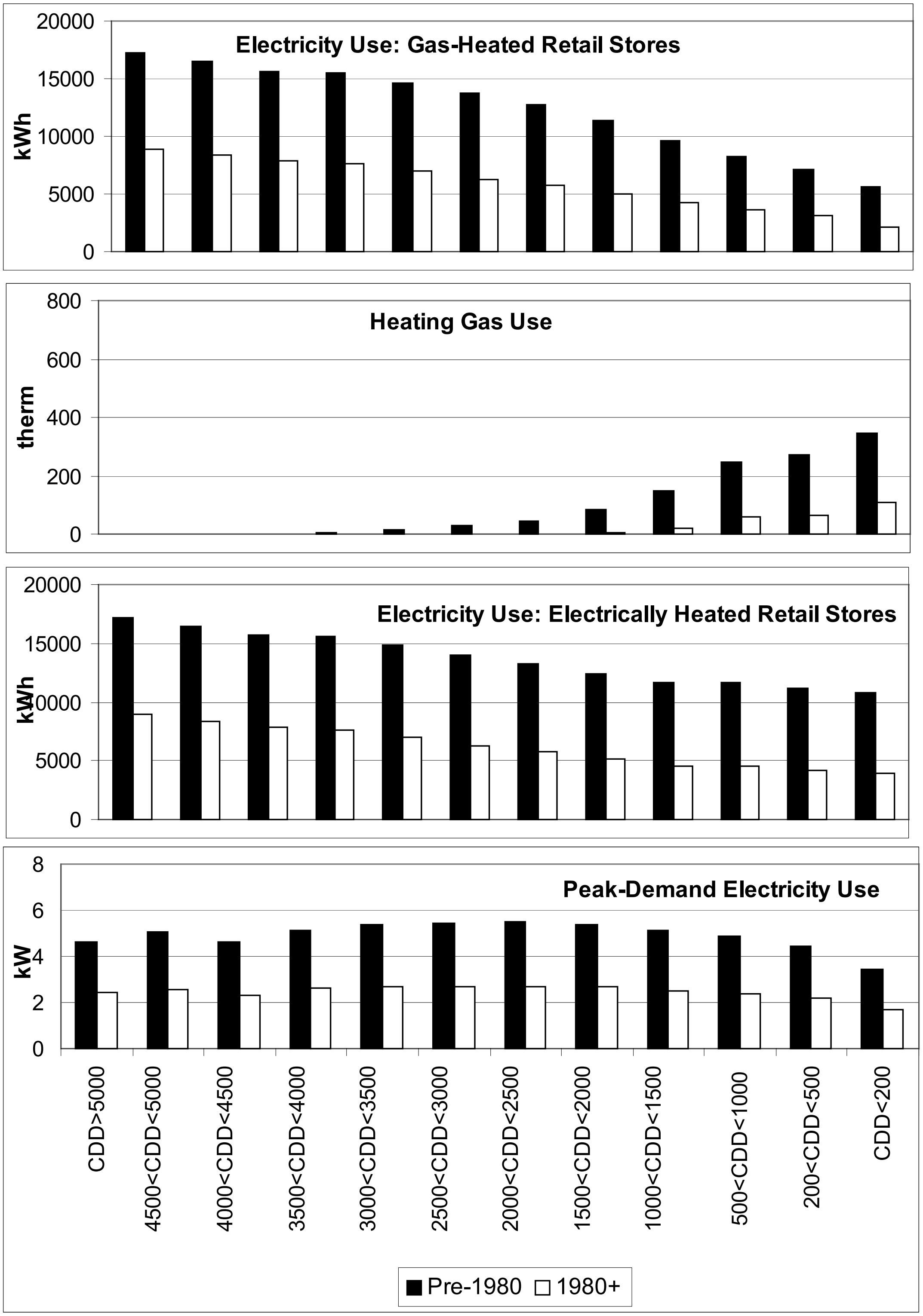

Figure 5b(i). Retail Store Buildings. Basecase Energy Use as a function of cooling-degree-days: Annual basecase cooling-electricity use and heating-gas use for gas-heated houses, combined heating- and cooling-electricity use for electrically heated houses, and peak-electricity demand. All estimates are normalized per 1000 ft^2 of roof area.

