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Multi-Family Metering Study

Engineering Estimates of Space Heat Consumption in Multi-Family Buildings

Final Report

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1. INTRODUCTION

Bonneville and Seattle City Light have sponsored three major end use load research studies in the Pacific Northwest that have successfully measured the hourly electric end use consumption patterns in a sample of commercial and residential buildings. The measurements were necessary to understand the consumption characteristics of buildings at the end use level and to quantify the impacts of conservation measures and other actions implemented in the sample buildings. The knowledge that is gained from the detailed analysis of the hourly data generated in these studies for a relatively small sample of buildings will provide input and direction to related research and provide guidance and insight to utility forecasting and planning activities that involve large samples of buildings.

The largest of these three efforts, the Bonneville sponsored End Use Load and Conservation Assessment Program (ELCAP), focused primarily on measurement of end use consumption in the single-family residential and commercial sectors. ELCAP did include a very limited sample (4 buildings) of new multi-family buildings that were built to the Model Conservation Standards (MCS). The Seattle City Light sponsored Commercial Hourly End Use Study (CHEUS) and Multi-Family Hourly End Use Study (MHEUS) focused on the commercial and multi-family sectors, respectively. The MHEUS project also was limited to a small (3 buildings) sample of existing buildings that were subjected to a pre/post retrofit analysis of implemented conservation measures. Although MHEUS and ELCAP included very limited samples of multi-family buildings, they both made a valuable contribution to the knowledge and understanding of consumption characteristics of this important building classification. A major contribution of these studies was the lessons that were learned regarding a range of topics including data requirements, data collection methodology, and data analysis techniques. These experiences will provide guidance to future end use load research in the region.

A historical problem with metering studies throughout the nation is that the planning for the studies is focused primarily on hardware specification and data collection. Little emphasis is placed on the specific analysis that is to be conducted on the data set. This often leads to either the collection of unnecessary data or the collection of a data set that is missing data elements that are critical to the eventual data analysis. The misspecification of data elements to be collected has proved to be a very inefficient use of resources due to the high cost of both initial data collection and the data analysis necessary to compensate for the collection of inappropriate information.

This study was specifically established to address the issue of data analysis. The primary purpose of the study was to conduct a hypothetical or "dry run" engineering analysis of the actual energy savings that would be achieved from the implementation of the Model Conservation Standards (MCS) in new multi-family buildings. This analysis provided an opportunity to determine the logical sequence of tasks that must be performed in an actual assessment of the MCS and to identify problem areas prior to data collection. In addition the analysis addressed the range of data requirements that are necessary to support the estimation of actual energy savings and specifically identified the minimum data requirements that would be necessary to calibrate a model of space heat consumption to within ten percent of measured space heat consumption on a monthly basis. A sensitivity analysis was also performed to assess the impact of the level of data collection of certain key data elements on the accuracy of the energy savings estimates.

The "dry run" analysis was performed as a specific application of a general Analysis Plan, that was also developed as part of this study. The Analysis Plan drew heavily upon the experience of MHEUS and ELCAP to develop a set of generic procedures that can be used to guide future end use load research in the multi-family sector. In an effort to provide a sense of realism to the "dry run" analysis, actual characteristics and load data from previous studies were used whenever possible. The intent of the analysis was not to project actual values for energy savings from the MCS; but rather to provide Bonneville with information necessary to make informed decisions regarding the appropriate level of data collection and data analysis that will occur in an actual study of the MCS.

This report documents the procedures used and results obtained from the "dry run" analysis. Section 2 describes the procedures used to conduct the "dry run" analysis. These procedures represent a specific application of the general Analysis Plan, presented in Appendix A. The results of the analysis are discussed in Section 3.

2. ANALYSIS PROCEDURES

A hypothetical or "dry run" analysis was conducted to assess the impacts of the Model Conservation Standards (MCS) on electric space heat consumption in new multi-family buildings. The "dry run" analysis establishes a reasonable and logical sequence of tasks that must be completed to evaluate energy savings from the MCS in new buildings. The analysis procedures were derived from the general Analysis Plan that is documented in Appendix A.

An integral part of the "dry run" analysis procedures is the specification of the minimum data requirements necessary to support a computer simulation of monthly space heat consumption that is within ten percent of measured space heat consumption. A sensitivity analysis was also conducted to assess the relative impact of certain data elements on the accuracy of energy savings estimates. To provide some realism to the "dry run" analysis, it utilized characteristics and load data that were measured as part of MHEUS and ELCAP. The use of actual data increased confidence that estimates of energy savings generated by the "dry run" analysis will be within the range of actual values that will be experienced in the eventual analysis of the MCS.

2.1 Define Measures

For the "dry run" analysis it was assumed that the test-reference experimental design was most appropriate for the estimation of actual savings from the MCS. The test building was constructed to the prescriptive provisions of the MCS. The reference building was constructed to meet the current requirements of the Washington State Energy Code (WSEC). Site inspections were made during construction to confirm that the features of both energy codes were implemented properly. Table 1 summarizes the respective features of these two energy codes relevant to the space heat end use. This table shows that the prescriptive provisions of the MCS are stricter than the current WSEC, except for the mandatory requirement to have an air-to-air heat exchanger (i.e., added consumption for AAHX fan). Each provision that differed between the two energy codes was defined to be a conservation measure for this analysis. The individual measures were grouped together to form a conservation package. Net total energy savings were computed for the conservation package. Because all of the measures impacted a single end use and the impact of each measure was relatively small, an attempt was not made to disaggregate total energy savings into the individual components of the MCS.

2.2 Data Collection and Preparation

Within the overall experimental design, it was assumed that an appropriate set of test and reference buildings were selected with all tenants willing to participate. Both test and reference buildings were all-electric and individually metered. Although an attempt was made to select buildings that were physically similar (except for the impacts of the MCS), some differences in geometry and envelope characteristics did exist. The test and reference buildings were located far enough apart that consideration was given to differences in outside air temperature between sites.

The test site was a 13 unit, motel style apartment building. It was built into a hillside with three full floors of housing units and a partial fourth floor on the downhill slope. The gross floor area of 9031 square feet consists of 8562 square feet of housing units (659 square feet per unit, average) and 469 square feet of unheated common area. The reference site consisted of two detached, motel style buildings that were connected by a breezeway. The larger building contained 8 housing units on two floors and a partial third (underground) floor for the common area. The two buildings had 8008 square feet of housing units (667 square feet per unit, average) and 564 square feet of common area for a gross floor area of 8572 square feet.

The balcony overhangs and exterior staircases in the motel style configuration provided external shading to much of the window area in both buildings. Trees and shrubs also provided some external shading at both sites. Both the test and reference buildings were of wood frame construction. The test building had a brick facade and the reference building had a raised-aggregate concrete panel facade. The exposed floor construction for both buildings was a combination of crawl space and concrete slab on grade. Salient characteristics of the test and reference buildings are summarized in Table 2.

For the test and reference buildings minimum data requirements were specified to support data verification and the calibration of the DOE-2 simulation. Both the data elements and the method of data collection for each element were judgementally selected to support a simulation of space heat consumption that was within ten percent of measured space heat consumption on a monthly basis. The selected minimum data requirements are summarized in Table 3. This table shows that a mixture of one-time, short term and continuous measurements are required to meet the data verification requirements and to fulfill the input requirements of the DOE-2 simulation. The data requirements listed in Table 3 for the "dry run" analysis are generally consistent with the measurement guidelines provided in the Analysis Plan (see Appendix A). Development of the specific data requirements for the "dry run" analysis was based upon the following assumptions:

(1) A satisfactory calibration of the simulation could not be made without continuous measurements of the lighting/appliance, hot water and space heat end uses. The continuous measurements of interior air temperature in each housing unit and the outside air temperature at each site were also essential to model calibration.

(2) The data verification procedures used in this analysis required that a continuous measurement of total electric consumption be made in each housing unit. This measurement combined with semi-monthly utility meter readings for each unit provided an adequate unit level sum check of the lighting/appliance, hot water and space heat measurements. A building level sum check (i.e. measurement of total building and house meter consumption) was not required to fulfill the accuracy criteria established for this study.

(3) A short term measurement of infiltration rate is required for the calibration of both the test and reference buildings. Measurement of air exchange rate with the PFT technique (single tracer) for a single 2 to 4 week period was judged to be adequate for this study.

Table 1

Summary of Energy Code Provisions
Related to Space Heat
New Multi-Family Buildings

Provision	Current Washington State Energy Code	Model Conservation Standards (Prescriptive)
Insulation Levels		
Exterior Walls	R-19	R-19
Roof	R-38	R-38
Below Grade Wall	R-19	R-10 (exterior) R-13 (interior)
Slab Floor Perimeter	R-7	R-10
Floor Over Unheated Space	R-19 R-19	R-25 (enclosed) R-38 (exposed)
Exterior Door	NC	R-7
Max. Total Glass Area*	21%	15%
Max. Glass U-Value	0.60	0.50
Example Window:	double glass/thermal brk metal frame	double glass/wood frame
Infiltration	0.50 cfm/lineal foot of crack length for windows/doors	0.3 cfm/lineal foot of window crack; 0.2 cfm of door crack; plus continuous infiltration barrier
A/A Heat Exchanger	No	Yes

NC = not considered
* percent of floor area

Table 2

Summary of Test and Reference
Building Characteristics

Characteristics	Test Building	Reference Building
Number of Housing Units	13	12
Avg. Unit Floor Area (SqFt)	659	667
Number of Floors	3.5	2
Energy Conservation Package	MCS	WSEC
Percent Glass (%)[1]	15	11
Construction Type	Wood Frame	Wood Frame
External Shading	Yes	Yes
Floor Type	70% Crawl 30% Slab	85% Crawl 15% Slab
Fireplace	No	No
Laundry	Common	Common

1 Percent of floor area.

Table 3

Minimum Data Requirements

SIMULATION INPUT REQUIREMENTS

Judgement

Contribution of loads to internal heat gain
Shading coefficient of windows

One-Time Measurements and Observations

Energy Audit

Building geometry
Envelope characteristics
Type and performance characteristics of heating system
External shading
(T) Flow rate of AAHX in test building
(T) Temperature difference across the AAHX
(T) AAHX fan power (kW)*

Tenant Survey (each unit)

Number and occupancy schedule of tenants

Short Term Measurements (each unit for single 2-4 week period)

Air exchange rate (PFT technique)

Continuous Measurements (each unit)

Lighting/appliance consumption
Domestic hot water consumption
Interior air temperature (near thermostat)
Outside air temperature (building level)
(T) AAHX fan on/off time*

OTHER ANALYSIS REQUIREMENTS

Continuous Measurements (each unit)

Space heat consumption
Total electric consumption

Other Data

Utility meter readings for each unit (twice monthly)

* AAHX fan on/off time and fan power were combined into a fan consumption schedule for input to the simulation.

