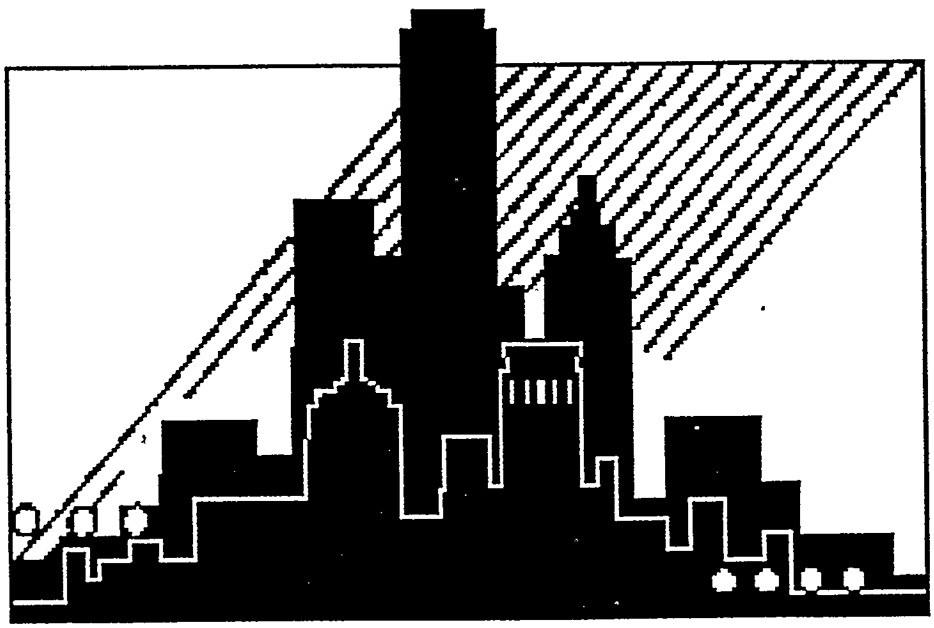
DOE/CE/21001--T1

The Multifamily Building Evaluation Project



A Report of the New York State Energy Office Bureau of Development, Reporting and Evaluation

With financial support from the U.S. Department of Energy

March 1995

Multifamily Building Evaluation Results

New York State Energy Office Bureau of Development, Reporting and Evaluation

Boiler and Burner Retrofits

- Reductions in weather-normalized mmBtu consumption from the pre period until spring 1994 ranged from approximately .42 to 55%. Average savings equalled 22.26%; median, 20%. MmBtu/HDD/square foot consumption scores during the post period varied from 15 to 38.

- Energy audits predicted fuel cost savings from 6-29%. Eight heating retrofits exceeded or approximated estimated savings. Six fell short. Overall, heating retrofits performed better than window projects.

- Quality of installations and maintenance varied over time. Inspectors discovered poorly set operational controls (e.g., pressure controls, heat timers), rusty boiler water, and a partially obstructed combustion chamber, incomplete combustion, dirty boiler firesides, excessive boiler sediment, high stack temperatures, excessive drafts, incorrect pressure settings, and steady state efficiency (SSE) ratings far below the boiler manufacturers' specifications (e.g., 74 instead of 82). Deficiencies rendered three "unacceptable." In general, well maintained buildings remained well maintained and poorly maintained buildings remained poorly maintained, with some exceptions.

- *Persistence:* Results showed no consistent persistence trends. Some buildings followed the expected pattern, a gradual decline in energy efficiency over time. But many buildings displayed erratic patterns. One building had excellent first year savings of 42% but the following year used 48% more energy than year one. In year three, the building consumed 15% less energy than in year two. Five buildings showed growing savings two years in a row but experienced modest declines in energy efficiency in the third year. Two buildings showed increased savings in all three winters.

THE MULTIFAMILY BUILDING EVALUATION PROJECT:
Do the Savings Persist ?