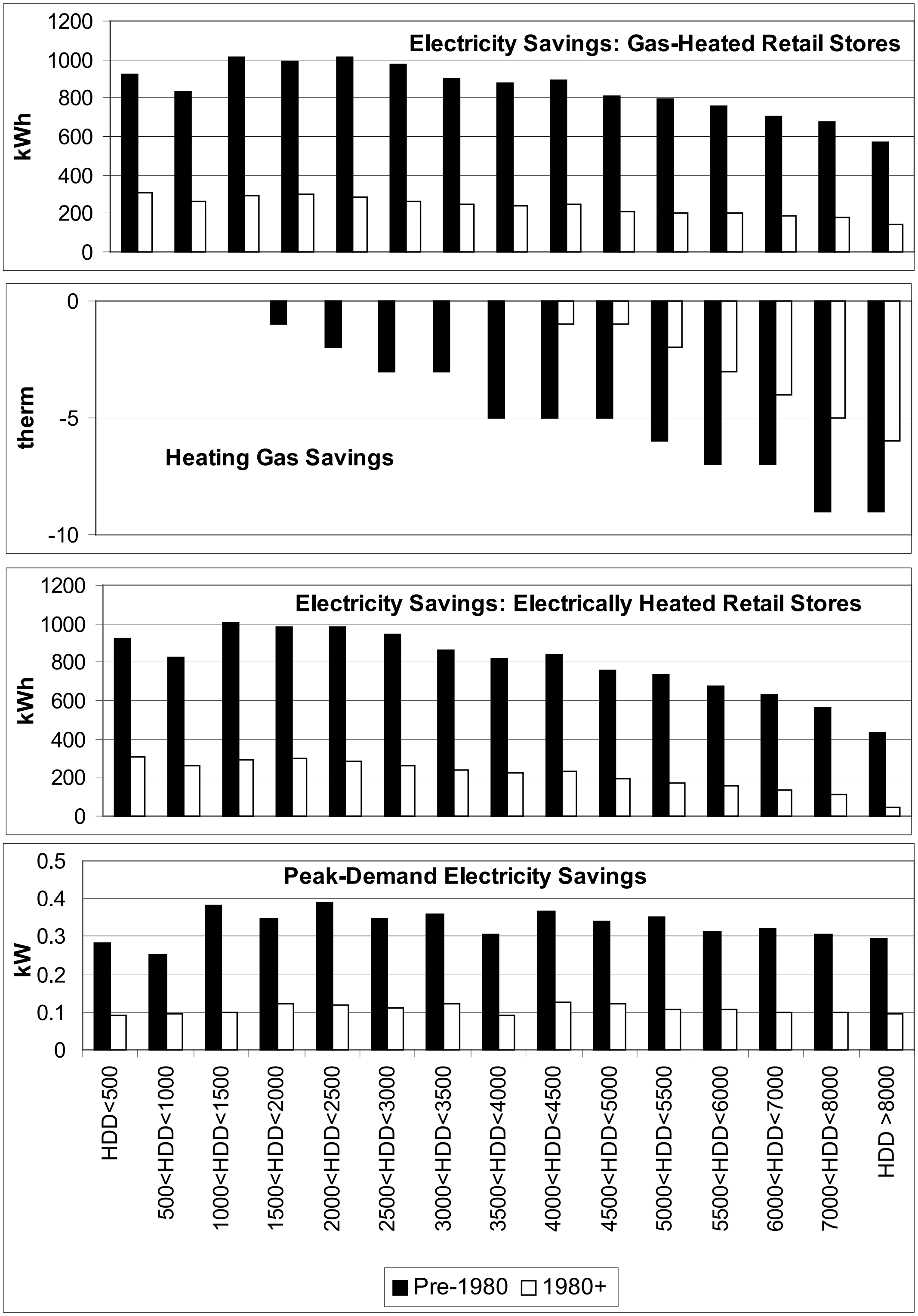

Figure 5a(ii). Retail Store Buildings. Effect of Cool Roofs, as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

