INFLUENCES OF ENERGY CONSERVATION IN THREE MULTI-FAMILY BUILDINGS IN THE PACIFIC NORTHWEST

Diana L. Ivey and Ela Esterberg
Seattle City Light
Marc Schuldt and Laura Wrench
United Industries Corporation

ABSTRACT

In 1983 Seattle City Light began the Multi-Family Hourly End Use Study (MHEUS) to study the energy consumption characteristics of multi-family buildings in its service area. The purpose of the study was to collect data on energy use and conservation potential in multi-family buildings to support conservation program planning and load forecasting activities within the utility. Microprocessor based data acquisition systems were used to continuously record hourly measurements of important consumption variables for each of the 38 individually metered, all-electric housing units in three multi-family buildings. These variables included total electric consumption, domestic hot water consumption, other (lights and appliances) consumption and interior air temperature.

In addition to the monitoring effort, an energy conservation analysis was performed on the three multi-family buildings. The energy conservation analysis consisted of a thorough audit of each building to collect baseline characteristics data and to identify a series of practical energy conservation measures. Baseline end use energy consumption for each building was estimated using the DOE-2.1 simulation model and calibrated to electric utility billing records. The simulation model was then used in conjunction with the City Light Life Cycle Cost program to determine an optimized set of cost-effective conservation measures applicable to each building.

Based on the results of the conservation analysis, Seattle City Light installed a series of conservation measures in each building. Hourly electric end use load and interior temperature data were collected for one year prior to and after the installation of the measures to provide the data necessary to evaluate the energy savings actually realized from the retrofits.

Two distinct approaches were used to evaluate energy savings. An empirically-based approach used regression analysis to estimate weather adjusted actual energy savings directly from the hourly data set. This approach resulted in a reduction of total housing unit consumption between the pre and post-retrofit periods that ranged from 4 percent to 13 percent among the three buildings. A simulation-based approach was also used to estimate actual energy savings with the DOE-2.1 model. This approach resulted in a reduction of total housing unit consumption between the pre and post-retrofit periods that ranged from 7 percent to 17 percent among the three buildings.

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INTRODUCTION

In 1983 Seattle City Light began the Multi-Family Hourly End Use Study (MHEUS) to study the energy consumption characteristics of multi-family buildings in its service area. The purpose of the study was to collect data on energy use and conservation potential in multi-family buildings to support conservation program planning and load forecasting activities within the utility. Microprocessor based data acquisition systems were used to continuously record hourly measurements of important consumption variables for each of the 38 individually metered, all-electric housing units in three multi-family buildings. These variables included total electric consumption, domestic hot water consumption, other (lights and appliances) consumption and interior air temperature.

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MHEUS PRE-RETROFIT BUILDING DESCRIPTIONS

Buildings 23 and 24 are mirror image, motel style, apartment buildings that face a central courtyard. Both buildings are of the same size and geometry, with 13 housing units and a common area. They are both built into a hillside with three full floors of housing units and a partial fourth floor on the downhill slope. Buildings 23 and 24 each have 8562 square feet of housing units (659 square feet per unit, average) and 469 square feet of common area for a gross floor area of 9031 square feet.

Building 22 consists of two detached, motel style, buildings that are connected by a breezeway. A total of twelve housing units are contained in the two buildings. The larger building contains 8 housing units on two floors. The smaller building contains 4 housing units on two floors and a partial third (underground) floor for the laundry/storage room. Building 22 has 8008 square feet of housing units (667 square feet per unit, average) and 564 feet of common area for a gross floor area of 8572 square feet.

TENANT TURNOVER AND VACANCY RATES

An inherent problem when studying multi-family buildings is tenant turnover and vacancy periods. Unfortunately, tenant turnover in this study was quite high. Over 80 percent of the units in each building changed occupants during the study period. Vacancy rate was defined as the number of housing unit-days with no occupants. Building 22 had the highest vacancy rates at 8.1 percent of the pre-retrofit period and 12.1 percent of the post-retrofit period. Buildings 23 and 24 had lower pre-retrofit vacancy rates at 2.2 and 1.7 percent, respectively. For both buildings the vacancy rate increased during the post-retrofit period to 4.9 and 4.3 percent, respectively.