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Overview

In 1991 the New York State Energy Office embarked on a comprehensive multi-year study of multifamily housing in New York City. The principal objective of the evaluation was to determine the degree to which new windows and boiler/ burner retrofits installed in 22 multifamily buildings located in the New York City region save energy and whether the savings persist over a minimum of two years. Window and boiler retrofits were selected because they are popular measures and are frequently implemented with assistance from government and utility energy programs.

Approached prospectively, energy consumption monitoring and a series of on-site inspections helped explain why energy savings exceeded or fell short of expectations. In 1993, the scope of the evaluation expanded to include the monitoring of domestic hot water (DHW) consumption in order to better understand the sizing of combined heating/DHW boilers and water consumption patterns.

The evaluation was one of ten proposals selected from over 100 candidates in a nationwide competition for a U.S. Department of Energy Building Efficiency Program Grant. The Energy Office managed the project, analyzed the data and prepared the reports, Lawrence Berkeley Laboratory served as technical advisor, and EME Group (New York City) installed meters and dataloggers, collected data, and inspected the retrofits. The New York State Energy Research and Development Authority colloraborated with the Energy Office on the DHW monitoring component.

Results did not always follow predictable patterns. Some buildings far exceeded energy saving estimates while others experienced an increase in consumption. Persistence patterns were mixed. Some buildings showed a steady decline in energy savings while others demonstrated a continual improvement. A clear advantage of the research design was a frequent ability to explain results.

Background

An estimated 16% of America's households live in 22 million multifamily housing units (*i.e.*, buildings with five or more units). Only single-family detached units constitute a larger percentage. In New York State, approximately 36% of the population reside in multifamily dwellings.

Despite the prominence of multifamily housing, this sector has, to a large extent, remained an untapped source of energy savings. The lack of action is attributable primarily to a combination of technical and institutional barriers.

Because owners and managers of multifamily buildings are rarely residents of the buildings, and because tenants are rarely responsible for the utility bills, there traditionally has been little motivation to install and maintain energy conservation measures. These behavioral factors make it difficult for engineering estimates of energy savings to accurately predict performance of specific measures under real life conditions.

An additional hindrance is the lack of reliable quantitative data about the impacts of multifamily energy water meters to measure DHW consumption. These meters were also read through the dataloggers.

A major objective of the study was to monitor the performance of the measures from approximately the time of installation to at least 20 months later. Several buildings were monitored for as long as 40 months. The use of data collected through the dataloggers decreased data problems such as estimated gas meter readings and oil consumption determined from periodic oil deliveries. When sufficient billing data was available, energy estimates from the billing data were compared with estimates from the end use meters. This allowed us to assess the viability of the lower cost billing data analysis and to double check the reliability of data being transmitted from the end use meters.

A simple regression model normalized for weather, dividing heating consumption by heating degree days for the relevant period. The study also examined energy savings as mmBtu/HDD/Square foot and tested the correlation of energy consumption to heating degree day through R-square and T-test analyses. This helped to flag possible data errors. Since the primary mission was to compare energy performance in the same building over similar timeframes, the regression model proved adequate. Experiments with PRISM generally failed to generate consistently reliable results, especially when examining energy consumption during a limited timeframe (e.g., four months of the heating season). Most savings comparisons used comparable four-month periods from the first three post-retrofit years. Persistence analysis included fourth-year data.

Regular surveys of building owners and managers revealed changes in building operation, occupancy and the installation of measures that would impact energy consumption. In general, the buildings were remarkably stable and fully occupied all the time. A few buildings reported some relatively minor changes such as the installation of a few additional radiators and new vestibule doors. Minimal building changes made adjustments to energy consumption analyses unnecessary. The only exception was a window building that installed a new boiler. The discussion of window test results addresses this addition.