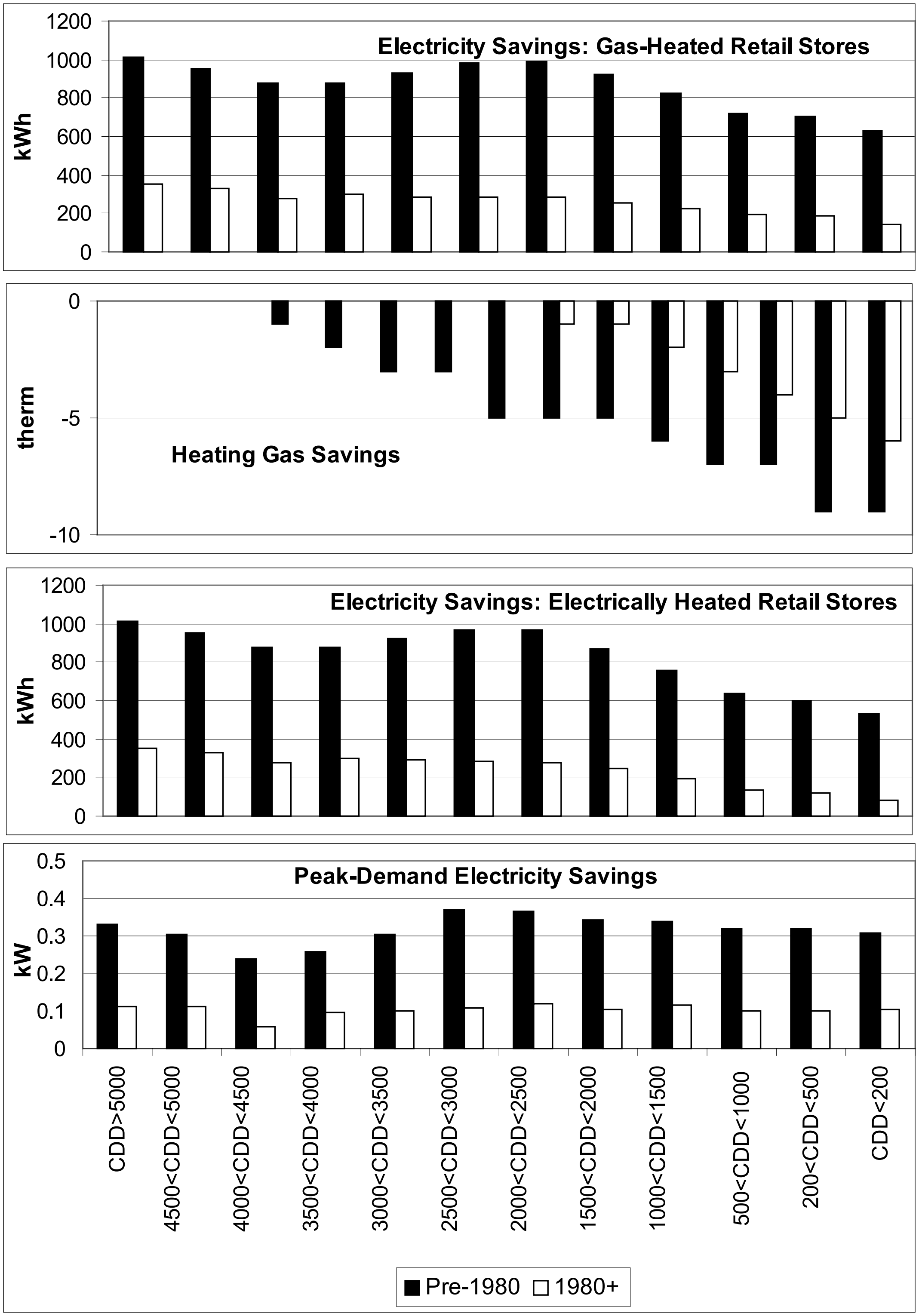

Figure 5b(ii). Retail Store Buildings. Savings from Cool Roofs as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