(T) Test building only

(4) Energy audit, tenant survey and professional judgement data listed in Table 3 were collected for the reference building with procedures that are typically used in traditional multi-family conservation analyses. For the test building additional continuous and one-time measurements were required to characterize the performance of the air-to-air heat exchanger (AAHX) and its impact on infiltration rate. For the level of accuracy desired in this study it was assumed that the implications of the AAHX could be adequately characterized by the continuous measurement of AAHX on/off time in each unit, supplemented with one-time measurements of AAHX flow rate, temperature differences and fan power. A continuous measurement of AAHX fan consumption could be used as an alternative to the on/off time and fan power measurements. The temperature difference across the AAHX was limited to a one-time measurement based on the assumption that there is little variation in the efficiency of the AAHX across the range of operating conditions. Since energy savings from the MCS are sensitive to the performance of the AAHX, the data collection methodology for the AAHX is a major focus of the sensitivity analysis (see Section 2.5).

For the "dry run" analysis it was assumed that sufficient resources existed to support the collection of the continuous measurements listed in Table 3 for a one year coincident study period. The study period was arbitrarily assumed to be calendar year 1990. Consideration was given to extending the length of the study period to include an additional 1 to 2 months of pre-occupancy (vacant) data. Although the additional data would be useful during model calibration, it was assumed that the calibration accuracy criteria could be met without pre-occupancy data.

Standard audit and survey procedures were used in the "dry run" analysis to collect the one-time measurement and observation data listed in Table 3. ELCAP procedures were used to make the short term infiltration measurements during the winter months and to develop separate measurement plans for the continuous measurements required in the test and reference buildings. ELCAP procedures were also used to install the sensors and data acquisition systems (DAS) necessary to implement the measurement plan. ELCAP on-site verification tests were performed as part of the installation. The continuous measurements were subjected to ongoing ELCAP data verification procedures on a monthly basis throughout the study period. The ELCAP verification procedures were supplemented with comparisons of measured total consumption to utility meter readings on a monthly basis. Measurements of total monthly electric consumption were found to within 5 percent of the utility meter for each unit throughout the study period.

The data preparation procedures assumed in the "dry run" analysis involved three separate manipulations of the data set as discussed in the Analysis Plan (see Appendix A). The manipulations included filling in missing data for the continuous measurements, aggregation of the filled data to the building level and preparation of microclimate weather files for input to the simulation. The microclimate weather fills for each building were prepared by the substitution of site specific outdoor temperature data onto weather tapes obtained from the nearest NOAA weather station. The mean temperature and heating degree day characteristics of the test and reference building microclimates are summarized in Table 4. Similar characteristics of the nearest NOAA weather station for 1990 and a typical year are also included in this table for comparison.

Table 4

Summary of Weather Data

Site	Period	Mean Temp (F)	HDD**
Test Building	1990	53.6	4498
Reference Building	1990	56.5	3761
Nearest Weather Station	1990	52.2	5010
Nearest Weather Station	TMY*	50.5	5530

* TMY = Typical Meteorological Year
** Heating degree days from DOE-2 weather packer summary, 65°F base temperature.

2.3 Simulation Calibration

A separate calibration of space heat consumption was performed for the test and reference buildings. The calibration process consisted of three major steps. First, the building characteristics data, tenant data and continuous measurements were integrated into the simulation to satisfy the input requirements. Second, the simulation was run under microclimate weather conditions to calculate the predicted space heat consumption and these results were compared to measured space heat consumption. In the final step adjustments were made to the simulation inputs until predicted space heat matched measured space heat within the established acceptability criteria.

Energy audit and tenant survey data were integrated into the simulation in a straightforward manner using standard conservation analysis procedures. An infiltration profile was developed from the short term measurements of air exchange rate and one-time measurements of AAHX air flow and temperature difference. The infiltration profile was directly input into the simulation. The SAS statistical package was used to prepare simulation inputs from the continuous measurements. It was used to compute average monthly consumption profiles (24-hour) for the hot water and lighting/appliance end uses. A separate profile was prepared for the air-to-air heat exchanger in the test building and subtracted from the lighting/appliance end use profile. The profiles were expressed as hourly decimal fractions of an assigned peak (or capacity) value. The statistical package was also used to develop profiles for measured interior air temperature, from which building level thermostat settings were derived. The derived thermostat setpoints and end use profiles were also input to the simulation.

Predicted space heat consumption was computed by the simulation using actual microclimate (outdoor temperature) data. Predicted space heat consumption was compared to measured space heat consumption. The comparison was made for both total monthly space heat consumption and average monthly, 24-hour space heat profiles. The statistical package is used to develop the measured space heat profiles. Adjustments were made to the simulation inputs until a reasonable match was achieved. The adjustments were made to variables that were prioritized by their relative impact on energy consumption and the degree of uncertainty associated with the value used. The highest priority was given to variables that relied heavily on professional judgement. The simulation was fully calibrated when monthly predicted space heat consumption was within 10 percent of measured space heat consumption and the 24-hour space heating profile generated by the simulation for each month approximated the corresponding monthly measured space heating profile. The test and reference building calibrations proceeded in parallel so that both models reflected similar inputs for variables that did not change between buildings.

2.4 Simulation Adjustments

The fully calibrated models represent the most accurate depiction of predicted end use consumption under the conditions that existed during the study year. However, a subtraction of calibrated test building and reference building consumption would not produce an accurate estimate of savings because of differences in weather conditions, tenant behavior and physical properties of the two buildings. To obtain an accurate estimate of actual energy savings, adjustments were made to account for these differences.

The weather summary data in Table 4 show significant differences in the study year ambient temperature characteristics of the two microclimates and the nearest NOAA weather station. The table also shows that the weather conditions in 1990 were significantly warmer than a typical year. A correction must be made to the energy savings to account for these difference in weather conditions. For the "dry run" analysis the weather correction included the resimulation of the calibrated test and reference buildings under typical weather conditions.

A variety of additional adjustments to energy savings could be made to account for differences in tenant behavior and building physical properties. For the "dry run" analysis, tenant behavior was defined to include three variables that are directly controlled by the tenants. The variables included hot water consumption, lighting/appliance consumption and thermostat setpoint. Physical properties included the characteristics of the buildings that are not controlled by the tenants and not impacted by the energy codes (e.g. percent glass, building geometry). Energy savings from the MCS (i.e. consumption difference between the WSEC and the MCS) were recomputed for the following four physical property/tenant behavior combinations under TMY weather conditions.

Case	Occupancy (Tenants)	Physical Properties
1	Constant Reference	Constant Reference
2	Constant Test	Constant Reference
3	Constant Test	Constant Test
4	Constant Reference	Constant Test

The simulation of these four cases produced a range of adjusted energy savings. None of the cases were selected as a preferred result. The range in savings reflects the fluctuation in the impact of the MCS that occurs with variations in tenant population and building physical properties.

2.5 Sensitivity Analysis

The accuracy of the energy savings estimates is directly dependent upon the quality and accuracy of the simulation input data. The greatest accuracy for each input variable is achieved by using the most sophisticated available level of data collection (i.e. minimize professional judgement and maximize the use of continuous measurements). However, the practical resource constraints that are encountered in most studies limit the use of sophisticated data collection techniques. The selection of the data requirements for each study must be based upon an evaluation and prioritization of the impact of each data element on energy savings and the cost-effectiveness of alternative data collection techniques.

To provide a sense of realism to the "dry run" analysis, it was assumed that resource constraints limited the use of continuous measurements to only those variables that were required to meet the desired accuracy level of predicted space heating. The minimum data requirements listed in Table 3 were judgementally selected as the balance of one-time, short term and continuous measurements needed to meet this criteria. Compromises were made in the selection of the data collection techniques for several variables. For example, single, one-time measurements were selected for the measurement of AAHX temperature difference, flow rate and fan power instead of continuous measurements or more frequent one-time measurements. A single, short term measurement period was also selected for air exchange rate instead of multiple measurements to assess seasonal effects. Undoubtedly these compromises resulted in some loss in the accuracy of the energy savings estimates. The exact impact of these compromises can not be known without the more sophisticated or more frequent measurements. In the "dry run" analysis an attempt was made to quantify the effects of variations in the level of data collection through a sensitivity analysis that estimated the impact on energy savings of the following presumed variations in these parameters.

1. AAHX Temperature Difference - The minimum data requirements in Table 3 limited the frequency of data collection to a single, one-time measurement. For the sensitivity analysis the level of data collection for this variable was increased to a continuous measurement. The net effect of the more accurate data collection method was assumed to be a decrease in the annual average AAHX efficiency (from 67 percent to 50 percent) for the test building.

2. AAHX Fan Consumption - Based on the minimum data requirements in Table 3, annual AAHX fan consumption was computed using a continuous measurement of on/off time and a single, one-time measurement of fan power (watts). For the sensitivity analysis the level of data collection was increased to a continuous measurement of fan consumption (kWh). The net effect of the more accurate data collection method was assumed to be an increase in average power from a multi-speed fan (65 to 100 watts) in the test building. An additional effect included an assumed increase (0.05 Ach) in the mechanical component of the air exchange (effective infiltration) rate in the test building.

3. Average Annual Infiltration Rate - The minimum data requirements in Table 3 limited the frequency of data collection to one, short term measurement of total infiltration with the PFT technique. The single measurement taken in the winter was assumed to be constant (0.1 Ach natural infiltration) throughout the year. For the sensitivity analysis, the level of data collection for this vari-

able in the test building was increased to a series of three short term measurements, that includes winter, summer and swing months (fall, spring). The net effect of the more frequent data collection was assumed to be a variable annual natural infiltration rate in the test building. The annual natural infiltration rate varied from 0.1 Ach in the winter to 0.2 Ach in the summer and 0.15 Ach in the swing months for the test building.

A separate sensitivity analysis was conducted on these three parameters. The changes made to each parameter were assumed to result in increased accuracy of measurement from the improvements in data collection techniques. The analysis did not consider the potential interactions between the assumed changes to these three parameters. The analyses were conducted on the test building under constant test building tenant behavior and TMY weather. The results of the sensitivity analysis provided information that will be of use in deciding the appropriate level of data collection and data analysis that will occur in an actual study of the MCS.

3. ANALYSIS RESULTS

For the "dry run" analyses, the procedures described in Section 2 were assumed to be successfully applied to both the test and reference buildings. The data collection procedures produced a data set that fulfilled the minimum data requirements necessary to support data verification and calibration of the simulation. The continuous measurements passed all ELCAP verification procedures. Measurements of total monthly electric consumption were found to be within 5 percent of the utility meter. The use of rigorous installation and verification procedures combined with a responsive DAS maintenance program resulted in a high data capture rate (greater than 90 percent) in both the test and reference buildings. The high data capture rate minimized the data preparation requirements for filling missing data.