An important element of this study was the series of on-site inspections of each building measure. For boiler/burner retrofits, a total of four visits were conducted. All visits included a steady-state efficiency test and an examination of the boiler insulation jacket, boiler and burner control settings, combustion air area, condensation leaks, boiler log, accessory equipment (*e.g.*, economizer, flu damper) and boiler room piping. The fourth visit also included an inspection of boiler fireside and waterside surfaces for soot accumulation (if assessable), analysis of boiler blow-down water, measurement of boiler water pH level, and inspections of the heating pipe distribution systems, including an inspection for leaks in buried condensate or hot water pipes using an infrared camera. The visits began soon after boiler installation and concluded in early 1995.

Like the boiler installations, window installations were subject to testing for product and installation quality. The windows most commonly installed in the building sample are vinyl-clad or aluminum double-hung thermal panes. Windows were tested soon after installation and again in early 1995. The objective of the tests was to inspect at least eight windows per building on different floors and sides of the buildings. The windows were tested to compare results with the manufacturer's infiltration specifications, and glazing, caulking, weatherstripping, balances, jambs and locks were inspected for evidence of wear, breakage or gaps. Also in early 1995, the window building sample was subject to a boiler inspection identical to the fourth visit provided to the boiler sample.

To check the accuracy of energy audit projections of energy savings, savings were calculated by comparing the pre- and post- installation energy consumption data. The pre-consumption was estimated either from audit

The building owners invested $13,000 to $72,000 in their heating system improvements. Most of the original boilers had steady state efficiency ratings of about .60 while a few were in the low seventies. Most new boilers were expected to have a steady state rating of approximately .82.

The boiler sample as a group showed diversity in building energy efficiency. MmBtu/HDD/square foot consumption scores during the post period varied from a low of about 15 to a high of 38.

All 14 boiler/burner buildings received four site inspection visits. The significant finding of the inspections was the variable quality of the installations and maintenance over time. While rating most of the installations "acceptable", inspectors uncovered a range of problems, including poorly set operational controls (e.g., pressure controls, heat timers), rusty boiler water, and a partially obstructed combustion chamber. Three boilers suffered from deficiencies that caused the installations to be described as "unacceptable."

In one 16-unit building, the newly installed heating system produced carbon monoxide levels considered dangerous to the building residents. In addition, the boiler pressure controls were incorrectly set, causing the equipment to cycle every few minutes during the heating season (every 30-40 minutes would be normal). During one month the boiler turned on and off 4000 times, or an average 135 times each day! (Excessive cycling not only wastes energy but places severe strain on burner relays and other system components.) The boiler room was also unusually hot (over 120 degrees). In fact, the relay on the datalogger burned out! This building showed a 13% increase in energy consumption during the first year but when the operational problems were resolved, the building experienced a weather adjusted drop in energy consumption from the first post reporting period of about 35% the following winter.

A common reason why energy retrofits in multifamily structures often disappoint expectations is the incorrect setting of heat timers, which are typical in New York City multifamily buildings. Heat timer equipment is tailored to the New York City Multiple Dwelling Law requirement that landlords maintain an indoor temperature during the day of 68° F when the outside temperature drops below 55° F and an indoor temperature of 55° F when the outside temperature drops below 40° F at night. These devices utilize an outdoor temperature sensor to turn the boiler on. The heat timer runs the boiler until it obtains indirect confirmation that steam has reached every radiator in the building. After any energy-related retrofit, the heat timer should be readjusted to realize maximum energy savings. About half of the heat timers in the sample were originally improperly set.