INSTALLATION OF ENERGY CONSERVATION MEASURES

Measures actually installed and the frequency of installation in the buildings varied from the recommendations of the conservation analysis due to discrepancies between the audits and existing conditions, structural limitations, owners' resistance to particular measures, and the installation of measures not considered in the conservation analysis. The actual measures installed in the buildings are summarized in Table I.

Table I. Energy conservation measures installed in the MHEUS buildings.

Building	Measure	Quantity	Percent
Bldg. 22	R-30 batts under floor	3,485 sq.ft.	(80% 1st floor area) (40% of total floor area)
	Double-glazing conversion	966 sq.ft.	(14% of wall area)
	Efficient shower heads	12	(100%)
Bldg. 23	R-30 batts under floor	938 sq.ft.	(31% of floor area) (8% of total floor area)
	Low-e double glazing	1,321 sq.ft.	(17% of wall area)
	Insulated doors	13	(100%)
	Efficient shower heads	13	(100%)
Bldg. 24	R-30 batts under floor	938 sq.ft.	(31% of floor area) (8% of total floor area)
	Double-glazing conversion	1,321 sq.ft.	(17% of wall area)
	Efficient shower heads	13	(100%)

RESULTS OF EMPIRICAL-APPROACH

A simple subtraction of post-retrofit consumption from pre-retrofit consumption would not yield an accurate estimate of actual savings because of differences in weather conditions that occurred between these two periods. The difference in consumption would also not reflect the performance of the measures under long term weather conditions. Both the pre-retrofit and post-retrofit periods were warmer than the historical average.

Weather normalization of the space heat end use load data was performed separately for the pre-retrofit and post-retrofit periods in each building using regression analysis. Average daily energy consumption for space heating was regressed on actual ambient temperature data collected at the building sites. The resulting estimated coefficients (see Table II) were used in conjunction with 40-year normal Seattle temperature data to create weather-adjusted, daily space heating loads. The adjusted space heating load data was then added to the hot water and other (lights and appliances) data to derive total energy consumption data for the housing units. Since energy consumption in the common areas was not impacted by the retrofits, the analysis considered only housing unit energy consumption.

Table II. Regression results for MHEUS buildings.

Bldg. 22	Pre Heat = 3.1528 − 0.0489 (AOT) (.0566) (.0012)	Post Heat = 2.3839 − 0.0384 (AOT) (.0825) (.0017)
Bldg. 23	Pre Heat = 2.2819 − 0.0393 (AOT) (.0905) (.0021)	Post Heat = 1.7497 − 0.0288 (AOT) (.0803) (.0018)
Bldg. 24	Pre Heat = 1.9030 − 0.0339 (AOT) (.1026) (.0024)	Post Heat = 1.7713 − 0.0291 (AOT) (.1014) (.0023)

Note: Numbers in parentheses are standard errors.
AOT = Ambient outside air temperature

Weather adjusted estimates of pre-retrofit and post-retrofit energy consumption under long term weather conditions is provided in Table III. This table shows a significant reduction in annual space heat consumption for Buildings 22 and 23. However space heat consumption increased for Building 24. Changes in the hot water and other (lights and appliances) end uses are also noted, due to differences in tenant behavior. The potential impact of the efficient shower heads on annual hot water consumption was not considered in this analysis. The change in total annual housing unit consumption between the pre-retrofit and post-retrofit periods ranged from 4 to 13 percent among the three buildings.

Table III. Estimated actual energy savings - regression analysis.

	Average Pre-Retrofit Use per Unit (kwh)	Average Post-Retrofit Use per Unit (kwh)	Average Unit Savings (kwh)	Average Unit Savings (%)
Bldg. 22				
Space Heat	5,653	3,741	1,913	34
Hot Water	2,826	3,104	−278	−10
Other	2,937	3,110	−173	− 6
TOTAL	11,416	9,954	1,462	13
Bldg. 23				
Space Heat	2,792	2,538	253	9
Hot Water	3,182	2,654	528	17
Other	1,741	1,660	81	5
TOTAL	7,715	6,853	862	11
Bldg. 24				
Space Heat	2,025	2,582	−562	−28
Hot Water	3,425	2,839	586	17
Other	2,596	2,328	268	10
TOTAL	8,046	7,749	292	4

RESULTS OF SIMULATION APPROACH

Pre-retrofit and post-retrofit simulations were developed using audit data, on-site temperature (exterior and interior) data and hourly end use load data. Pre-retrofit and post-retrofit monthly consumption profiles were developed for the hot water and other (lights and appliances) end uses and integrated directly into the model. This reduced the role of the DOE-2.1 model to the simulation of only the space heating end use. Space heating thermostat setpoints were derived from the hourly interior air temperature measurements. The resulting monthly estimates of total housing unit consumption were then compared to total measured consumption. Adjustments were made to the simulation inputs not addressed by the end use load data until a reasonable match was achieved. The final pre-retrofit and post-retrofit consumption estimates were then resimulated under long term weather conditions.