A summary of measured building level end use consumption is provided on a monthly basis in Tables 5a and 5b for the test and reference buildings, respectively. These tables show that hot water is the largest end use and space heat represents the smallest end use in both the test and reference buildings under conditions that existed during the study year.

A separate calibration of space heat consumption was successfully performed for the test and reference buildings. Several iterations of the model were required for each building to produce a set of simulation inputs that accurately reflected actual consumption characteristics. As shown in Tables 6a and 6b, predicted space heat consumption was within 4 percent of measured space heat consumption for each month in the study period. In addition, the 24-hour space heating profiles generated by the simulation for each month approximated the corresponding measured profiles for both buildings. These results easily met the simulation acceptability criteria established for the "dry run" analysis and confirmed that the minimum data requirements in Table 3 were adequate for this application. The test and reference building calibrations proceeded in parallel so that both models reflected consistent inputs for the variables that did not change between buildings.

The fully calibrated end use estimates shown in Table 6 represent the most accurate depiction of end use consumption under the conditions that existed during the study year. However, the subtraction of space heat consumption between the test and reference buildings does not produce an accurate estimate of energy savings from the MCS until space heating is adjusted for differences in weather conditions, tenant behavior and the physical properties of the two buildings.

The weather correction used for both the test and reference buildings in the "dry run" analysis included the resimulation of the calibrated models under typical weather conditions at the nearest NOAA weather station. The impact of this weather correction is shown in Table 7. For both the test and reference buildings space heat increased significantly (53 to 65 percent) under the colder TMY weather conditions. Weather corrected energy savings from the MCS were computed to be 50 percent of space heat consumption and 27 percent of total building consumption under variable building and tenant conditions.

Table 5a

Measured* End Use Consumption
Microclimate Weather
Housing Units

Month	Test Building Measured Consumption (kWh/sqft)			
	Space Heat	Hot Water	Other**	Total
January 1990	0.32	0.41	0.34	1.07
February	0.29	0.38	0.30	0.97
March	0.09	0.35	0.29	0.73
April	0.11	0.30	0.25	0.66
May	0.05	0.33	0.27	0.65
June	N/A	0.34	0.27	0.63
July	N/A	0.36	0.28	0.66
August	N/A	0.28	0.28	0.56
September	0.01	0.36	0.30	0.67
October	0.02	0.43	0.32	0.77
November	0.18	0.38	0.34	0.91
December	0.28	0.37	0.33	0.98
YEAR	1.35	4.29	3.61	9.25

Table 5b

Measured* End Use Consumption
Microclimate Weather
Housing Units

Month	Reference Building Measured Consumption (kWh/sqft)			
	Space Heat	Hot Water	Other	Total
January 1990	0.62	0.45	0.41	1.49
February	0.42	0.45	0.38	1.25
March	0.27	0.50	0.38	1.15
April	0.22	0.46	0.37	1.05
May	0.13	0.44	0.35	0.92
June	N/A	0.34	0.28	0.63
July	N/A	0.34	0.29	0.64
August	N/A	0.26	0.27	0.54
September	0.09	0.24	0.23	0.57
October	0.19	0.34	0.31	0.84
November	0.41	0.38	0.41	1.20
December	0.59	0.43	0.44	1.46
YEAR	2.94	4.63	4.16	11.73

* Includes adjustment for missing data.
** Includes AAHX fan consumption.
N/A = Not applicable (no consumption)

Table 6a

Comparison of Simulated and Measured
Housing Unit Consumption
Test Building

Month	Space Heating: Simulated Energy (DOE-2)	Space Heating: Actual (DAS)	Space Heating: % Diff	Total: Simulated Energy (DOE-2)	Total: Actual (DAS)	Total: % Diff
	Monthly Consumption (kWh/SqFt)					
January 1990	0.320	0.316	1.3	1.070	1.067	0.3
February	0.284	0.286	-0.7	0.971	0.969	0.2
March	0.093	0.091	2.2	0.735	0.734	0.1
April	0.113	0.109	3.7	0.664	0.662	0.3
May	0.052	0.051	2.0	0.656	0.654	0.3
June	N/A	N/A	N/A	0.611	0.626	-2.5
July	N/A	N/A	N/A	0.641	0.658	-2.6
August	N/A	N/A	N/A	0.558	0.561	-0.5
September	0.009	0.009	0.0	0.665	0.665	0.0
October	0.021	0.022	-4.8	0.772	0.772	0.0
November	0.181	0.182	-0.6	0.904	0.906	-0.2
December	0.278	0.278	0.0	0.986	0.987	-0.1
TOTAL	1.351	1.344	0.5	9.233	9.251	-0.2

Table 6b

Comparison of Simulated and Measured
Housing Unit Consumption
Reference Building

Month	Space Heating: Simulated Energy (DOE-2)	Space Heating: Actual (DAS)	Space Heating: % Diff	Total: Simulated Energy (DOE-2)	Total: Actual (DAS)	Total: % Diff
	Monthly Consumption (kWh/SqFt)					
January 1990	0.613	0.624	-1.8	1.476	1.486	-0.7
February	0.421	0.424	-0.7	1.249	1.253	-0.3
March	0.267	0.265	0.8	1.141	1.146	-0.4
April	0.221	0.221	0.0	1.047	1.047	0.0
May	0.132	0.129	2.3	0.922	0.921	0.1
June	N/A	N/A	N/A	0.621	0.634	-1.1
July	N/A	N/A	N/A	0.619	0.638	-3.1
August	N/A	N/A	N/A	0.536	0.537	-0.2
September	0.092	0.093	-1.1	0.567	0.567	0.0
October	0.188	0.189	-0.5	0.836	0.836	-0.2
November	0.407	0.407	0.0	1.196	1.196	0.0
December	0.570	0.585	-2.6	1.442	1.459	-1.2
TOTAL	2.911	2.937	0.9	11.658	11.728	-0.6

N/A = Not applicable (no consumption)

Additional adjustments were made to the estimated energy savings from the MCS by resimulating space heat consumption under the four variations in tenant behavior and physical properties of the test and reference buildings that are described in Section 2.4. The results of these analyses are shown in Tables 8 to 11. In all four cases the adjustments for physical properties and tenant behavior reduced the savings in space heat consumption from the values shown in Table 7. Energy savings ranged among these four alternative adjustment scenarios from 38 to 45 percent of the space heat consumption computed under the WSEC. These values correspond to a range of 13 to 15 percent energy savings (1.5 to 2.0 kWh/sq.ft.) in total housing unit consumption under typical weather conditions. None of these four cases were selected as a preferred result. The range in savings reflects the fluctuation in the impact of the MCS that naturally occurs with variations in tenant population and building physical properties.

3.1 Sensitivity Analysis

The minimum data requirements selected for the "dry run" analysis were a balance of one-time, short term and continuous measurements necessary to meet the established acceptability criteria for data verification and model calibration. Compromises were made in the selection of the data collection techniques for several variables due to presumed constraints in available resources. A sensitivity analysis was performed in an attempt to quantify the impact on estimated energy savings of compromises made to three variables. The analysis considered an increase in the sophistication of data collection for the measurement of AAHX temperature difference, AAHX fan consumption and infiltration rate, as described in Section 2.5. The level of data collection for both AAHX related variables was increased from one-time to continuous measurements. The level of data collection for infiltration was increased from one to a series of three, seasonal, short term measurements. In each of these cases the increase in the level of data collection resulted in a change to the simulation inputs to reflect the collection of more accurate information. The sensitivity analysis was conducted on the test building under constant test building tenant behavior and TMY weather.

Energy savings from the MCS were recomputed to reflect the changes made for these parameters. The changes made for each parameter were assumed to result from the increased accuracy of measurement caused by improvements in the data collection techniques. The results of the sensitivity analysis are summarized in Table 12. This table shows the consequence of the presumed changes to these three variables to be more conservative estimates of energy savings in the test building. Energy savings were reduced from the 41 percent of space heat consumption shown in Table 10 to a range of 33 to 38 percent of space heat across the three cases. The magnitude of the savings was reduced from 1.6 kWh/sq. ft. to a range of 1.3 to 1.4 kWh/sq.ft.. Energy savings from the MCS were degraded by 8 to 19 percent as a result of these three presumed changes. The degradation is savings, rather than the magnitude of the savings, should be viewed as the major result of the sensitivity analysis. From this analysis it is concluded that the estimated energy savings from the MCS is relatively insensitive to plausible variations in the three tested parameters.

Table 7

Weather Corrected Energy Savings
Variable Physical Properties
Variable Occupancy
TMY Weather

	Monthly Consumption (kWh/SqFt)							
	Total				Space Heat			
Month	Reference	Test	Savings	%	Reference	Test	Savings	%
January	1.71	1.17	0.54	31.6	0.84	0.46	0.38	45.2
February	1.37	0.96	0.41	29.9	0.55	0.30	0.25	45.5
March	1.52	0.90	0.62	40.8	0.65	0.29	0.36	55.4
April	1.22	0.69	0.53	43.4	0.39	0.17	0.22	56.4
May	1.06	0.69	0.37	34.9	0.27	0.12	0.15	55.6
June	0.63	0.61	0.02	3.2	0	0.04	-0.04	-
July	0.62	0.64	-0.02	-3.2	0	0.04	-0.04	-
August	0.54	0.56	-0.02	-3.7	0	0.04	-0.04	-
September	0.62	0.66	-0.04	-6.1	0.15	0.04	0.11	73.3
October	1.03	0.83	0.20	19.4	0.38	0.12	0.26	68.4
November	1.30	0.90	0.40	30.8	0.51	0.21	0.30	58.8
December	1.62	1.09	0.53	32.7	0.74	0.41	0.33	44.6
TOTAL	13.23	9.68	3.55	26.8	4.49	2.23	2.26	50.3

Table 8

Adjusted Energy Savings
Constant Reference Building Physical Properties
Constant Test Building Occupancy
TMY Weather