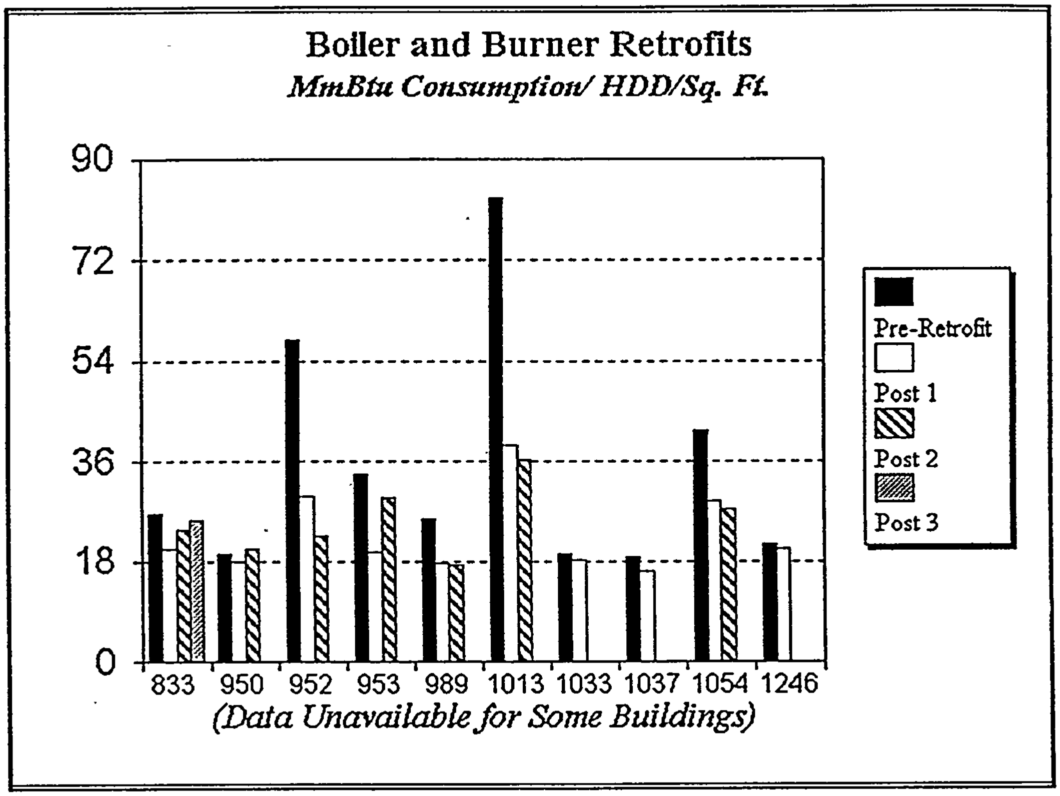
Third and fourth boiler inspections found maintenance varied. Most buildings had acceptable maintenance practices but suffered from some deficiencies, usually relatively minor ones. Four buildings suffered from more serious maintenance related problems, including incomplete combustion, dirty boiler fireside, incomplete combustion, excessive boiler sediment, high stack temperature, excessive draft, incorrect pressure settings, and a steady state efficiency (SSE) rating far below the boiler manufacturer's specifications (e.g., 74 instead of 82).

In general, well maintained buildings remained well maintained; poorly maintained buildings tended to remain poorly maintained. There were some exceptions. One building that received high marks in the first inspection was discovered about 9 months later with a partially blocked air louver and incorrect heat timer settings. The SSE dropped into the seventies but by the last inspection in 1995 the boiler efficiency was nearly 85, exceeding the manufacture's specifications. Another building followed the opposite pattern, starting out meeting manufacturer's specifications with an SSE of over 82 but dropping to 74 in early 1995.

degradation." A survey of the tenants of two buildings receiving new windows suggested general satisfaction with the new windows. Most respondents claimed that the new windows were not drafty and operated smoothly.

Overall, most windows showed some deterioration in their infiltration scores but a few windows actually achieved slightly better results. Engineering models suggested that infiltration reductions will contribute 60-67% of the savings attributable to windows meeting the .37 standard. The remaining savings are attributable to reduced conduction. According to the model, air infiltration in the range typical of non-complying windows could reduce expected energy savings by 8-40%.