Simulated pre-retrofit and post-retrofit annual space heat consumption is summarized in Table IV. A comparison of simulated space heat consumption in Table IV to empirically derived space heat consumption in Table III shows similar results for Buildings 22 and 23. A significant difference is noted for Building 24. The simulation approach predicted a 4 percent decrease in space heat consumption for the building compared to the 28 percent increase in consumption from the empirical approach. Further research is required to understand the reasons for this significant difference between the two approaches.

Table IV. Predicted space heat consumption-simulation approach.

	Average Pre-Retrofit Space Heat Use Per Unit (kwh)	Average Post-Retrofit Space Heat Use Per Unit (kwh)	Average Unit Space Heat Savings (kwh)	Average Unit Space Heat Savings (%)	Average Savings Total Unit Consumption (%)
Bldg. 22	5,929	3,964	1,965	33	17
Bldg. 23	2,961	2,754	207	7	12
Bldg. 24	2,949	2,832	117	4	7

Additional simulations were performed under long term weather conditions to assess the impact of tenant behavior. For this analysis it was assumed that tenant behavior was characterized by three consumption variables, including thermostat setpoint, hot water consumption and consumption for the other (lights and appliances) end use. The final pre-retrofit simulation was rerun with the installed space heating retrofits. The results of this simulation were subtracted from the final pre-retrofit simulation to produce an estimate of energy savings under pre-retrofit tenant behavior. The final post-retrofit simulation was also rerun with the installed space heating retrofits removed. The results of this simulation were subtracted from the final post-retrofit simulation to produce an estimate of energy savings under post-retrofit tenant behavior. These simulations produced a range of long term energy savings under constant pre-retrofit and post-retrofit tenant behavior.

This adjustment for tenant behavior resulted in no change in energy savings for Building 22. The energy savings remained at 17 percent of total housing unit consumption. However, estimated energy savings increased significantly for Buildings 23 and 24. For Building 23 the retrofits reduced total housing unit consumption by 15 to 17 percent for constant pre-retrofit and post-retrofit occupancy, respectively. For Building 24 total consumption was reduced by 12 to 15 percent for constant pre-retrofit and post-retrofit occupancy, respectively.

The simulation approach also estimated the energy savings associated with each of the space heating conservation measures within the retrofit package. The City Light Life Cycle Cost program was used to evaluate the cost-effectiveness of the individual measures. The floor insulation and double glazing measures were found to save less energy than anticipated in the initial conservation analysis but remained cost-effective. The insulated door measure was not cost-effective because the actual installed cost was significantly higher than anticipated. The cost-effectiveness of the efficient shower head measure will be evaluated as part of future research.

CONCLUSIONS

1. The empirical and simulation approaches provided similar estimates of space heat savings for Buildings 22 and 23. A significant difference in space heat savings was estimated for Building 24. A more detailed assessment of Building 24 will be performed as part of future research.

2. Tenant behavior had a significant influence on the energy savings realized in Buildings 23 and 24. Future research will focus more specifically on the influences of tenant behavior on energy savings in all three buildings. Analyses will be conducted on individual housing units to more accurately determine the impacts of change in consumption patterns for the hot water and "other" end uses, average indoor temperature, and other tenant characteristics.

SELECTED READINGS

Sumi, D.H. and Newcomb, T.M. "The Multi-Family R&D Project - Electricity Conservation Report". Seattle City Light, Seattle, WA. September, 1987.

Coates, B. "Cost-Effectiveness Evaluation for the Multi-Family Research and Development Project". Seattle City Light, Seattle, WA. September, 1987.

Esterberg, E. "End Use Loads in Multi-Family Buildings: Some Preliminary Findings". Seattle City Light, Seattle, WA. 1986 ACEEE Summer Study.

Schuldt, M. "Multi-Family Hourly End Use Study - Energy Conservation Analysis of Three Monitored Buildings". United Industries Corporation, Bellevue, WA. June, 1988.