	Monthly Consumption (kWh/SqFt)							
	Total				Space Heat			
Month	WSEC	MCS	Savings	%	WSEC	MCS*	Savings	%
January	1.46	1.20	0.26	17.9	0.75	0.48	0.26	35.0
February	1.20	0.99	0.21	17.8	0.55	0.33	0.21	39.0
March	1.15	0.94	0.21	18.4	0.54	0.33	0.21	38.9
April	0.91	0.74	0.18	17.8	0.40	0.22	0.18	44.5
May	0.83	0.71	0.12	14.2	0.26	0.14	0.12	45.2
June	0.58	0.61	-0.04	-6.4	0	0.04	-0.04	-
July	0.60	0.64	-0.04	-6.1	0	0.04	-0.04	-
August	0.52	0.56	-0.04	-7.1	0	0.04	-0.04	-
September	0.70	0.66	0.04	5.5	0.08	0.04	0.04	47.2
October	1.01	0.86	0.14	14.1	0.29	0.15	0.14	48.8
November	1.13	0.93	0.20	17.8	0.45	0.24	0.20	45.2
December	1.36	1.11	0.25	18.3	0.69	0.44	0.25	36.2
TOTAL	11.45	9.95	1.51	13.2	4.00	2.50	1.51	37.7

Table 9

Adjusted Energy Savings
Constant Reference Building Physical Properties
Constant Reference Building Occupancy
TMY Weather

	Monthly Consumption (kWh/SqFt)							
	Total				Space Heat			
Month	WSEC	MCS	Savings	%	WSEC	MCS*	Savings	%
January	1.71	1.39	0.31	18.3	0.84	0.53	0.31	37.1
February	1.37	1.14	0.24	17.6	0.55	0.31	0.24	44.0
March	1.52	1.26	0.27	17.5	0.65	0.38	0.27	41.0
April	1.22	1.01	0.20	16.8	0.39	0.19	0.20	52.1
May	1.06	0.92	0.14	13.2	0.27	0.13	0.14	51.4
June	0.63	0.66	-0.04	-5.9	0	0.04	-0.04	-
July	0.62	0.66	-0.04	-6.0	0	0.04	-0.04	-
August	0.54	0.57	-0.04	-6.9	0	0.04	-0.04	-
September	0.62	0.55	0.08	12.5	0.15	0.07	0.08	52.5
October	1.03	0.85	0.18	17.3	0.38	0.20	0.18	47.0
November	1.30	1.06	0.24	18.3	0.51	0.27	0.29	46.8
December	1.62	1.32	0.30	18.5	0.74	0.45	0.30	40.1
TOTAL	13.23	11.38	1.85	14.0	4.49	2.63	1.85	41.3

* Includes AAHX fan consumption.

Table 10

Adjusted Energy Savings
Constant Test Building Physical Properties
Constant Test Building Occupancy
TMY Weather

	Monthly Consumption (kWh/SqFt)							
	Total				Space Heat			
Month	WSEC	MCS	Savings	%	WSEC	MCS*	Savings	%
January	1.45	1.17	0.28	19.4	0.74	0.46	0.28	38.1
February	1.19	0.96	0.23	19.5	0.54	0.30	0.23	43.3
March	1.12	0.90	0.22	20.0	0.51	0.29	0.22	43.5
April	0.88	0.69	0.19	21.7	0.37	0.17	0.19	52.2
May	0.80	0.69	0.12	14.7	0.24	0.12	0.12	50.0
June	0.58	0.61	-0.04	-6.4	0	0.04	-0.04	-
July	0.60	0.64	-0.04	-6.1	0	0.04	-0.04	-
August	0.52	0.56	-0.04	-7.1	0	0.04	-0.04	-
September	0.67	0.66	0.01	2.1	0.05	0.04	0.01	27.7
October	0.97	0.83	0.14	14.1	0.25	0.12	0.14	53.8
November	1.12	0.90	0.21	19.3	0.43	0.21	0.21	50.1
December	1.35	1.09	0.27	19.8	0.68	0.41	0.27	39.3
TOTAL	11.26	9.68	1.57	14.0	3.81	2.23	1.57	41.4

Table 11

Adjusted Energy Savings
Constant Test Building Physical Properties
Constant Reference Building Occupancy
TMY Weather

	Monthly Consumption (kWh/SqFt)							
	Total				Space Heat			
Month	WSEC	MCS	Savings	%	WSEC	MCS*	Savings	%
January	1.72	1.38	0.34	19.7	0.85	0.52	0.34	39.7
February	1.38	1.12	0.26	19.1	0.55	0.29	0.26	47.8
March	1.51	1.23	0.29	19.0	0.64	0.35	0.29	45.0
April	1.20	0.98	0.22	18.1	0.37	0.16	0.22	58.0
May	1.05	0.90	0.15	14.0	0.26	0.11	0.15	56.1
June	0.63	0.66	-0.04	-5.9	0	0.04	-0.04	-
July	0.62	0.66	-0.04	-6.0	0	0.04	-0.04	-
August	0.54	0.57	-0.04	-6.9	0	0.04	-0.04	-
September	0.59	0.52	0.07	11.6	0.12	0.05	0.07	58.0
October	1.00	0.81	0.18	18.3	0.35	0.17	0.18	52.2
November	1.29	1.04	0.25	19.7	0.50	0.25	0.25	50.5
December	1.63	1.30	0.32	19.9	0.75	0.43	0.32	42.9
TOTAL	13.15	11.17	1.98	15.0	4.41	2.43	1.98	44.9

* Includes AAHX fan consumption.

Table 12

Comparison of Energy Savings Estimates
Sensitivity Analysis

	Energy Savings (Space Heat)	
Case	(kWh/SqFt)	%
Fully Adjusted Energy Savings*	1.57	41.4
Continuous AAHX Temperature Diff	1.44	37.8
Continuous AAHX Fan Consumption	1.27	33.3
Multiple, Short Term PFT Tests	1.43	37.5

* MCS energy savings computed under constant test building physical characteristics, constant test building tenant behavior and TMY weather conditions (see Table 10)

A-1. INTRODUCTION

This Analysis Plan was developed to help guide the analysis to be performed as part of future regional end use load research on multi-family buildings. The Plan draws heavily upon the experiences of MHEUS and ELCAP to develop a set of procedures that can be used to evaluate the performance of implemented conservation measures. The Plan is designed to be as general as possible in its treatment of the subject of actual energy savings. It provides a generic understanding of the data elements necessary as inputs to model energy use in multi-family buildings. It does not include a specific methodology for use in a particular application. The Analysis Plan considers experimental designs that are relevant to both existing and new vintages of multi-family buildings. The analysis techniques common to both designs involve the calibration of a simulation with measured performance data under conditions with and without a selected set of conservation measures. The unique aspect of this Analysis Plan that makes a full calibration possible is the continuous measurement of end use consumption. The calibrated simulations are used to evaluate the effect on actual energy savings of variations in tenant behavior, building physical properties and weather conditions.

The Analysis Plan is organized into eight sections. The sequence of tasks that would typically be completed in a study of actual energy savings from a series of conservation measures are addressed in Sections A.2 through A.8. The last section provides additional discussion regarding the extrapolation of the study results to the larger population of buildings in the multi-family sector.

The major focus of this study was to conduct a hypothetical or "dry run" analysis of the actual energy savings that would be achieved from the implementation of the Model Conservation Standards (MCS) in new multi-family buildings. The hypothetical analysis was used to test the reasonableness of this Analysis Plan and its data requirements. The Plan should be viewed as a set of general procedures, that have in part been used successfully in this and other previous studies and will be improved upon as more experience is gained in this area of research. Indeed a portion of the scope of future studies that use this Analysis Plan should be devoted to improving upon these procedures and updating this document to reflect these improvements.

A.2 EXPERIMENTAL DESIGN

The first step to be completed in any study of actual energy savings is the development of the study objectives and the further identification of research questions to be addressed in meeting the study objectives. After these critical items have been determined, an experimental design can be selected to establish the overall context in which the research is organized and directed. Within the selected experimental design, appropriate analytic techniques are developed and used to meet the research objective. Data requirements necessary to support the analytic techniques and answer the research questions are identified. A detailed methodology is then formulated to lay out the sequence of tasks that must be performed and to place specific bounds on the scope of these tasks so that they are completed within the limits of available time and resources.

This Analysis Plan is directed toward end use load research that has a primary objective of determining the change in electric energy consumption associated with the implementation of one or more energy conservation measures in new or existing multi-family buildings. Some of the research questions that are addressed in meeting this overall objective include:

1. What measurements are required to support the estimation of actual energy savings?

2. How closely can a simulation be calibrated to measured end use consumption and what procedures should be used?

3. What adjustment factors must be considered in calculating actual energy savings and what is their relative impact? Which tenant characteristics most strongly influence consumption patterns and energy savings?

4. What is the contribution of individual measures to total energy savings?

5. What are the end use interactions for each measure?

6. What is the long term persistence of the energy savings?

One of three experimental designs can be employed to assess the impacts of implemented conservation measures. They include:

1. <u>On-off</u> - The on-off experimental design is applicable to conservation measures that can be turned on and off. When the measure is turned off the building operates as though the measure did not exist. The length of the on-off periods is determined by the particular requirements of the experiment. This design offers the advantage of allowing the test building to be its own reference. It is useful for measures whose performance can be evaluated with short on-off periods and where performance is not highly sensitive to fluctuations in tenant behavior and climate conditions. This type of design is not discussed further in this Analysis Plan because of its severe limitations on measure applicability.

2. Before-after - The before-after or pre/post-retrofit design is the most widely used method for evaluating existing building retrofits. For retrofits that are sensitive to weather and tenant behavior, pre-retrofit and post-retrofit periods of one year are typically used. The post-retrofit period is sometimes extended for an additional time period to evaluate the long term persistence of actual energy savings. The pre-retrofit and post-retrofit periods are often separated by a transition period during which the retrofits are implemented. Data from this type of design are easily integrated with a simulation to evaluate the effect of variations on tenant behavior and weather effects on energy savings.

3. Test-reference - The test-reference design is the most commonly used method for evaluating conservation measures in new buildings. It requires the use of at least two buildings; a test building that contains the conservation measure and a reference (or control) building that does not. This configuration is necessary because "before conservation" data can not be collected on a new building. Ideally, the two buildings would be identical in all respects except the conservation measure. In practice this will seldom be possible; although an attempt should be made to make them as identical as possible in terms of physical properties, tenant mix and microclimate. Data from this type of design must also be integrated with a simulation to adjust energy savings for these factors.

A key element of both the before-after and test-reference designs is the use of a simulation as the means to adjust energy savings for variations in tenant behavior, physical properties and climate. For these adjustments to be realistic, they must be made by a simulation that consistently and accurately predicts space heat consumption under conditions that are directly measured or observed in the buildings under study. For this reason the calibration of a simulation with measured performance data becomes a major part of the analysis methodology. The DOE-2 simulation, developed by the Department of Energy, is one of several available software packages that is capable of being accurately calibrated to measured space heat consumption. The DOE-2 simulation is particularly attractive for use in this type of work because it is a widely used, publicly available research tool that calculates space heat consumption at the hourly level. Although DOE-2 will be referred to as the simulation of choice in this Analysis Plan, it is recognized that other hourly simulations (e.g. BLAST) and some simplified models (e.g. SUNDAY) could potentially be used as substitutes.