The building reporting a 20% increase in energy consumption had a poorly operating boiler which was replaced in the summer of 1994. In addition, the building manager reported that in February 1994 he raised the temperature to about 80 degrees to keep one half of the apartment warm. Tenants in the other half of the building were opening windows in the winter because it was too hot! (Nearly 75% of the respondents surveyed complained about their apartments being too hot or too cold.)



Analyses of the boilers in these buildings found SSE of 80 or higher in all but one exception (.78). Despite these positive results, inspectors found three boilers in "poor operating condition", one fair, and the remaining four in good condition. These factors may have negatively impacted the window energy savings results.

Comments on the Testing Procedures

One possible reason for the variance in performance is differences in window size and location. For example, a bathroom window may be considerably smaller than a living room window. The locations of the windows in the building could also impact results because of differing architectural characteristics, even in the same building. The wall and window frame connections can vary from apartment to apartment and room to room.

Persistence of Energy Savings

A key element of the evaluation was to determine persistence of energy savings associated with the boiler and window retrofits. A major finding was that there was no consistency to persistence trends. Some buildings followed the expected pattern, a gradual decline in energy efficiency over time. But many buildings displayed erratic patterns. One building had excellent first year savings of 42% but the following year used 48% more energy than year one. In year three, the building consumed 15% less energy than in year two. Five buildings showed growing savings two years in a row but experienced modest declines in energy efficiency in the third year. Two buildings showed increased savings in all three winters.

Considering persistence in a broader perspective, if poor persistence resulted from improper maintenance, this problem would have likely impacted the original equipment and energy consumption might have also suffered.

Domestic Hot Water: Consumption and Efficiency

The ERDA data was originally expected to be available in January, 1995. Since the report is now not expected to be available until April 1995, we have requested that ERDA forward the report directly to DOE. An examination of Energy Office data based on a smaller sample and less extensive analysis shows:

> There are wide variances in consumption and energy used to heat the water. One building with a new gas tankless coil boiler produces 173 gallons of hot water per ccf of natural gas while another new boiler produces about 66 gallons of hot water per ccf. Average monthly DHW consumption per apartment varied in test buildings from a low of 944 gallons to a high of 8,265. It is also not unusual to see variations of 10-20% in monthly DHW consumption in the same buildings.

Conclusions

This study proves that the installation of replacement windows and boilers in multifamily buildings can result in significant energy savings (20% or more), especially if the measures are properly installed and maintained. In some cases buildings were able to achieve savings that exceeded audit estimates. Three buildings posted savings in excess of 50%! On the other hand, poorly installed and maintained equipment resulted in negligible energy savings and in one case an increase in consumption. For a variety of reasons, some investments fell far short of potential. Commissioning of the measures may prove a valuable technique.

From an evaluation perspective, persistence may be more difficult to measure than originally thought. Installations do not necessarily start at peak efficiency and then experience a gradual decline. The sample buildings showed a wide variety of patterns, suggesting that the timing of the measurement could prove critical. For example, one building experienced a 12% gain in energy use the first year and a 35% reduction the next. The next two winters, the building experienced a 6% reduction in energy consumption from year two. In year four the building consumed 15% more energy than in year three.

The project also demonstrated that interest in multifamily evaluation is stronger than originally