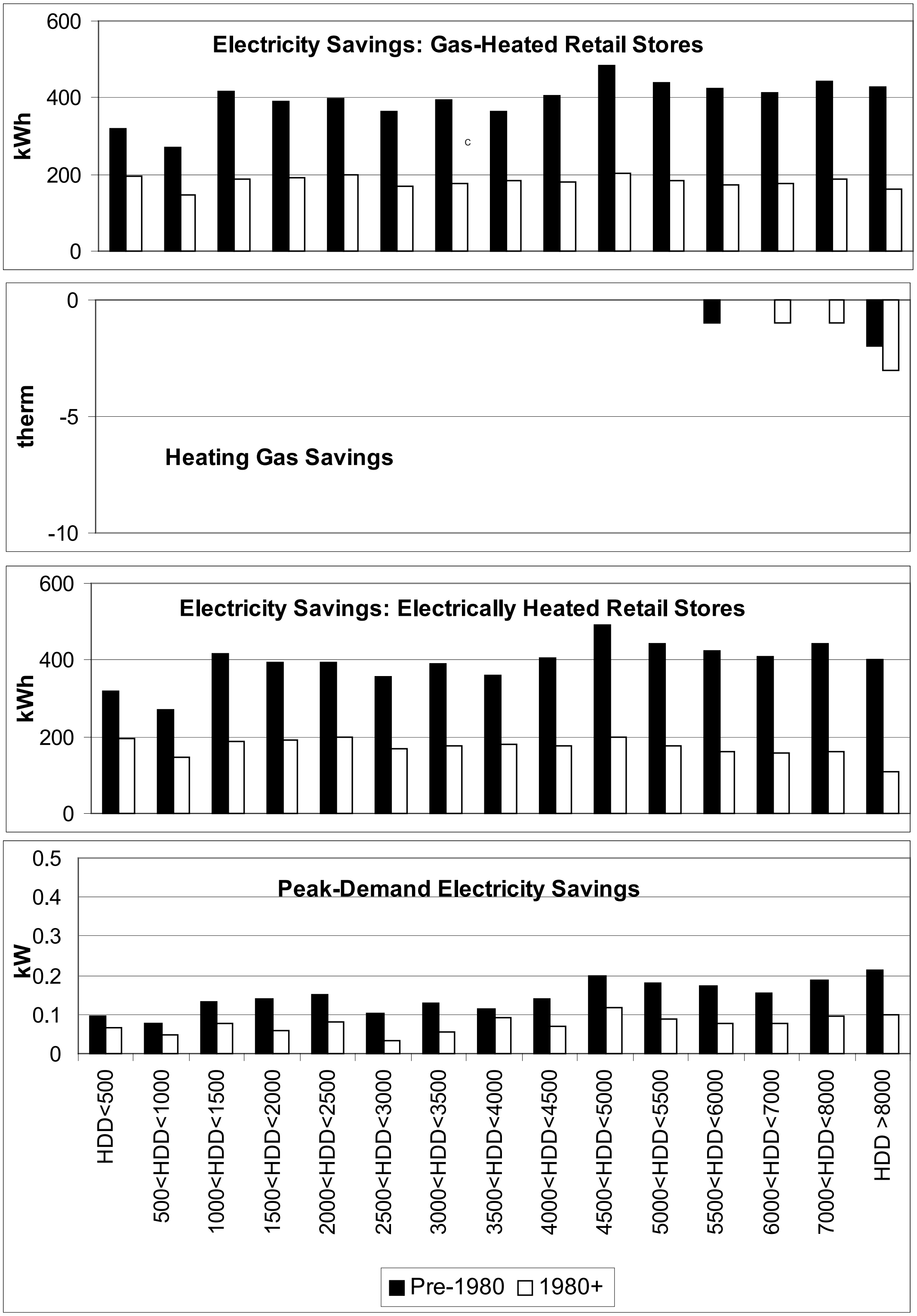

Figure 5a(iii). Retail Store Buildings. Savings from Shade Trees as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