The Analysis Plan addresses both the before-after and test-reference designs. Although it attempts to be flexible in the cases that it considers, the Plan had to be written within certain limitations. The Analysis Plan is limited in the following ways:

- It considers only all-electric, individually metered housing units. This is the most typical configuration encountered in the Pacific Northwest.

- Data are collected and verified at the housing unit level but are aggregated to the building level for analysis. It was assumed that the benefits of a unit level analysis could not be justified by the significant increase in analysis cost. This does not preclude the selective use of unit level analysis for small buildings or to explore a particular issue that might arise during the building level analysis.

- House meter (common area) loads are not considered except as a means of verifying the accuracy of housing unit consumption measurements. Although most multi-family buildings have house meter loads, such as external lighting, laundries, pools and common area internal lighting, these loads rarely influence housing unit consumption and are usually not addressed in conservation programs. In cases where they are considered, a more simplified analysis can usually be used to evaluate energy savings. Rigorous analysis can be limited to cases where space heating of common areas is a major house meter load.

- Procedures for simulation calibration and estimating actual energy savings address only the space heating end use since it is highly interactive and the target of most conservation measures. Although not specifically stated in every procedure, the overall methodology can easily be extended to other end uses such as space cooling, hot water and lighting/appliances.

- It assumes that studies of actual savings consider a limited sample of case studies. Although the general procedures discussed in the Plan are applicable to samples of any size, further attention must be given to issues such as analysis automation, cross building averaging and sample weighting if large samples of buildings are considered.

- The Plan does not provide specific procedures for the extrapolation of the results of case studies to the larger population of buildings in the multi-family sector. The subject of regional extrapolation would best be addressed in a separate document. Treatment of sector extrapolation is limited to a brief discussion of issues relevant to the Plan that should be considered in the preparation of extrapolation procedures.

A.3 DEFINE CONSERVATION MEASURES

The conservation measures to be implemented in the sample buildings must be selected from the available candidates that were identified in an energy audit. For both the before-after and test-reference designs, the selection process should occur prior to data collection, so that a measurement configuration can be selected to support the evaluation of measure performance. The conservation measures can be chosen based upon a preliminary assessment of anticipated measure performance and cost-effectiveness, energy code requirements or an arbitrary selection of measures of interest. Ideally, the selection should be limited to a single measure per end use to simplify the analysis of energy savings. In reality, the practical limits of available resources, the inconveniences created for the tenants and the large number of available measures dictates that combinations or packages of measures be implemented at a single time. In anticipation of the eventual analysis of energy savings, some care in selecting the package of measures should be observed. If end use resolution of individual measures is desired, the package should include measures that are anticipated to have a large impact on the consumption of that end use. Although a combination of measures with both large and small impacts can be installed, it should be realized that the ability of the data analysis to disaggregate total end use savings among the measures becomes very limited. For example, while it is possible and even desirable to implement all provisions of the MCS in a test building, it may not be possible to disaggregate the total savings in space heat energy into the individual components of the Standard. The assessment of cost-effectiveness will therefore be limited to groups of provisions and/or the entire package of measures included in the Standard.

If a preliminary analysis of cost-effectiveness is desired before final measure selection, it must be based upon engineering estimates of pre-retrofit (or test building) end use consumption and measure performance and vendor quotations of measure cost. Total retrofit costs should be considered for the before-after design. Incremental costs should be considered for the test-reference design. Although the eventual data analysis may show that these estimates were incorrect, it is recommended that they be completed as part of the data analysis. A comparison of the anticipated and actual energy savings could provide valuable insights that could be extended to other conservation analyses that do not have the benefit of continuous measurements. Other considerations that should be made during measure selection and implementation include:

1. The measure must satisfy the building owner. The owner should be allowed to control aspects of measure selection dealing with choice of contractor, aesthetic appearance and tenant impact.

2. The implemented measures should conform to all relevant state and local building codes and safety requirements.

3. A series of bid specifications should be prepared for each measure to be sure that the measure is bid and installed in the desired fashion. The competitive bid process should be used whenever possible to help reduce measure cost. However, in this type of research the selection of the minimum bid should not be mandatory,

given the importance of quality workmanship, timely installation and adherence to the desired specifications. Physical inspections should be made at appropriate intervals in the installation.

4. Measures should be allowed to change to some degree during installation. For some measures, such as insulation in existing buildings, the existing conditions and barriers to implementation can not be fully known until installation begins. Once these factors are determined, this measure may need to be reconsidered in light of changes to costs, performance and applicability. The measure may need to be reconfigured or an alternative measure may be substituted. All changes made to the measures must be thoroughly documented.

5. Cost sharing with the building owner should be avoided in this type of research. If resource limitations of the study dictate some contribution from the owner, it should be dealt with early on in the study and documented in the access agreement.

6. Actual installed capital costs should be thoroughly documented. At a minimum the documentation should include the cost (labor and materials) for individual measures in the conservation package. For the test-reference design, costs should be normalized to building gross floor area if a comparison across buildings is required. Further disaggregation of the cost components of each measure is recommended to the extent that it is available and useful in the analysis of cost effectiveness. Determination of appropriate cost breakdowns should be made prior to the solicitation for bids from the competing installation contractors.

A.4 DATA COLLECTION

Both of the primary experimental design alternatives employ analysis techniques that require the use of a simulation that is calibrated with measured performance data. If the simulation can consistently and accurately predict space heat consumption under conditions that are directly measured in a sample of buildings, confidence is built in its ability to accurately predict consumption under conditions that are not measured. This will allow the simulation to be successfully used to estimate space heat consumption under any reasonable combination of weather, tenant and building physical characteristics.

The calibration process requires that data be collected to satisfy as many of the input requirements of the simulation as possible. The necessary input data are collected from several sources, including an energy audit, a tenant characteristics survey, professional judgement and continuous monitoring with a data acquisition system. A listing of the data input requirements that are met by each of these data sources is provided in Table A-1. The entries in Table A-1 were categorized by the most accurate data source, i.e. to minimize the use of professional judgement and maximize the use of continuous measurements. It is noted that professional judgement and/or one-time measurements can always be substituted for the more costly continuous measurements.

Data collection from the energy audit, tenant survey and professional judgement will not be addressed further in this Plan. The procedures used to collect these data are a well known part of the conservation analysis that is traditionally performed on multi-family buildings. The unique aspect of this Analysis Plan that makes a full calibration of DOE-2 possible is the continuous measurement of end use consumption and inside air temperature and the short term measurements of air exchange rate. In the traditional energy audit, professional judgement and energy audit observations are heavily relied upon to estimate appropriate values for these critical parameters. With little data on which to base these judgements, the results of traditional conservation analysis are often subject to uncertainty. With the recent advent of metering technology, it has become possible to collect and store detailed and accurate end use and temperature data on a continuous basis at an affordable cost for research purposes. Although still too costly to incorporate into large scale conservation analysis programs, the results of detailed monitoring will provide useful insights into the consumption characteristics of multi-family buildings that will contribute to the base of knowledge on which informed judgement is based.

In addition to the input data requirements listed in Table A-1, the simulation calibration process must also be supported by the continuous measurement of space heat consumption for each housing unit. Measured space heat consumption is the standard against which the adequacy of simulated (predicted) space heat consumption is judged. The simulation is considered to be calibrated when predicted space heat matches measured space heat within an established accuracy level.

It is recommended that additional data be collected to support data verification and the analysis of energy savings. Measured space heat con-

Table A-1

Simulation Input Requirements

Judgement

- Contribution of loads to internal heat gain
- Shading coefficient of windows

One-Time Measurements and Observations

- Energy Audit
  - Building geometry
  - Envelope characteristics
  - Type and performance characteristics of heating system
  - External shading
  - Items of special interest (e.g. flow rate of AAHX in MCS housing units)

- Tenant Survey (each unit)
  - Number and occupancy schedule of tenants

Short Term Measurements (each unit)

- Air exchange rate (PFT technique)

Continuous Measurements (each unit)

- Lighting/appliance consumption
- Domestic hot water consumption
- Interior air temperature (near thermostat)
- Outside air temperature (building level)

- Special equipment consumption*
- Special temperatures**

Other Analysis Requirements

Continuous Measurements

- Space heat consumption (each unit)
- Total electric consumption (each unit, house meter, total building)

Other Data

- Utility billing records (or independent meter readings for each unit)

- Historical vacancy data (each unit) from owner records and/or utility billing records

- Conservation measure performance data from manufacturers literature

- Conservation measure capital cost data from contractor bids

* Special equipment is a portion of the lighting/appliance end use. It is limited to individual pieces of equipment that are of special interest (e.g. AAHX fan consumption in MCS housing units, clothes dryer in housing units).

** Limited to temperature measurements of special interest (e.g. temperature difference across AAHX in MCS housing units, fireplace flue temperature, space temperature in adjacent conditioned common area).

sumption can not be considered an adequate standard for simulation calibration unless there is confidence that space heat is being accurately measured. The collection of utility billing records and total electric consumption for each housing unit are an essential part of the data verification process. In some cases the continuous measurement of total electric consumption for the building and the house meter can also be valuable to data verification. The measurement of total electric consumption is redundant in the sense that total consumption for each unit could alternatively be calculated by summing the measurements of the space heat, domestic hot water and light/appliance end uses. Total building consumption could also be calculated as the sum of the individual housing units. However total consumption is a valuable measurement to make because it provides confidence in the individual end use and housing unit measurements, if it can be shown that this independent measurement of total consumption is equivalent to the sum of its components. With these measurements a "sum check" can be performed at both the building and unit levels. The collection of utility billing records provides yet another degree of confidence in the measurements in that the utility meter is the standard against which the adequacy of the measurement of total electric consumption can be judged. Although the utility meter is an instrument that is itself subject to measurement error, it is generally regarded as the most accurate means possible for measuring total electric consumption. A comparison of total electric consumption, as measured by the utility meter and the data acquisition system, can be easily made during data verification for the time interval (usually bi-monthly) included in the billing records. If this time interval is too long, the utility meter can easily be read on a more frequent basis by a researcher or a utility representative. Historical utility billing records serve another useful purpose in that they are often an excellent source of information regarding vacancy characteristics of the housing units.

The data requirements discussed above are considered to be the minimum requirements necessary to support an acceptable estimate of actual space heat savings from an implemented conservation measure. Because the minimum data requirements will vary somewhat with each application, entries for the continuous measurement of special equipment and special temperatures have been included in Table A-1 as options that should be exercised when performance measurements of specific equipment are required to meet the study objective. Beyond these minimum requirements, additional data could be collected to support a more in-depth analysis of energy savings. Data elements such as extended tenant questionnaires and more detailed measurements of interior temperatures and individual appliances could contribute to a better understanding of causes of specific consumption patterns that are observed.