Acknowledgements

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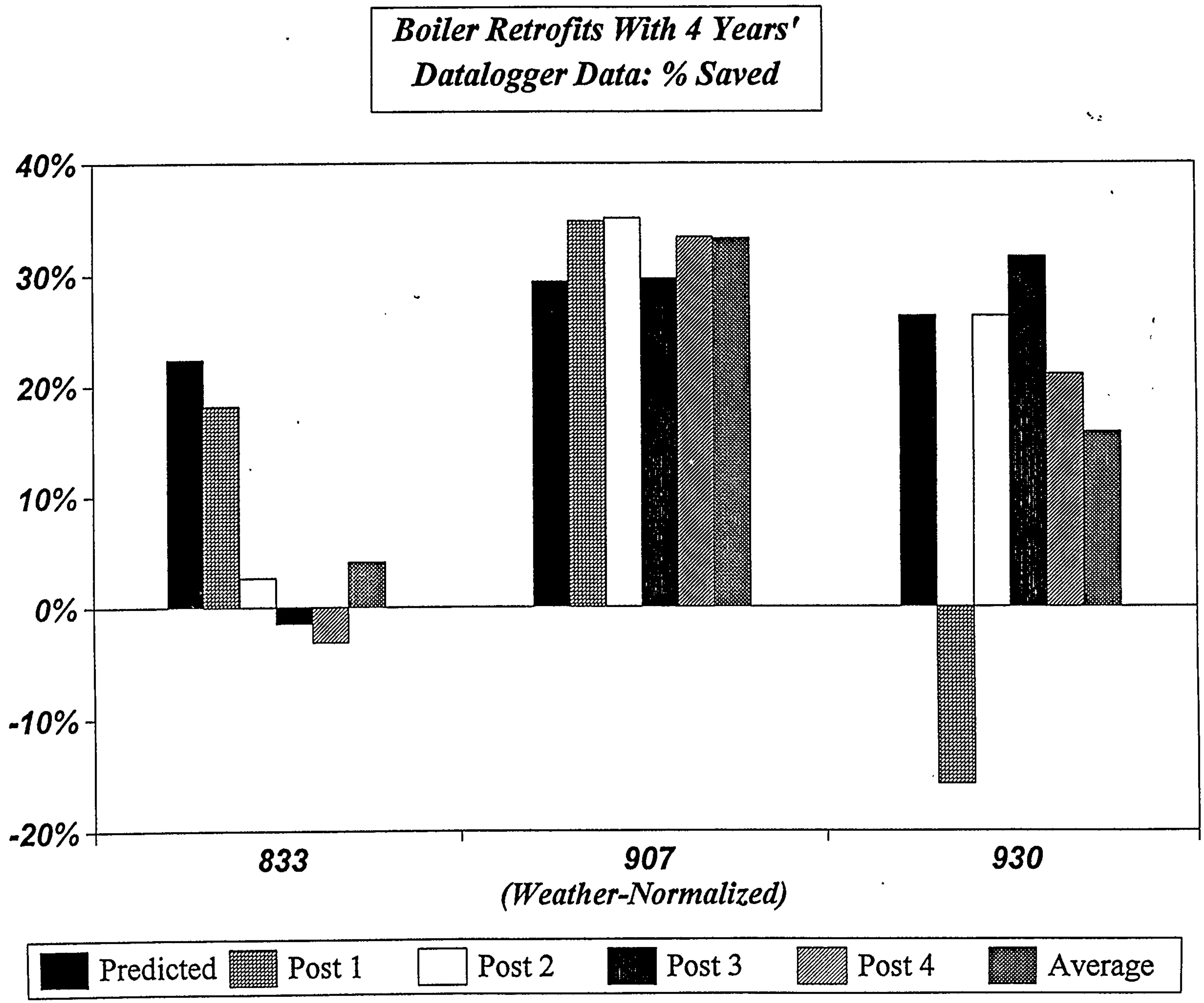
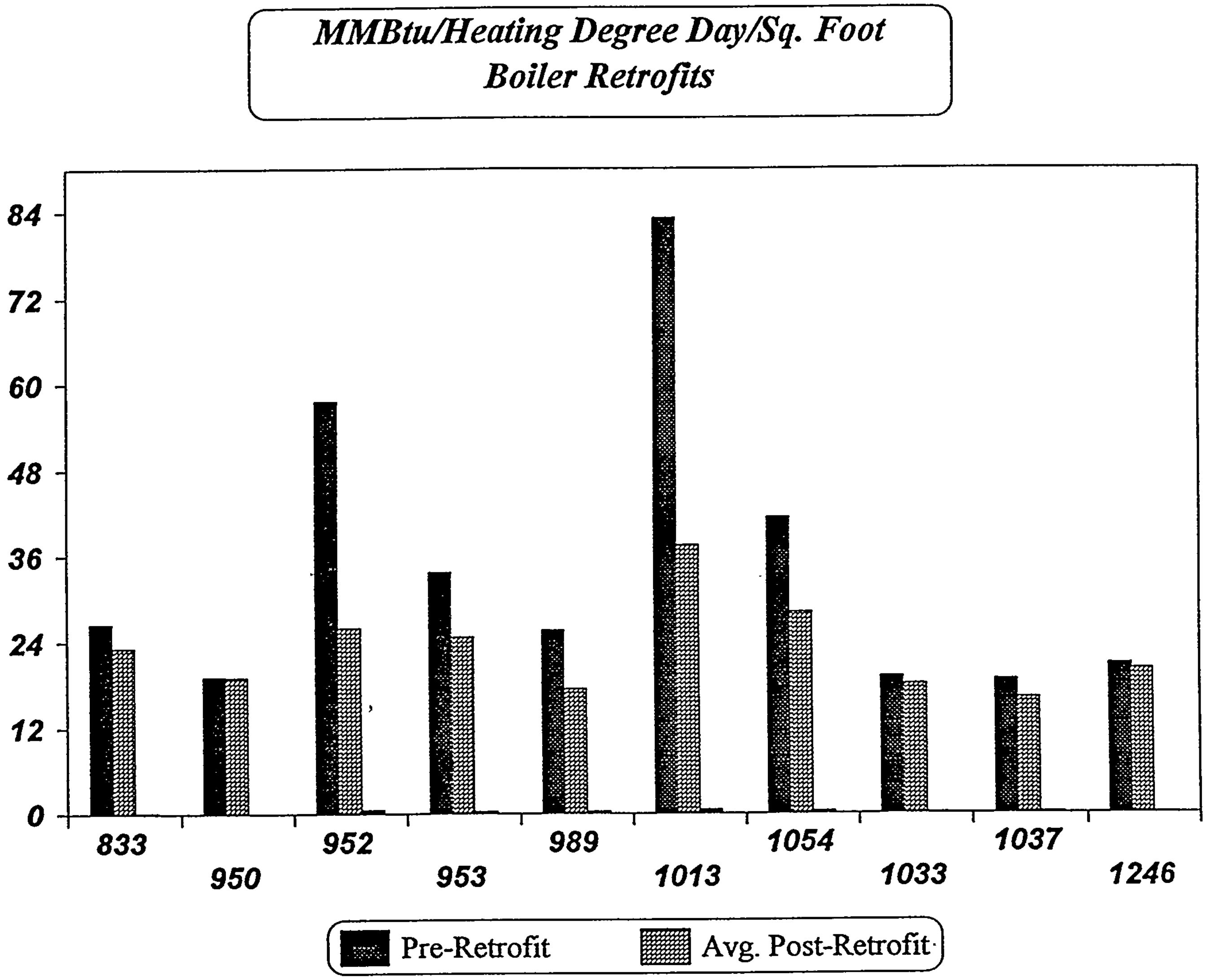
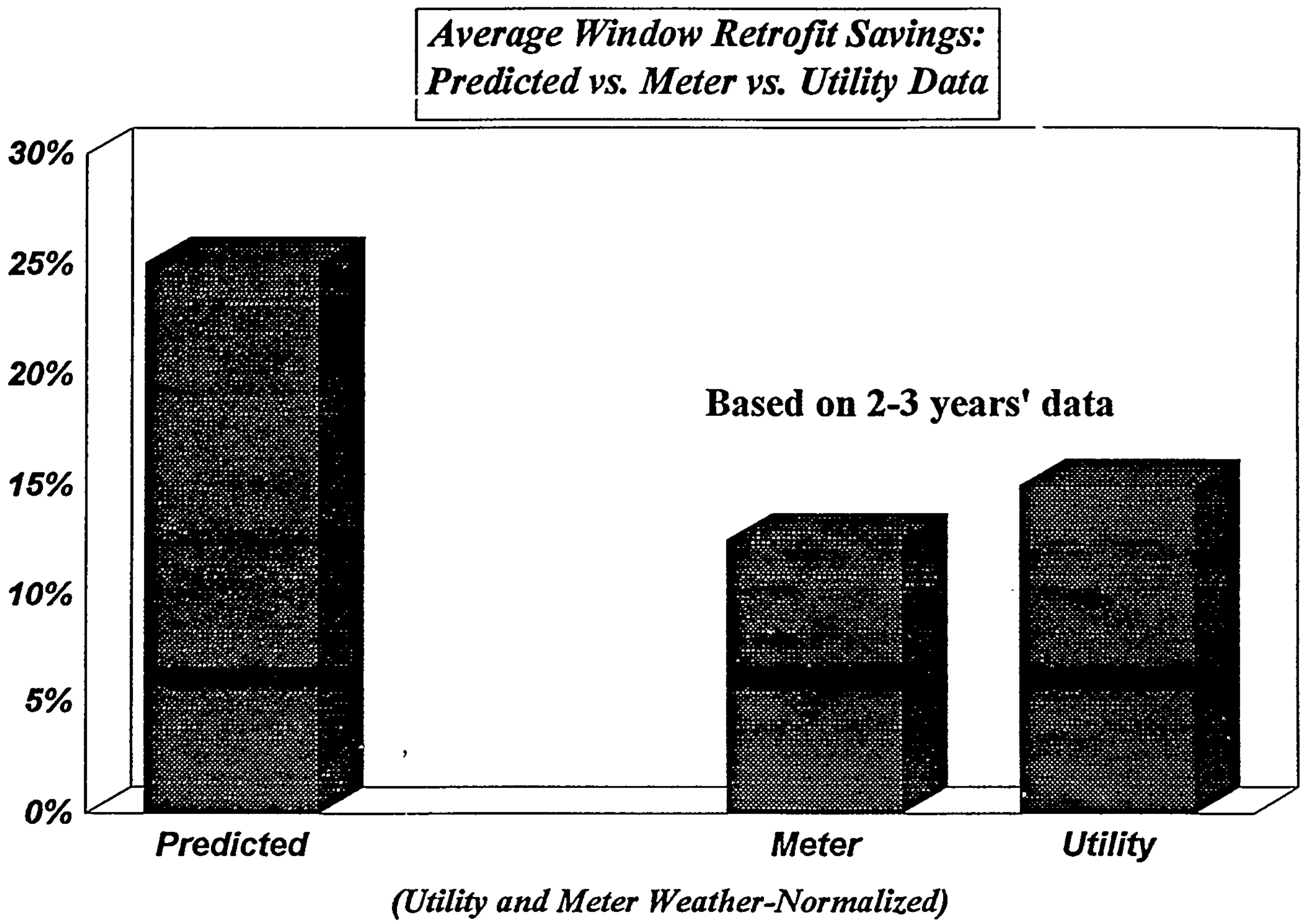

Boiler Retrofits With 4 Years' Datalogger Data: % Saved
40%
30%
20%
10%
0%
-10%
-20%
833
907
930
(Weather-Normalized)
Predicted
Post 1
Post 2
Post 3
Post 4
Average



MMBtu/Heating Degree Day/Sq. Foot
Boiler Retrofits
84
72
60
48
36
24
12
0
833
950
952
953
989
1013
1054
1033
1037
1246
Pre-Retrofit
Avg. Post-Retrofit


Average Window Retrofit Savings:
Predicted vs. Meter vs. Utility Data
30%
25%
20%
15%
10%
5%
0%
Based on 2-3 years' data
Predicted
Meter
Utility
(Utility and Meter Weather-Normalized)