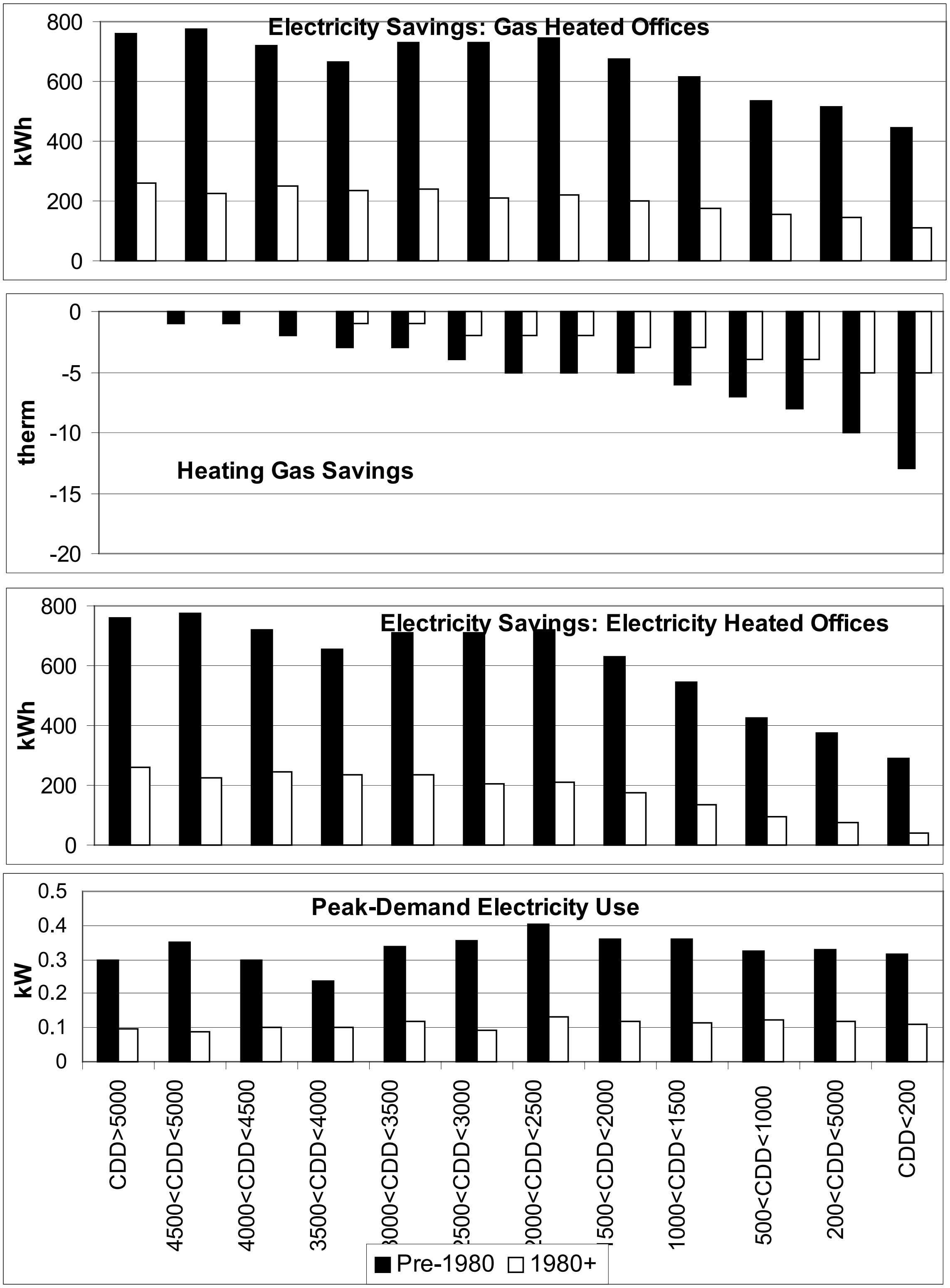

Figure 5b(iii). Retail Store Buildings. Savings from Shade Trees as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