A data collection methodology must be developed to collect and record the required information in an efficient and cost-effective manner. Although the specific procedures are dependent upon the particular application, the general procedures summarized below are recommended for consideration in any data collection effort. Many of these general procedures take advantage of the large investment in hardware and software design that was made in the ELCAP project.

1. Select Study Sample - The number of buildings to be included in the study must be determined based upon the study objective and available

resources. Although a statistically valid sample of buildings is desirable, there are rarely (if ever) sufficient resources to support a study sample of this size. Instead the study sample usually includes a series of case studies that are carefully selected to be representative of the targeted building population. For the before-after experimental design, the sample can be as small as one building, since the test building can act as its own reference. For the test-reference experimental design, the sample must be at least two buildings, since a separate reference (or control) building is required.

The size and type of building must also be considered during sample selection. For both experimental designs the total number of housing units contained in each building must be consistent with the number of desired data points, the channel configuration chosen for the data acquisition system (DAS) and available resources. Data acquisition systems can be configured for any number of housing units. However, it is recommended that the size of the buildings be limited to 10-15 housing units to produce a practical and manageable data set for each sample building. The type of building selected, in terms of construction type and tenant mix, is an important consideration for both designs. For the test-reference (new construction) design an attempt should be made to make the test and reference buildings as identical as possible, except for the implemented conservation measures. Although no two buildings are exactly the same, care should be taken to minimize the confounding effects of differences in physical construction, tenant mix and microclimate that will complicate data analysis. For the before-after design (existing buildings) consideration should be given to the wide variety of construction practices, tenant mixes and locations within the existing building stock. These factors will significantly impact baseline (pre-retrofit) end use consumption, the applicability of available retrofits and the energy savings that are realized from the retrofits. All buildings should be subjected to a thorough on-site inspection before the sample is finalized.

The selection of a study sample is particularly difficult for existing multi-family buildings because permission is required from the individual tenants in addition to the building owner. Since the consensus of all tenants is difficult to achieve, the strategy that was successfully used in MHEUS included formal permission from only the building owner. The individual tenants were written a letter explaining the value of the study and the desire of the installation team to minimize the inconvenience to them. Although the tenants were not specifically asked for permission, they were instructed to contact the building manager if they strongly objected to having the installation team enter their unit. Allowing for this additional contact with the manager (who was also a tenant) stimulated interaction among the tenants and increased confidence in the legitimacy of the study. Using this method, none of the tenants refused entry to the installation team. For new buildings the process of getting tenant permission is much simpler, since the monitoring equipment can be installed in the buildings before tenant occupancy begins. Tenants would be informed of the study before they occupied the unit, so that they would be aware of the need to enter their unit for ongoing maintenance and decommissioning at the end of the study. Written notice should be given to tenants at least 48 hours prior to entry.

It is recommended that a formal access agreement, similar to one developed in ELCAP, be signed with the building owner to minimize the possibility of a building owner withdrawing permission before the study is completed. In the MHEUS study such an instance resulted in a significant loss of valuable study resources. It is suggested that condominiums be excluded from the sample, unless specifically required to fulfill the study objective. Since condominium units are owned by the individual occupants, formal access agreements would likely be required for each unit. It is also recommended that a building be eliminated from the sample if access is denied by any of the tenants or if the building manager is uncooperative. The cost of recruiting a different building is usually less than the added data analysis cost required to compensate for an incomplete data set. The possibility of financial incentives to the tenants should be explored as a means of increasing the participation rate, if it increases the cost-effectiveness of the recruiting process.

2. <u>Select Study Period</u> - The length of the data collection period should be carefully selected to provide a sufficient amount of data for the intended analysis. Because of the high cost of hardware and initial installation and the relatively low cost of ongoing data collection, multiple phases of data collection should be considered. First phase data collection would include the minimum amount of data necessary to begin formal data analysis. The determination of this period is important to the overall study schedule, allowing data analysis to begin in the most timely manner possible. Additional phases of data collection could occur concurrently with the data analysis. The length of data collection is typically shorter for a test-reference design than a before-after design, since data for the buildings with and without conservation can be collected concurrently. For a before-after design, separate data must be collected in the transition period, during which the retrofits are implemented.

The specific length of the data collection period is dependant upon the nature of the analysis that is to be conducted. For conservation measures that impact space heating it is recommended that data be collected for at least one year with and one year without the measures to allow for an annual weather cycle under both conditions. This would correspond to a minimum one year data collection period for the test-reference design and two year period for the before-after design (excluding the transition period). For the test-reference design (new construction) it is recommended that an additional pre-occupancy data collection period of 1 to 2 months be considered for both the test and reference buildings, if sufficient resources are available to compensate the building owner for lost revenue. During this period data can be collected under internal load and thermostat conditions that are set by the installation team, without the confounding effects of tenant behavior. These data are particularly useful during the simulation calibration process (see Section A.6). The one-year data collection period should not begin until the tenant population has stabilized after occupancy begins. It is also recommended that additional data be collected with the measures in place for both experimental designs, if the persistence of energy savings issue is to be evaluated in the data analysis.

The selection of a specific start date for the data collection period should account for the amount of time necessary to complete the many initial tasks in the study. These tasks include sample selection, owner/tenant recruitment, measurement plan development, ordering/receipt of hardware, and development of data verification software. All of these items must be in place before a realistic start date can be set.

3. Select Data Acquisition System (DAS) - Based upon the requirements for continuous monitoring and the characteristics of the sample buildings, a selection of sensor type and data acquisition system must be made. In selecting an appropriate data acquisition system, consideration must be given to issues such as:

- o capacity to collect the desired number of data channels
- o ability to directly measure electric energy consumption (i.e. power factor corrected watts)
- o capacity to temporarily store data
- o compatibility with existing data retrieval and data verification software
- o commercial availability
- o reliability and maintenance requirements
- o initial capital cost
- o signal compatibility with sensors
- o means for downloading data to central computer
- o recovery from power outages

Several commercially available data acquisition systems could be used to collect the required data. The most promising alternative appears to be the DAS developed under ELCAP by Battelle PNL. The version of the ELCAP logger that was developed specifically for the multi-family sample offers several advantages such as large channel capability in a slave/master configuration, ability to directly measure power factor corrected watts, and the ability of the master logger to serve as a single communication terminal. This system is recommended for use in either experimental design if the hardware and software problems encountered in ELCAP have been corrected.

4. Develop Measurement Plan - The selected sensor configuration and measurement scheme should be documented in a measurement plan. This documentation includes items such as the electric panel configuration in each housing unit, sensor type and location, end use assignments and channel assignments. It is recommended that the measurement plan procedures developed in ELCAP be followed for the continuous monitoring of electrical consumption and temperatures.

5. Logger and Sensor Installation - It is recommended that the procedures developed in ELCAP be used to install the sensors and the data acquisition system. Important features of these procedures include:

- o meet with electrical inspectors in affected jurisdictions to be sure that all relevant state regulations will be followed. For example, Washington State code requires that only UL Approved current transformers can be installed. All installations should be inspected before data collection begins.

- o all current transformers should be installed by a licensed, bonded electrician

- o for new construction the building can be pre-wired to avoid the need for exposed sensor cable. However, pre-wiring requires careful planning with the builder/developer so that the installation team is prepared to respond quickly during the window of time available in the construction schedule.

- o each installation should be thoroughly checked by the installation team before leaving the site, using ELCAP on-site verification procedures. These procedures include items such as a sum check of each housing unit and a sum check across every logger in the network.

After each housing unit passes the on-site verification tests, an initial data set is collected for a period of about two weeks. These data are downloaded via a modem, to a central computer where they are subjected to more rigorous verification procedures. It is recommended that the methodology developed in ELCAP be used for the formal verification process. It is recommended that these procedures be enhanced to include a formal comparison of total measured electric consumption to consumption read from the utility meter for each housing unit. Meter readings would be made at the beginning and end of the initial data collection period by the installation team or utility personnel.

It is also recommended that each housing unit be subjected to ongoing data verification procedures throughout the study. Data should be downloaded to the central computer on a weekly basis and subjected to software tests to check for logger or sensor malfunction. On a monthly basis the data set should be subjected to a more rigorous verification procedure that includes sum checks and a comparison of total consumption to utility meter readings. It is recommended that utility meter readings be taken for each housing unit on a weekly or bi-weekly basis throughout the study. Although only monthly totals would be used in the ongoing verification procedures, the collection of weekly or bi-weekly readings will be of benefit during data preparation.

6. Air Exchange Rate - The natural air exchange (infiltration) rate is an important simulation input that should be measured as accurately as possible in every study. For certain cases, such as the evaluation of the MCS, the measurement of the AAHX mechanical air exchange rate is also important. Total air exchange rate should be measured for each housing unit through one or more short term (2-4 week duration) measurements that can be combined into an annual schedule for input to the simulation. It is recommended that the air exchange rate be measured using the PFT technique and the measurement protocol recently developed by Battelle PNL for multi-family buildings. When mechanical ventilation is present, the protocol combines the PFT measurements with one-time measurements of AAHX air flow and the continuous measurement of the AAHX fan consumption (or on/off time) by the data acquisition system to separate the total building air exchange rate into its natural and mechanical components. PFT measurements can include either a single tracer gas technique that includes a hand correction for air exchange between housing units or a multiple tracer gas technique that directly accounts for the inter-unit air exchange. The measurements discussed in the protocol must be supplemented with measurements of temperature difference across the AAHX (see Table A-1) so that the measured mechanical air exchange rate can be expressed in terms that are compatible with the simulation input requirements.

7. Documentation - It is highly recommended that all data collection and verification procedures used in the study be thoroughly documented in a timely manner (i.e. before data analysis begins).

A.5 DATA PREPARATION

The verified data set must be manipulated in several ways to prepare it for data analysis. The first and most important of these manipulations is the treatment of missing entries in the hourly data set. A complete data set is required for an accurate calibration of the simulation. Although the installation, verification and maintenance procedures are developed to maximize the data capture rate, some missing data will inevitably occur. The missing data could occur in two ways. The entire system could fail (i.e., no data at all) or the failure could be limited to certain system components (i.e. the hardware in individual housing units). The missing data could also be short term (i.e. a few hours to a few days) or long term (i.e. several days to several months). The specific procedures used to fill in missing data will vary with both the type and length of the occurrence.