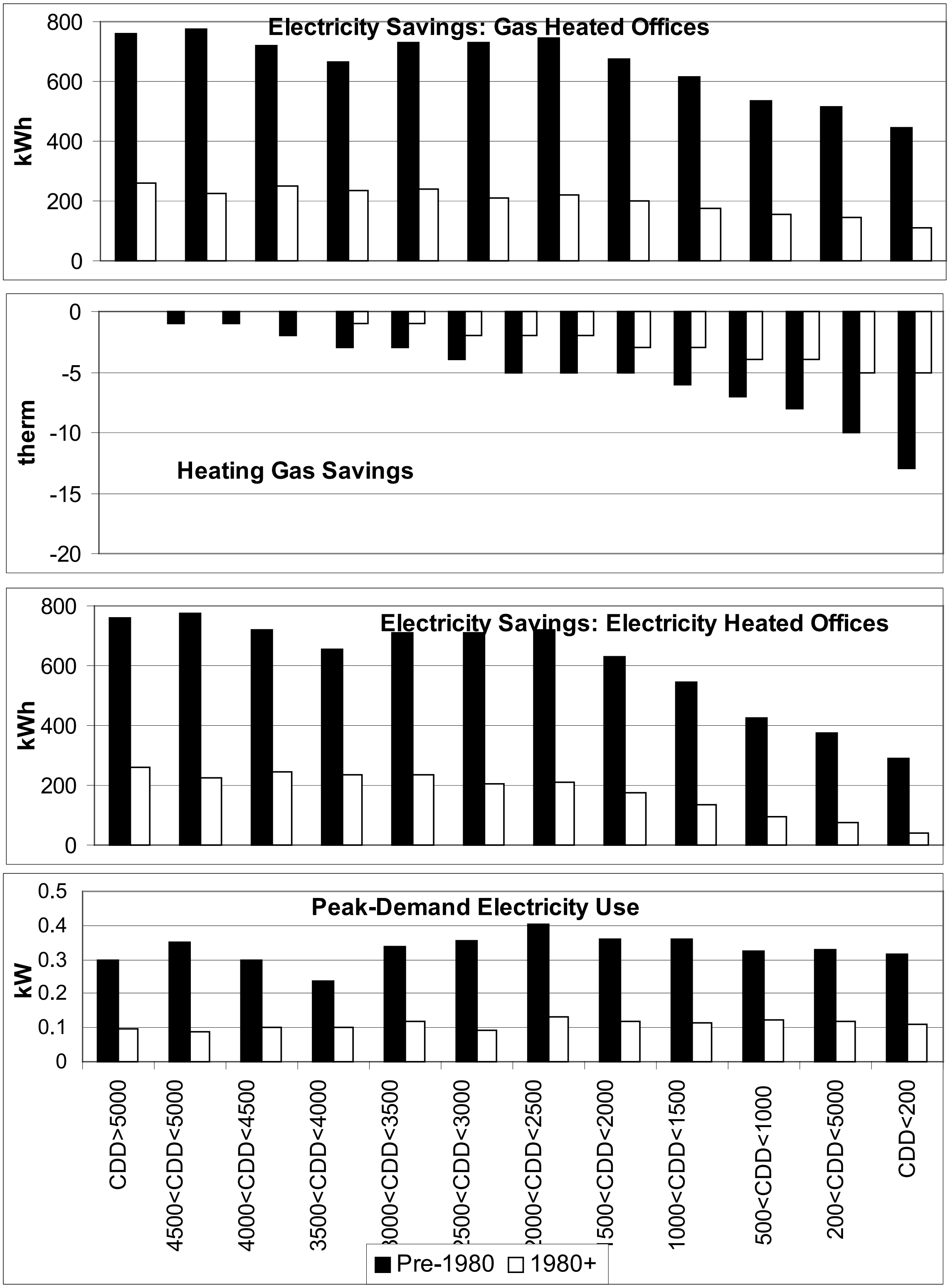

Figure 5a(iv). Retail Store Buildings. Indirect Savings as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

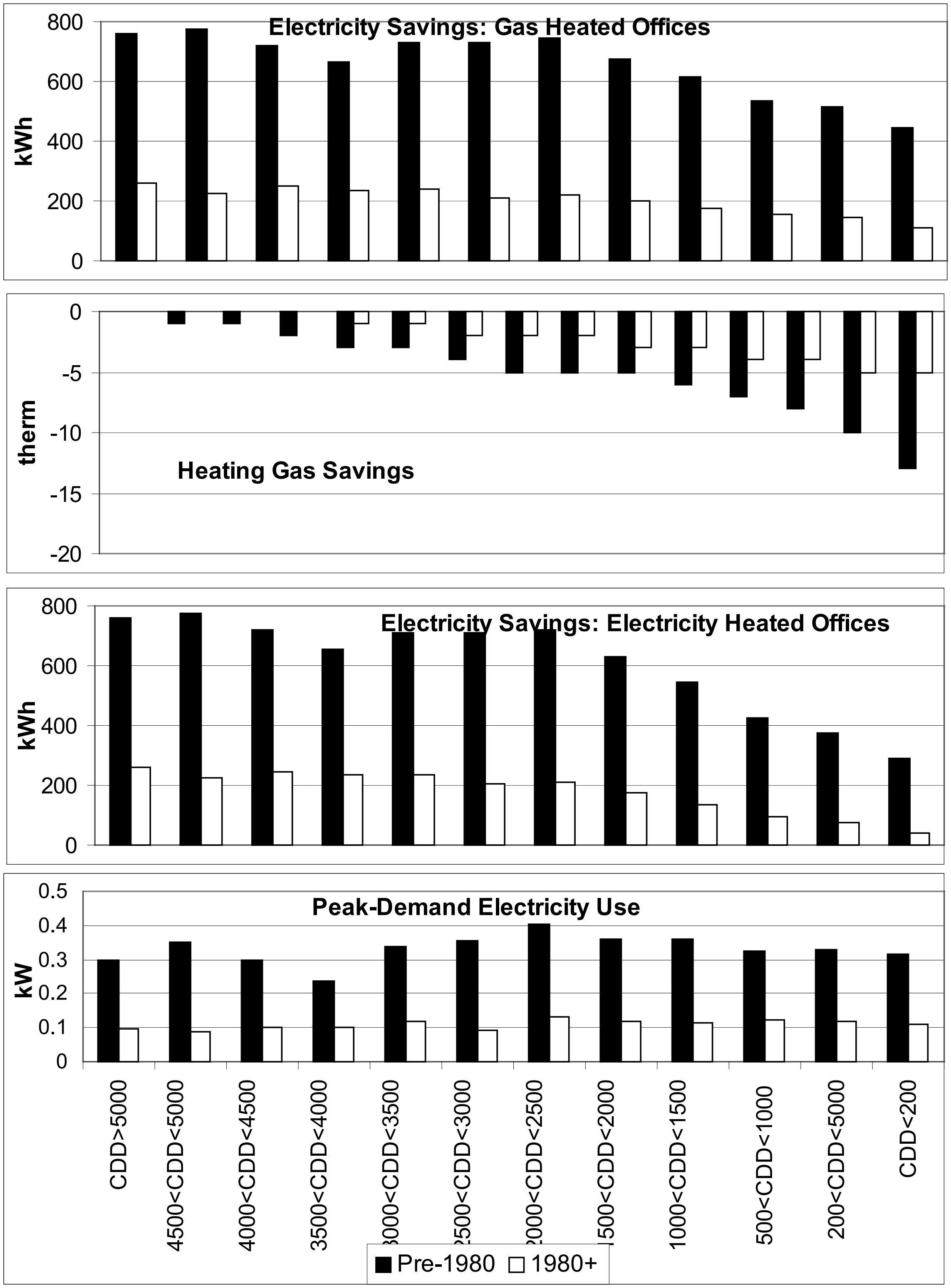

Figure 5b(iv). Retail Store Buildings. Indirect Savings as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

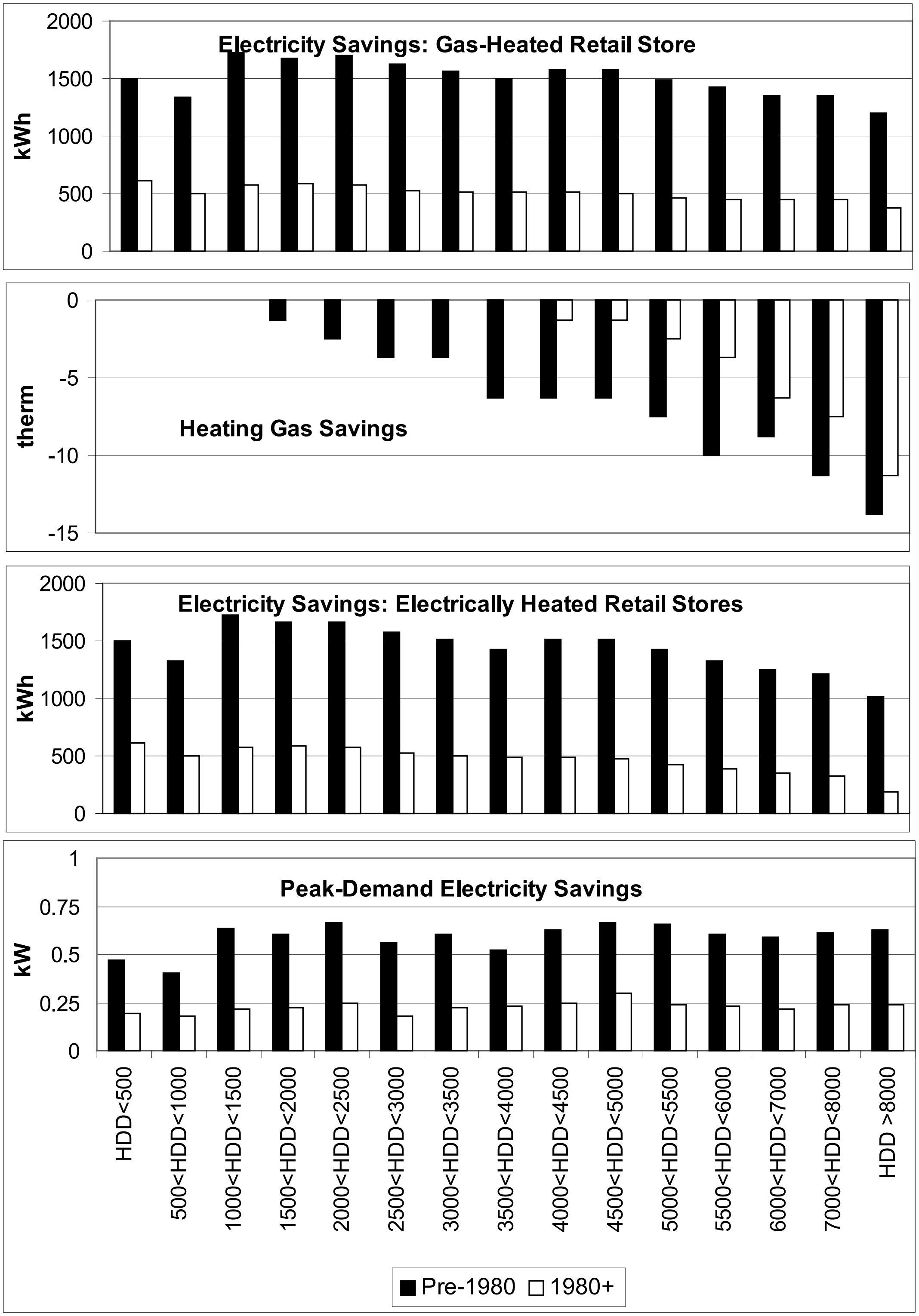

Figure 5a(v). Retail Store Buildings. Combined Direct and Indirect Savings as a function of heating-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.