Some flexibility must be allowed in the development of specific data preparation procedures for filling missing data because each application will present a unique situation. Some general procedures that should be considered include:

1. Data filling should begin by performing a day type analysis on the non-missing data to determine if there are large and systematic differences in consumption patterns between days of the week for each of the non-space heat end uses. Based upon this analysis it should be determined if multiple day types (e.g. weekdays, weekends) are required. It should be recognized that minimizing the number of day types simplifies the analysis. The use of multiple day types should be justified by significant differences in the end use consumption patterns.

2. Total electric consumption should be filled first. Data filling should begin by simply assuming that mean hourly consumption during missing hours is the same as non-missing hours for each day type. The non-missing hourly means should be substituted into the missing hours on a monthly basis and consumption for all hours in the month should be summed. The specific hours to be included in this summation should correspond to the monthly meter reading cycle. Alternatively, a curve fit procedure could be applied to the utility meter readings to achieve coincident time periods. The summation of total adjusted electric consumption for each unit should be compared to utility meter consumption. If a reasonable match is found, the data filling procedure is acceptable. The definition of reasonable match is situation dependent. If a reasonable match is not found, then the process should be repeated for weekly intervals. Examination of end use and temperature profiles during surrounding periods of non-missing hours may also be useful for difficult situations.

3. After acceptable values for total electric consumption are determined, the process described in item 2 should be repeated for the individual end uses. The acceptability of the filled end use consumption values is determined by comparing the sum of the individual end uses to total electric consumption. Reduced time in-

tervals and plots of end use and temperature profiles for surrounding periods may be useful for difficult situations. For partial system failure (selected components only), an examination of the end use consumption patterns of other housing units during the period of missing data may also be beneficial. Customized end use multipliers may have to be applied to the most variable end use(s) in some cases to achieve an acceptable end use sum check. The ability to realize accurate end use resolution diminishes rapidly with the length of the missing time period.

The second required manipulation of the data set involves the preparation of hourly weather files for input to DOE-2. The weather files must be customized to the selected study periods and the hourly ambient outside air temperature measurements collected with the data acquisition system. The weather files are prepared by purchasing a NOAA hourly weather tape for the nearest weather station. The tape would span the entire study period. The outdoor ambient temperature channel is deleted from the weather station data set and is replaced with the corresponding microclimate temperature measurements recorded by the data acquisition system. The weather files can be prepared only after missing on-site temperature data are filled in using appropriate regression analysis. Statistical methods are used to establish a functional relationship between the weather station and microclimate outdoor air temperatures during the non-missing hours. This relationship is then applied to the missing hours to create a continuous hourly record of microclimate temperatures. The continuous record must then be broken into pieces that correspond to the selected study periods.

The final manipulation of the hourly data set involves the aggregation of the filled in data set to the building level. A separate aggregation of the individual housing units to the building level is made for each measured end use and building total electric consumption. A suitable averaging technique is used to establish annual building level infiltration rate and interior temperature profiles for the building.

A.6 SIMULATION CALIBRATION

As discussed previously the calibration of a simulation with measured performance data is a key element of the analysis methodology. The calibrated simulation will be used to make realistic adjustments to energy savings to account for temporal and cross building variations in tenant behavior, physical properties and climate. The calibration process consists of three major steps. First, the building characteristics data, tenant data and continuous measurements listed in Table A-1 are integrated into the simulation to satisfy the input requirements. Second, the simulation is run to calculate predicted space heat consumption under microclimate weather conditions and these results are compared to measured space heat consumption. In the final step adjustments are made to the simulation inputs until a satisfactory match (see below) of predicted and actual space heat is achieved. For the before-after experimental design the simulation must be calibrated to both pre-retrofit and post-retrofit consumption. For the test-reference design both the test and reference buildings must be calibrated. For each of these cases the simulation is generally calibrated over a one year period; although the simulation is capable of being calibrated to shorter time periods.

Energy audit and tenant survey data are integrated into the simulation in a straightforward manner using standard conservation analysis procedures. Professional judgement must often be used to supplement these data sources. The infiltration profile developed from the short term measurements of air exchange rate can also be directly input into the simulation. The SAS statistical package (or equivalent) is used to prepare simulation inputs from the continuous measurements. This tool is used to compute average monthly consumption profiles (24-hour) by day type (if appropriate) for the hot water and lighting/appliance end uses. A separate profile is prepared for the miscellaneous equipment end use, if an equipment load of special interest is being monitored as a subset of the lighting/appliance end use. If necessary, the consumption for this specialty equipment is subtracted from the lighting/appliance profile to avoid double counting. The end use profiles are prepared in a format that is consistent with the simulation input requirements. For the DOE-2 simulation the profiles are expressed as hourly decimal fractions of a peak (or capacity) value, that is arbitrarily assigned by the analyst. The statistical package is also used to develop profiles for measured interior air temperature, from which building level thermostat settings are derived. The specific procedures used to derive thermostat setpoints must be allowed to vary with the situation encountered in each building. The derivation of thermostat setpoints is complicated by several factors including:

1. Average building setpoints are derived from average interior temperatures that were controlled by the individual tenants in each housing unit.

2. Thermostat setpoints are usually derived for only those hours when space heating occurs. This is particularly difficult in spring and fall months when space heating is used intermittently across the housing units.

3. Changes in thermostat setpoint could produce a similar effect on space heat consumption as changes to the other consumption variables not addressed by the end use load data (e.g., infiltration rate and hot water internal gains).

The derived thermostat setpoints and end use profiles are then input to the simulation. For the post-retrofit building in the before-after design and the test building in the test-reference design the assumed performance of the conservation measures are also input to the simulation. Predicted space heat consumption is computed using actual microclimate outside temperature data. Predicted space heat consumption is compared to measured space heat consumption. The comparison is made for both total monthly space heat and average monthly space heat consumption profiles. The statistical package is used to develop the measured space heat profiles. The simulation is fully calibrated when the comparison of predicted and measured space heat consumption meets an established set of acceptability criteria. It is recommended that two acceptability criteria be met. First, simulated space heat consumption should be within 5 percent of measured space heat consumption on a monthly basis. Second, the average, daily, 24-hour space heating profile generated by the simulation for each month should approximate the corresponding monthly measured space heating profile.

In most cases several iterations of the simulation are required to achieve a comparison that satisfies both acceptability criteria. For each iteration changes are made to the simulation inputs that have the most uncertainty, i.e., inputs that are not directly measured. Changes to the assumed performance of the conservation measures in the post-retrofit (or test) building simulation should be considered as part of the tuning process. For the before-after experimental design the pre-retrofit and post-retrofit calibrations should proceed in parallel so that both models will reflect similar inputs for variables that do not change between the two study periods. For the same reason a similar parallel calibration should be performed for the two models in the test-reference design. If a large sample of buildings is monitored in either of the designs, cross building comparisons may also be of use in determining appropriate changes during final calibration. A fully calibrated model should be consistent across buildings when like conditions exist.

The fully calibrated models represent the most accurate depiction of predicted end use consumption under the conditions that exist during the study years. For the before-after design a simple subtraction of calibrated pre-retrofit and post-retrofit consumption would not produce an accurate estimate of actual energy savings from the retrofits because of differences in weather conditions and tenant behavior that are not related to the retrofits. For the test-reference design a subtraction of calibrated test building and reference building consumption would also not produce an accurate estimate of savings for these two reasons and the added complication of differences in the physical properties of the two buildings. To obtain an accurate estimate of actual energy savings, corrections must be made to account for these differences.

A.7 SIMULATION ADJUSTMENTS

Ideally, conditions in the test buildings would be identical except for the impacts of the implemented conservation measures. However, in reality significant differences in weather conditions, tenant behavior and/or physical properties of the buildings are encountered in addition to the conservation measures. The objectives of the analysis may also require that energy savings be evaluated at yet another set of conditions that are not present at any of the sample buildings. Because these factors can have a significant impact on actual energy savings, they must be specifically accounted for in the analysis of energy savings. The primary purpose of the calibration process discussed above was to prepare the simulation for the task of computing the adjustments that must be made to energy savings to account for these factors. The specific procedures that are used to make these adjustments will vary somewhat with the particular conditions encountered. Some general procedures that should be considered are discussed below.

Weather Conditions - Differences in weather conditions are particularly important in the before-after design because the use of two study years is required. Although only a single study year is required in the test-reference design, weather adjustment can be important if microclimate differences exist between the test and reference buildings. For both designs, weather adjustment can also be important if the objective of the analysis includes an assessment of energy savings under weather conditions other than what is encountered during the study period.

An adjustment to energy savings is quite straightforward when calibrated simulations are available. For the before-after design adjusted space heat consumption can be computed under either constant pre-retrofit weather or constant post-retrofit weather. The two calibrated simulations are rerun by switching the weather inputs to the model. Adjusted energy savings under constant pre-retrofit weather are computed as the difference between calibrated pre-retrofit consumption and the adjusted post-retrofit simulation under pre-retrofit weather conditions. Adjusted energy savings under constant post-retrofit weather are computed as the difference between calibrated post-retrofit consumption and the adjusted pre-retrofit simulation under post-retrofit weather conditions. A similar procedure can be used for the test-reference design.

A variety of other weather adjustments can be made to meet the specific study objectives. Weather adjustments that are commonly made include energy savings during the study period at a different location, energy savings during a different study period at a different location and energy savings under typical or average weather conditions. These adjustments can be made quite easily if hourly weather data from a NOAA weather station are used. Typical Meteorological Year (TMY) weather data are usually used to reflect average weather conditions. TMY data are available from major NOAA weather stations. Some data processing is usually required to compile the weather data into a format that is consistent with the input requirements of the simulation.

Physical Properties - Differences in physical properties of buildings are particularly important to the test-reference design where the use of two separate buildings is required. This factor can also be important in the before-after design when similar conservation measures are implemented in multiple buildings. Differences in physical properties of buildings that are commonly encountered include:

- o number of housing units
- o size of average housing unit
- o amenities provided in each unit
- o construction type and geometry.

In the test-reference design an attempt should be made during sample selection to minimize the difference in these properties between the test and reference buildings. However, it may be desirable to allow differences in one or more of these properties to occur between pairs of buildings to assess the sensitivity of savings to variations in these properties. Whenever a difference in the number of units and/or the average size of a unit occurs, energy consumption should be normalized to kWh/sqft of housing unit floor area to minimize the effect of these differences on the calculation of energy savings. Differences in construction type and geometry were captured in the individual building simulation inputs developed during the calibration process. Differences in amenity level between buildings are important only to the extent that they have a significant impact on the calculation of energy savings. Adjustments to energy savings for differences in amenities are often difficult to make without direct measurements. Therefore it is recommended that consideration be given to this issue prior to data collection. The miscellaneous equipment end use (see Table A-1) provides a convenient means for tracking the consumption of particular pieces of equipment, if the effect of amenity level can be captured through continuous measurements. A series of one-time measurements, combined with an examination of hot water and lighting/appliance profiles and professional judgement, can serve as an alternative means for capturing the effect of amenity level on simulation inputs when continuous measurements are not appropriate. The specific impact of differences in construction type/geometry and amenity level on energy savings can best be calculated through the simulation. Inputs relevant to these factors can be switched between the test and reference buildings and the simulations can be rerun. As a result adjusted energy savings can be computed in two ways; under constant test building conditions and under constant reference building conditions. The analyst can then select which of these two estimates is most appropriate or can view the two estimates as a range of energy savings.