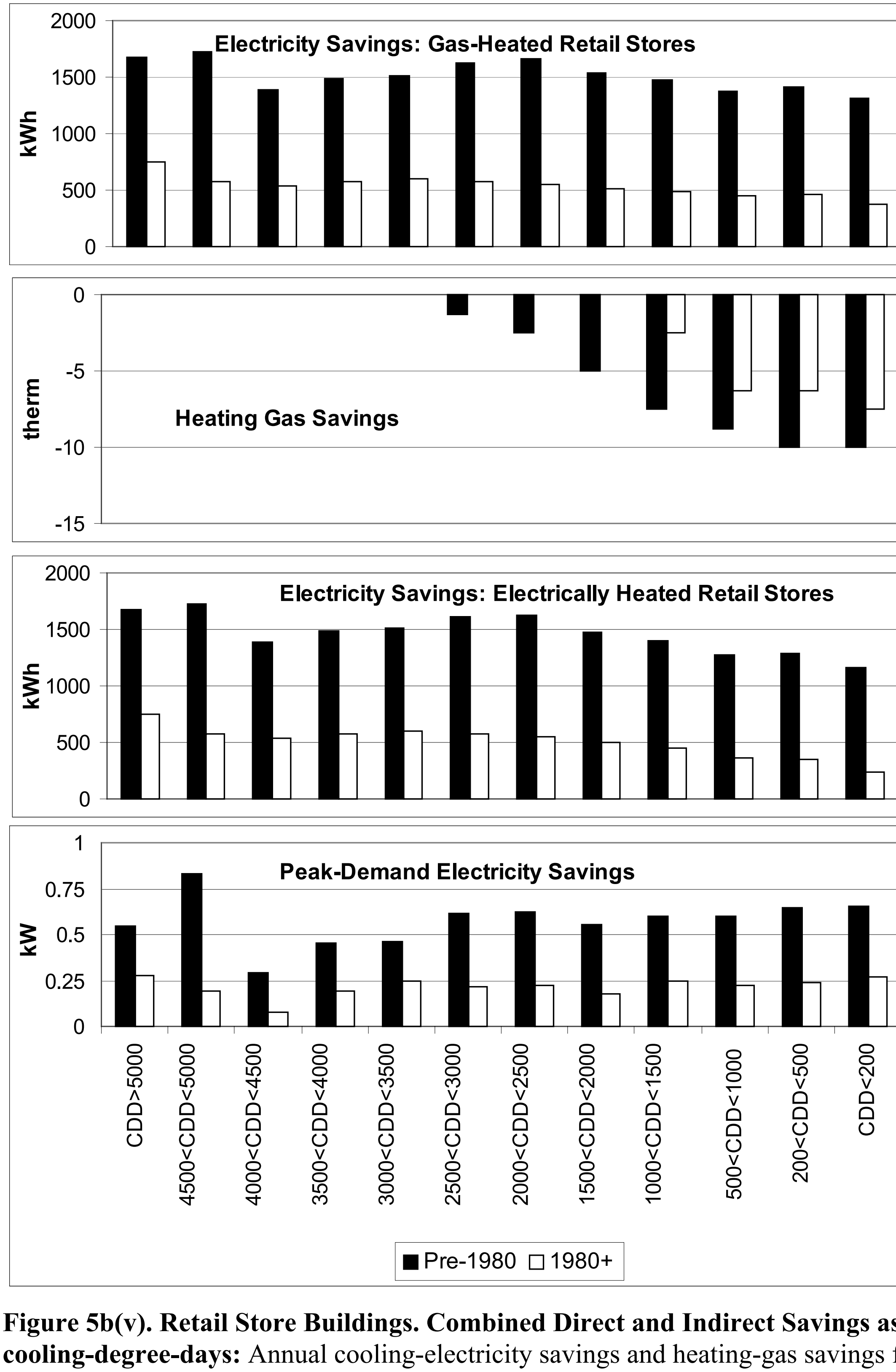

Figure 5b(v). Retail Store Buildings. Combined Direct and Indirect Savings as a function of cooling-degree-days: Annual cooling-electricity savings and heating-gas savings for gas-heated houses, combined heating- and cooling-electricity savings for electrically heated houses, and peak-electricity demand savings. All estimates are normalized per 1000 ft^2 of roof area.