<u>Tenant Behavior</u> - Differences in tenant behavior are important for both experimental designs. The need for a tenant behavior correction is obvious in the test-reference design because two separate buildings are being evaluated. A tenant behavior correction is required in the before-after design as well because of the large tenant turnover that is typically experienced across the study period. A tenant behavior correction should also be considered if a stable tenant population is experienced because the consumption patterns of a given tenant are likely to change somewhat across a study period that is usually greater than two years.

The adjustment process must begin with a formal definition of tenant behavior. It is suggested that tenant behavior be defined prior to data collection so that its impact on energy savings can be isolated to the extent possible with direct measurements (continuous and/or one-time). For the MHEUS project tenant behavior was defined to include three variables that are directly controlled by the tenants. They included thermostat setpoints, hot water consumption and lighting/appliance consumption. Infiltration rate and AAHX fan consumption should also be considered as potential contributors to tenant behavior if they are directly measured and determined to be highly occupant dependent. Because of high tenant turnover, no attempt was made in MHEUS to account for the fact that some of the change in thermostat setpoints between the pre-retrofit and post-retrofit periods may have been caused by a tenant reaction to the conservation measures (i.e., take back effect). It is recommended that consideration be given to measure induced effects in the before-after design when tenant behavior is examined. If a take back effect is found, it should be considered in the calculation of net energy savings and not included in the tenant behavior correction. An analysis of take back effect is most likely to be successful at the housing unit level rather than the building level. Examination of the consumption and interior temperature characteristics of housing units with constant tenancy will likely produce inconclusive results but may provide sufficient information to base an estimate of the take back effect. The take back effect will probably account for only a portion of the differences in thermostat setpoints. This effect must be removed by adjusting the thermostat setpoint schedule so that take back effect is excluded from the tenant behavior adjustments. Although not specifically considered to be a take back effect, the tenant adjustments to energy savings must also account for any increases in end use consumption that are caused by the implemented measures (e.g. AAHX fan consumption). The impact must be removed in the calculation of net energy savings. The take back effect is not likely to be of concern in the test-reference design because the test and reference buildings have different tenant populations.

The impact of tenant behavior on energy savings should be assessed in a manner similar to that used for weather and physical properties. Relevant simulation inputs can be switched between the test and reference buildings and the simulation can be rerun. Adjusted savings can be computed under constant test building and/or constant reference building tenant behavior. A similar procedure should be followed for the before-after design.

The adjustments discussed above can be assessed individually or in a variety of combinations, depending upon the objectives of the analysis. As noted above, each adjustment will produce two revised values for energy savings. Values of adjusted energy savings under both constant test building and reference building conditions will be produced for each pair of test-reference buildings. A similar range of adjusted energy savings will be produced for each building in the before-after design. Unless the study objectives dictate which of the two conditions is preferred, the range of adjusted savings should be viewed as the final result of the adjustment process for the conservation package. This result is indicative of the fact that conservation measures in multi-family buildings often do not produce a fixed amount of energy savings. Actual energy savings will fluctuate somewhat with the tenant population, physical properties and weather conditions.

A.8 INDIVIDUAL CONSERVATION MEASURES

The objectives of many studies require that an attempt be made to disaggregate the adjusted energy savings of the conservation package into its individual components. Disaggregation of energy savings is particularly useful when the cost-effectiveness of the conservation package is to be evaluated. This level of detail is often not possible or severely limited when the entire package of measures is implemented for a coincident time period. The disaggregation process would be simplified greatly for both designs if staggered implementation of the measures were allowed. However, staggered implementation can rarely be tolerated due to its implication on the study schedule. Therefore the disaggregation of individual measures should be approached from a perspective that accepts whatever level of resolution that is achievable with the available data. Resolution is likely to be limited for measures that directly impact the same end use and measures that are highly interactive. Disaggregation is also difficult for measures that have a small impact on consumption, even if only a single end use is impacted. In these cases the energy savings are lost in the "noise" of variations in end use consumption that naturally occur in a dynamic population of tenants.

Some disaggregation of the conservation measures will undoubtably occur during the simulation calibration process. As discussed in Section A.7, changes to the assumed performance of individual measures or groups of measures in the conservation package are often made as iterations in the calibration process for the test building in the test-reference design. Similar performance changes are made for the post-retrofit building in the before-after design. Because a successful test (or post-retrofit) building calibration was achieved, the measure performance assumptions made during calibration should be used for this task. Further definition of measure performance was developed as engineering estimates during the measure selection process (see Section A.5). These two sources of performance data should be used collectively to make an initial determination of the level of disaggregation that is achievable and to estimate performance for each measure or group of measures under the chosen level of disaggregation.

A baseline end use consumption scenario must be selected from the range of pre-retrofit (or reference) building combinations produced by the adjustment factors described in Section A.7. A post-retrofit end use consumption scenario must also be selected as the post-retrofit (or test) building simulation adjusted for the same factors. The difference in end use consumption for these two scenarios represents the conservation package energy savings that must be distributed among the individual measures. The simulation inputs for the baseline scenario are modified to incorporate the measures. The simulation is run for the individual measures and actual energy savings are computed with respect to the selected baseline scenario. The savings of the individual measures are summed and compared to the actual savings computed for the conservation package. The sum of the individual measures will rarely equal the conservation package because of interactive effects between measures. Therefore further adjustments must be made to one or more of the individual savings values so that they sum to the conservation package value. The adjustments are limited to the individual measures with end use interactions. The method to be used to determine these adjustments will depend upon the particular situation. Most methods use a hierarchical approach, where the individual measures are ranked by cost-effectiveness, initial capital cost, magnitude of energy savings or other appropriate criteria. In the rolling baseline method the measure in highest rank order is added to the baseline scenario, without adjustment. The remaining interactive measures are resimulated on an individual basis and energy savings are calculated with respect to the new baseline. The measures are reranked and the method is repeated until all of the measures have been absorbed into the conservation package. A simplified version of this method reduces the number of simulations by assuming that the rank order of the measures will not change between iterations. With this simplification, the measures are successively added to the package based on the initial rank order. A third method that has been used in this type of analysis involves removing measures, in rank order, from the final post-retrofit scenario instead of adding them to the baseline scenario.

Each of these methods will result in a net energy savings for each measure that will sum to the total conservation package. These savings values, together with the actual installed capital cost, and estimates for O/M cost and economic lifetime can be used as inputs to an evaluation of cost-effectiveness.

A.9 ISSUES FOR SECTOR EXTRAPOLATION

The discussion of actual energy savings in this Analysis Plan has been limited to the specific sample of buildings included in the study. As mentioned previously, limitations of sample size require that this sample be viewed as a series of case studies. Although very practical and useful results are obtained from the case studies, the value of the study would be enhanced greatly if these results could, at least in part, be extended to similar types of buildings located elsewhere in the region. The development of specific procedures for sector extrapolation is not part of this Analysis Plan. However, a brief discussion of issues relevant to the relationship between this Plan and a regional extrapolation is provided for consideration during development of extrapolation procedures.

If one of the objectives of the end use load research is to support an extrapolation of the study results to similar multi-family buildings in the region, consideration must be given to target populations during sample selection (see Section A.3). The review of previous multi-family building characteristics surveys and demographic research will assist in the identification of homogeneous groups of multi-family buildings and the determination of which groups should be represented in the study sample. These data sources can also be used to develop regional floor area estimates and determine the general applicability of candidate conservation measures for the population represented by the sample. Statistical procedures can then be used to develop appropriate sample weighting factors that can be used to support a regional extrapolation.

The results of the study sample must be structured in a way that is readily usable as input to the extrapolation procedures. If a particular building group is represented by more than one building in the study sample, the results of the individual buildings must be averaged in an appropriate manner so that the entire group is represented by a single set of actual energy savings values. If the average characteristics of the sample buildings does not adequately represent the target population, additional adjustments must be made to the actual energy savings to make them representative. Important population characteristics for which adjustments should be considered include construction/geometry, tenant behavior and vacancy rate. The issues of construction/geometry and tenant behavior have been discussed in previous sections. The subject of vacancy rate was not specifically addressed in the discussion of adjustments to energy savings. However, the effect of vacancy rate in the sample buildings was inherently included in the treatment of tenant behavior, in that thermostat setpoint and end use consumption are occupant controlled. In the extrapolation procedures vacancy rate must be analyzed more explicitly because vacancy data are readily available for the regional population and vacancy rate has a significant influence on building energy consumption.

To adjust energy savings for variations in vacancy rate, a relationship must be established between vacancy rate and the variables that are highly occupant controlled. To establish this relationship analysis will most likely be required at the housing unit level. One method for determining this relationship includes the creation of a "full house" scenario, which estimates end use consumption with the building fully occupied (i.e., no vacancy). Based on an examination of the historical and cross-unit end use consumption patterns in the study sample during occupied periods, projections can be made of the consumption patterns that would have occurred if there were no vacancies. Consumption for each of the end uses during vacant periods can be deleted and replaced with the projections of full occupancy. The simulation inputs can be modified to reflect these changes and the building can be recalibrated and re-adjusted using the procedures described in Section A.6 and A.7. The results of this analysis will produce pre-retrofit and post-retrofit (or test-reference) consumption estimates that are associated with a known vacancy rate of zero. Full-house energy savings are calculated as the difference between these two values. By examining the utility billing records or building owner records during the selected study period, the vacancy rates that occurred during the actual pre-retrofit and post-retrofit years can be determined. Adjusted end use consumption under both constant occupancy conditions will provide additional data points. The three available vacancy/consumption conditions can then be plotted and a line can be drawn through the points. From this line consumption can be estimated under any reasonable vacancy rate that is desired for the regional extrapolation.

Adjustments to actual energy savings for these factors can be made through sensitivity analyses on the sample buildings or the development of a prototypical building with the simulation. Although the prototypical building is not a real building, it is intended to represent real buildings in that each component of the prototype is defined by examination of characteristics data from real buildings. Either the sensitivity analyses or the prototypical analysis can be used to adjust the savings estimates from the sample to account for differences with the target population. The final extrapolation adjustments are usually calculated under TMY weather so that long term weather conditions are considered for a variety of cities across the region.